PLANNING FOR WILDLIFE: AN URBAN PLANNING AND DESIGN EXPLORATION TO SUPPORT MEXICAN FREE-TAILED BATS

by

DALE BRADLEY

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning & Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Approved by:

Major Professor
Brent Chamberlain

Abstract

Anthropocentric disturbances are often the main driver behind the population decline of wildlife species. Bat species are of particular concern recently with large declines in populations worldwide. The conservation of bat species relies on knowledge about the relationship between species-specific needs and the effect urban environments have on individual species. Mexican Free-Tailed Bats (MFTBs) are listed on the IUCN Red List and play an important role in many ecosystems within the United States. Austin, Texas is home to the largest urban bat colony in the world, including MFTBs. Austin can continue to benefit from millions of dollars from ecotourism bat viewing sites and the natural control of insect populations provided by this species if urbanization does not cause a reduction in their population. The focus of this research is to develop a quantitative habitat suitability model for the MFTBs in urban areas to increase the understanding of possible MFTB habitat in the Austin Metropolitan area.

A geographical information system was used to map the suitability of habitats for MFTBs in urban areas based off a typology for the needs of the species, which was created through a literature review of expert knowledge. This study will help to quantify the relationship between urban environments and the MFTBs, showing that urban areas in the Austin Metropolitan area are suitable for the species. A predictive model, like the one described here, can act as a crucial assessment and planning tool for bat conservation by helping to eliminate challenges of tracking populations or identifying bats during nocturnal activities.

This model informs the proposal of planning and design policy changes in Austin, Texas to better support MFTB's habitat needs. Adjustments to current site plans in Austin are explored understand the effect the proposed MFTB planning policies could have on current development while exploring the application of the MFTB typology at a site scale. Application of the understanding created through habitat-suitability modelling helps to visualize how current projects in Austin, Texas can better support MFTBs to create an understanding of how these policies may affect the development of urban environments.

Table of Contents

List of Figures

List of Tables

List of Supplemental Files

1) MFTB_SuitabilityModel.tbx

Files included within ArcGIS Toolbox:

- Foraging Model
- Edge Density Model
- Distance to Water Model
- Distance to Highways Model
- Building Stories Model
- Building Density Model
- MFTB Final Combination Model

*This ArcGIS Toolbox contains each individual Mexican Free-Tailed Bat variables model. The *MFTB Final Combination Model* uses the output from each variables model to combine each final suitability layer into a final suitability map. The GIS data used in this project can be found in Appendix C, Table 7-2: GIS References.

Acknowledgements

This project is the result of the continued support of numerous individuals within the College of Architecture, Planning and Design during my education at Kansas State University. Thank you to all of the faculty and staff of the Department of Landscape Architecture and Regional Community Planning, who have provided me with endless guidance and support. I would like to thank my major professor Dr. Brent Chamberlain, without your guidance, this project would not have been possible. Also, thank you to my secondary committee member Dr. Jason Brody and tertiary committee member Dr. Kimberly With – your insights and guidance helped shape my project and its outcomes more than you will ever know. Thank you for your input and commitment that has helped me expand my understanding of ecology, planning, and landscape architecture.

I would like to thank my family and friends for all the love and support throughout my entire college career. Thank you for always supporting me, listening to my ideas, and helping me to shape to who I am today.

Dedication

This project is dedicated to my wife, Kelsey. Thank you for your continued support and constant contribution throughout this process.

1 Introduction

In a world where humans continue to shape and develop the environment, the interaction between urbanization and wildlife becomes increasingly important. Urbanization has played a major role in the 52 percent decline in wildlife species worldwide over the past 40 years (World Wildlife Fund, 2014). With over half of the world's population living in cities currently, and an estimated 75% of the world's population living in cities in 2050 (Burdett et al., 2007), urbanization is expected to have increasing impacts on wildlife. Urbanization presents the largest indication of alterations to the natural environment because natural habitats have been completely removed or altered to provide important goods and services for the people living in urban areas (van der Ree & McCarthy, 2005). Therefore, continued urbanization at its current rate will likely only further contribute to negative impacts on wildlife.

A better understanding of wildlife habitat and its relationship to the urban environment could help mitigate impacts caused from urbanization. Although the relationship between wildlife and urbanization is complex and poorly studied (McKinney 2002), the impacts of urbanization on bat species have been shown to decrease species richness (Coleman & Barclay, 2012). Bats are important because of the ecosystems services they provide, such as control of insect populations, pollination, and seed dispersal (Ghanem & Voigt, 2012; Kunz, Braun de Torrez, Bauer, Lobova, & Fleming, 2011). Ecosystems services are, "the production of [ecosystem] goods…[and] life support functions, such as cleansing, recycling, and renewal, and they may confer many intangible aesthetic and cultural benefits" (Daily, 1997). Bat species have been declining in population recently (O'Shea & Bogan, 2003; Hoyle, 2009). In fact, nearly a quarter of the world's bat populations are threatened with extinction (Hoyle, 2009). The need for bat habitat in the future will continue to grow with the decline in populations and the continued loss and fragmentation of habitat from urbanization. With increased urbanization and the decrease in bat populations, it becomes important to understand:

Are urban environments suitable for wildlife species?

The focus of this work is to explore the relationship between Mexican Free-Tailed Bats and urbanization in order to gain a better understanding of the species' habitat requirements, which is necessary first step before we can begin to understand how urban planning and design can impact the future of Mexican Free-Tailed Bats. Mexican Free-Tailed Bats (*Tadarida brasiliensis*) are a common and well-studied bat species in the United States (Sosnicki, 2012). Mexican Free-Tailed Bats are also a publicly well-known and appreciated bat species in the United States (Bat Conservation International, n.d.) thus allowing Mexican Free-Tailed Bats to act as the focus for this study. Although Mexican Free-Tailed Bats are listed on the IUCN Red List (2014) as a species of least concern, populations have been declining (Schmidly, 1994; McCracken, 1986; Clark, Martin, & Swineford, 1975). Additionally, Mexican Free-Tailed Bats tend to roost in massive colonies in caves and many human-built structures (Schmidly, 1994; Sgro & Wilkins, 2003), which increases the vulnerability of Mexican Free-Tailed Bats to human disturbances and habitat destruction (Texas Parks & Wildlife, n.d.). These phenomena lead to two primary research questions:

1. *Are urban environments suitable for the Mexican Free-Tailed Bat?*
2. *How can urban planning and design better support Mexican Free-Tailed Bats habitat requirements?*

Although Mexican Free-Tailed Bats have been shown to roost in urban areas (Schmidly, 1994; Sgro & Wilkins, 2003; Allen et al., 2009; Davis & Cockrum, 1963; Scales & Wilkins, 2007) the relationship between Mexican Free-Tailed Bats and urbanization is complex and not well understood (Williams, 2012; Gehrt & Chelsvig, 2004). I propose to gain a better understanding of the relationship between urbanization and the habitat requirements of the MFTBs through the development of a habitat-suitability model, which is informed by a review of the literature regarding the habitat requirements of Mexican Free-Tailed Bats. Habitat Suitability modelling (HSM) has been used to predict the distribution of a species in an area to help understand what habitats are important for the species (Bellamy, Scott, Altringham, & Minderman, 2013; Bollmann, Graf, & Suter, 2011; Larson, Dijak, Thompson, & Millspaugh, 2003) by relating environmental variables to the likelihood of occurrence for a species (Hirzel & Le Lay, 2008). After better understanding the relationship between the Mexican Free-Tailed Bats and their environments, I then explore planning and design of urban environments to enhance the habitat suitability of these areas for Mexican Free-Tailed Bats.

The design of urban areas to support bat habitat has been explored recently, mainly in the UK (Gunnell, Grant, & Williams, 2012), but few if any species-specific urban-design guidelines for bats exist. In addition, broader scale planning for bat habitat has not been fully explored or understood. Habitat Suitability Models are useful for predicting wildlife distribution (Larson, Dijak, Thompson, & Millspaugh, 2003). Using GIS, I will locate opportunities for improved and better connected bat habitat in urban areas to support Mexican Free-Tailed Bat's needs by analyzing recent or confirmed future projects in Austin, Texas and proposing changes to confirmed development that would better support Mexican Free-Tailed Bats.

In order to identify the suitability of Mexican Free-Tailed Bats and locate projects that can be improved for Mexican Free-Tailed Bats the following objectives will guide the research project:

1) Analyze Mexican Free-Tailed Bats needs and habitats to create a typology for the Mexican Free-Tailed Bats habitat in urban areas.
2) Apply the typology to a spatial model in urban areas to understand Mexican Free-Tailed Bats habitat suitability in and around urban areas.
3) Use the understanding gained by the typology and modelling to show how current or recently completed projects in Austin, Texas can better support Mexican Free-Tailed Bats needs.

The needs of Mexican Free-Tailed Bats can help to guide a new understanding of urban development and its impacts on more than just human needs. This study envisions a more sustainable urban development that not only takes into account the needs of Mexican Free-Tailed Bats but also helps start to explore how urban planning and design could evolve in the future.

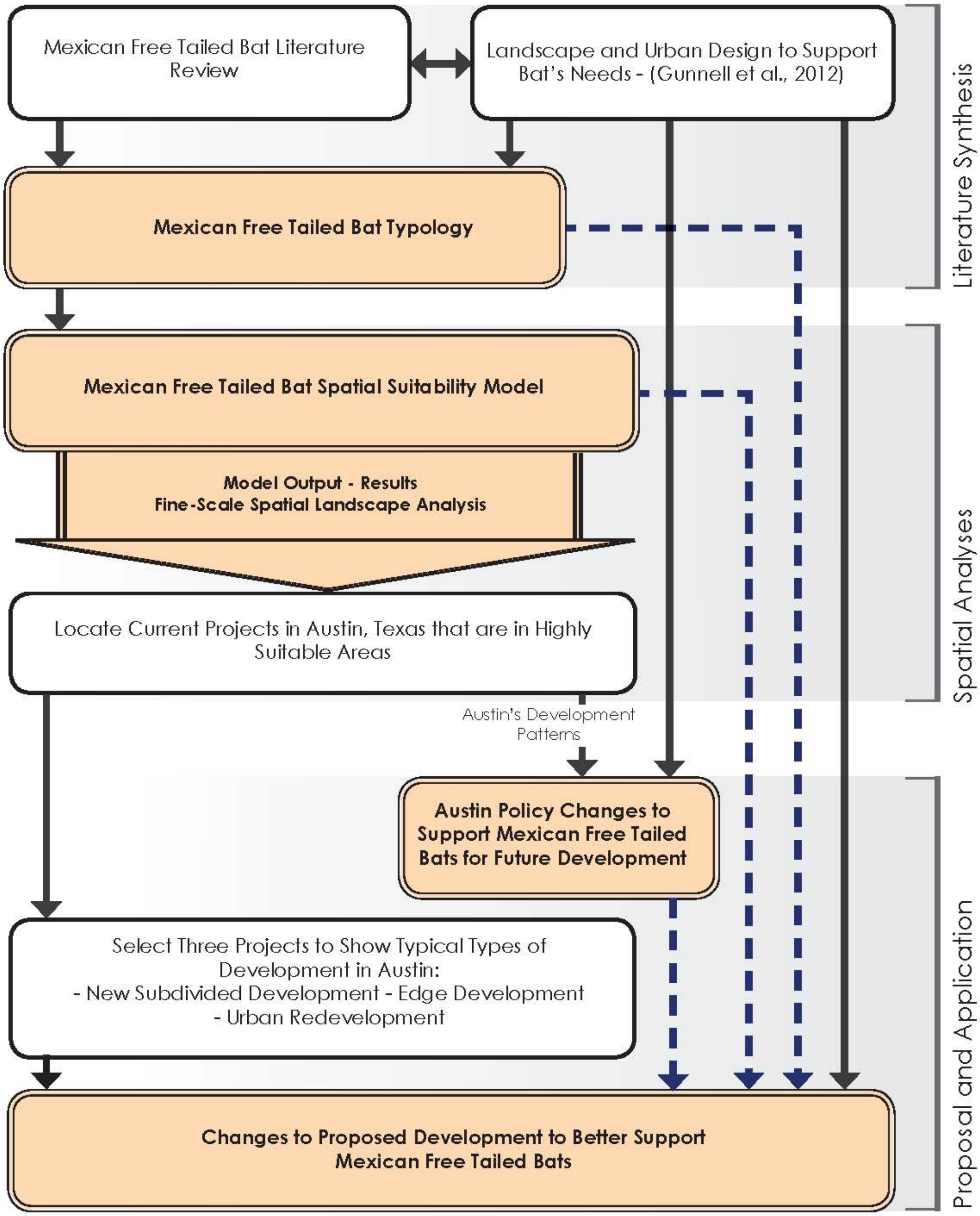
1.1 Thesis

Integrating Mexican Free-Tailed Bat's needs into development plans in Austin, Texas will help to decrease the city's need for insect control and increase Austin's opportunities for ecotourism revenue while helping to improve the population of Mexican Free-Tailed Bats in the area. Examples of how current projects in Austin, Texas can better support Mexican Free-Tailed Bat's needs will establish greater opportunity for future development to include Mexican Free-Tailed Bats needs.

1.2 Design Methodology

This project's design methodology is visualized in Figure 1-1. The three parts of this project are literature synthesis, spatial analyses, and the proposal and application. Orange boxes are proposals or analyses that are being created. White boxes are literature or selections used to inform the next step in the process. Dashed blue connections are findings that are being used to create or apply information to a proposal or application, whereas solid black connections are the flow of information and processes in this project.

Figure 1-1: Design Methodology Diagram



1.3 Relevance and Necessity

This project is important for many different professions and explores opportunities to integrate the needs of Mexican Free-Tailed Bats into current urban planning policy in Austin, Texas. The relevance of this proposal and its significance to individual professions are summarized below.

Relevance:

- Supports a declining bat population.
- Cities could benefit from millions of dollars of direct income from ecotourism opportunities.
- Natural control of insect populations.
- Indirect income from the reduction in pesticide needs.

Necessity:

Multidisciplinary:

- Combines architecture, landscape architecture, planning, and ecology to support bat's habitat needs.

- **Architecture**:
  - Supports Mexican Free-Tailed Bats habitat suitability through dense urbanization - tall urban structures with better opportunities for integrated roosting opportunities.
- **Landscape Architecture:**
  - Supports sustainable water management and techniques for maintaining public open space.
- **Planning**
  - Opportunities to improve connectivity for bats and development, while supporting public health.
- **Ecology**
  - Opportunities to improve public interpretation and support of wildlife ecology through a multidisciplinary visual approach that ecology may be currently lacking.

2 Background

2.1 Urbanization

2.1.1 Urbanizations Effect on Wildlife

The effect of urbanizations on native wildlife species are complex and poorly studied (McKinney 2002). McKinney (2008) found that the effects of moderate levels of urbanization have varying effects on species richness of wildlife. While the general trend of decreasing species richness holds true for most species, in suburban areas some 12% of non-avian vertebrate species show an increase in species richness (McKinney, 2008). Although it has been shown that typically urbanization causes species richness to decline (McKinney, 2008; McKinney, 2002; Basham, 2011) the differences in studies most likely occur because of the differences in adaptations and suitability for different wildlife species. Species that show an increased species richness is likely because the species is nonnative or preadapted to the urban habitats created (McKinney, 2006). This is concerning because the preadapted species are likely to dominate urban areas which creates an overall less healthy environment because of a loss of biodiversity.

Urbanization causes destruction and fragmentation of wildlife habitat, which is the main cause behind the tendency of urbanizations to decrease species richness (Pauchard, Aguayo, Peña, & Urrutia, 2006). Urbanization presents the largest indication of alteration to the environment because in many cases natural habitat has been completely removed to make room for urban constructs or spaces that support urban areas (van der Ree & McCarthy, 2005). However, the space occupied by urbanized areas is only a portion of the overall problem with habitat destruction and fragmentation because of the area needed to sustain urbanized areas. These areas needed to support urbanization are evident most often in industrial areas such as agriculture, forestry, and mining areas. The sheer amount of space and supplies required to support urbanized areas further compound the problem of habitat fragmentation and destruction.

Urbanization has grown to the point where almost any environment is either human-dominated or human-impacted (Vitousek, Mooney, Lubchenco, & Melillo, 1997) and it has become difficult to define where urban boundaries end to the point that the world is almost completely urbanized (Brenner, 2014). If urbanization has no defined boundaries then the chance that wildlife habitat will be destroyed or altered rises greatly. Overall urbanizations dominance on the environment has had a negative effect on wildlife species.

2.1.2 Trends in Urbanization

An unprecedented transition to urbanization is taking place around the world (Burdett et al., 2007; Seto, Fragkias, Güneralp, & Reilly, 2011; Batty, 2008) and the transition toward urbanization is different than historical patterns of urbanization in terms of scale, rate, location, form, and function (Seto, Snchez-Rodrguez, & Fragkias, 2010). The scale and rate of urban growth have increased dramatically, to the point where urban environments are one of the dominate land types around the world making up approximately 5% of the total area of the world's surface (Seto, Snchez-Rodrguez, & Fragkias, 2010). With an estimated 75% of the world's population to be living in urban areas by 2050 (Burdett et al., 2007), it seems that trends in urbanizations scale and rate of growth will continue to increase. With the increase in urbanizations scale and rate, urbanizations future effects on wildlife will likely continue to grow.

2.2 Austin Texas

2.2.1 Study Area

This study takes place in Austin, Texas. The city of Austin is the focus but the Austin Metropolitan area is important for the understanding of how Mexican Free-Tailed Bats inhabit the area.

2.2.2 Why Austin?

Austin, Texas was chosen for the base of this study because it is the self-proclaimed Bat Capital of America and the home of the largest urban colony of bats in the world (Bat

Conservation International, n.d.). Austin also provides a great example of current trends in urbanization in the United States. Currently, Austin is the United States fastest growing city on the Forbes list of Fastest Growing American Cities ("America's Fastest-Growing Cities - In Photos," 2015). Austin's development is expanding rapidly and the need to plan for the population growth in the city will become even more important with the rapid growth of the city.

OFF! Insect Repellent (2012) found Austin to have the 16th worst flying biting bug problem out of the 50 largest metropolitan areas in the United States. These findings were based off multiple methods including meta-analysis of insect supporting climates, insect repellant sales data, data on insect concentrations, and surveys on local insect activity. These findings are alarming because they already include the Mexican Free-Tailed Bats currently foraging in Austin that help to control these flying insect populations. With the rapid growth in Austin the opportunity to disturb Mexican Free-Tailed Bat habitat increases. If Austin were to disturb Mexican Free-Tailed Bat habitat enough to cause a decline in Mexican Free-Tailed Bat populations the insect problem in Austin could grow drastically. This growth in insect populations could also increase the need for harmful pesticide use in the city, which could cause many problems with the environment.

2.3 Mexican Free-Tailed Bats

2.3.1 Importance

Mexican Free-Tailed Bats are an important part of the ecosystems they are a part of, providing important insect control services (Cleveland et al., 2006) and creating guano that can be harvested for use as fertilizer (Wilkins, 1989). A study conducted in south central Texas to estimate the value of Mexican Free-Tailed Bats to the agriculture in the area found that the populations of Mexican Free-Tailed Bats provided an annual value of $741,000 per year on average but up to $1,725,000, depending on insect populations in a given year (Cleveland et al., 2006). With a total harvest value of $4.6-$6.4 million a year (Cleveland et al., 2006), Mexican Free-Tailed Bats can provide great economic value to agricultural areas. Urban areas can benefit from the same type of insect control but for different reasons. Insects can be more abundant in urban areas (Meineke, Dunn, Sexton, & Frank, 2013),can carry diseases, and can cause stress on vegetation (Meineke, Dunn, Sexton, & Frank, 2013). The insect control provided by Mexican Free-Tailed Bats can also reduce the need for harmful pesticides, which can save money and reduce the harmful effects of chemical pesticides on the environment (Cleveland et al., 2006). Finally, large urban roosts, such as the one in the Congress Avenue Bridge in Austin, Texas, can create ecotourism destinations attracting over 100,000 people annually while bringing over $10 million dollars to the local ecosystem (Bat Conservation International 2, n.d.). Overall Mexican Free-Tailed Bats can benefit a city's budget and health in directs and indirect ways.

2.3.2 Biology/Overview

Mexican Free-Tailed Bats are small brown furred mammals with large dark ears, short snouts and a wrinkled upper lip that are capable of flight (See Figure 2-1). Mexican Free-Tailed Bats are nocturnal and spend much of the daytime in a state of torpor (LaVal 1973). Adults range in size from 79 to 98 mm in length with a 31 to 41mm tail. The typical weight of adult Mexican Free-Tailed Bat is 11 to 15 g but seasonal changes affect their weight (Anthony M. Hutson, Simon P. Mickleburgh, & Paul A. Racey, 2001). Male and female Mexican Free-Tailed Bats live roughly the same amount of time with the longest living to over eight years old. The longest recorded living species in captivity was 12 years old (Weigl, 2005).

Figure 2-1: ***Mexican Free-Tailed Bat Image***

(USFWS/Ann Froschauer, 2012)

Mexican Free-Tailed Bats are one of the most widely distributed species of bats in North and South America (Hall, 1981). Although extensive studies on their range have yet to be completed they are found throughout much of southern North America, Mexico, and northern South America (Sosnicki 2012; International Union for Conservation, 2014) (See Figure 2-2).

Figure 2-2: ***Mexican Free-Tailed Bat Range***

(Bradley, 2015)

The IUCN Red List (2014) lists Mexican Free-Tailed Bats as a species of least concern. Although Mexican Free-Tailed Bats are only listed as a species of least concern, populations have been declining recently (McCracken, 1986; Clark, Martin, & Swineford, 1975). One of the largest colonies of Mexican Free-Tailed Bats in the world at Carlsbad Cavern, New Mexico, has declined from 8.7 million in the 1930's to around 500,000 recently (McCracken, 1986). Another large colony at Eagle Creek Cave, Arizona, was estimated to have over 25 million Mexican Free-Tailed Bats in 1963 to an estimated 30,000 only six years later (McCracken, 1986). These are two important examples showing the decline of Mexican Free-Tailed Bat populations, but Mexican Free-Tailed Bats tend to roost in urban constructs (Davis & Cockrum, 1963; Allen et al., 2009; Vander Pol, 2012), which increases interferences with large roosts from human interference (Texas Parks & Wildlife, n.d.).

2.3.3 Safety

Many cultures view bats with fear or distrust (Mickleburgh, Hutson, & Racey, 2002). This fear causes many people to overreact to the danger of situations that involve bats (Texas Parks & Wildlife, 2007). The danger of bats living closely with people is often over exaggerated. Bats are not accustomed to human interaction and avoid any conflicts with humans (University of Calgary, 2011). Being nocturnal bats natural decrease the time that it is possible for interaction with humans. While bats are carriers for rabies less than one percent of bats are infected with the disease (University of Calgary, 2011). In fact bat rabies only accounts for about one human death each year in the United States (Bat Conservation International, 2008). To put bat rabies deaths in perspective, dogs kill more people each year than bats from rabies in a decade (Bat Conservation International, 2008). Since bats are feared and often misunderstood it becomes important to educate people about bats benefits.

Education becomes an important part of keeping people and bats safe when there is a large number of bats roosting or foraging closely to where people are located (Texas Parks & Wildlife, 2007) such as urban areas. When people are not educated on why bats are important and how to live alongside them people tend to overreact or take distorted media reporting as the truth. When people overreact and are uneducated it causes people to employ methods of keeping bats out of their homes or area that may actually put them in more consistent contact with bats than a person would normally have on a daily basis therefore actually increasing the chances of a bat related incident or encounter(Texas Parks & Wildlife, 2007). An example of putting oneself at unneeded risk because of lack of education is when someone may try to cover an exterior hole in their attic to not allow bats entry, which puts the person in close contact with the bats and may cause trapped bats to find other ways out of the home usually through the house itself. Finally, education is very important for people to coexist with bats for the safety of both bats and humans.

2.4 Modelling

2.4.1 Habitat Modelling

Habitat modelling has been used to better understand how bats and other wildlife species use the environment and what habitats are most important for different species (Rittenhouse, Dijak, Thompson III, Millspaugh, 2007; Larson, Dijak, Thompson, & Millspaugh, 2003; U. S. Fish And Wildlife Service, 1980). With recent advances in technology Geographical Information System (GIS) based modeling has become an important tool for modeling (Store & Jokimäki, 2003). Before the technology was available The U.S. Fish and Wildlife Service (1980, 1981) created a method for habitat evaluation based on Habitat Suitability Indexes. These models are based off of Habitat Units (HU's) for each species being evaluated which are calculated by the product of the Habitat Suitability Index (quality) and the total area of available habitat (quantity). The combination of quality and quantity of habitat allows for the model to weigh the habitat in a studied area to locate the most suitable or least suitable areas for a specific species. The goal of Habitat Suitability Index models are to produce an index with a proven quantified positive relationship to carrying capacity such as units of biomass/unit area or units of biomass production/unit area (U. S. Fish And Wildlife Service, 1980). Although this ideal outcome is often unobtainable, a more acceptable goal may be to create a model that an expert would believe has a positive relationship to long term carrying capacity (U. S. Fish And Wildlife Service, 1980). The Habitat Suitability Index can be seen as a mathematical formula such that: HSI = Study Area Habitat Condition / Optimum Habitat Condition (U. S. Fish And Wildlife Service, 1980). The HSI can then be used to make maps, which can be used to compare different management alternatives (Larson, Dijak, Thompson, & Millspaugh, 2003). Early use of HSI models helped evaluate management alternatives for the total amount of habitat loss or gained (U. S. Fish And Wildlife Service, 1980, 1981). Habitat occupancy depends on not only the HSI but the spatial composition and configuration of habitat units which should be incorporated into HSI models (Rittenhouse, Dijak, Thompson III, & Millspaugh, 2007). To incorporate spatially explicit attributes recent advances in technology can be used to include spatial information.

Species Distribution Models remain a common approach for assessing wildlife habitat quality with GIS being an important tool used today. One method recent models are using transforms the information spatially, which allows for relationships between variables to be compared easily while being used to create suitability maps by overlaying the HSI layers and creating a mathematical relationship between the values. This final relationship can be seen as the suitability for species in the area of study intended for the use of locating important conservation areas or areas to improve habitat quality (Rittenhouse, Dijak, Thompson III, & Millspaugh, 2007; Larson, Dijak, Thompson, & Millspaugh, 2003).

Methods of overlaying suitability layers to create a geometric mean have been used in the past for other types of suitability mapping originally developed by Ian Mcharg (1992) although Mcharg used suitability mapping to help inform planning and design decisions. Mcharg's (1992) method involved mapping different important geological features such as riparian areas, aquifers, forests, woodlands, slope, soils, and other natural features to look for overlaps and holes in suitability to help locate the most or least suitable areas for development. Overlapping layers to create suitability maps is how Species Distribution Modelling for wildlife has evolved as well (Rittenhouse, Dijak, Thompson III, & Millspaugh, 2007; Larson, Dijak, Thompson, & Millspaugh, 2003).

2.4.2 Model Formation

The formation of HSI models have been based off simply measured variables (U. S. Fish And Wildlife Service, 1980). These variables are usually based off of empirical distribution data (Buckland & Elston, 1993) or found through another modelling technique, such as max entropy modelling (Buckman-Sewald, Whorton, & Root, 2014; Bellamy, Scott, Altringham, & Minderman, 2013), both of which are used to create species distribution models allowing for Habitat Suitability Index curves to be created from the information on relationship to spatial data. Many GIS based models are based off empirical presence-absence or presence-only field data, but when that data may not be available models can be based off expert's knowledge and findings (Jyrki Kangas, 1993; Store & Kangas, 2001; Yamada, Elith, McCarthy, & Zerger, 2003). Models are often build off other models allowing for new models to be created by adapting past models with new information or for a different purpose (U. S. Fish And Wildlife Service, 1980; Larson, Dijak, Thompson, & Millspaugh, 2003).

Originally the U.S. Fish and Wildlife Service (1980) summarized the general steps to create a HSI model as: "1) establish a model goal; 2) define the habitat variables that are related to the model goal; and, 3) define model relationships that combine measurements of the variables to achieve model goals" (pg. 102-ESM-4-4). This generalization is further broken down to include two aspects of model goals: 1) output specifications and 2) a definition of potential variables the field biologist is able to measure (U. S. Fish And Wildlife Service, 1980). These variables should be easily measurable physical, chemical, or vegetative variables for a specific species. Then the relationship between variables can be defined in a mathematical formula or by explanation in word format. With the mathematical format being more rigorous and needing to be mathematically defined allows for clearer statement of model relationships but is not less subjective than a model in word format (U. S. Fish And Wildlife Service, 1980).

2.5 Design for Mexican Free-Tailed Bats

2.5.1 Mexican Free-Tailed Bats

To understand how to planning and design can support Mexican Free-Tailed Bats it becomes important to reference guidelines for designing wildlife habitat. Design guidelines for wildlife habitat often exist, but the guidelines often focus on generalized ranges of multiple species or are guidelines for water based ecosystems ("Washington Habitat Guidelines," 2014). Recently a comprehensive landscape and urban design guidelines for bats was created in the UK, named *Landscape and Urban Design for Bats and Biodiversity,* to help planners and designers create habitats and connections to support bat species in the region (Gunnell, Grant, & Williams, 2012). Although these guidelines are focused on UK bat species it helps provide a good overall understanding of how bats use their habitats and how design can support bat species and biodiversity.

The design guidelines will then be directly related to Mexican Free-Tailed Bats through an understanding of Mexican Free-Tailed Bats habitat needs.

Landscape and Urban Design for Bats and Biodiversity (2012) lays out guidelines related to: 1) Foraging; 2) Roosting and Commuting; and 3) Landscape connectivity. The first two sections of *Landscape and Urban Design for Bats and Biodiversity* helps to achieve a better understanding of types of bat habitats, how bats use their habitats, and where bats roost, whereas the third section focuses on landscape connectivity and elements that make up the landscape, especially in urban areas. The understanding of *Landscape and Urban Design for Bats and Biodiversity* will be vital in the understanding of how to support site scale interventions for Mexican Free-Tailed Bats.

2.5.2 Foraging

Foraging is an important part of any bats behavior and, "providing and enhancing foraging habitat is probably the most important intervention that can be done to improve landscapes for bats" (Gunnell, Grant, & Williams, 2012, pg. 4). The importance of planting and woodlands are emphasized in this section focusing on creating and providing opportunities for insects to support bats' foraging needs. Some suggestions for attracting nocturnal insects are to plant a mixture of plants, vegetables, trees, and shrubs with varying color, fragrance, shape, and structures. In woodland areas to help support a diverse insect population, it becomes important to leave some areas unmanaged, retain native climbing plants, and retain a dense woodland understory. Open habitats and grasslands are also discussed with the key improvements to consider are plating diverse grasslands and establishing un-mowed areas. These guidelines help to understand some techniques for creating quality insect habitat therefore helping to support a quality foraging habitat (Gunnell, Grant, & Williams, 2012). Mexican Free-Tailed Bats have very diverse diets (Lee & McCracken, 2005; McWilliams, 2005) so generally supporting insect abundance through using a diverse planting palette and allowing for naturalized or unmanaged areas can be an important design technique at a site scale for the species.

After generally focusing on design guidelines the *Landscape and Urban Design for Bats and Biodiversity (2012)* offers suggestions on urban design guidelines for wetlands, water management, and urban design elements. Freshwater is important for bats foraging, drinking, and attracting insects. Ponds and rivers are the two important water features to increase biodiversity and maintain vegetation near the banks. Important considerations for ponds are the location of ponds within 40m of other important landscape features, create ponds as large as possible, and maintain natural or install artificial roosting opportunities near the edge of the water. Rivers are another important feature, especially in urban areas, to preserve or improve to support bat habitat. Some important suggestions to consider for rivers are to retain natural river features, retain bankside trees, avoid pollution and nutrient enrichment, and restrict or remove lighting near river footpaths. These river suggestions focus mainly on attracting insects while cutting down on negative associations such as lighting and pollution around natural foraging areas and roosts (Gunnell, Grant, & Williams, 2012). Mexican Free-Tailed Bats can benefit from all of the design suggestions for ponds. Locating water bodies near other important landscape features would support Mexican Free-Tailed Bats needs because landscape elements and edges have shown to be important for the species (see Table 4-2) to support safe flight routes to quality foraging areas near water. The water and space around the water provides the open space needed for Mexican Free-Tailed Bats to forage (Vaughan, 1966; Simmons et al., 1978)(see Table 4-2). Although 40m from water edges to the nearest landscape feature is a suggestion based of UK bat species, it is based off a range of species so it seems reasonable to assume a similar distance would support Mexican Free-Tailed Bats. Maintaining or installing roosting opportunities for Mexican Free-Tailed Bats can be beneficial but challenging because of the species' tendency to roost in massive groupings reaching numbers up to tens of millions (Zubaid, McCracken, & Kunz, 2006). Mexican Free-Tailed Bats are found in smaller groupings in trees, bridges, buildings, and other man-made structures (Krutzsch, 1955) so maintaining access to suitable structures and entryways near water can help support Mexican Free-Tailed Bat habitat. The suggestions for improving rivers in urban areas can help support Mexican Free-Tailed Bats needs as well. Retaining natural river features and bankside trees will help to support insect abundance while providing important linear elements for quality flight routes, which are important for Mexican Free-Tailed Bats (see Table 4-2). Restricting or removing lighting on river footpaths is not extremely important for Mexican Free-Tailed Bats because of the their tendency to favor lit urban foraging areas over more nature areas (Avila-Flores & Fenton, 2005) and light may actually play an important role in Mexican Free-Tailed Bats visual navigation (Mistry, 1990; Mistry & McCracken, 1990).

Urban design elements that *Landscape and Urban Design for Bats and Biodiversity (2012)* offers suggestions for include rain gardens, swales, insect hotels, green roofs and walls. Rain gardens and swales provide more opportunities to attract insects in urban areas but also help to improve habitat connectivity through linear tree and shrub plantings. Insect hotels, or wildlife stacks that can support and house insects, and green roofs offer even more opportunities to attract insects. Walls in urban areas can offer habitat for bats while giving more opportunities to increase plant diversity. Green walls and climbing plants can attract insects (Gunnell, Grant, & Williams, 2012). Supporting higher insect abundance has already been established that it helps improve Mexican Free-Tailed Bat habitat so these suggestions relate to improving insect abundance in urban areas.

2.5.3 Roosting

Landscape and Urban Design for Bats and Biodiversity (2012) considers the design of new buildings to be important to consider when building new constructs. New buildings tend to be well sealed so roosting opportunities should be planned into the building's design (Gunnell, Grant, & Williams, 2012). Mexican Free-Tailed Bats roost in a range of constructs such as caves (Allen et al.; 2009; Geluso; 2008; Wilkins, 1989) and structures like bridges (Davis & Cockrum, 1963; Allen et al., 2009; Wilkins, 1989), buildings (Vander Pol, 2012; Wilkins, 1989), trees, and other structures (Wilkins, 1989). While buildings make up much of Mexican Free-Tailed Bats available roosts, other urban structures, especially bridges, could benefit from having roosting opportunities planned into construction. Bat boxes can provide an artificial way to create roosting opportunities for bats especially in more urban environments and can be easy to install. Bat boxes are similar to bird houses and can be installed in many different places including on the side of a building or home, on a tall pole, or in a tree. Location of external bat boxes needs to be carefully considered to provide the best opportunity for use. It is best to locate boxes on

the side of the structure that gets the most sun. Locating the bat box at least 2m off the ground is needed but 5-7m is better for keeping the roost away from predators. Location of a bat box must also consider the surrounding habitat and structure. Locating the box away from ledges or windows to keep cats or other predators away from the roost while stopping the accumulation of droppings on such features can be important for increasing the chances of use by bats. The location of hedges of trees nearby is important to provide close to roost foraging opportunities where some bats do not like to fly in the open or exposed areas (Gunnell, Grant, & Williams, 2012). Providing bat boxes in urban areas may result in use by smaller groupings of Mexican Free-Tailed Bats but the most important roosts are the massive breeding colonies Mexican Free-Tailed Bats form (Krutzsch, 1955). It is more difficult to plan or add enough space for a large colony, which is why considering bridge design or other urban constructs as possible artificial roost locations could be important for Mexican Free-Tailed Bats.
After presenting design suggestions for improving roosting and foraging opportunities *Landscape and Urban Design for Bats and Biodiversity (2012)* offers ways to improve overall habitat and biodiversity for bats and other wildlife species in urban and suburban residential areas. These suggestions can be seen in Figure 2-3 and Figure 2-4.

Figure 2-3: ***Residential Bat and Biodiversity Improvements***

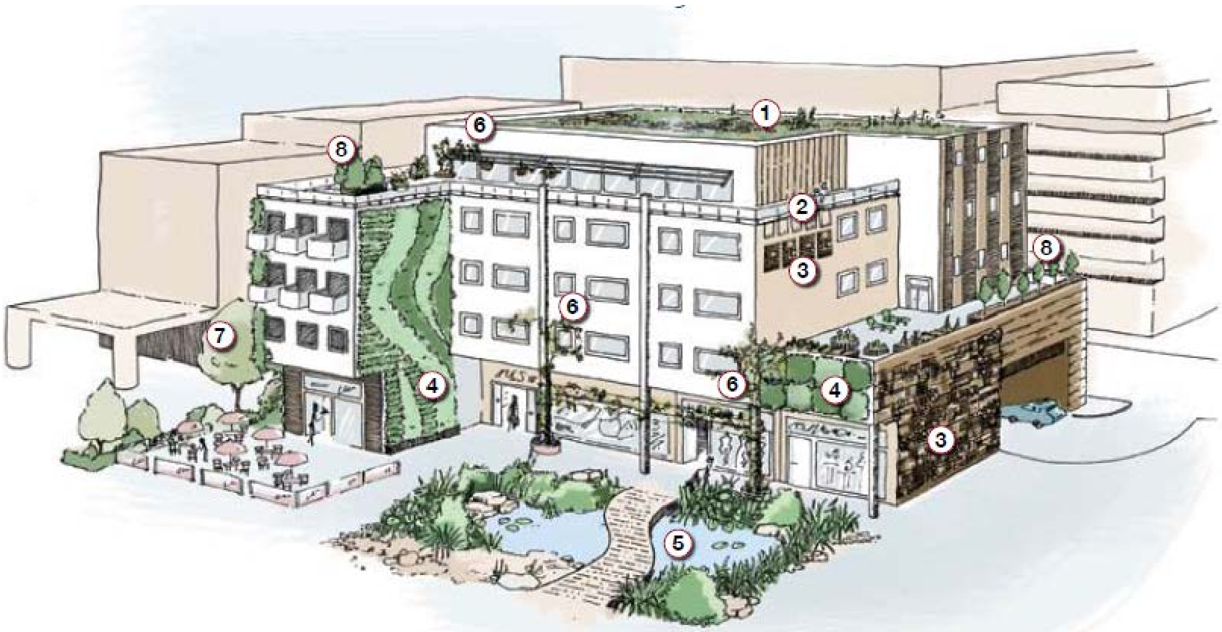
Residences can incorporate the following features for biodiversity:

1 Bird boxes (shady orientation)
2 Green roof
3 Integrated bat boxes (majority located on southern orientations)
4 Tree clusters
5 Hedgehog passages (+ 15cm gap)
6 Hedgerows
7 Standard trees
8 Climbing plants
9 Permable paving for drainage
10 Habitat walls
11 Planters and baskets
12 Rain garden
13 Wildlife pond
14 Street tree
15 Unmown edges and verges

The orientation of the features and proximity to artificial lighting should be carefully considered.

(Gunnell, Grant, & Williams, 2012, pg. 6 used with Permission)

Figure 2-4: ***Urban Bat and Biodiversity Improvements***



Built up areas can be improved for biodiversity by adding a combination of the following features:

1 Biodiverse green roof
2 Integrated bat boxes (majority located on sunny orientations)
3 Habitat walls (sunny orientation)
4 Green / Living walls (shady orientation easier to establish)
5 Sustainable Urban Drainage features (combine hard and soft landscape to create rain gardens, rills and swales, filter strips, detention and retention ponds)
6 Climbing plants and creepers
7 Large native trees
8 Planters

The orientation of the features and proximity to artificial lighting should be carefully considered.

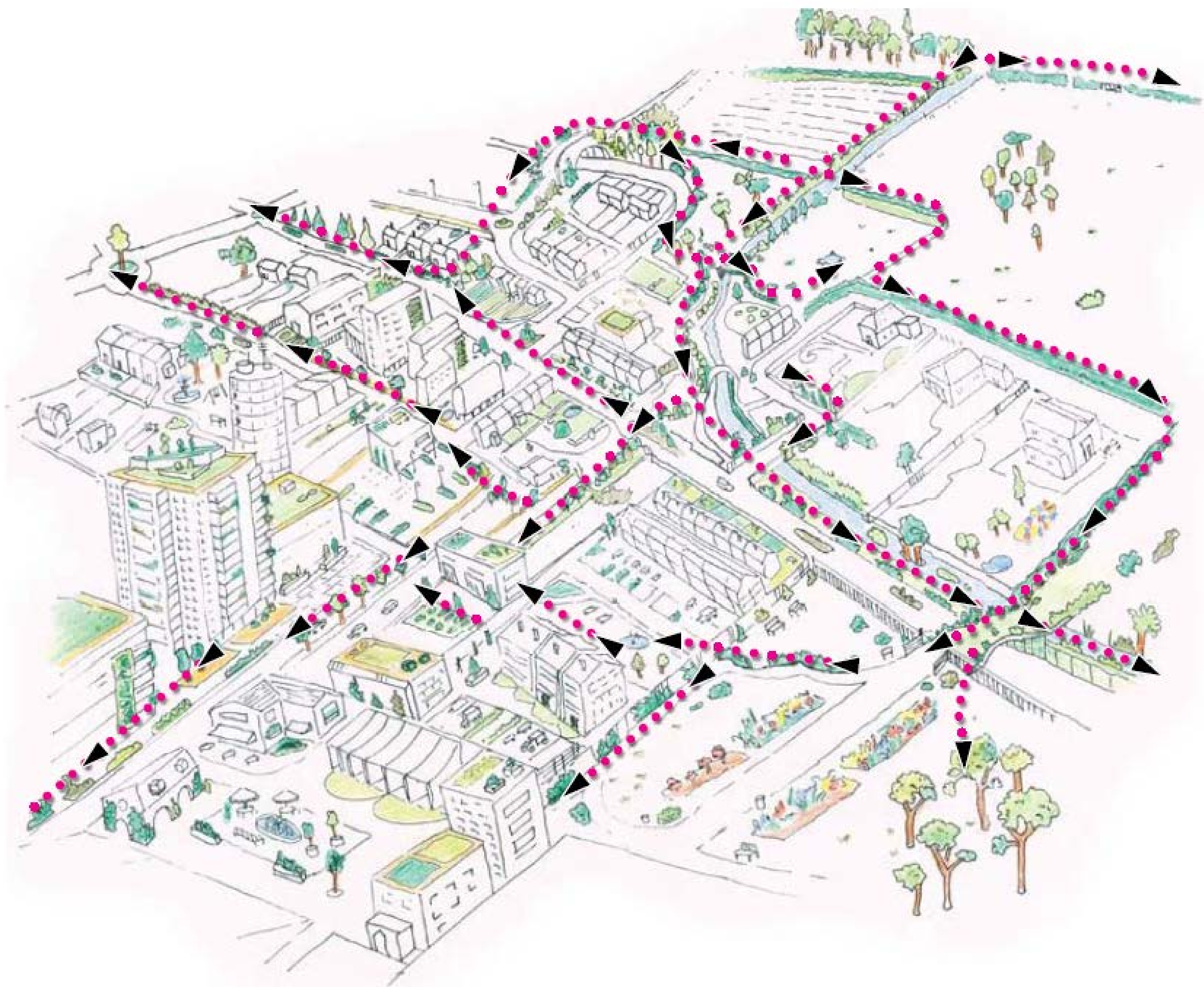
(Gunnell, Grant, & Williams, 2012, pg. 22 used with Permission)

2.5.4 Landscape Connectivity

Landscape connectivity is important to bat species because it provides good opportunities for commuting routes. Bats use commuting routes such as avenues, street tree lines, waterways, hedgerows, woodland edges and other corridors as safe routes to commute between roosts and foraging areas. Landscape connectivity becomes more important in urban areas where gaps that may be large enough to cause bats to avoid crossing are much more common. For this reason street trees should be continuous and as large as possible. These commuting routes should be unlit if possible to provide the best commuting routes. Hedgerows and tree lines should strive to be thick and dense while maintaining a range of different species. These commuting routes are one of the most important aspects for bats especially in urban areas so considerations for better landscape connectivity can provide bats with the best opportunities to use the environment (Gunnell, Grant, & Williams, 2012). Improving and supporting better landscape connectivity can benefit Mexican Free-Tailed Bats greatly. Landscape connectivity is important because edge habitat and linear landscape elements are important for the species (see Table 4-2) while Mexican Free-Tailed Bats have been shown to favor urban areas over more natural foraging areas (Avila-Flores & Fenton, 2005) so supporting landscape connectivity through urban areas becomes more important for Mexican Free-Tailed Bats.

In urban areas small green spaces play an important role in the overall connectivity of the landscape. Small green spaces such as pocket parks, gardens, squares and balconies all provide foraging opportunities. While these spaces are important, it is the role they play together that makes small urban green spaces significant. If there is no connectivity then these small urban green spaces can be underused or completely avoided by bat species (see Figure 2-5 for example of how bats use landscape connectivity to move throughout urban spaces) (Gunnell, Grant, & Williams, 2012). These small green spaces making up the large landscape is understood in landscape ecology in which the green spaces are a part of a broader landscape pattern where different ecological process are taking placeat different spatial and temporal scales (Turner & Bogucki, 1987). Although these anthropogenic green spaces are a part of this ecological system, these disturbances have played a major role in the formation of the current landscape pattern (Turner & Bogucki, 1987). The range in spatial compositions create a heterogeneity of the landscape which, “may enhance or retard the spread of disturbances” (Turner & Bogucki, 1987; v). Disturbances, including anthropogenic changes, are guided by and affect the landscape pattern where anthropogenic changes exhibit more simple patterns than natural landscapes (Turner, 1989). The landscape pattern in urban areas will greatly affect how and where Mexican Free-Tailed Bats choose to forage. Mexican Free-Tailed Bats have evolved for rapid direct flight with reduced maneuverability (Vaughan, 1966) which helps show how important open space can be when foraging for the species.

Figure 2-5: ***Example of How Bats Use Green Infrastructure to Move Through Urban Environments***

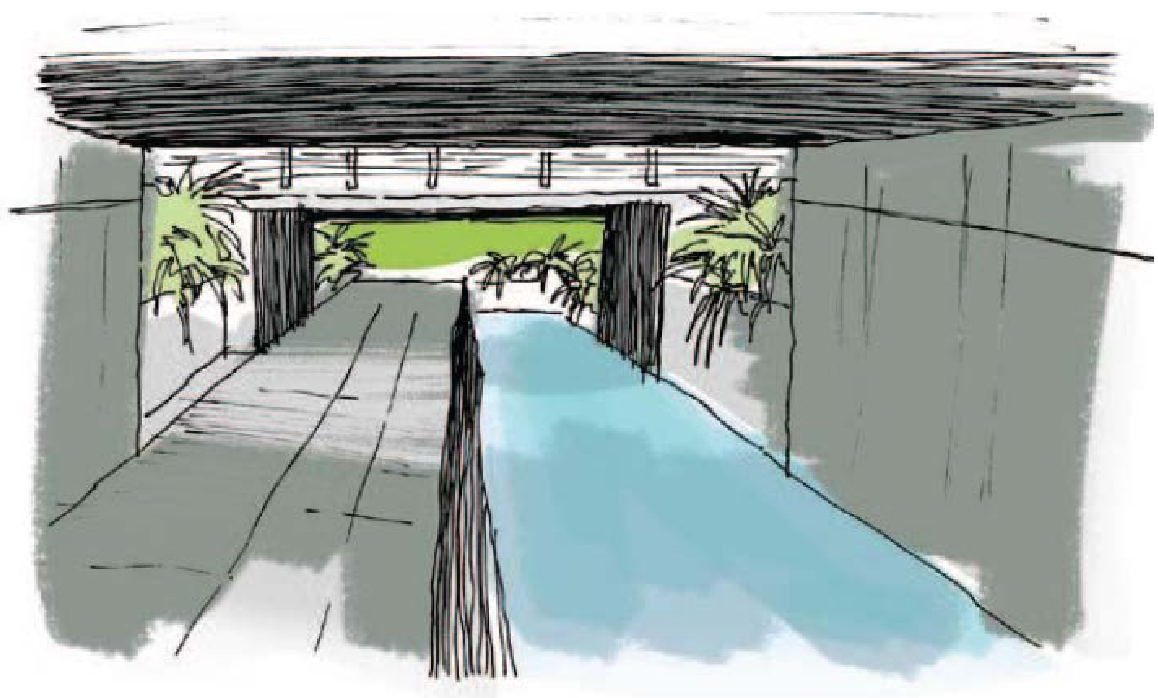


(Gunnell, Grant, & Williams, 2012, pg. 30)

In urban areas roads tend to interrupt landscape connectivity and act as barriers for many species of bats. Creating eco-passages can help to improve landscape connectivity and safety for bat species. The ways bats cross large streets can be looked at as underpasses and overpasses. Underpasses usually consist of culverts or tunnels. Some important aspects to consider for underpasses is the size of the opening should be as large as possible, plantings around the opening should help to direct bats through the underpass, and keep the passage unlit if possible (see Figure 2-6 for a good example of an underpass). Overpasses usually are either hop over points or green bridges. Hop overs are points where tree canopies are either touching or near touching where bats can fly along or over to cross a street or highway (see Figure 2-6). Green bridges, which are bridges that are vegetated along portions of the bridge, can help to provide safe crossing points for bats and other wildlife species (see Figure 2-6). The most important thing to consider for these green bridges is the absence of light through strategic planting to help block traffic lights and create a corridor for crossing.

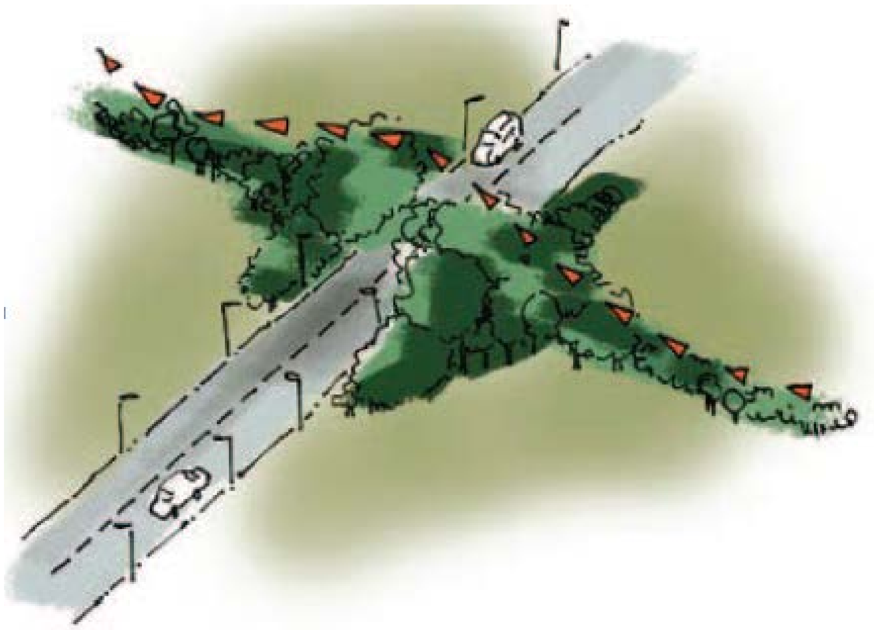
Figure 2-6: ***Examples of Eco-Passages***

Underpass



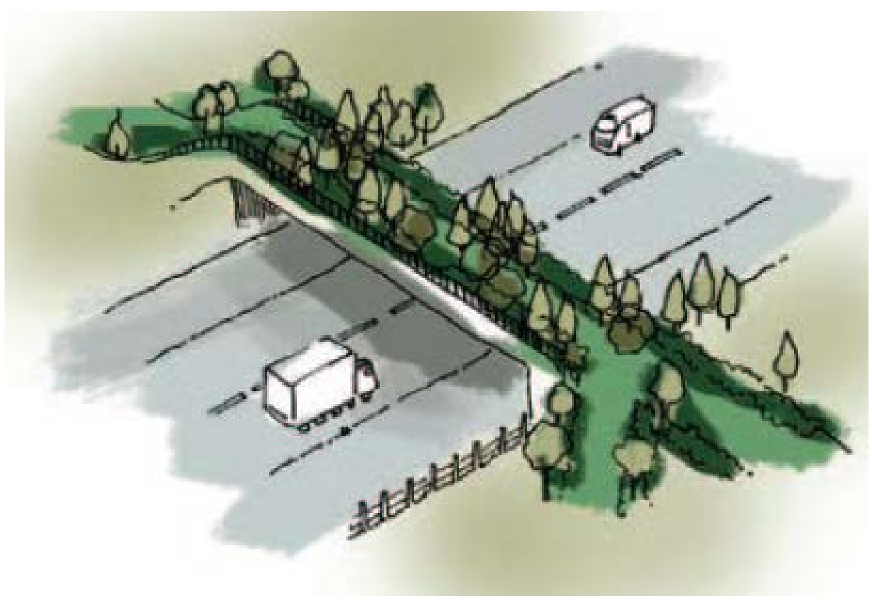
(Gunnell, Grant, & Williams, 2012, pg. 26)

Hop Over



(Gunnell, Grant, & Williams, 2012, pg. 27)

Green Bridge



(Gunnell, Grant, & Williams, 2012, pg. 27)

3 Methods

3.1 Typology

A typology for Mexican Free-Tailed Bats habitat relationships was created to understand Mexican Free-Tailed Bats needs, while succinctly communicating those needs to planners and designers. The base of the understanding for the typology was created through a literature review on Mexican Free-Tailed Bats. Examining literature on Mexican Free-Tailed Bats began with broad literature on the general characteristics and needs of the species and was refined toward studies that are more specific toward the species and the relationships the species has with different landscape elements. This understanding was used to create a structured typology table for Mexican Free-Tailed Bats habitat relations.

The structure of the typology table is set up easily understand Mexican Free-Tailed Bats needs and challenges (see Table 3-1). Types of habitat relationships are divided into subtypes, habitat elements and behavioral elements. A brief description of the relationship the element has with Mexican Free-Tailed Bats follows the each subtype. This description is meant to allow the average person to understand the basic relationship Mexican Free-Tailed Bats have with the each element. The last column is a reference to more detailed information on the species, bats in general, and the spatial model variables. Along with the full Mexican Free-Tailed Bat typology, a more detailed spatial modelling typology is presented to help understand the modeling process. The structure of the spatial modelling typology is the same as the Mexican Free-Tailed Bat typology with two additional columns of information (see Table 3-2). A spatial description of the relationship that is used to inform individual variables for the spatial model follows the description. This spatial description column is meant to help understand specific spatial relationships that are important enough to Mexican Free-Tailed Bats to be included in the spatial model. Following the spatial description is a column that is meant as a simple way to keep track of data availability to be able and locate holes in knowledge or data. Creation of the typology leads to a better understanding of Mexican Free-Tailed Bats, which was used as a base of knowledge to create a spatial suitability model.

Table 3-1: ***Full Typology Structure***

Types	Subtypes	Description (Non-Spatial)	Further Info

Table 3-2: ***Spatial Modelling Typology Structure***

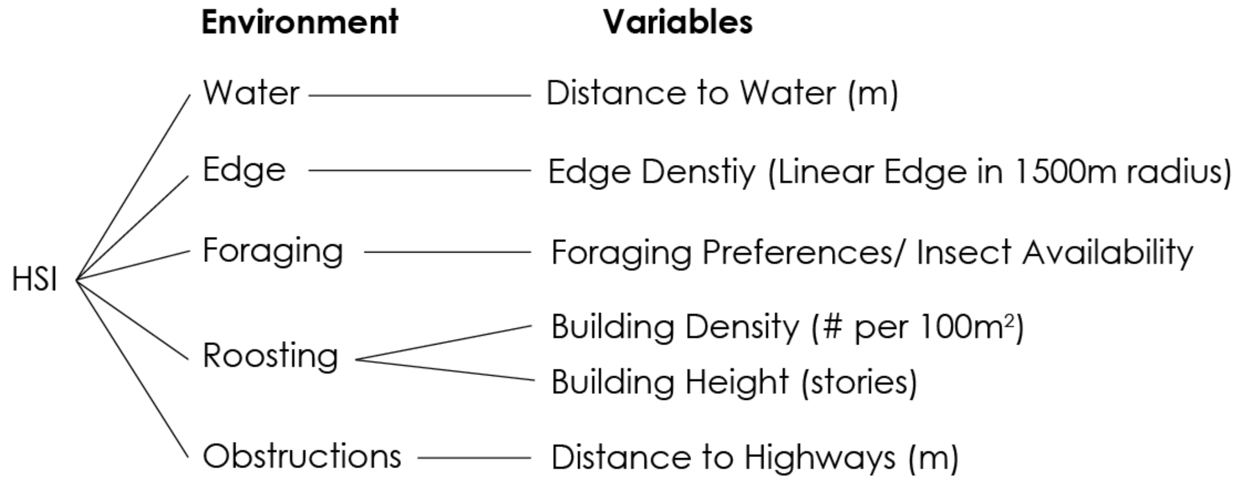
Types	Subtypes	Description (Non-Spatial)	Spatial Suitability Relationship (Habitat Suitability Index)	Data Available	Appendices

3.2 Spatial Suitability Model

Six variables were considered when creating the spatial suitability model for Mexican Free-Tailed Bats. The habitat variables considered are distance to water, total linear edge habitat length in a 1500m radius, foraging habitat preferences, roost density (building density), building height, and distance to highways (see Figure 3-1 for an understanding of what each variable is measuring). Model variables were selected using the understanding of how to identify model variables, originally created by U. S. Fish and Wildlife Service (1980) that states:

> *…variables must meet three criteria: (1) the variable is related to the capacity of the habitat to support the species; (2) there is at least a basic understanding of the relationship of the variable to habitat (e.g., what is the best or worst condition of the variable and how does the variable interact with other variables?); and (3) the variable is practical to measure within the constraints of the model application. (103-ESM-3-5)*

Figure 3-1: ***Mexican Free-Tailed Bat Spatial Suitability Model Diagram***



Habitat Suitability Index (HSI) curves for each variable was created through an in depth literature review on the habitat relationships and resource needs of the Mexican Free-Tailed Bat (U. S. Fish and Wildlife Service, 1981; U. S. Fish And Wildlife Service, 1980). Individual variables understanding of habitat relationships affect the variables strength of classification (U. S. Fish And Wildlife Service, 1980). Understanding wildlife's relationship with their surroundings and the effects changes to those surroundings can have on wildlife species can be complex and poorly studied (McKinney 2002). Therefore, unless detailed data of a variables relationship was available a linear relationship was assumed where the upper and lower limits were derived from individual study's findings on Mexican Free-Tailed Bats. A detailed description of how each HSI curve was created follows:

3.2.1 Creation of HSI for Each Variable

3.2.1.1 Distance to Water:

The distance to water HSI was created through understanding other bats species relationship with water used in other bat species models and then adjusted based on species flight capabilities. Larson, Dijak, Thompson, & Millspaugh (2003) developed HSI models for two bat species in southern Missouri, the Red Bat and the Northern Long-Eared Bat. Using the relationship to water described for each species the distance at which the distance to water shows no suitability for each species is 1.5km and 2km respectively a comparison to Mexican Free-Tailed Bats flight capabilities was made to adjust the curve based on bats flight capabilities. To further the comparison to other bat species, Rittenhouse, Dijak, Thompson III, & Millspaugh (2007) developed a HSI for the Indiana Bat in the Central Hardwoods Region in which 4km was the maximum distance that water provided no suitable areas. The Red Bat and the Indiana Bat are migratory species (Larson, Dijak, Thompson, & Millspaugh, 2003; Rittenhouse, Dijak, Thompson III, & Millspaugh, 2007) similar to Mexican Free-Tailed Bats which shows the species are all capable of long distance flights. Although the species are capable of long-distance flights for migration, nightly foraging ranges and home ranges help to understand the ability and willingness of the individual species to fly nightly. The Red Bats nightly forging range was found to be 1.75km maximum (Ritzi, Sparks, & Whitaker, 2007) while the Indiana Bats nightly foraging range was found to be 4.2km maximum (Murray & Kurta, 2004). Mexican Free-Tailed Bats have shown the ability and willingness to travel up to 56 km a night for foraging (Best et al.,2003) which is a much greater nightly foraging range compared to the other bat species. Using this knowledge the maximum distance from water where there would be no suitability for Mexican Free-Tailed Bats was assumed to be 6km.

3.2.1.2 Distance to Highways:

The distance to highway HSI was created through transforming Mexican Free-Tailed Bats recorded relationship to highways found by Kitzes & Merenlender (2014) into a suitability curve. Mexican Free-Tailed Bat activity was found to be lower as the distance to highways was reduced. The activity of bats was recorded at 0m, 100m, and 300m from highways where the number of Mexican Free-Tailed Bats recorded was 7, 13, and 16 bat recordings respectively (Kitzes & Merenlender, 2014). The same distances were used in the HSI then the curve was adjusted to meet the same ratio of 13/16ths at 100m. Therefore, the suitability at 100m was assigned a value of 0.8125 with 300m used as the upper limit of suitable area.

3.2.1.3 Edge Habitat:

The edge habitat HSI was created through transforming known relationships for bat species into a suitability curve. Duff and Morrell (2007) used mist netting to capture bats at 47 different sites for a base for logistic regression analysis to find what landscape variable are the most important for bat species in the Whiskeytown National Recreation Area to create a predictive occurrence model. It was found that for all species in the area that total linear edge habitat in a 1500m radius had the greatest relative importance in their model to correctly predict a species occurrence. Linear edge habitat was a moving window landscape metric calculated using FRAGSTATS based off the land cover in the area. Total linear edge habitat had a predicted probability between 70-100% where there was at least 39,000m of linear edge habitat in the area (Duff & Morrell, 2007). The upper limit of suitability was then set at 39,000m and assumed to decline linearly towards zero edge habitat in a 1500m radius and no suitability.

3.2.1.4 Roost Quality – Building Height:

Building height HSI was created through another study on Mexican Free-Tailed Bats building roosting preferences. Li and Wilkins (2014) used mobile transect survey echolocation recordings through Waco, Texas to define sites to compare variables in active bat locations to no recording locations using Bayesian logistic effect models. One of the variables that were measured was presence of a tall building in the area, which was found to have a significant positive relationship for Mexican Free-Tailed Bats. Tall buildings were defined as having four or more stories, which was based off studies on other bat species relationship to building roosts. Buildings with four or more stories were set at the upper limit, with the highest suitability, and assumed to decline linearly to no suitability.

3.2.1.5 Roost Density – Buildings:

Roost Density HSI was created through another study on Mexican Free-Tailed Bats building roosting preferences. Li and Wilkins (2014) used mobile transect survey echolocation recordings through Waco, Texas to define sites to compare variables in active bat locations to no recording locations using Bayesian logistic effect models. One of the variables that were measured was building density, which was found to have a significant positive relationship for Mexican Free-Tailed Bats. Building density was manually calculated in 100m radius buffer zones for each site. The mean (24.8) and standard deviation (16.5) from Mexican Free-Tailed Bat recordings for building density was added to each other to get the upper limit of suitability of 40 buildings in a 100m radius.

3.2.1.6 Foraging Preferences:

Foraging preference suitability was based off a study looking to understand the patterns of habitat use by bats in Mexico City. Avila-Flores and Fenton (2005) recorded bat activity in a range of urban and natural sites to compare the use of features by bats in the area. Total number of calls and number of calls with a feeding buzz were recorded at sites such as large parks over 100ha, small parks under 100ha, illuminated open areas (plazas, monuments, temples, parking lots, etc.), residential areas, and natural forested areas. These spaces were converted to a more general classification based off land cover so these areas can be more easily measured (see Table 3-3). The USGS land cover classifications is made up of 21 different classes, which make it more difficult to relate the areas measured by Avila-Flores and Fenton (2005) to a land cover classification type. In addition, the distinction between different types of land cover classes such as forest (deciduous, evergreen, mixed) is not necessary for how each area would be used by bats. Therefore, the USGS land cover classes were simplified to 7 classes based off an individual based ecological model for Mexican Free-Tailed Bats (Taylor, 2009). Taylor (2009) used water, suburban, urban, barren, forest, and agriculture as a simplified land cover classification system for Mexican Free-Tailed Bats. These land cover classifications were modified to include parks bringing the land cover classes represented in this model to water, suburban, urban, barren, forest, agriculture, and parks (see Table 3-4).

Suitability values were assigned to each reclassified land cover class as values from 0-100, with zero offering absolutely no foraging habitat and 100 offering the best foraging habitat, based off Mexican Free-Tailed Bats use of different habitats and willingness to forage in those areas from Avila-Flores and Fenton (2005) findings. Although the foraging preferences of Mexican Free-Tailed Bats in agriculture, water, and barren type areas are not covered in Avila-Flores and Fenton (2005) so these areas have some assumptions. Barren areas are assumed to provide little to no foraging habitat because of the areas are made up of almost completely sand, clay , or rock with less than 15% vegetation (MRLC, 2015) which would not support a high insect abundance or provide many quality flight routes with the lack of vegetation. Agricultural areas have high incest abundance (Horn & Kunz, 2008) but with Mexican Free-Tailed Bat's preference toward foraging in more developed areas (Avila-Flores & Fenton, 2005) agriculture was assigned an intermediate value (see Table 3-5 for suitability values for each land cover class).

Table 3-3: ***Study Data Areas Reclassification Table***

Areas Studies in Avila-Flores & Fenton (2005)	Reclassification to Simplified Bat Land Cover
Large Parks	Park
Small Parks	Park
Illuminated Areas	Urban
Residential Areas	Suburban
Narutal Forest	Forest

Table 3-4: ***Land Cover Reclassification Table***

Areas Studies in Avila-Flores & Fenton (2005)	Reclassification
11 - Open Water	Water
21- Developed, Open Space	Park
22 - Developed, Low Intensity	Suburban
23 - Developed, Medium Intensity	Suburban
24 - Developed, High Intensity	Urban
31 - Barren Land (Rock/Sand/Clay)	Barren
41 - Deciduous Forest	Forest
42 - Evergreen Forest	Forest
43 - Mixed Forest	Forest
52 - Shrub/Scrub	Forest
71 - Grassland/Herbaceous	Forest
81 - Pasture/Hay	Agriculture
82 - Cultivated Crops	Agriculture
90 - Woody Wetlands	Forest
95 - Emergent Herbaceous Wetland	Forest

Table 3-5: ***Land Cover Suitability Value Table***

Reclassified Land Cover Classes	Suitability Value
Water	40
Park	90
Suburban	30
Urban	70
Barren	10
Forest	60
Agriculture	50

All relationships included in the Mexican Free-Tailed Bat suitability model are spatial relationships. Mexican Free-Tailed Bats are generalist species (McCracken, McCracken, & Vawter, 1994; McCracken et al., 2012) and are able to roost in many different roosting structures both natural and manmade (Allen et al. 2009; Geluso 2008; Davis & Cockrum, 1963; Vander Pol, 2012). Therefore, no limiting factor variables were used. The model was created and ran in ArcGIS Desktop Version 10.2.2, 2014. GIS data was collected through online searches for national, state, county, and city databases (refer to Appendix C- Spatial Analysis - Table 7-2 for GIS data references). An output resolution of 30m raster cell size was used because that is the highest resolution of the USGS land cover data available while providing a relatively fine scale analysis over the Austin Metropolitan area. The individual variables in the model were constructed using ArcMap Model Builder. Each variable raster layer is transformed into suitability based off its HSI (refer to Appendix B GIS Modelling for HIS and further information for each variable) and used as a layer for the final suitability map. A more detailed explanation of each variables methods and the resulting GIS layers are as follows:

3.2.2 GIS Methods

3.2.2.1 Distance to Water:

Figure 3-2: ***Distance to Water GIS Methods***

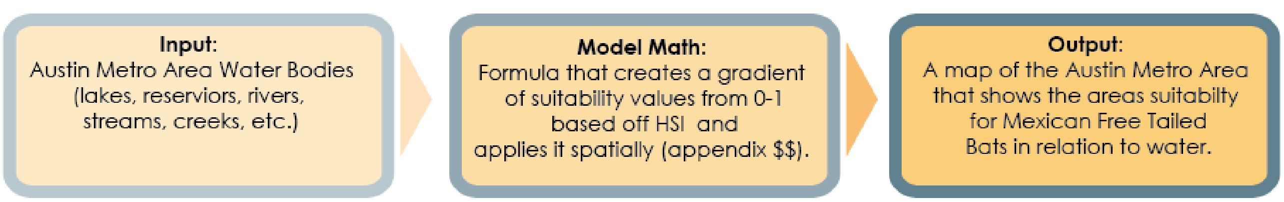


Figure 3-2 visualizes the distance to water modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for distance to water is the Austin metropolitan area water bodies data (Appendix C – Table 7-2). The modelling process takes the HSI curve for the distance to water vairable and applies the information spatially over the Austin metropolitain region. This creates a map of the Austin metropolitian area that shows areas of suitability from high (1) to low (0) in relation to distance to water. The resulting GIS layers can be seen in Figure 3-3 where the process begins with water features and then a distance tool is applied which creates a gradient that is transformed to suitability based on the HSI for distance to water (see Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*Table 4-1Mexican Free-Tailed Bat Spatial Modelling Typology for HSI information for each variable).

Figure 3-3: ***Distance to Water GIS Layers***

3.2.2.2 Distance to Highways:

Figure 3-4: ***Distance to Highways GIS Methods***

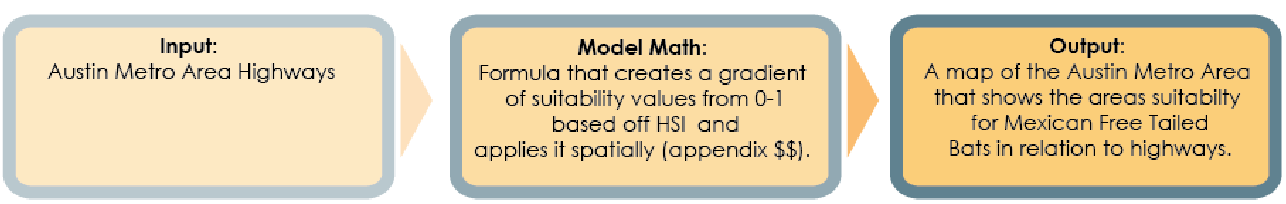
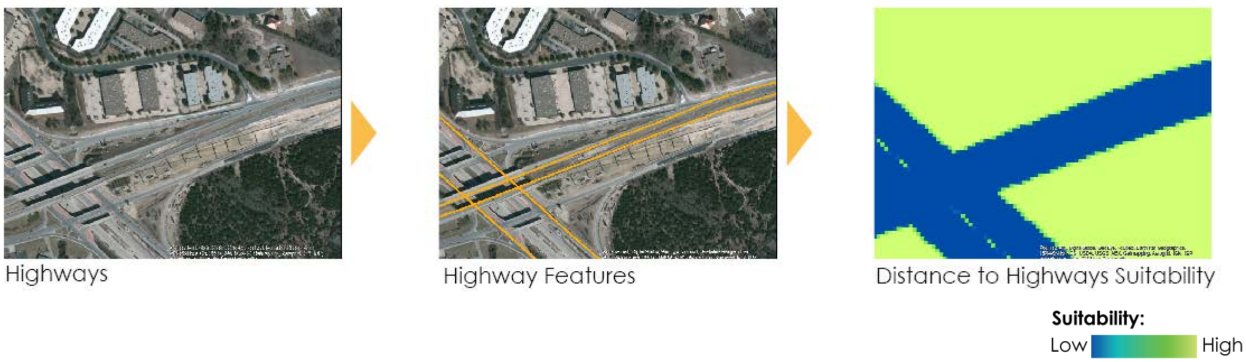


Figure 2-5 visualizes the distance to highways modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for distance to highways is the Austin metropolitan area highways data (Appendix C – Table 7-2). The modelling process takes the HSI curve for the distance to highways variable and applies the information spatially over the Austin metropolitan region. This creates a map of the Austin metropolitan area that shows areas of suitability from high (1) to low (0) in relation to distance to highways. The resulting GIS layers can be seen in Figure 3-5 where the process begins with highways and then a distance tool is applied which creates a gradient that is transformed to suitability based on the HSI for distance to highways (see Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*Table 4-1Mexican Free-Tailed Bat Spatial Modelling Typology for HSI information for each variable).

Figure 3-5: ***Distance to Highways GIS Layers***



3.2.2.3 Edge Habitat:

Figure 3-6: ***Edge Habitat GIS Methods***

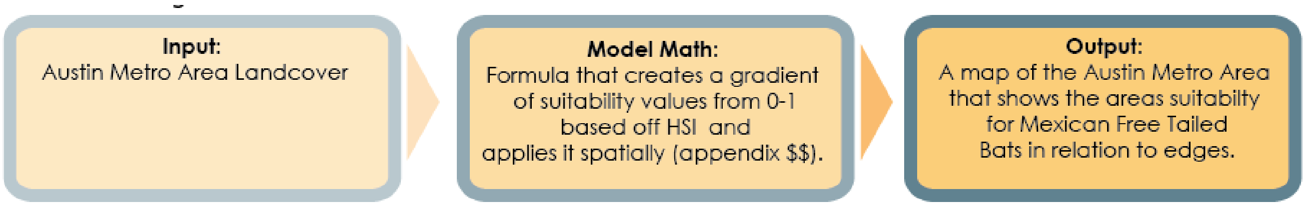


Figure 3-6 visualizes the edge habitat modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for edge habitat is the Austin metropolitian area landcover data (Appendix C – Table 7-2). The modelling process takes the HSI curve for the edge vairable and applies the information spatially over the Austin metropolitain region. This creates a map of the Austin metropolitian area that shows areas of suitability from high (1) to low (0) in relation to surrounding linear edge habitat . The resulting GIS layers can be seen in Figure 3-7 where the process begins with existing land cover which is converted to only the lines (edges) of the landcover to which a density fomula is applied based on the HSI for Edge Habitat. This forumla converts the density gradient to suitability based of the HIS for edge habitat (see Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*Table 4-1Mexican Free-Tailed Bat Spatial Modelling Typology for HSI information for each variable).

Figure 3-7: ***Edge Habitat GIS Layers***

3.2.2.4 Roost Quality – Building Height:

Figure 3-8: ***Building Height GIS Methods***

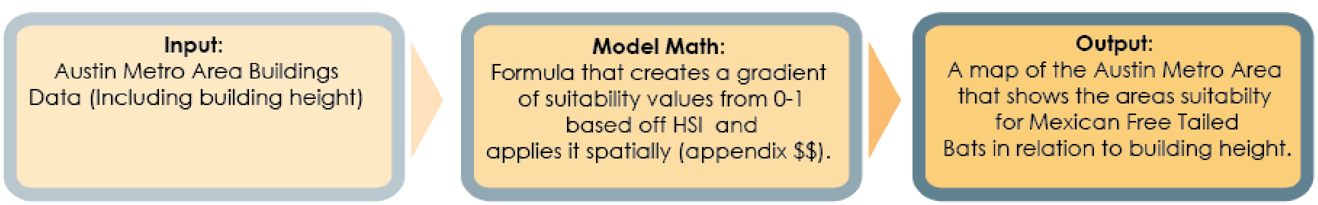


Figure 3-8 visualizes the building height modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for building height is the Austin metropolitian area building data (Appendix C – Table 7-2). The HIS curve for building height is relating building stories to suitability so the building height data had to be transformed into stories. Since buildings range greatly in construction and there is no standard height for a building story, a story was assumed to be 11.5 feet tall. The height of 11.5 ft was used because it is the height used by The Council on Tall Buildings and Urban Habitat (2015) to calculate mixed used buildings height. Mixed use buildings height was chosen because it is the median value and the building types in the Austin metropolitan area rage greatly. The modelling process takes the HSI curve for the distance to highways vairable and applies the information spatially over the Austin metropolitain region. This creates a map of the Austin metropolitian area that shows areas of suitability from high (1) to low (0) in relation to surrounding building height . The resulting GIS layers can be seen in Figure 3-9 where the process begins with existing buildings and then a formula assigns suitability values based off the HSI for building height (see Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*Table 4-1Mexican Free-Tailed Bat Spatial Modelling Typology for HSI information for each variable).

Figure 3-9: ***Building Height GIS Layers***

3.2.2.5 Roost Density – Buildings:

Figure 3-10: ***Building Density GIS Methods***

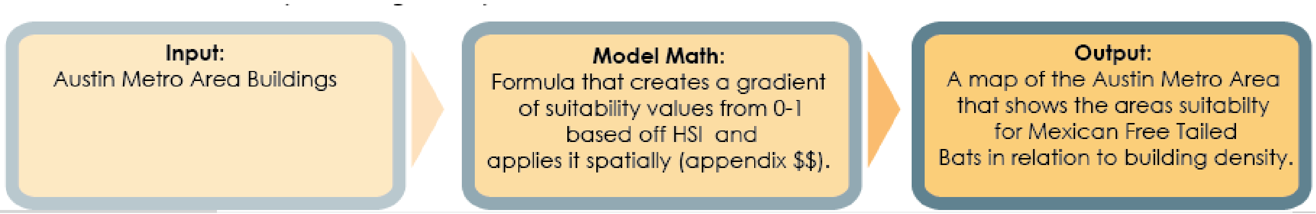


Figure 3-10 visualizes the roost density modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for roost density is the Austin metropolitian area building data (Appendix C – Table 7-2). The modelling process takes the HSI curve for the roost density vairable and applies the information spatially over the Austin metropolitain region. This creates a map of the Austin metropolitian area that shows areas of suitability from high (1) to low (0) in relation to building density . The resulting GIS layers can be seen in Figure 3-11 where the process begins with existing buildings and then the buildings are converted to points to run a point density formula. Then the point density gradient is converted to suitabiliy based of the HSI for building density (see Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*Table 4-1Mexican Free-Tailed Bat Spatial Modelling Typology for HSI information for each variable).

Figure 3-11: ***Building Density GIS Layers***

3.2.2.6 Foraging Preferences:

Figure 3-12: ***Foraging Preferences GIS Methods***

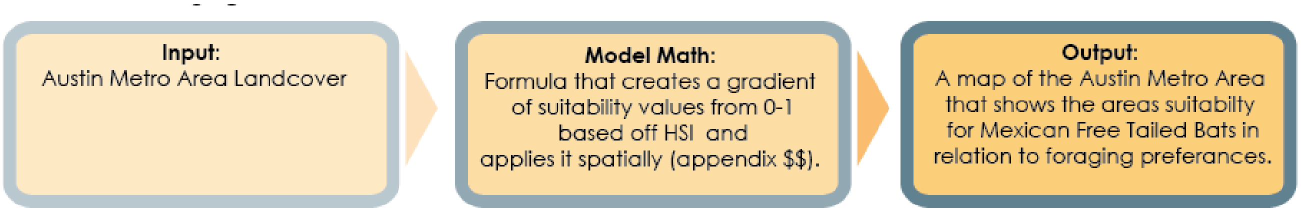
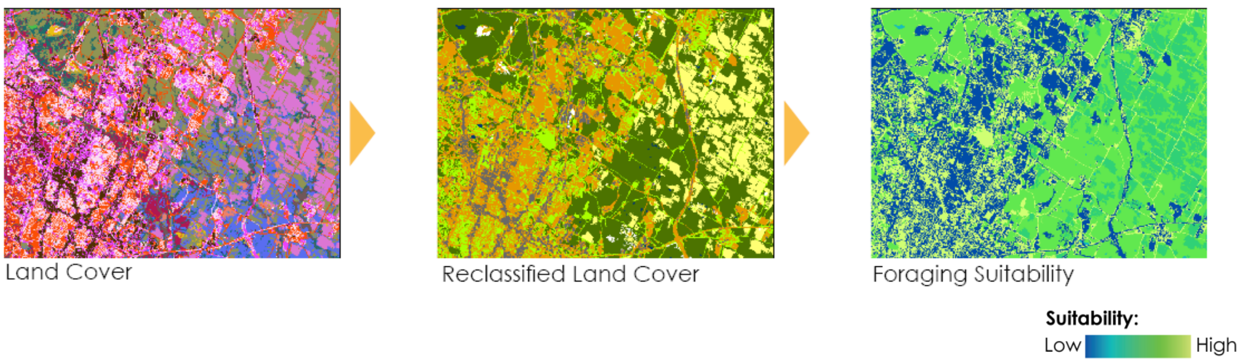


Figure 3-12 visualizes the foraging preferences modelling process to simpler terms (reference Appendix B – GIS Modelling for exact ArcGIS modeling tools). The model input for foraging preferences is the Austin metropolitian area landcover data (Appendix C – Table 7-2). The modelling process takes the HSI curve for the foraging preferences vairable and applies the information spatially over the Austin metropolitain region. This creates a map of the Austin metropolitian area that shows areas of suitability from high (1) to low (0) in relation to Foraging Preferences. The resulting GIS layers can be seen in Figure 3-13 where the process begins with existing land cover and then is reclassified to a simplified landcover. This simplified land cover is converted to suitability using Table 3-5 (as described in foraging preference methods).

Figure 3-13: ***Foraging Preferences GIS Layers***



The process that results in a suitability map begins as individual raster suitability layers, which are the final (furthest right) layers from each variable, described previously. These raster layers are pixilated images where each cell holds a value. The process of combining each variable suitability layer involves “stacking” each raster layer where each cells value is to be used in the model formula (see Figure 3-14 for visualization of this process). Individual variable outputs were combined using an unweighted arithmetic mean to limit assumptions about individual variables importance to Mexican Free-Tailed Bats (see Figure 3-15).

Figure 3-14: *Suitability Modelling Process*

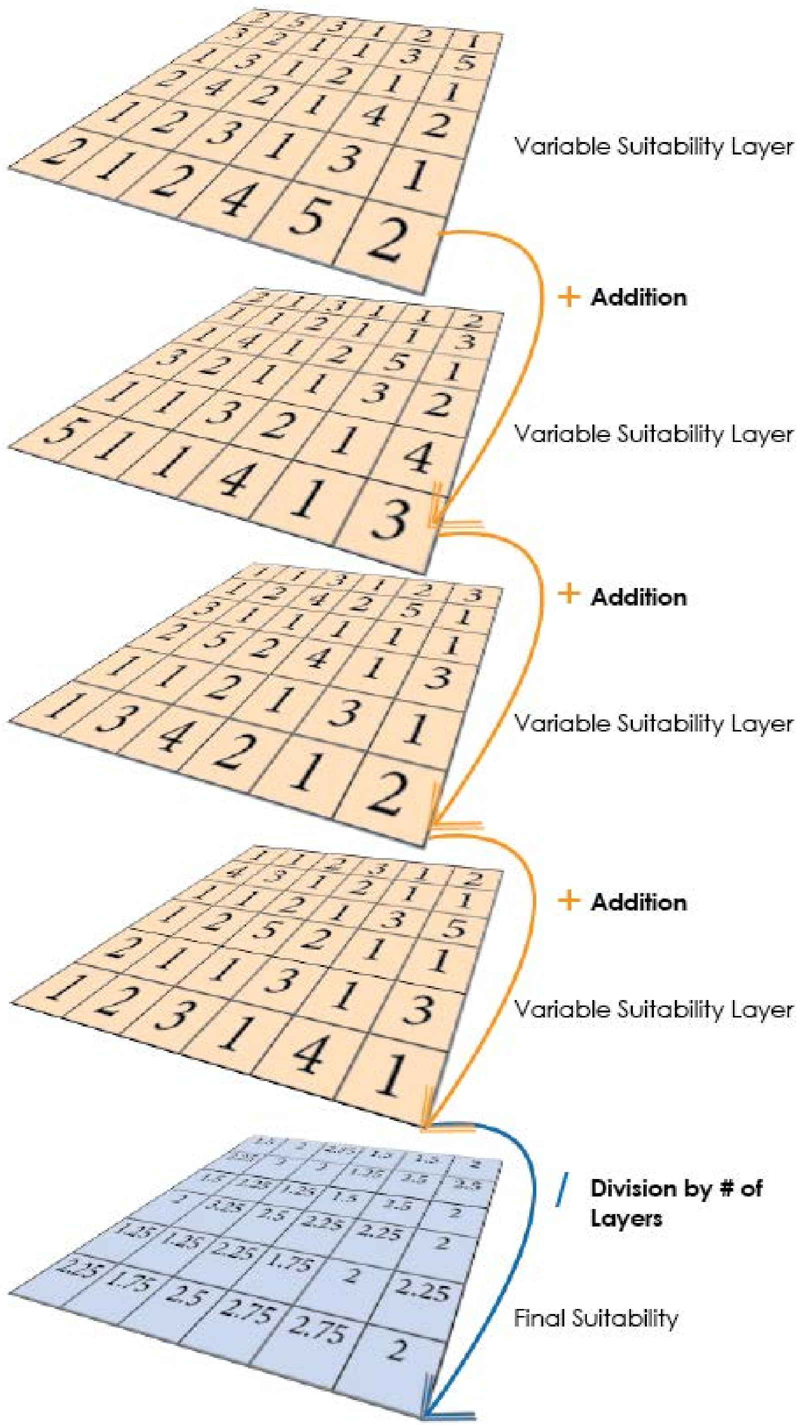


Figure 3-15: ***Final Suitability Model Equation***

$$Suit_i = \left(\sum_{n=1}^{i} V_n \right) / n$$

i=pixel value
V=habitat variables
n=number of variables

3.2.3 Spatial Analysis

3.2.3.1 Goals

The goals of conducting this spatial analysis are to:

1) Check the spatial model quality to make sure areas being classified as highly suitable in fact offer quality habitat opportunities for Mexican Free-Tailed Bats.
2) Gain an understanding of highly suitable areas at a finer scale than the suitability model.
3) Link examples of habitat to habitat opportunities and use by Mexican Free-Tailed Bats.

3.2.3.2 Analysis Methods

A spatial analysis was conducted where the largest groupings of top 40% suitable areas in the Austin Metropolitan Area are located from the model output (see Figure 3-16 the model output and analysis locations). The most suitable areas were chosen by the largest groupings of the top 40% suitability in the Austin Metropolitan Area. Areas that were almost completely in the top 40% suitability for the entire Austin Metropolitan Area were focused around the largest groupings of the highest 10% suitability when locating areas to analyze. By concentrating around the top 10% suitable areas the spatial analysis looks to understand the most suitable areas at a scale of 1:10,000. This scale was chosen because it allowed for a good understanding of the landscape and development, in a large area, from only an aerial image. At this scale it is easy for someone to understand the location of major elements such as development patterns, large structures, waterways, water bodies, vegetated corridors, and possible landscape obstructions from only the aerial. This allows for a good understanding of each area without conducting an in depth analysis of a large portion of the Austin Metropolitan Area because of time constraints.

Fifteen areas were identified for further analysis (see Figure 3-16). After identifying areas within the top 40% suitability the analysis began with exploring major landscape elements with Google Street view. The development in the each area was the next areas explored, with Google Street View, for the analysis. When exploring each area the vegetation arrangement, vegetation quality, the presence of water, open space arrangements, typical building construction, and landscape corridor quality were all considered during the analysis. A literature review on Mexican Free-Tailed Bats guided the understanding of the quality of the elements and how the elements are important for Mexican Free-Tailed Bats. This understanding is visualized in the Mexican Free-Tailed Bat Typology (see Table 4-2 in the Typology Results section). Along with looking at these landscape features each areas access to water, presence of urban land cover, presence of suburban land cover, presence of unprotected open space, and the presence of a highway was recorded to help inform policy proposals. Unprotected open space is open space includes golf courses, campuses, private schools, estates, farmland, and forests that provide open space in which are not being actively protected by the city of Austin.

The structure of each analysis included each location comparing an aerial with the suitability output from the model while further supporting the understanding of each area with Google Street View images showing the typical development and major landscape elements in the area (see Figure 3-17 for example spatial analysis layout). At the top of each layout the areas coordinates help to locate the exact location while a major identifying element is provided to help quickly locate the area in a Google Earth search. Street view images are bordered with a color (red, yellow, blue) to help locate where the view was taken in each area on the aerial image. Each area has an overall description of the development, vegetation, and Mexican Free-Tailed Bat habitat quality and possible uses in the area. This overall description is supported with a description of each of the major identified elements or typical development under each street view image. Each description provides an understanding of the composition of the area and a description of the quality of each element individually and as a whole.

Figure 3-16: ***Model Output – Spatial Analysis Locator Map***

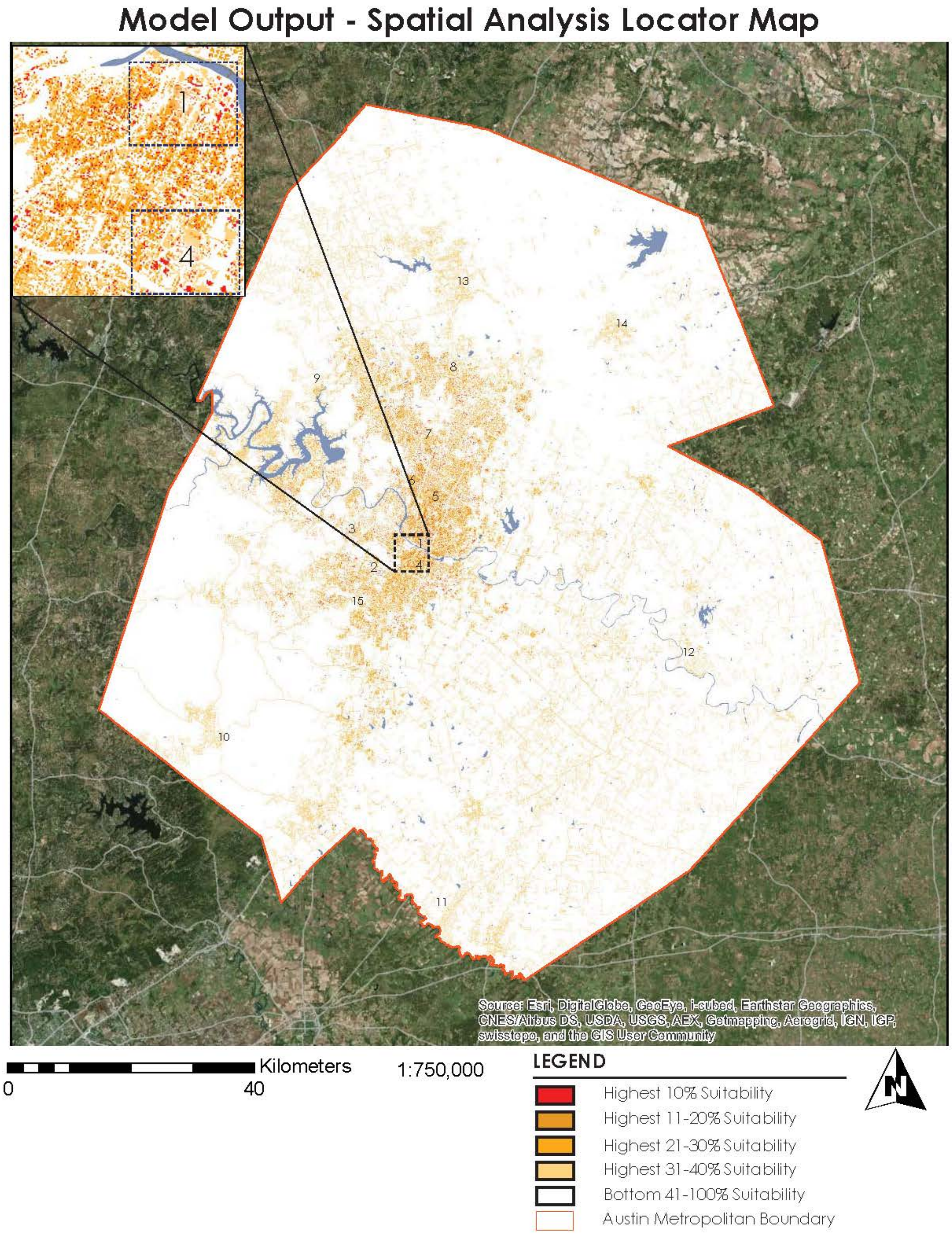
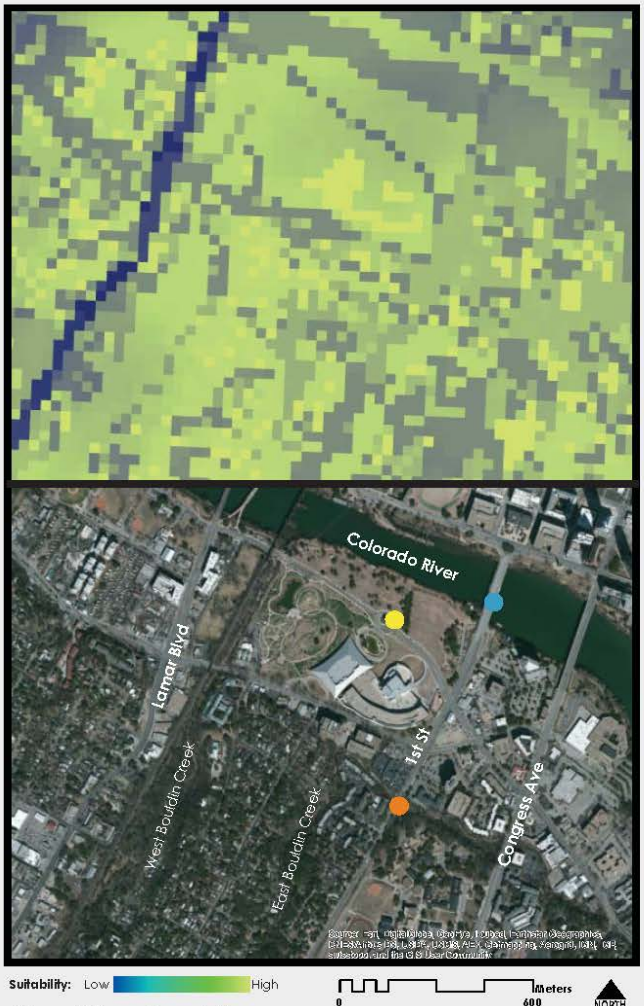


Figure 3-17: ***Spatial Analysis Layout Example***

Spatial Analysis 1

Location: 30°15'36.34" N 97°45'08.76" W
near The Long Center for Performing Arts



Overall Area Description:
The area is on the south side of the Colorado River adjacent to the Austin downtown area. Within this area is the Congress Ave Bridge which is the home of the largest urban Mexican Free Tailed Bat colony in the world. This area provides abundant high quality Mexican Free Tailed Bat habitat because of easy access to lit urban areas, which have shown to be important for the species, and high quality open space along the Colorado River. The area provides many opportunities for roosting as well. With the high density development comes more opportunities for small groupings or day roosts. In addition, the bridges in the area provide high quality large grouping or maternity roost opportunities.

East and West Bouldin Creek
Two large, seemingly unmanaged, creeks that weave through much of the single family low density housing that is in the area. East Bouldin Creek creates a boundary between highly developed urban areas and the low density single family housing in the area. The unmanaged nature of the creeks could create good foraging areas where open space permits and most likely provides good flight paths through the urban areas.

Auditorium Shores at Town Lake Metropolitan Park
A large open green space along the Colorado River that could provide high quality foraging areas because of the open space and proximity to the Colorado River. The close proximity to the Austin downtown area, seen in the background, provides both urban and more natural foraging opportunities.

Colorado River
A large river that runs almost directly through the center of downtown Austin. Although development is concentrated along the river in this area much of the vegetation along the river is maintained. The Colorado River provides a large safe flight path through downtown while most likely providing a wealth of high quality foraging areas along or above the river.

4 Results

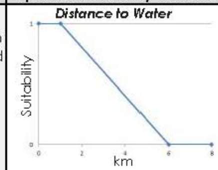
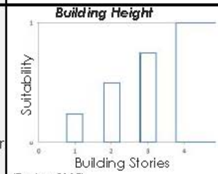
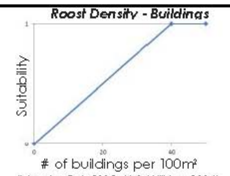
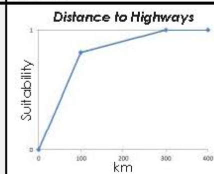
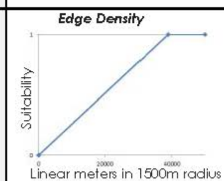
4.1 Typology

A typology is a way of classifying information. This typology represents important habitat elements that affect Mexican Free-Tailed Bats. The following section presents the typology in two ways: 1) only the spatial elements used to better understand habitat suitability modelling for Mexican Free-Tailed Bats and 2) the full Mexican Free-Tailed Bat typology to give a more general understanding of the species needs. The typology shows and describes each type, including subtypes. These types have simple descriptions of an element or a relationship that Mexican Free-Tailed Bats have with an element. Further detailed descriptions of each relationship can be found in the corresponding appendices for each element.

4.1.1 Mexican Free-Tailed Bat Spatial Model Typology

This section provides an understanding of the most important elements, used in the suitability model, with relationships to Mexican Free-Tailed Bats. The spatial model typology (see Table 4-1) is adapted from the full typology, in the following section (see Table 4-2 for full Mexican Free-Tailed Bat typology); to help understand what elements are the most important for the Mexican Free-Tailed Bats and what relationship Mexican Free-Tailed Bats have with each element. This spatial relationship can be seen in the Spatial Suitability Relationship column as represented by a Habitat Suitability Index curve, which relates a spatial quantity to suitability for Mexican Free-Tailed Bats. The Further Info column locates detailed information about each elements relationship and modelling methods.

Table 4-1: *Mexican Free-Tailed Bat Spatial Modelling Typology*

		Description (Non-Spatial)	Spatial Suitability Relationship (Habitat Suitability Index)	Data Available	Further Info
Habitat Elements	**Water**	Mexican Free Tailed Bats are highly evolved to a relatively low daily water intake. Observations on the dietary energetics of the Mexican Free Tailed Bat show it is unclear if Mexican Free Tailed Bats actually drink water at all. Although Mexican Free Tailed Bats may not actually drink water, but water sources are still important for foraging because water tends to attract insect prey (Kunz, Jr, & Wadanoli, 1995)	 (Bellamy et al, 2013; Larson et al., 2003)	Species - No GIS - Yes	Further Information: Appendix A - (H) GIS Modelling: Appendix B - (16)
	Roosting Sites	Roosting sites include caves (Allen et al.; 2009; Geluso; 2008; Wilkins, 1989) and man-made structures like bridges (Davis & Cockrum, 1963; Allen et al., 2009; Wilkins, 1989), buildings (Vander Pol, 2012; Wilkins, 1989), trees, and other man-made infrastructure (Wilkins, 1989).	 (Taylor, 2009)  (Vander Pol, 2012; Li & Wilkins, 2014)	Species - Yes GIS - Caves - No Buildings - Yes Bridges - No	Further Information: Appendix A - (H) GIS Modelling: Appendix B - (11& 12)
	Roads	Activity of Mexican Free Tailed Bats has been shown to have a negative relationship in relation to distance from highways in more natural environments (Kitzes & Merenlender, 2014). While highways may cause some disruption to Mexican Free Tailed Bats, it can be seen that because Mexican Free Tailed Bats tend to favor urban areas to surrounding natural areas (Avila-Flores & Fenton, 2005) typical urban road structures do not seem to have much effect on the species ability or willingness to forage.	 (Kitzes & Merenlender, 2014)	Species - Yes GIS - Yes	Further Information: Appendix A - (H) GIS Modelling: Appendix B - (13)
	Foraging Space	Mexican Free Tailed Bats flight patterns are rapid and direct making open uncluttered space a necessity for foraging (Vaughan, 1966; Simmons et al., 1978).		Species - Yes GIS - Yes	Further Information: Appendix A - (H) GIS Modelling: Appendix B - (15)
	Linear Landscape Elements/Edge Habitat	Edge habitat is important for Mexican Free Tailed Bats because they provide great opportunities for foraging (Swift, Racey, & Avery, 1985; Grüebler, Morand, & Naef-Daenzer, 2008), act as safe navigation routes for bats to fly along providing protection from the elements and predation (Limpens & Kapteyn 1991; Verboom & Spoelstra, 1999), and are along open space which is needed for foraging because of the way Mexican Free Tailed Bats have evolved to fly (Vaughan, 1966; Simmons et al., 1978).	 (Duff & Morrell, 2007)	Species - Yes GIS - Yes	Further Information: Appendix A - (H) GIS Modelling: Appendix B - (14)

4.1.2 *Mexican Free-Tailed Bat Typology*

The Mexican Free-Tailed Bat typology presented here (see Table 4-2) shows important information and relationships to understand Mexican Free-Tailed Bats and their habitat needs. The typology is split into two main subtypes: habitat elements and behavioral elements. Habitat elements are elements that have shown to either be important or have a measurable effect on Mexican Free-Tailed Bats habitat needs. Behavioral elements illustrate behaviors of Mexican Free-Tailed Bats that improve understanding of the species and its habitat needs. Overall, this typology is meant to give the average person a good understanding of Mexican Free-Tailed Bats and their habitat needs.

Additionally, this typology is a way for planners and designers to understand what is important when creating master plans or designing sites for Mexican Free-Tailed Bats benefit. The Further Info column locates more detailed information on each element.

Table 4-2: *Mexican Free-Tailed Bat Typology*

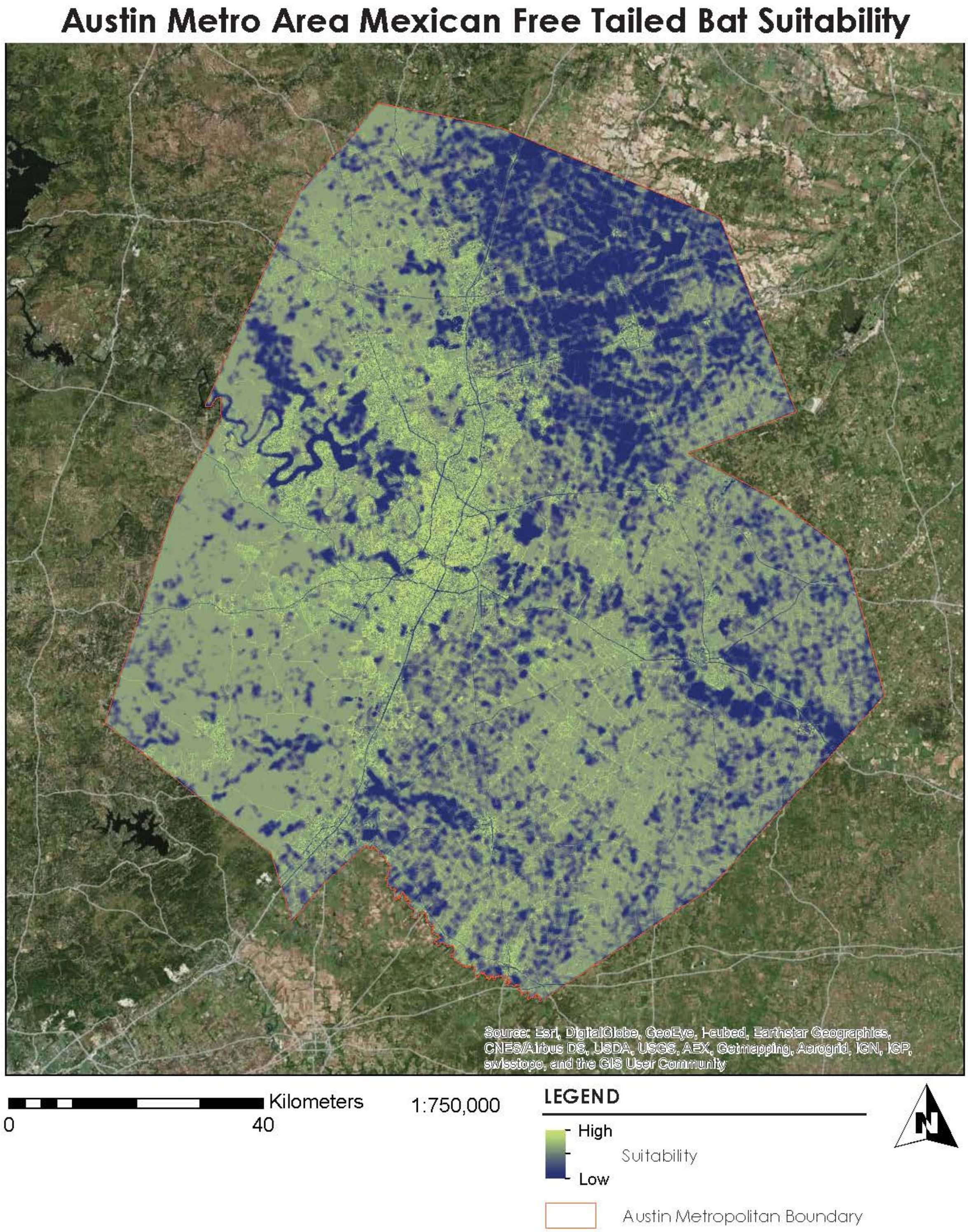
		Description (Non-Spatial)	Further Info
Habitat Elements	Water	Mexican Free Tailed Bats are highly evolved to a relatively low daily water intake. Observations on the dietary energetics of the Mexican Free Tailed Bat show it is unclear if Mexican Free Tailed Bats actually drink water at all. Although Mexican Free Tailed Bats may not actually drink water, water sources are still important for foraging because water tends to attract insect prey (Kunz, Jr, & Wadanoli, 1995)	Appendix A: H-6-N
	Roosting Sites	Roosting sites include caves (Allen et al.; 2009; Geluso; 2008; Wilkins, 1989) and man-made structures like bridges (Davis & Cockrum, 1963; Allen et al., 2009; Wilkins, 1989), buildings (Vander Pol, 2012; Wilkins, 1989), trees, and other man-made infrastructure (Wilkins, 1989).	Appendix A: H-1-D
	Roads	Activity of Mexican Free Tailed Bats has been shown to have a negative relationship in relation to distance from highways in more natural environments (Kitzes & Merenlender, 2014). While highways may cause some disruption to Mexican Free Tailed Bats, it can be seen that becasue Mexican Free Tailed Bats tend to favor urban areas to surrounding natural areas (Avila-Flores & Fenton, 2005) typical urban road structures do not seem to have much effect on the species ability or willingness to forage.	Appendix A: H-4-J
	Artificial Light	Mexican Free Tail Bats have been observed feeding around artificial lights at night (Bell, 1980). In fact Mexican Free Tailed Bats tend to actually favor illuminated areas over other sites such as small parks, residential areas and natural forests (Avila-Flores & Fenton, 2005). Studies have shown that not only will Mexican Free Tailed Bats feed around light, light may actually play an important role in Mexican Free Tailed Bats visual navigation (Mistry, 1990; Mistry & McCracken, 1990).	Appendix A: H-5-K
	Foraging Space	Mexican Free Tailed Bats flight patterns are rapid and direct making open uncluttered space a neccessity for foraging (Vaughan, 1966; Simmons et al., 1978).	Appendix A: F, H-2-F
	Linear Landscape Elements/Edge Habitat	Edge habitat is important for Mexican Free Tailed Bats because they provide great opportunities for foraging (Swift, Racey, & Avery, 1985; Grüebler, Morand, & Naef-Daenzer, 2008), act as safe navigation routes for bats to fly along providing protection from the elements and predation (Limpens & Kapteyn 1991; Verboom & Spoelstra, 1999), and are along open space which is needed for foraging because of the way Mexican Free Tailed Bats have evolved to fly (Vaughan, 1966; Simmons et al., 1978).	2.5.4 - Landscape Connectivity
Behavioral Elements	Anthropocentric Noise	Studies have shown that Mexican Free Tailed Bats are able to adjust their frequencies of echolocation for different situations (Hill, 1984) allowing them to prevent overlap with other bats calls or avoid any environmental noise overlap (Gillam & McCracken, 2007; Simmons et al., 1978). Although bats have been shown to avoid foraging where noise may interfere with echolocation calls (Frenckell & Barclay, 1987) or avoid anthropocentric noise (Hage & Metzner, 2013) the Mexican Free Tailed Bat's ability to adjust echolocation call frequencies could reduce the avoidance of noise clutter or anthropocentric noise. Also Mexican Free Tailed Bats tendacy to favor urban areas over surrounding natural areas (Avila-Flores & Fenton, 2005) shows that anthropcentric noise may not play a major role in the distruption Mexican Free Tailed Bats.	Appendix A: G-B
	Range	Mexican Free-Tailed Bats are one of the most widely distributed species of bats in North and South America (Hall, 1981). Although extensive studies on their range have yet to be completed they are found throughout much of southern North America, Mexico, Central America, and northern South America (Sosnicki 2012; International Union for Conservation, 2014).	Figure 2-2

		Description (Non-Spatial)	Further Info
Behavioral Elements	Communication and Perception	Brazilian free-tailed bats use echolocation as their primary mode of navigation and detecting prey (Gillam & McCracken, 2007; Simmons et al., 1978).	Appendix A: G-B
	Roosting Behavior	Mexican Free Tailed Bats colonies are some of the largest congregations of mammals in the world (Wilkins, 1989) reaching numbers up to tens of millions (Zubaid, McCracken, & Kunz, 2006). Females gather in large maternity roosts usually in caves while smaller groups of both males and females can be found in trees, bridges, buildings, and other man-made structures (Krutzsch, 1955).	Appendix A: H-1-D
	Diet/Prey	Mexican Free Tailed Bats are insectivorous and have a relatively diverse diet compared to most other bat species (Lee & McCracken, 2005; McWilliams, 2005). Mexican Free Tailed Bats have a diet that consisted of 12 insect orders and 35 families of insects, which is the highest diversity recorded in a single study for any bat species (Lee and McCraken, 2005). Another study confirmed the highly diverse diet by finding similar ranges in insect diet diversity (11 orders and 38 families)(McWilliams, 2005).	Appendix A: H-2-F
	Migration	Mexican Free Tailed Bats are a migratory species that have been shown to migrate with different migratory groupings (McCracken, & Vawter, 1994; Davis, Herreid, & Short, 1962). Winters are spent in Mexico and Central America where as individuals migrate north into the United States during summer months. Females often stop further south in large breeding colonies, where as males often venture further north after breeding season.	Appendix A: H-3-G
	Roost Fidelity	Studies on Mexican Free Tails Bats have shown the ability to return to their roosts on a daily (Sgro & Wilkins, 2003) and yearly basis (Schmidly, 1994; Scales & Wilkins, 2007). This shows that roosts are important for the species, even yearly after roosts may not have been occupied during periods of migration.	Appendix A: H-1-D
	Nocturnal	Mexican Free Tailed Bats are nocturnal therefore they employ a daily state of torpor to regulate body temperature and conserve energy (Wilkins, 1989; Krutzsch, 1955).	Appendix A: H-13-H
	Foraging Range	The nightly foraging range of Tadarida brasiliensis at Carlsbad Cavern in New Mexico was recorded to be at least 56 km from the cave (Best et al., 2003). The entire colony had a forging space nearly 4,000 km3 with individual bats being recorded at altitudes of 750m (Best et al., 2003) with he capability to fly at altitudes of up to 1300m (WIlliams et al. 1997).	Appendix A: H-2-F
	Foraging Times	Mexican Free Tailed Bats usually start forging after sunset and feed throughout the night (Best et al., 2003). Observations of Mexican Free Tail Bats from the Orient Mine in the San Luis Valley, California showed that bats on average emerged 15 minutes after sunset (ranging from 25 minutes before to 46 minutes after sunset) (Svoboda & Choate, 1987).	Appendix A: H-2-F
	Flight	Mexican Free Tailed Bats have evolved long narrow wings which makes Mexican Free Tailed Bats most suited to rapid long distance flights with reduced maneuverability (Vaughan, 1966).	Appendix A: F, H-2-F

4.2 Modelling

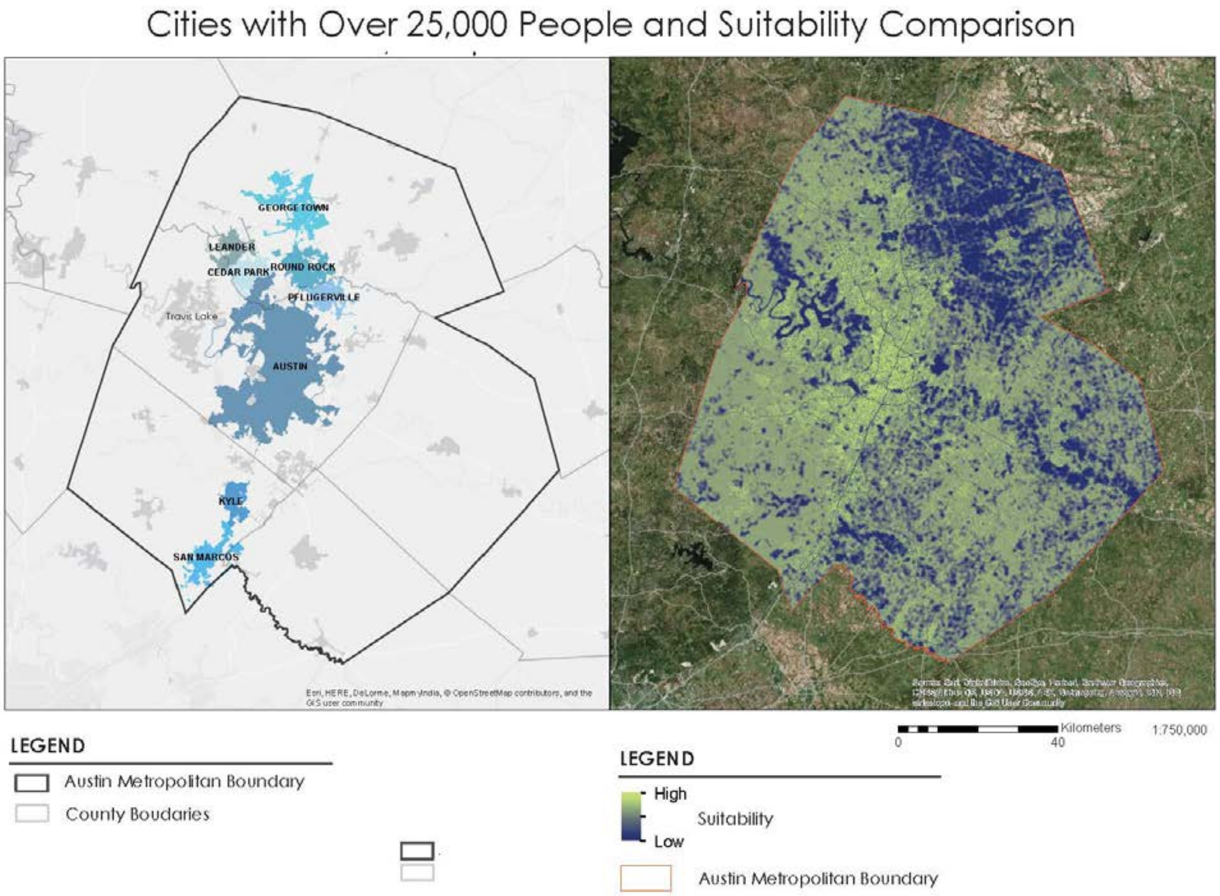
A habitat suitability model for Mexican Free-Tailed Bats was used to create an understanding of Mexican Free-Tailed Bat habitat in the Austin Metropolitan area. The final suitability map (see Figure 4-1) shows a range of suitability across the area with the central Metropolitan area, surrounding Austin, containing the highest suitability for the species. It is important to understand where the urbanized development is located in Austin Metropolitan area to understand the relation to the suitability findings (see Figure 4-2). When comparing the final suitability map to the simplified land cover (see Figure 4-3) the areas of highest suitability coincide mainly with park and urban land cover areas. The areas of lowest suitability coincide with mainly areas of suburban, forest, and agriculture land cover. Forested areas contain a range of suitable values with no visually identifiable pattern. Areas of high suitability, especially in forested areas, coincide with water bodies in the Austin Metropolitan area (see Figure 4-4).

Figure 4-1: ***Austin Metropolitan Area Mexican Free-Tailed Bat Suitability***



(Bradley, 2015)

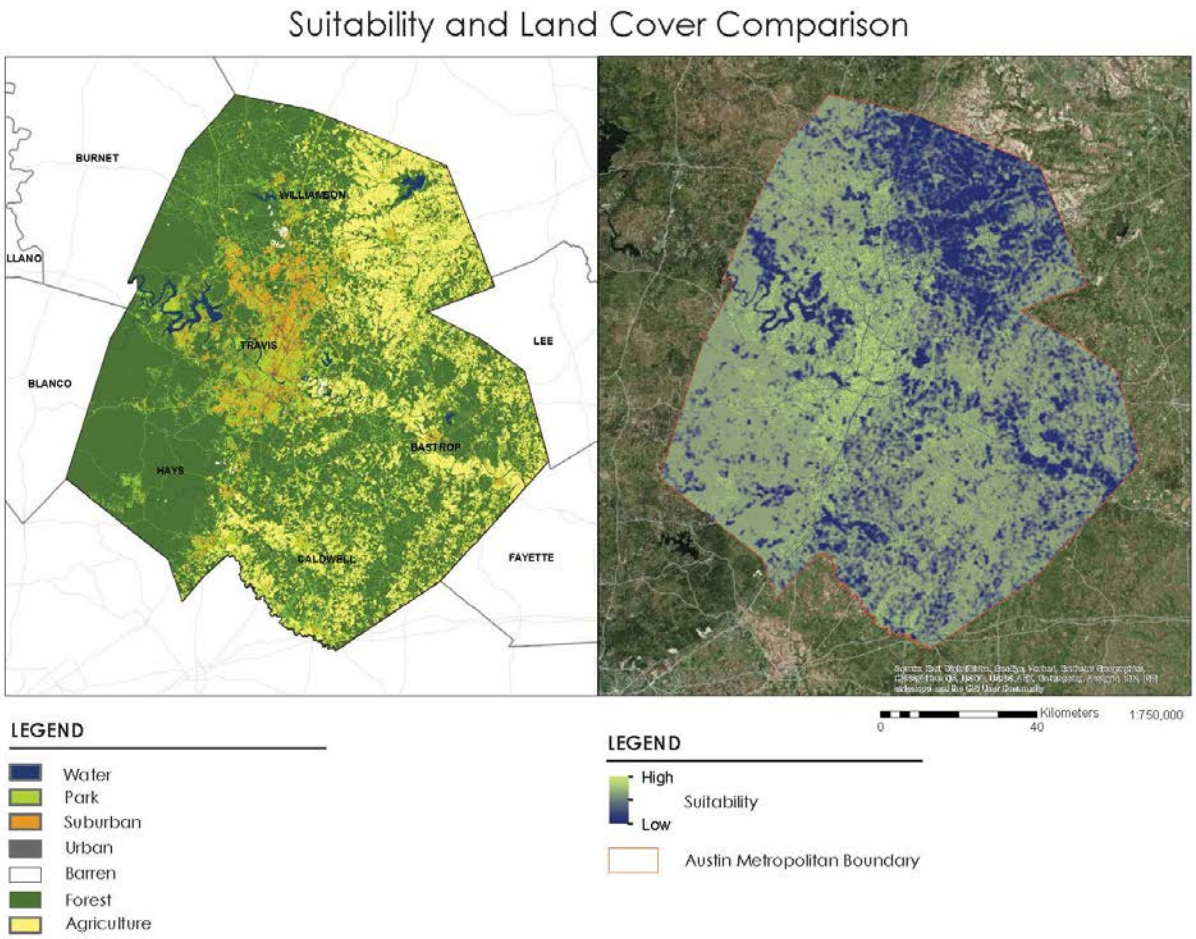
Figure 4-2: ***Cities with Over 25,000 People and Suitability Comparison***



(Bradley, 2015)

The final suitability closely resembles the largest developed areas in the Austin Metropolitan area (see Figure 4-2). It is clear that developed areas in the Austin Metropolitan area provide many highly suitable opportunities for Mexican Free-Tailed Bat habitat. Development around Travis Lake also provides many suitable opportunities for Mexican Free-Tailed Bat habitat.

Figure 4-3: ***Suitability and Land Cover Comparison***



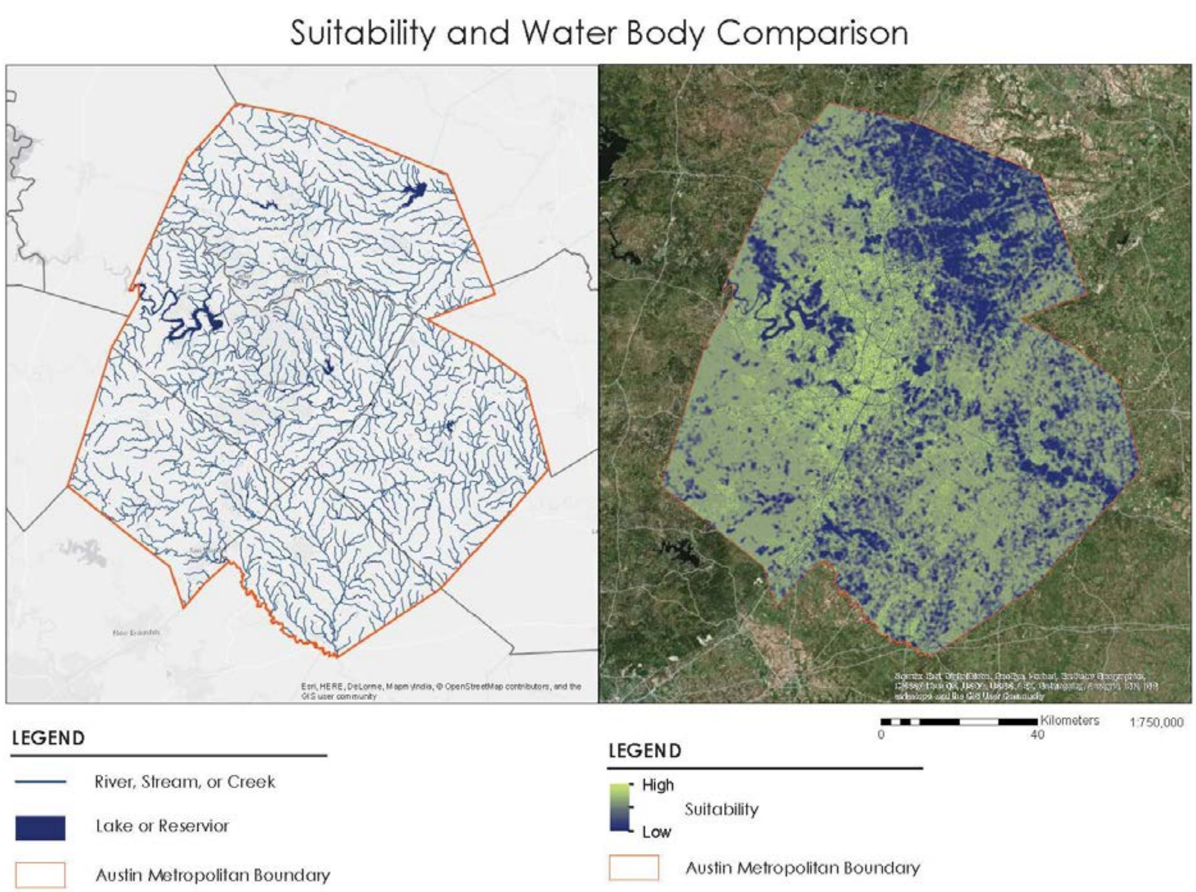
(Bradley, 2015)

Suitability percentages that are located in simplified land cover classes are seen in Table 4-3. Most of the top 20% of suitable areas are located in park simplified land cover areas. Park space makes up 89% of the top 20% suitable areas where the remaining top suitable areas are in urban simplified land cover areas. Most of the top 21-40% suitable areas are also located in the park simplified land cover areas. Park space makes up 39% of the top 21-40% suitable areas. Suburban areas make up the next greatest top 21-40% areas with 29% of the top 21-40% suitable areas being suburban simplified land cover areas. The bottom 20% suitable areas are made up of mostly suburban simplified land cover areas. Suburban areas make up 89% of the bottom 20% suitable areas in the Austin Metropolitan Region.

Table 4-3: ***Simplified Land Cover Located in Suitable Areas***

Suitability Ranges	Water	Park	Suburban	Urban	Barren	Forest	Agriculture
Top 20%	0%	89%	0%	11%	0%	0%	0%
21-40%	0%	39%	29%	14%	0%	17%	1%
41-60%	1%	11%	5%	1%	0%	70%	13%
61-80%	4%	1%	3%	0%	2%	39%	50%
Bottom 20%	0%	1%	89%	0%	0%	4%	2%

Figure 4-4: ***Suitability and Water Body Comparison***



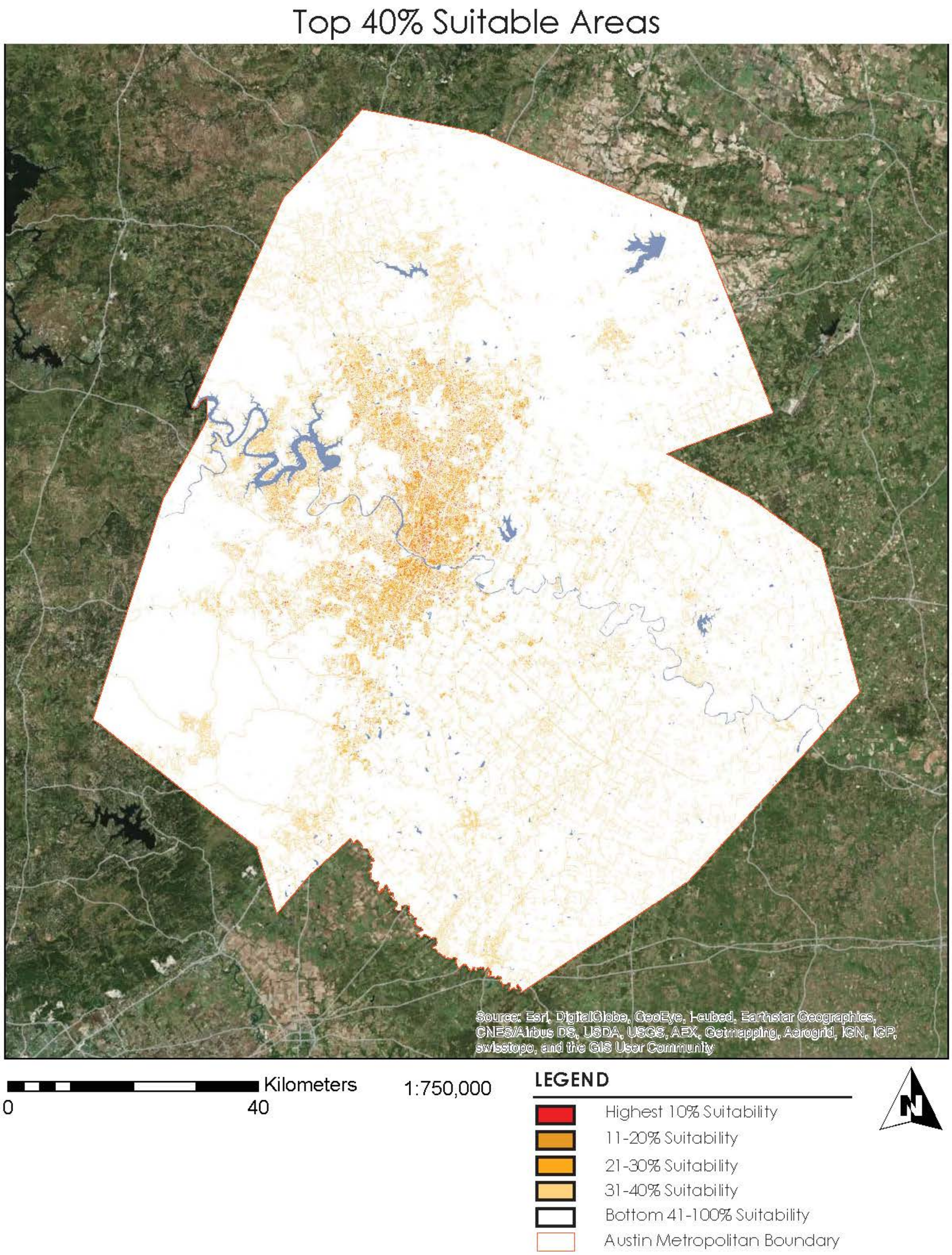
(Bradley, 2015)

Suitability percentages that are located within 300m from water sources are seen in Table 4-4. Suitability results in relation to 300m from water sources are evenly distributed between the top 40% and the bottom 40% of suitable areas. The top 61-80% of suitable areas make up 32% of the total area that is within 300m from water sources. The next greatest suitable areas within 300m from water sources are the top 21-40% suitable areas, which make up 31% of the total areas within 300m form water.

Table 4-4: ***Suitability Results within 300m from Water***

Suitability Ranges	Percent Suitability 300m from Water
Top 20%	24%
21-40%	31%
41-60%	4%
61-80%	32%
Bottom 20%	22%

Figure 4-5: ***Top 40% Suitable Areas***



(Bradley, 2015)

Areas with the highest 40% suitability are located centrally in the Austin Metropolitan area and closely follow the largest development in the Austin Metropolitan area. This shows that much of the developed area in and around Austin is highly suitable for Mexican Free-Tailed Bats. Another large grouping of the highest suitable areas is concentrated around Travis Lake. Overall, the highest suitability closely follows development in the Austin Metropolitan Region.

4.3 Spatial Analysis

A spatial analysis was conducted to better understand the landscape at a finer scale while helping to confirm the models results. This analysis was meant to allow the author to better understand the Austin area and explore some of the finer scale landscape qualities that were identified at the metropolitan scale to be highly suitable for Mexican Free-Tailed Bats. No recorded Mexican Free-Tailed Bat location data was used in this analysis so it is only looking at an areas ability to support Mexican Free-Tailed Bats habitat needs.

All the areas that were analyzed at a finer scale except one included some amount of residential development. Out of the 15 areas that were analyzed only one area provides few opportunities for quality Mexican Free-Tailed Bat habitat. In this case the area was almost completely dominated by an energy plant that limited the areas vegetation cover and access to resources. Additionally, operation of the plant could cause disturbances to Mexican Free-Tailed Bats. All other areas provided highly suitable habitat opportunities for Mexican Free-Tailed Bats. Table 4-5 shows the percentages out of the 15 total areas analyzed that included unprotected open space, a water source, urban land cover, suburban land cover, and a highway that intersects the area. For a more detailed breakdown of each area analyzed, see Appendix C – Spatial Analysis.

Table 4-5: Spatial Analysis Results

Percent of Spatial Analysis Areas that Include	Unprotected Open Space	Water Source	Urban	Suburban	Highway
	93%	93%	73%	93%	46%

An important observation from the spatial analysis is residential areas contain mostly mature vegetation, which help to support foraging needs by supporting a high insect abundance. Waterways located in the areas of high suitability are mostly naturalized with dense mature vegetation along the waterway and its banks. These vegetated waterway corridors help support a high insect abundance and provide good opportunities for quality flight paths, which help to support landscape connectivity allowing Mexican Free-Tailed Bats to access resources in the area. Of the areas analyzed, no area included waterways that have been paved over or where vegetation had been completely removed over a long distance. Areas along waterways that have been obstructed by roads are the most common feature that interrupts waterway corridors. It is important that these points where roads cross waterways that vegetation be present, because it can improve a bats willingness to cross street gaps in flight paths. It will be important to maintain quality-crossing points over highways in highly suitable areas, while future development should look to maintain or enhance highway-crossing points.

5 Design Methodology

5.1 Introduction

To understand how planning and design can support Mexican Free-Tailed Bats this section synthesizes the methods and results up to this point and provides an understanding Austin's current development patterns that will allow for the proposal of planning policies to help protect and provide Mexican Free-Tailed Bat habitat in future development. After proposing policies, examples of current projects in Austin are used to demonstration what affect these policies can have proposed development and how the Mexican Free-Tailed Bat habitat needs can be better supported using the proposed planning policies. Further site-specific considerations for Mexican Free-Tailed Bats, from the understanding of the Mexican Free-Tailed Bat Typology, are discussed for each site to support Mexican Free-Tailed Bats habitat. The following planning and design goals will guide these policies and site design considerations:

1) Improve landscape connectivity.
2) Create quality or improve exiting Mexican Free-Tailed Bat habitat opportunities.
3) Integrate Austin's future master plan goals into the Mexican Free-Tailed Bat planning policies to support Austin's current culture and vision.

5.2 Austin's Current Development

Understanding Austin's current development and Austin's future goals for development is important to guide proposed policy interventions to benefit Mexican Free-Tailed Bats. Austin is guided by many master plans (City of Austin, n.d.) but the comprehensive master plan, Imagine Austin, gives a good understanding of Austin's future goals and development patterns.

5.2.1 Austin's Future – Imagine Austin Comprehensive Plan

Imagine Austin is guided by an overall vision, which lays out the most important goals for the future of Austin development. Austin's vision is divided into seven main goals: Austin is livable, Austin is natural and sustainable, Austin is mobile and interconnected, Austin is prosperous, Austin values and respects its people, Austin is creative, and Austin is educated (Imagine Austin Partnership, 2012). Each goal is further described to give a understanding of priorities for each goal. The following summaries of Austin's goals provide a good understanding of how Austin is planning on developing.

Austin being livable focuses on resident's access to a range of diverse housing options that support each areas history and character. Another important aspect of Austin being livable is the access to quality public facilities such as schools, parks, libraries, recreation, and health and human services. Livability as a goal goes beyond just providing a range or quality living opportunities. Austin wishes to support developing in a connected and pedestrian friendly manner that would help reduce sprawl. Reducing sprawl and improving connectivity for both bats and pedestrians is important for the proposed Mexican Free-Tailed Bat planning policies and helps to support Austin's future goals. Supporting the needs of people with disabilities is another important part of livability. Downtown development is important and Austin's downtown should support a safe vibrant urban lifestyle. The final priorities for Austin being livable are to supports local businesses and to provide Austin's population with healthy living opportunities. (Imagine Austin Partnership, 2012)

Austin being natural and sustainable focuses on Austin's future as a green city. Austin is looking to support the long-term health of the community through responsible resource management. The main resources that Austin wishes to protect or improve are open space and parks, the Colorado River, Hill Country, Blackland Prairie, local farmland, water, energy use, and reducing greenhouse gas emissions (Imagine Austin Partnership, 2012). These types of resources are important for Mexican Free-Tailed Bats an supporting sustainable practices is important for the proposed Mexican Free-Tailed Bat planning policies.

Austin being mobile and interconnected focuses on Austin's accessibility and sustainability. Interconnectivity and mobility are planned to be achieved by creating a variety of affordable transit options while supporting public transit. Transit options should help reduce sprawl, travel times, and negative impacts on the environment or protect Austin's natural resources. (Imagine Austin Partnership, 2012)

Austin being prosperous focuses on continuing to improve the health, vitality, and sustainability of the city to create an economy that is resilient and responsive to global trends. Austin sees it creativity and innovation as the drivers behind Austin's current economy in arts, research and development, and technology. These are all to be integrated with Austin's ecology to create an overall more sustainable and prosperous city. Austin plans on continuing these trends by providing everyone opportunities to quality education, training, and jobs. (Imagine Austin Partnership, 2012)

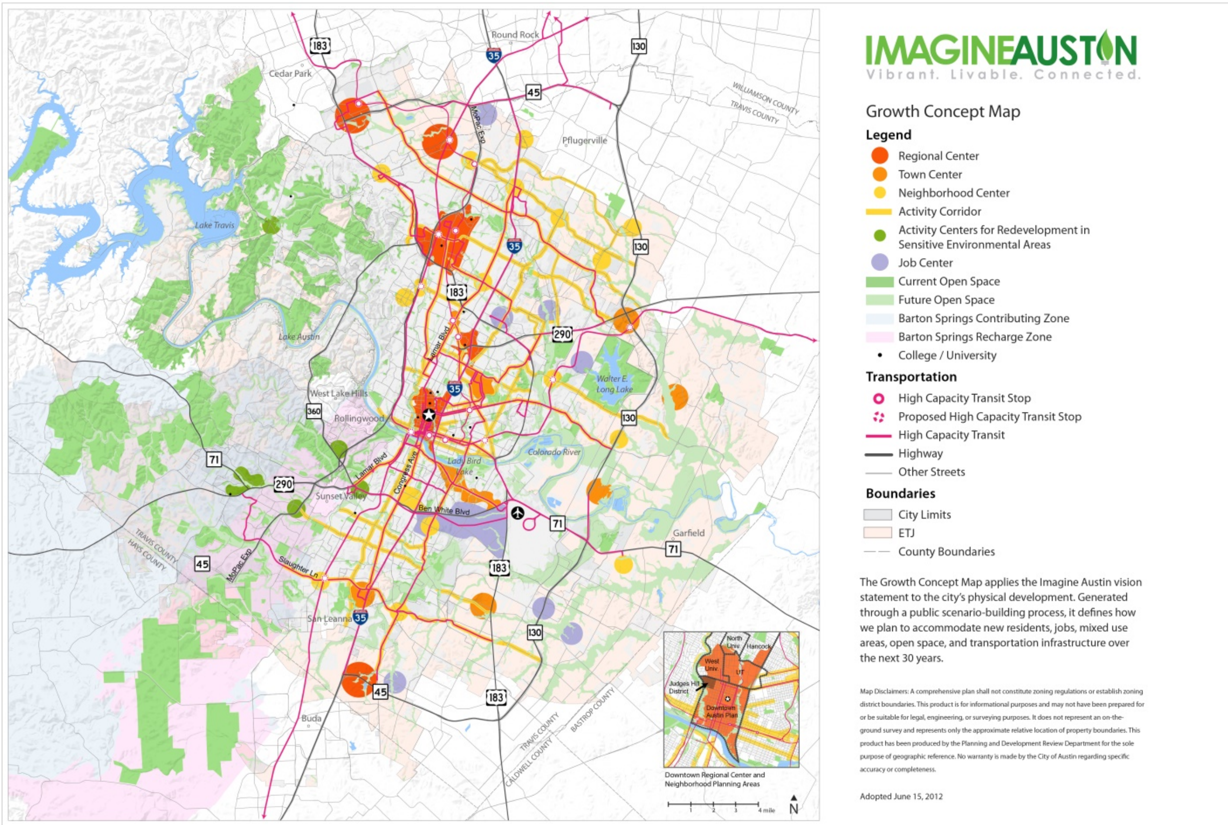
Austin valuing and respecting its people begins with supporting diversity and creativity that is currently helping drive the city of Austin. Austin plans on supporting this by providing a range of living, economic, healthcare, education, and transportation opportunities to help support diversity while preserving the history of its areas and people. The Austin government also supports equal rights while being transparent and accountable in its actions. Overall the goal of Austin valuing and respecting its people comes to down supporting the people's needs and understanding how important the people are in the shaping the future of Austin. (Imagine Austin Partnership, 2012)

Austin being creative focuses on Austin's identity, quality of life, and economy being driven by creativity. This includes opportunities for residents and visitors to participate in arts and cultural activities by making the activities accessible, visible, and valuable. The last piece of making Austin creative is creating an environment that reflects people's creativity through design, public art, and accessible public spaces. (Imagine Austin Partnership, 2012)

Austin being educated focuses on providing quality resources for everyone which help to develop peoples full potential. These resources are concentrated around community schools and library that along with private partnerships provide opportunities for community collaboration, recreation, social events, and learning. Overall Austin's education is built on making everything easily accessible to everyone in the city. (Imagine Austin Partnership, 2012)

These goals are important for directing policy changes where overlaps with supporting Mexican Free-Tailed Bat habitat exist. In addition, Austin's goals will be incorporated into the Mexican Free-Tailed Bat policy changes to help support Austin's future plans. Austin's goals for development are visualized in Imagine Austin's Growth Concept Map, which helps locate major centers for development and future activity corridors to increase accessibility to parks, open space and these development centers (see Figure 5-1).

Figure 5-1: ***Imagine Austin Growth Concept Map***



(City of Austin, 2012, p. 103)

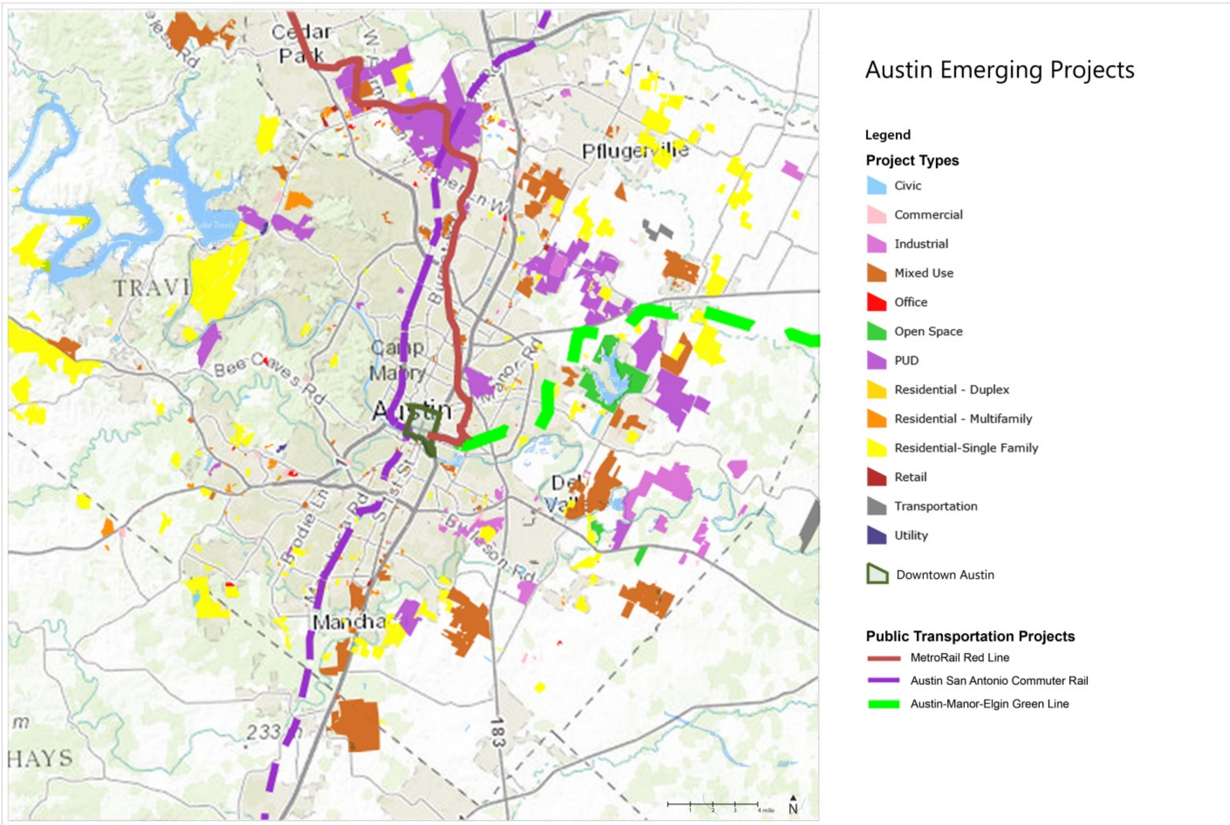
Figure 5-1 visualizes where Austin is trying to create or improve major development centers and shows the important activity corridors that are planned to connect future development and open spaces. This growth concept map is important because it provides an understanding of future development patterns. After understanding how and where Austin is planning to develop in the future, it becomes important to understand current development trends in Austin.

5.2.2 Current Development in Austin

It is important to understand current development trends in Austin to understand what types of development are most common and to see how closely current development trends are following the comprehensive master plan. Comprehensive master plans are visions of the future that help guide major development trends but real world situations guide current development at a finer scale that relate to what is economically feasible at the time. Austin keeps track of prominent ongoing development in an online database on the cities website, http://www.austintexas.gov/page/emerging-projects. This database shows prominent projects in the planning or construction phases in Austin that are more than 10 acres or that will have at least 20 residential units planned for development (Austin Planning and Development Review Department, 2015). Although these may not include all development in Austin these projects are the main projects driving trends in current and future development in the area. These developments provide a good understanding of Austin's current development patterns.

Most of Austin's large development is on the edge of the city with smaller projects located throughout the city (see Figure 5-2 for a visualization of Austin's current development). The projects on the edge of Austin are made up of mainly mixed use, planned unit developments (PUD), and single-family residential developments. In addition, much of the development is concentrated to the east, which shows that Austin is currently expanding east faster than any other direction. Centrally located projects are mostly smaller mixed use and multifamily residential projects. Much of the development on the west side of Austin consists of single-family residential development. Development trends are important in relation to current and planned public transportation projects. Two major rail projects are being planned in Austin. The Metro Rail Red Line is a metropolitan line that currently connects downtown Austin to Leander. The Austin-San Antonio Commuter Rail is a large commuter rail planned to connect Georgetown, which is just north of Austin, to San Antonio. The second project that is being planned is an expansion of the current commuting rail system to add a green line which connects downtown Austin to Elgin, to the east, which will complement the westward red line. This proposed green line further supports Austin's trend of expanding east and would help connect future development centers to downtown Austin and Elgin, if or when the proposal is confirmed (Austin Planning and Development Review Department, 2015).

Figure 5-2: ***Austin Emerging Projects***



(Bradley, 2015)

5.2.3 *Current Development in High Suitability Areas*

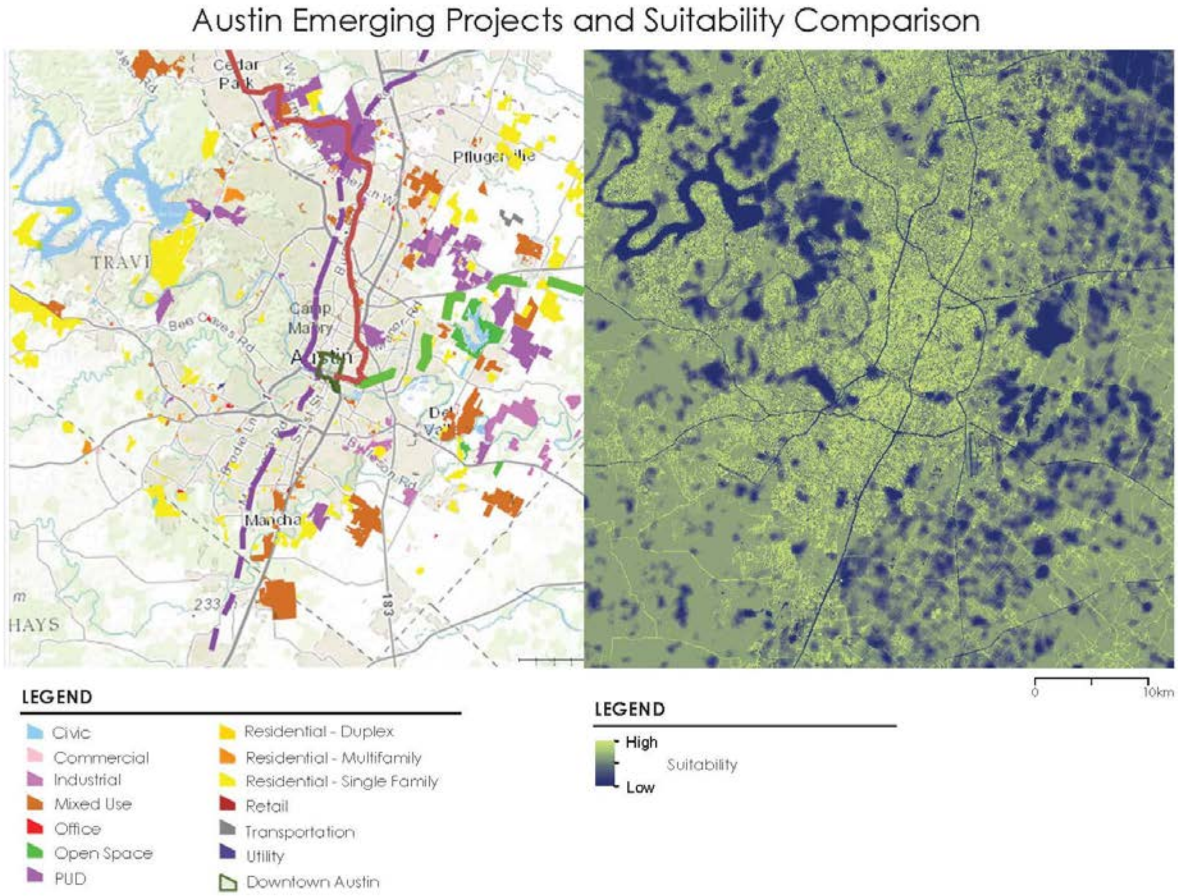
After understanding Austin's current development patterns it is important to understand how the proposed development can affect highly suitable Mexican Free-Tailed Bat habitat areas. This allows for an understanding of scale and rate at which Austin's current development could disturb Mexican Free-Tailed Bat habitat. Projects that could disturb highly suitable areas were located using ArcGIS Desktop Version 10.2.2, 2014. There are currently 715 projects in development in Austin (Austin Planning and Development Review Department, 2015). Out of the 715 total current projects in Austin, zero projects have the opportunity to disturb the highest 10% of suitable habitat. This shows that all of the highest suitable habitat in the Austin Metropolitan area is not at current risk of harm, but future projects should consider the projects location if it is located in these areas and carefully consider how the development could affect Mexican Free-Tailed Bat habitat. There are 43 projects currently being developed in the

Austin area that have the opportunity to disturb the top 25% of suitable habitats in the Austin Metropolitan area. Additionally, 663 current projects in Austin have the opportunity to disturb the top 50% of suitable habitat (see Table 5-1). This shows that 93% of current Austin projects have the opportunity to disturb the top half of suitable Mexican Free-Tailed Bat habitat in the Austin area. With so much development that can disturb quality Mexican Free-Tailed Bat habitat it is even more important to set up policies that will guide development and development patterns in the future.

Table 5-1: Austin Development in Highly Suitable Areas

Suitability Ranges	Projects Located in Suitable Areas
Top 10%	0
Top 25%	43
Top 50%	663

Figure 5-3: Austin Emerging Projects and Suitability Comparison



(Bradley, 2015)

5.2.4 Findings Relevance to Planning Policies

5.2.4.1 Model Findings

One of the most important findings from the model output is that 89% of the top suitable areas were located in the simplified land cover class park. This class was reclassified from USGS land cover class 21, developed open space. This type of space will be important for maintaining high quality habitat for Mexican Free-Tailed Bats. Park simplified land cover is defined as:

> *"areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot*

single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes." (U.S. Geological Survey (USGS), 2006)

This type of open space is important to Mexican Free-Tailed Bats for quality foraging opportunities (Vaughan, 1966; Simmons et al., 1978) and to provide opportunities for flight paths which allow safe movement across the landscape (Swift, Racey, & Avery, 1985; Grüebler, Morand, & Naef-Daenzer, 2008) (refer to Table 4-2: *Mexican Free-Tailed Bat Typology*). Open space should be an important consideration for future development policies to help Austin support Mexican Free-Tailed Bats.

The other 11% of the top 20% suitability was located in the simplified land cover class Urban. This class was reclassified from USGS land cover class 24, developed high intensity. Urban simplified land cover is defined as:

> "highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover." (U.S. Geological Survey (USGS), 2006)

Urban areas provide opportunities for and some of the most suitable roosting opportunities in the area. Buildings in urban areas are constructed taller because of the increased density. Therefore, urban structures offer more suitable roosting opportunities for Mexican Free-Tailed Bats (Taylor, 2009). In addition, Mexican Free-Tailed Bats have been shown to favor these types of paved areas for foraging space when the required open space is provided (Avila-Flores & Fenton, 2005) (refer to Table 4-2: *Mexican Free-Tailed Bat Typology*). Urban areas provide some of the highest quality Mexican Free-Tailed Bat habitat in the Austin area so future development should strive to be higher density urban development. Another supporting finding for development being urban is the fact that suburban areas provided the highest percent of the bottom 20% suitable areas. Although suburban areas made up 29% of the top 21-40% of suitable areas it is clear that high density urban development better supports Mexican Free-Tailed Bats needs in Austin. The major difference between suburban and urban development for Mexican Free-Tailed Bats is the number of quality roosting opportunities and open space for foraging. Although suburban areas typically offer more open space, Austin's urban development provides overall more suitable habitat than suburban development areas. Policies related to increasing density or providing better roosting opportunities in urban areas will be important to support Mexican Free-Tailed Bats habitat needs.

5.2.4.2 Spatial Analysis

The results of the spatial analysis showed that 93% of the areas that were analyzed contained unprotected open space. These spaces contributed to the areas suitability but because they are not being actively protected, these important habitat elements have a risk of being harmed in the future. Protection of unprotected open space will be important for Mexican Free-Tailed Bats and will be incorporated into policy proposals to support Mexican Free-Tailed Bats.

Both urban and suburban land cover classes were located in 73% and 93% of the areas analyzed respectively. This shows that both types of development can be supportive of Mexican Free-Tailed Bat habitat but may depend on other elements. Most developed areas that were analyzed offered a wealth of mixed open space and mature vegetation throughout the areas, which helps support a high insect abundance while providing the open space required for foraging. In addition, these types of developed areas typically offer the most roosting opportunities anywhere in the Austin Metropolitan Area. Mexican Free-Tailed Bats could further benefit from policies related to construction of development structures that incorporate more roosting opportunities or that are specifically designed for the use of bats.

Almost half, 46%, of the areas analyzed had highways intersecting the area. Highways have shown to reduce Mexican Free-Tailed Bat activity (Kitzes & Merenlender, 2014))(refer to Table 4-2: *Mexican Free-Tailed Bat Typology*) so it is important to consider the finer scale design of areas near highways while considering how to reduce the overall negative effect highways have on landscape connectivity. In most of the highly suitable areas with highways the points where highways interrupt linear landscape elements or waterways, vegetation is mature and dense to provide better opportunities for Mexican Free-Tailed Bats to cross highways. This can be accomplished through maintaining existing crossing points while helping to create more opportunities for quality highway crossing points with eco-passages. Policy related to reducing the effect highways can have on landscape connectivity will be important for future development policies. (see Appendix C for details on individual areas spatial analysis results)

5.3 Proposed Policies

There are many opportunities to protect and improve Mexican Free-Tailed Bat habitat in Austin, Texas. Through the findings that were summarized and known information on Mexican Free-Tailed Bats and how to support bat habitat, from literature reviews, policies can be developed to help Austin start to understand what areas are important and how to best protect or improve these areas during development. Unprotected open space has shown to be important in Austin for Mexican Free-Tailed Bats. These spaces will be referred to as the open space character of Austin for the use in policy proposals. Open space character includes parcels or private land not permanently protected from development such as gold courses, campuses, private schools, estates, farmland, or forests, which contribute to the open space character of an area. Austin's proposed policies to support Mexican Free-Tailed Bats are as follows:

In identifying lands to be acquired or otherwise protected, the city will be guided by the following policies:

Policy 1. Open Space Character

It shall be the policy of the City of Austin to encourage preservation of open space character as an important element in shaping Austin's future development patterns and in preserving its aesthetics and environmental quality.

Priorities: The City of Austin will give priority to maintaining open space elements that:

- Define and separate development centers and corridors.
- Provide buffers between development groupings and limit urban sprawl.
- Protect unique environmental resources.
- Are adjacent to vegetated or waterway corridors.

Policy 2. Connectivity

It shall be the policy of the City of Austin to encourage connectivity, which creates a system of connected parks, parkways, and other open space character areas.

Priorities: The City of Austin will give priority to elements or properties that:

- Create or enhance connections between communities, development centers, parks, or other open space character areas.

Policy 3. Waterfront

It shall be the policy of the City of Austin to encourage and protect properties along major waterways or waterbodies.

Priorities: The City of Austin will give priority to properties that:

- Contain unique or natural features especially which offer roosting opportunities for Mexican Free-Tailed Bats.
- Contain unsuited, declining, or low quality development that can be reclaimed for open space, park, or better suited development that could be used as foraging habitat.

Policy 4. Environmental Resources

It shall be the policy of the City of Austin to preserve and protect properties that have special or unique natural, scenic, or environmental significance.

Priorities: The City of Austin will give priority to properties or elements that:

- Protect surface and groundwater quality.

- Are adjacent to waterways or water bodies.
- Provide quality agricultural land.
- Offer potential for reclaiming environmentally sensitive lands that have been adversely affected by development.
- Currently provide excellent habitat for vegetation that would help support biodiversity.

Policy 5. Maintaining Vegetation

It shall be the policy of the City of Austin to preserve and protect properties that contain mature or areas of unmanaged vegetation.

Priorities: The City of Austin will give priority to properties or elements that:

- Provide or enhance areas of naturalized and unmanaged vegetation.
- Adjacent to or near waterfronts or waterways.
- Create or enhance corridors or open space.
- Provide support for biodiversity especially when the area is composed of a range of native plants.

Policy 6. Street Easements

It shall be the policy of the City of Austin to manage or maintain street easements that would allow for public creation of street trees and provide incentives for green water management techniques.

Priorities: The City of Austin will give priority to areas that:

- Would help maintain or allow for transplanted trees along streets or roads.
- Can utilize green infrastructure (rain gardens, vegetated swales, etc.).
- Are planned to be high density urbanized areas or are located adjacent to high density urban areas.

Policy 7. Highway Connectivity Disruption Mitigation

It shall be the policy of the City of Austin to manage and maintain vegetation where highways may interrupt or cross major landscape elements that could provide corridors for connectivity.

Priorities: The City of Austin will give priority to areas where:

- Highways cross major linear landscape elements such as waterways, vegetated corridors, or open space corridors.
- Property could provide opportunities for wildlife crossing points such as green bridges, hop overs, or eco passages.

Policy 8. High Density Urban Development

It shall be the policy of the City of Austin to support high density urban development.

Priorities: The City of Austin will give priority to development that:

- Helps to limit urban sprawl.
- Creates opportunities to maintain open space, natural resources, or helps support connectivity.
- Offers suitable roosting opportunities for bats, especially when roosting opportunities can specifically integrated into structures.

5.4 Application of Proposed Policies and Further Typology Considerations for the Benefit of Mexican Free-Tailed Bats

To understand how proposed Mexican Free-Tailed Bat policies could affect design proposal three projects were chosen from Austin's list of emerging projects. Projects were selected based on their ability to show how the proposed policies would affect a range of different project types such as urban redevelopment projects, new subdivided development, and urban civic development. Projects selected have also been approved for development and are beginning or have recently begun construction. In addition, projects were only selected if a plan was able to be located that would allow for a good understand of what is proposed for development in each area to allow for an understanding of the effect development can have on Mexican Free-Tailed Bat Habitat.

5.4.1 Project 1: Crestview Station

Project Type: Mixed Use - Transit Oriented

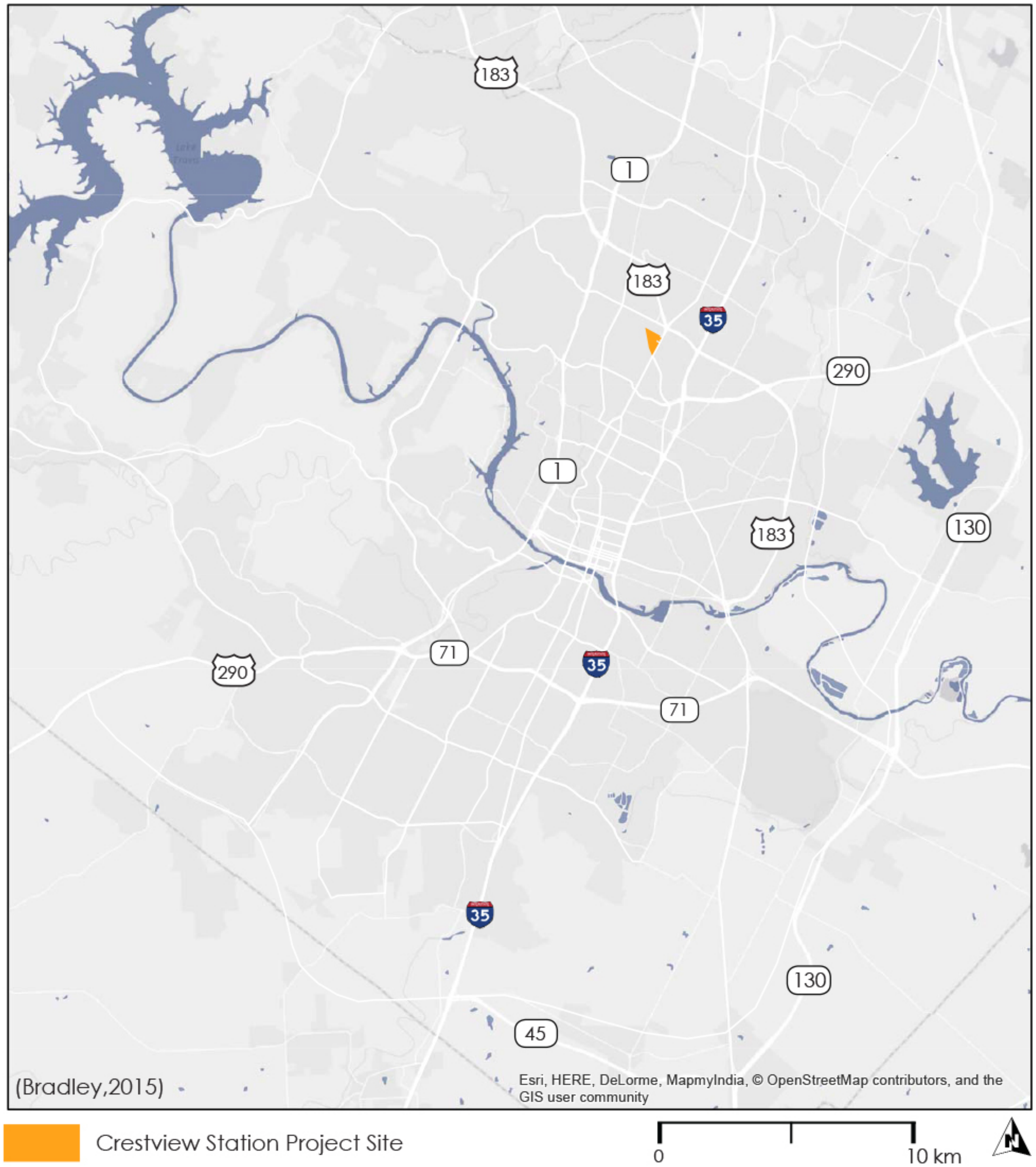
Project Location: Located across from the intersection of Lamer Blvd and Airport Blvd

Project Size: 73 Acres

Project Plans: 41 Single Family Homes; 459 Condominiums/Townhomes; 850 Multifamily Apartments; Retail and Office Space; Park and Ride Station

Project Website: http://www.midtowncommons.com/

Figure 5-4: ***Project 1 Crestview Station Locator***



5.4.1.1 Site Existing

Figure 5-5: ***Project 1 Site Exiting***

Site Overview: The site was the home of the Huntsman Chemical Facility for over 50 years but the it closed in 2005. Shortly after the Huntsman Facility closed the land required an environmental remediation to rid the soils and groundwater of any leftover toxins from the Huntsman Facility. A Metro Rail Station was planned and opened in 2008 on the southernmost corner of the site shortly after the clean was finished (Nichols, 2006). This station was to serve as the base for transit oriented development that has been proposed on site.

The site is located in the Crestview area where there are no buildings over 2 stories, showing that the area is mostly low density suburban development (Nichols, 2006). The development along Lamar Blvd is a combination of retail buildings and industrial buildings. The surrounding residential development is low density single family housing. Residential areas have a wealth of mature vegetation and small open spaces that provide quality opportunities for foraging.

Figure 5-6: Metro Rail Red Line Corridor

A view of the Metro Rail Red Line corridor. The corridor is lined with mature vegetation. Much of the vegetation is naturalized and unmanaged. The corridor runs along the west side of the site and is mostly continuous with a few gaps created where highly developed areas or large roads intersect the corridor. This corridor offers great opportunities for high quality flight paths while supporting insect abundance with the quality of the vegetation.

Figure 5-7: Morrow St

A view down Morrow St looking southeast. The street is lined with almost continuous trees on the north side (left in the photo) and a single row of trees along the south side of the street (right in the photo). The vegetation is mature and helps support a higher insect abundance. Morrow St also provides high quality flight paths along the street.

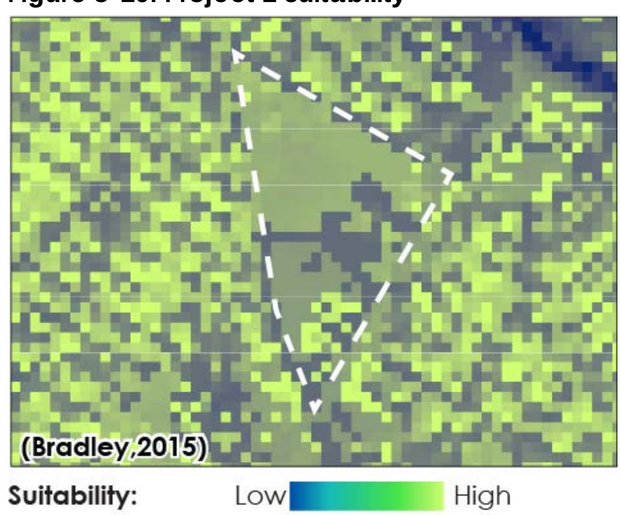
Figure 5-8: Lamar Blvd

A view down Lamar Blvd looking southwest. This view looks over the site and provides a good understanding of the sites existing conditions after the Huntsman Chemical Facility was removed and cleanup of the soil was completed. There are a few mature trees lining Lamar Blvd on site. These trees improve the quality of the Lamar Blvd corridor while making up most of the existing trees that exist on site.

5.4.1.1.1 Site Scale

Figure 5-9: Project 1 Aerial

Figure 5-10: Project 1 Suitability



A site scale aerial helps to locate the site

The suitability from the model output is while understanding the types of development surrounding the site.

shown over a site scale aerial. The nearby highways offer the lowest areas of suitability for Mexican Free-Tailed Bats where the rest of the site has a range of suitability.

Figure 5-11: Project 1 Top 50% Suitability

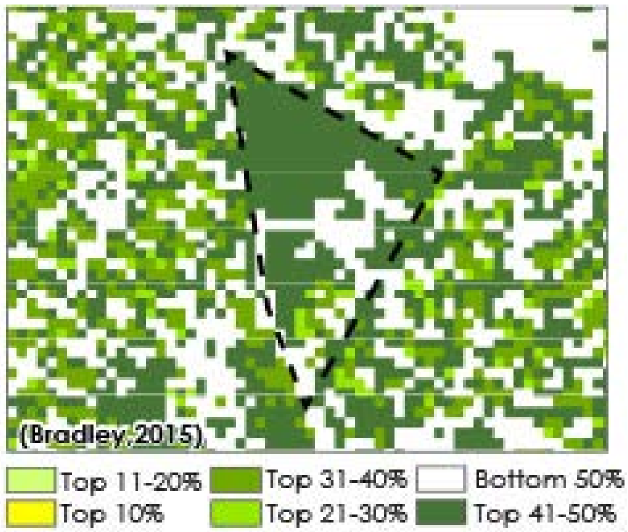
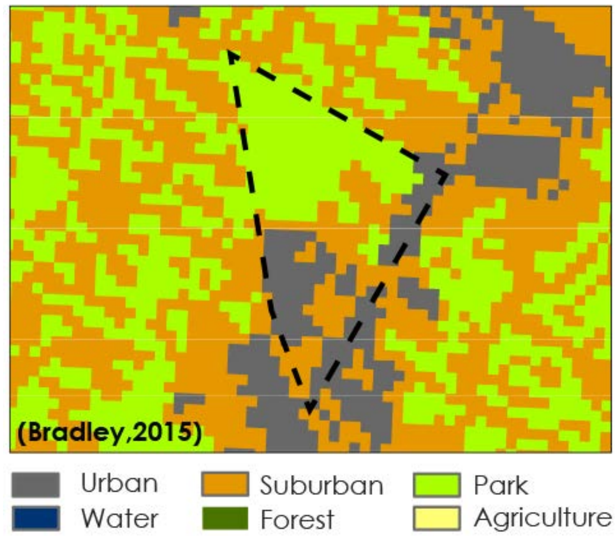


Figure 5-12: Project 1 Land Cover

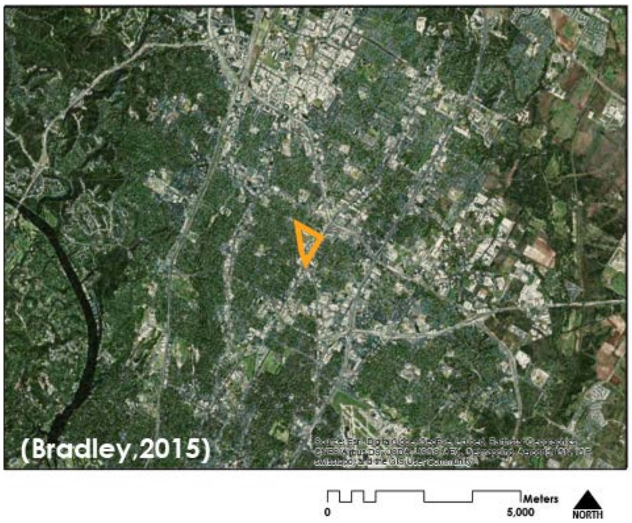


The top 50% suitability from the model output. The site is almost completely in the top 50% suitability in the Austin Metropolitan Area with the southern portion of the site being in the top 21-30% suitability. The greatest suitability near the site is to the west but the surrounding area provides many opportunities for quality habitat.

The simplified land cover helps to understand the composition of the landscape for Mexican Free-Tailed Bats. The site provides the largest open space in the area, which could be important for providing a substantial foraging space. The land cover also helps to understand where open space connects to the site, which is important for how bats could access to the site.

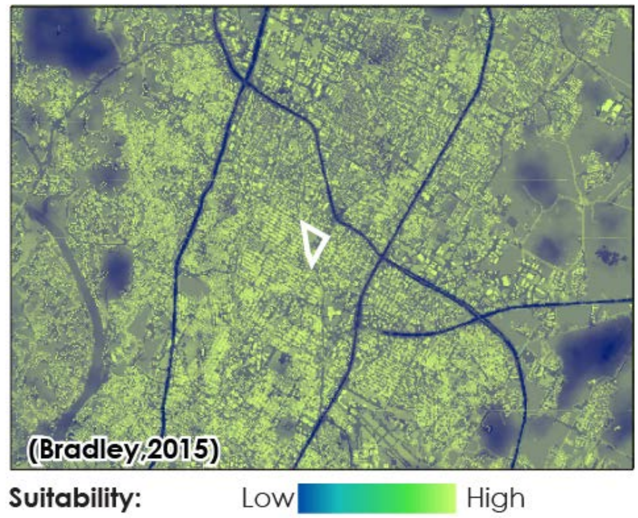
5.4.1.1.2 Regional Scale

Figure 5-13: Project 1 Aerial



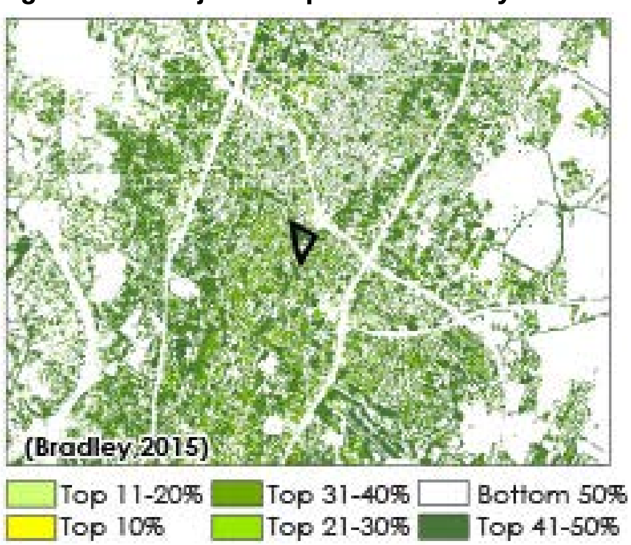
A site aerial helps to locate the site while showing the broader context. The site is located in the middle of northern Austin development.

Figure 5-14: Project 1 Suitability



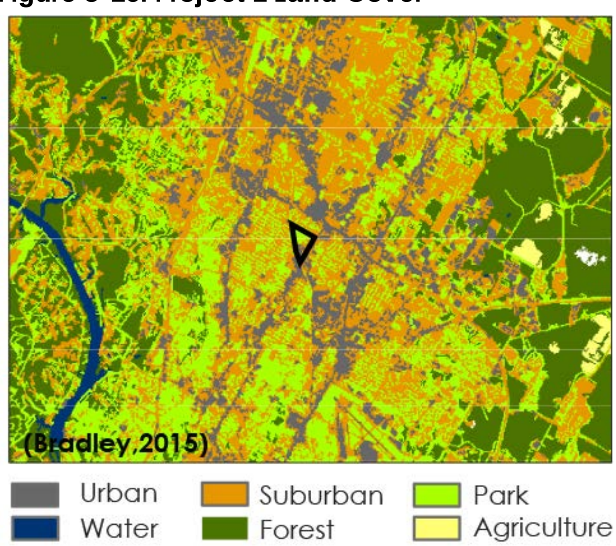
The suitability for the model output is shown over the broader scale aerial. The site is located in the center of a large grouping of highly suitable habitat with high contrast in suitability where highways are located.

Figure 5-15: Project 1 Top 50% Suitability



The top 50% suitability from the model

Figure 5-16: Project 1 Land Cover



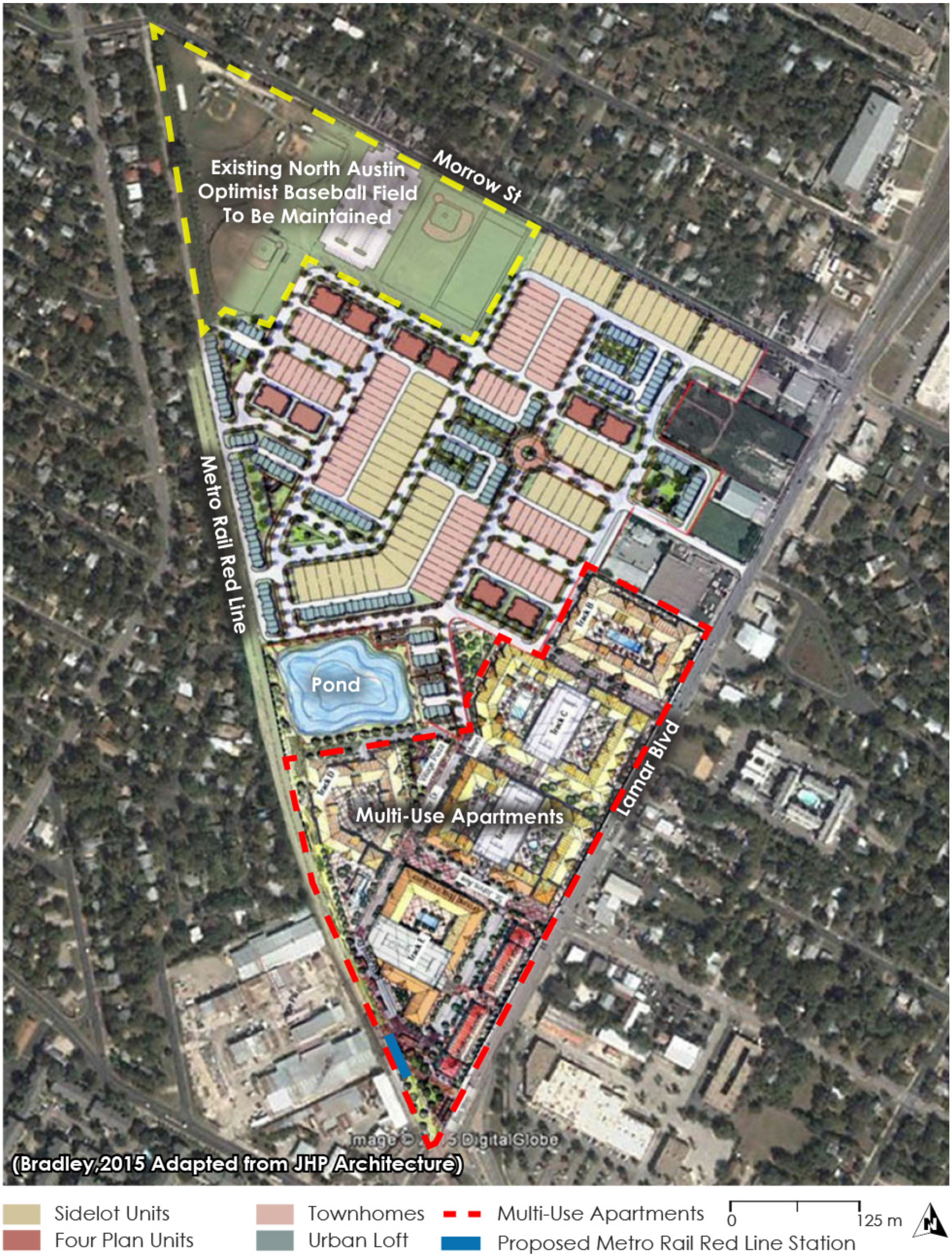
The simplified land cover helps to

output at a broader scale. At the regional scale this site is located in the middle of large groupings of high suitability areas. Thus it will be important to maintain highly suitable habitat on site.

understand the broader scale composition of the landscape. At the broader scale the sites open park space is not as substantial as some of the available open park space nearby, mainly to the west and southeast on the map.

5.4.1.2 Proposed Development

Figure 5-17: Project 1 Proposed Development



5.4.1.3 Proposed Development Analysis

5.4.1.3.1 Open Space

The main effect the proposed development has on the existing site is eliminating almost all large open space by completely developing the site. The only large open space that is proposed is located over the water feature on the west side of the site. There is also very little open space proposed around the water with development lining the east edge and streets abutting both the north and south edges of the water. The substantial open spaces proposed can be seen in Figure 5-18.

The streets provide some open space that could be used for foraging. The vegetation that is seen on the plan along the streets would help to increase the overall sites vegetation while supporting quality flight paths through the development. Therefore, the arrangement of these proposed streets is important for how Mexican Free-Tailed Bats may access or traverse the site and as connections to open spaces on or near the site. The street trees seen in the plan will support insect abundance and could provide quality foraging spaces.

Figure 5-18: Proposed Open Space

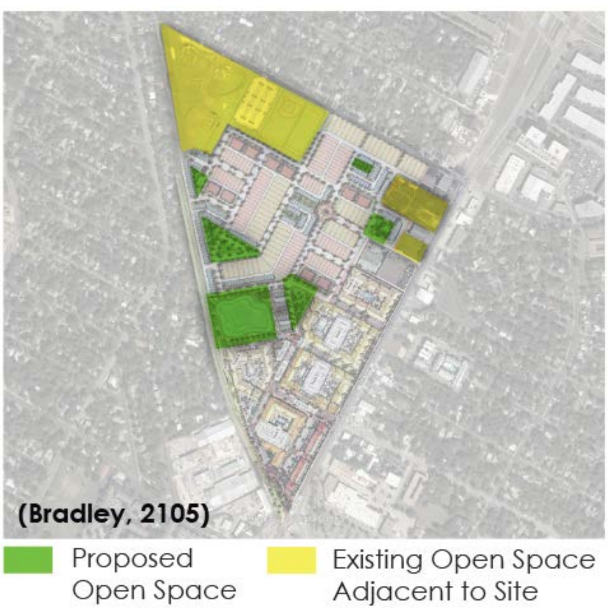


Figure 5-19: Proposed Continuous Corridors

5.4.1.3.2 Proposed Corridors

A major effect of developing the entire site besides the loss of open space is changing the way bats traverse the site. Mexican Free-Tailed bats have developed to fast flights with less maneuverability so continuous corridors would better support the species flight abilities. Many of the points where the corridors meet the edge of the site will be important for increasing tree cover to help improve the species willingness to cross into the site.

The continuous proposed corridors can be seen in Figure 5-19. There are very few northwest to southeast continuous corridors and the one that is proposed has an island of development that may interrupt that corridor enough to reduce the use by Mexican Free-Tailed Bats. Providing more continuous corridors or by adjusting some of the proposed corridors to be more continuous could improve the sites connectivity and use by Mexican Free-Tailed Bats. These corridors relationship to open spaces are important for improving the sites internal connectivity of open spaces.

5.4.1.3.3 Water

The existing site has no water features but the development proposal calls for a small pond on the west side of the site (see Figure 5-20). The addition of a pond could improve insect abundance in the area while providing opportunities to support biodiversity through bank and edge plantings around the pond. Although, with the lack of vegetation and open space proposed around the pond it may not provide high quality areas for foraging. This is one area that has a lot of potential to create a very high quality foraging space for Mexican Free-Tailed Bats with a more generous open space and more vegetation near the pond’s edge.

Figure 5-20: Proposed Pond

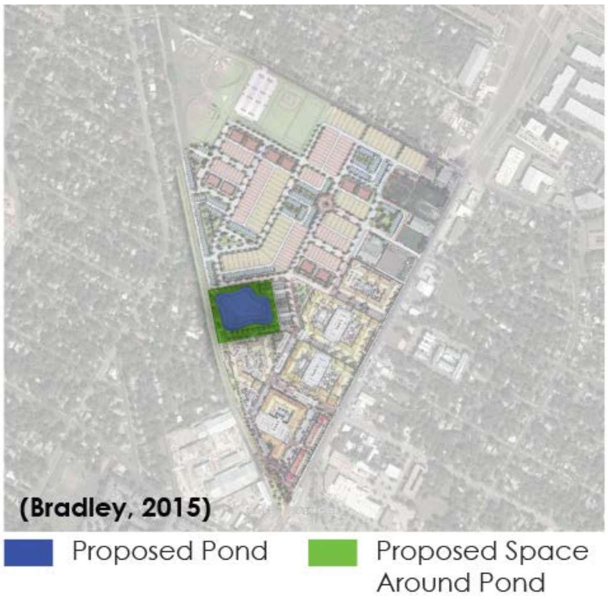
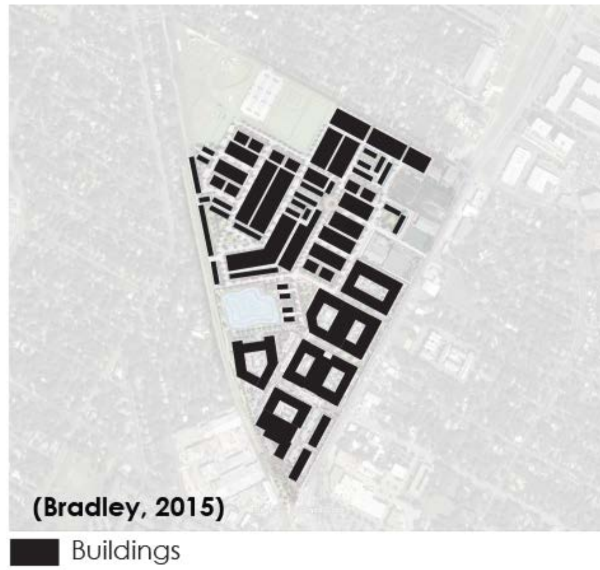


Figure 5-21: Proposed Roosting Opportunities



5.4.1.3.4 Roosting Opportunities

The existing site offered little to no roosting opportunities for Mexican Free-Tailed Bats. The sparse vegetation and few industrial buildings were likely to provide very few roosting opportunities. The proposed development increases the number of opportunities for building roosts, especially in the taller mixed-use structures in the southern most corner (see Figure 5-21). The proposed trees should not offer many roosting opportunities until the vegetation matures. Although there may be more opportunities for roosting most of development proposed is residential development, so unless roosting opportunities are specifically designed into the buildings there may not be many suitable roosting opportunities in the proposed development.

5.4.1.4 Summary of Relevant Proposed Policies

The proposed development maintains small amounts of unprotected open space, which is addressed in the proposed Mexican Free-Tailed Bat policy 1. Although the amount of open space is minimal, the location of the open space being maintained is well located. Also the main open space proposed over the proposed pond is adjacent to the Metro Rail Red Line corridor which further supports proposed policy 1's priorities of maintaining open space along vegetated corridors. The proposed design offers opportunities for access to open space from Lamar Blvd by not developing small lots in the northeast corner of the site.

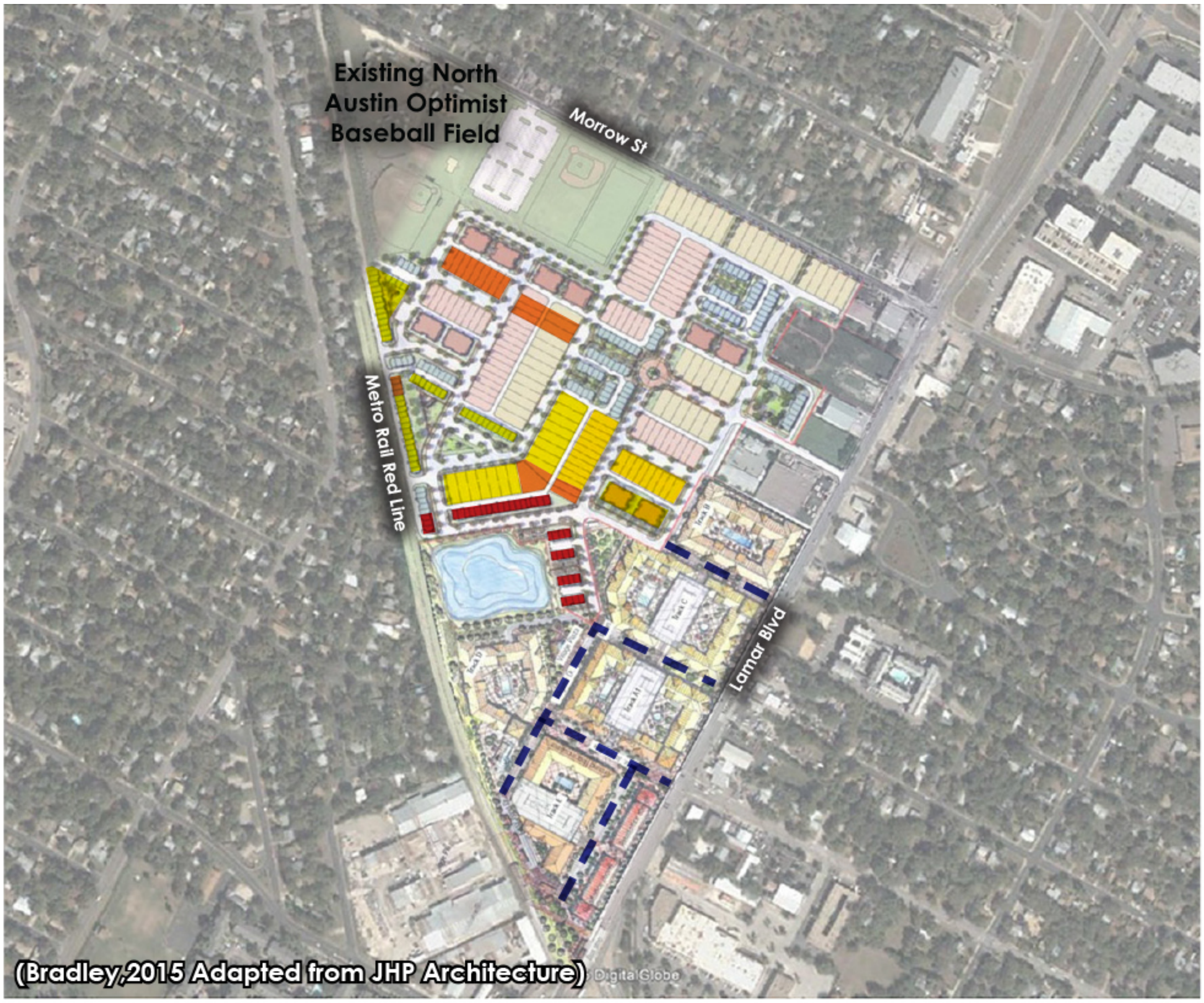
The most important proposed policy this development begins to address is policy 4, which addresses protecting environmental resources. This site was a redevelopment project that utilized environmental remediation before new development started. This helps to improve and protect soil and groundwater quality. In addition, the chemical facility was removed helping to stop any further contamination of environmental resources. Overall, this protect closely follows proposed policy 4.

The proposed development is already supporting two of the seven proposed Mexican Free-Tailed Bat planning policies. This shows that the development is already supporting Mexican Free-Tailed Bats habitat opportunities in a few ways, but with a few changes to the proposed development, the site could provide many quality habitat opportunities for Mexican Free-Tailed Bats.

5.4.1.5 Changes to Proposed Development to Support Mexican Free-Tailed Bats

This section addresses how the proposed design can better follow the proposed Mexican Free-Tailed Bat planning policies and addresses site related opportunities that could further support Mexican Free-Tailed Bats.

Figure 5-22: Changes to Proposed Development with MFTB Policy



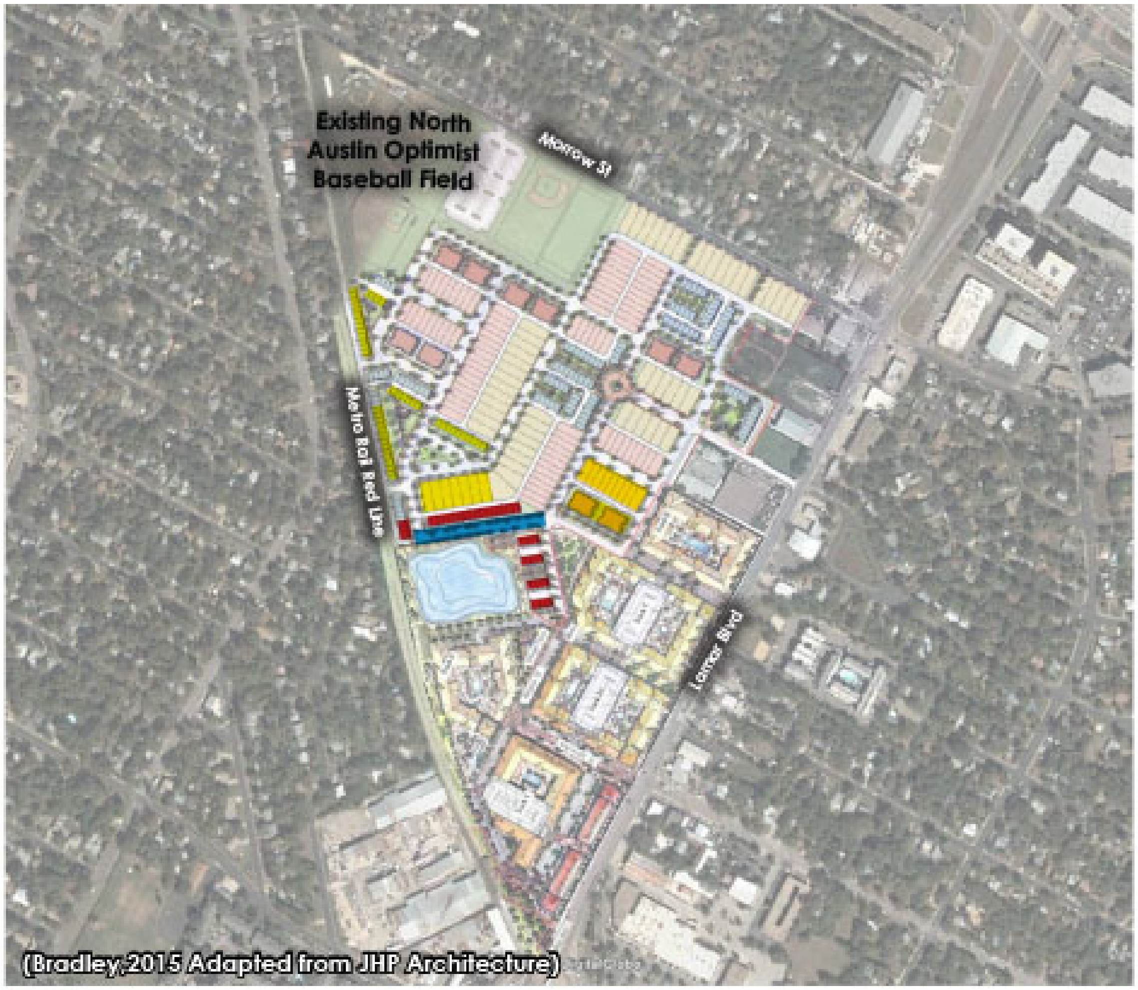
Buildings to be Relocated to Maintain Open Space:
These structures should be relocated or combined with other structures to maintain larger open spaces. These should be replaced by additional open space, especially to increase the size of other proposed open spaces.

Buildings to be Relocated to Increase Connectivity:
These structures should be relocated or combined with other structures to increase connectivity through the proposed design. These should be replaced by more open space including parks, plazas, or streets.

Possible Areas to Increase Density:
These areas offer the good opportunities to increase density. Increasing density can be done by increasing the number of stories or by rearranging development to allow for more buildings in the area.

Areas to Concentrate Green Water Management Infrastructure:
These urbanized areas offer less vegetation. Therefore, using green street water management, rain gardens, and naturalized swales in these areas will help to increase insect abundance.

Figure 5-23: Changes to Proposed Development Explanation 1

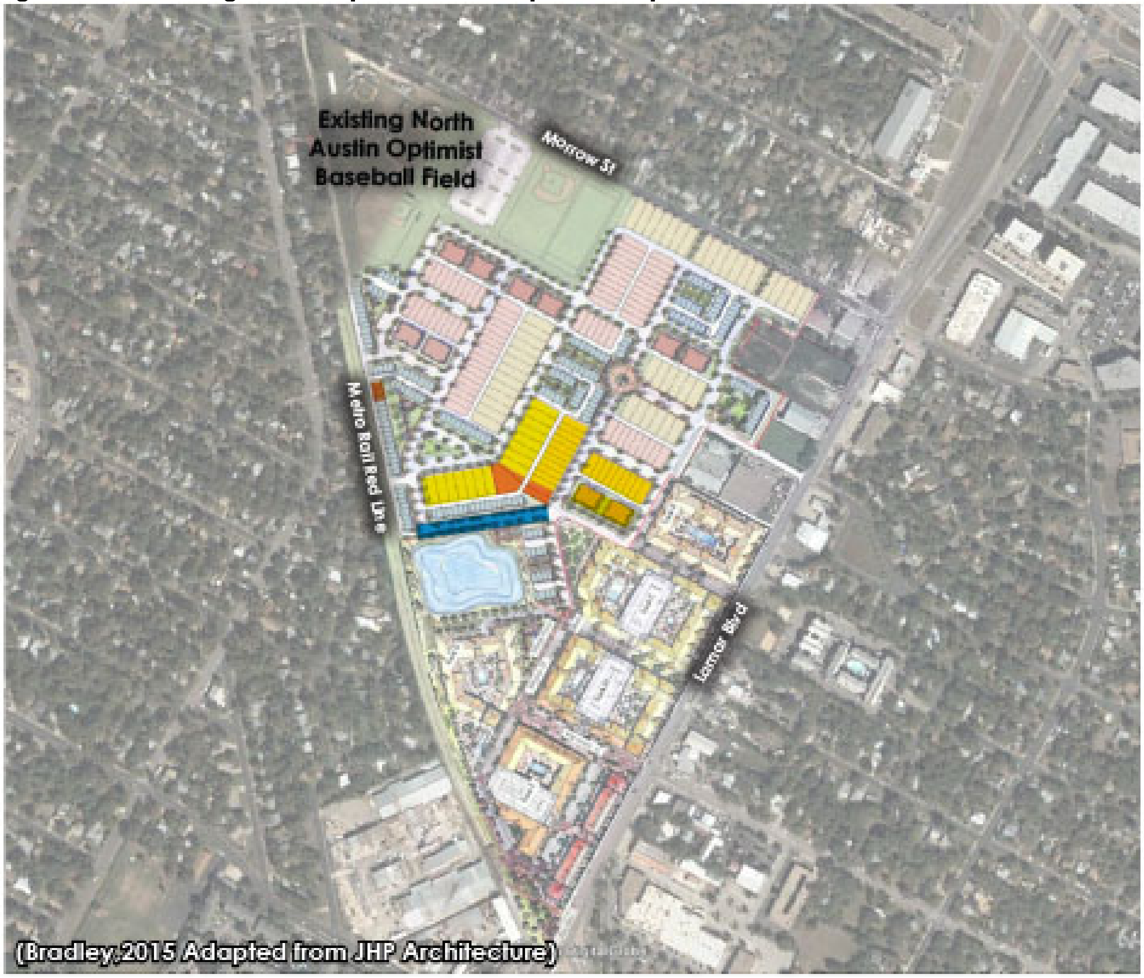


Buildings to be Relocated to Maintain Open Space:
These structures surround and encroach on the smaller proposed open space around the proposed pond. By removing these structure and increasing density in other areas this proposed open spaces can be enlarged, which will offer more opportunities for vegetation surrounding the pond. In addition, the proposed space around the pond is located along the Metro Rail Red Line corridor, which increases opportunities for Mexican Free Tailed Bats to access the space from the surrounding landscape.

Possible Areas to Increase Density:
These areas are located near the proposed higher density development along the Metro Rail Red Line Station on the southern most point of the site. The other areas that are highlighted are the same types of urban loft development which offer opportunities to increase the height of these loft structure to accommodate the lost structures proposed to be removed around the pond.

Street to be Removed:
With the removal of the surrounding structures this street can be removed to allow for the increased open space and vegetation near the pond. To make up for the lack of vehicle circulation another route will be explored.

Figure 5-24: Changes to Proposed Development Explanation 2

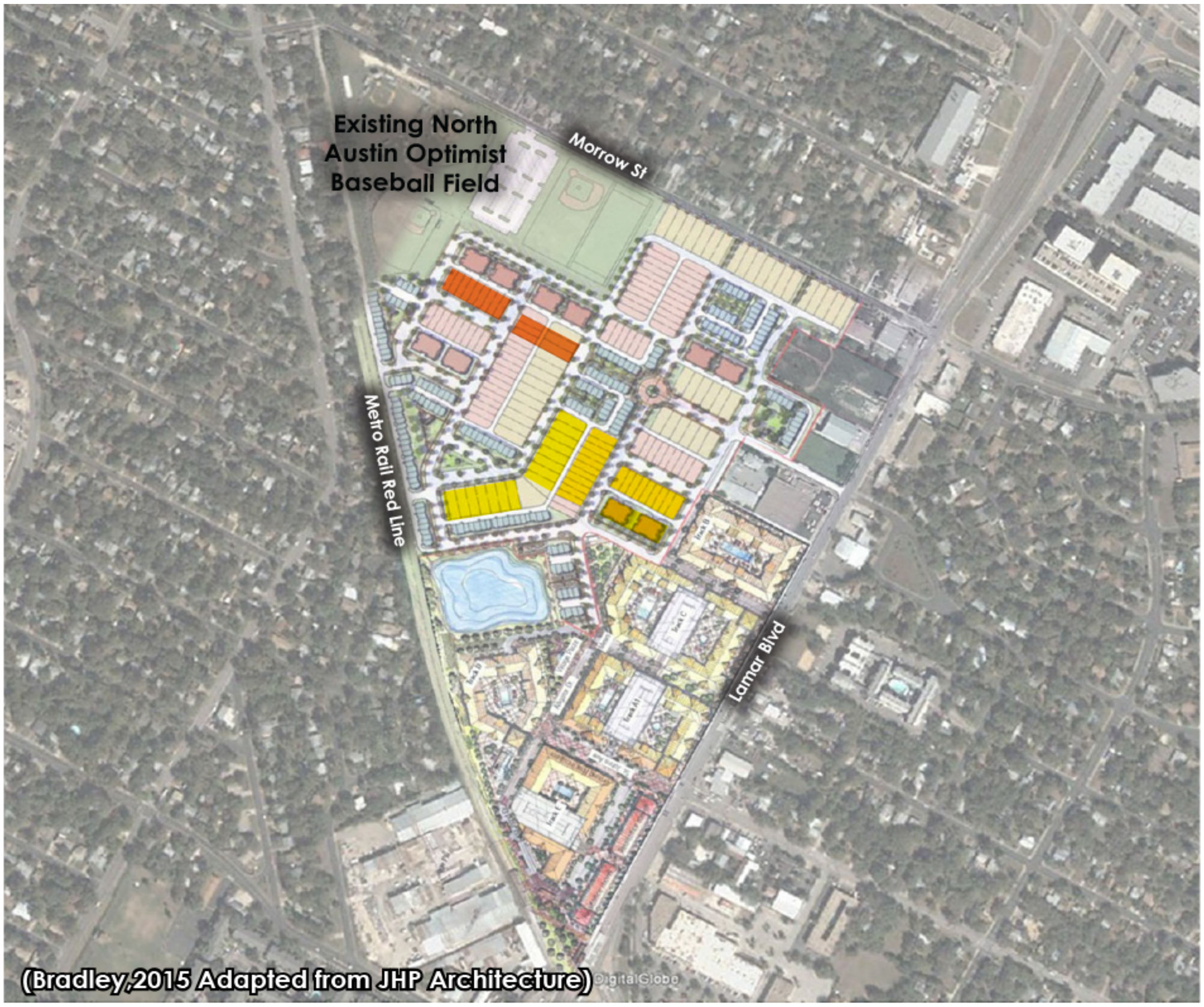


Buildings to be Relocated to Increase Connectivity:
These structures interrupt proposed connectivity through the site and interrupt connections between proposed open spaces. With the removal of the street proposed around the pond this area should become a new street that extends the current proposed street through this area. This street should continue the use of street tree lining each side of the street to help increase bats willingness to use the street corridor and help to support higher insect abundance.

Possible Areas to Increase Density:
These areas are located near the proposed higher density development along the Metro Rail Red Line Station on the southern most point of the site. The other areas that are highlighted are the same types of townhome and sidelot unit development which offer opportunities to increase the height of these structures to accommodate the lost structures proposed to be removed to increase connectivity

Street to be Removed:
To make up for the lack of vehicle circulation another route is created through where the buildings were located that are being removed to increase connectivity.

Figure 5-25: Changes to Proposed Development Explanation 3



Buildings to be Relocated to Increase Connectivity:
These structures interrupt proposed connectivity through the site and interrupt connections between proposed open spaces. By relocating a few townhomes and sidelot units this space can expand on the central green space spine that is proposed. By creating a green spine through the area it will help improve the connectivity through the site while connecting to the North Austin Baseball Fields. This space is large enough to accommodate an alley of trees which would further increase the spaces opportunity for use. This green spine could also provide amenities to the community and new development. Some possible uses to consider would be play areas for children, community gathering spaces, a small pavilion, or a community garden.

Possible Areas to Increase Density:
These areas are located near the proposed higher density development along the Metro Rail Red Line Station on the southern most point of the site. The other areas that are highlighted are the same types of townhome and sidelot unit development which offer opportunities to increase the height of these structures to accommodate the lost structures proposed to be removed to increase connectivity

5.4.1.6 Project Summary

With a few adjustments, Crestview Station can better support Mexican Free-Tailed Bats by supporting more of the proposed planning policies. Although not every projects site in Austin allows for support of every proposed policy, these changes to development will allow Crestview Station to support five of the proposed policies well. These changes allow for the development to support policies 2 (Connectivity) , 6 (Street Easements) and 8 (High Density Urban Development). These changes increase the connectivity through the site and to surrounding existing open spaces, increases the density to maintain open space and connectivity, and provides opportunities to support the management of street easements to increase street trees and support sustainable water management.

5.4.2 Project 2: Estancia Hill Country

Project Type: Mixed Use

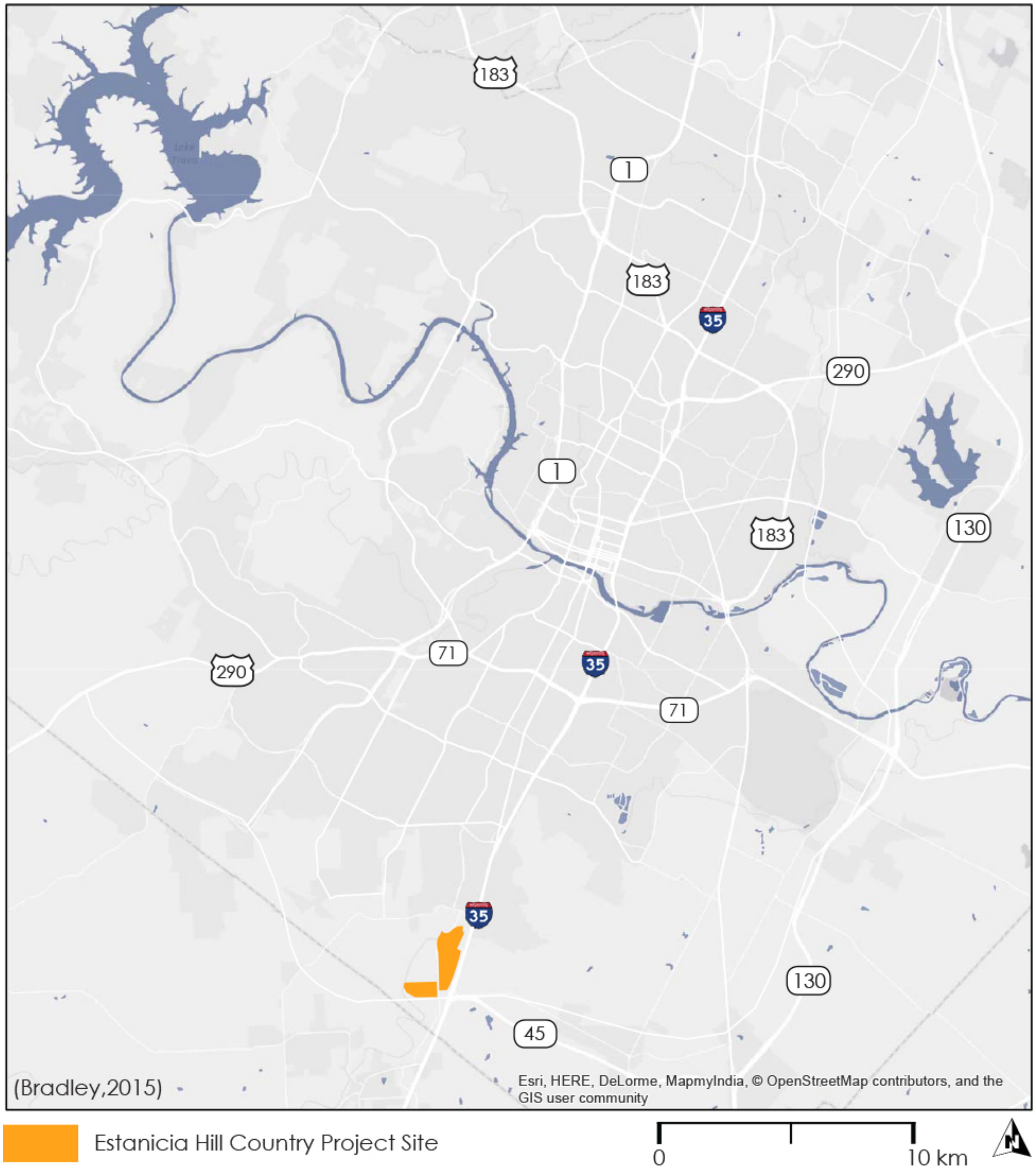
Project Location: Along the I-35 Corridor between Austin and San Marco

Project Size: 559 Acres

Project Plans: 1.9 Million Square Foot Corporate Office Campus; 1.5 Million Square Feet of Office Space, a Hospital, and a Hotel; Approximately 1,600 Apartments and Townhomes; Approximately 277,000 Square Feet of Shops and Restaurants.

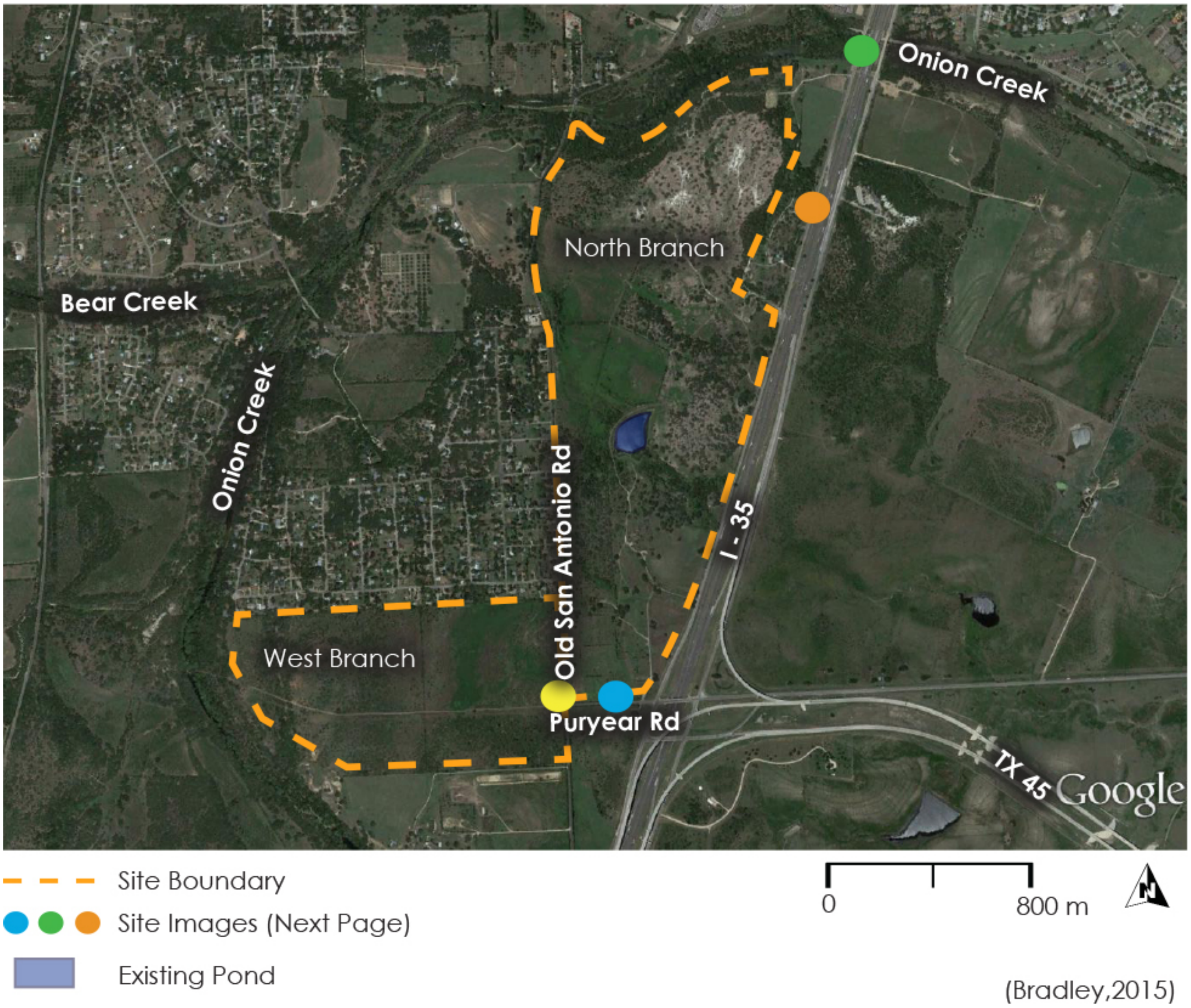
Project Website: http://estanciahillcountry.com/

Figure 5-26: Project 2 Estancia Hills Country



5.4.2.1 Site Existing

Figure 5-27: Project 2 Site Existing



Site Overview: The site is located just outside the City of Austin on what used to be a part of the historic Heep Ranch. The site is undeveloped and mostly naturalized. Grass and shrublands make up most the existing site with scatter vegetation throughout the site. The north branch of the site has more mature vegetation with a greater number of trees. Dense vegetation lines Onion Creek, which borders the site on the furthest north and west edges of the site. Onion Creek and the existing pond in the central portion of the north branch provides immediate access to water, which help support a high insect abundance.

The nearby development consists of low density residential housing. The surrounding residential areas contain a wealth of open space with mature vegetation scattered throughout. Residential areas contain some groupings of dense vegetation, especially near Onion Creek. Other than the adjacent residential area, there is no nearby development and the adjacent land east of I-35 is mostly undeveloped naturalized areas. Although there is little nearby development, the site was selected for development because of its adjacency to I-35 and being located almost exactly half way from the downtown areas of both Austin and San Marco. This allows people easy access to both large cities.

Figure 5-28: Puryear Rd

A view on Puryear Rd looking northwest. This view shows the typical landscape on the southern portion of the north branch of the site. The area consists of mainly grasslands with a few scattered trees. Most of the trees in the distance line Old San Antonio Rd. Since this site is undeveloped most of the vegetation is mature and undisturbed.

Figure 5-29: Onion Creek

A view off I-35 over Onion Creek looking toward the west. Onion Creek borders the north end of the site. Onion Creek is lined with dense mature vegetation. Onion Creek's vegetation and access to water supports a high insect abundance while providing a quality flight route through the area.

Figure 5-30: I-35

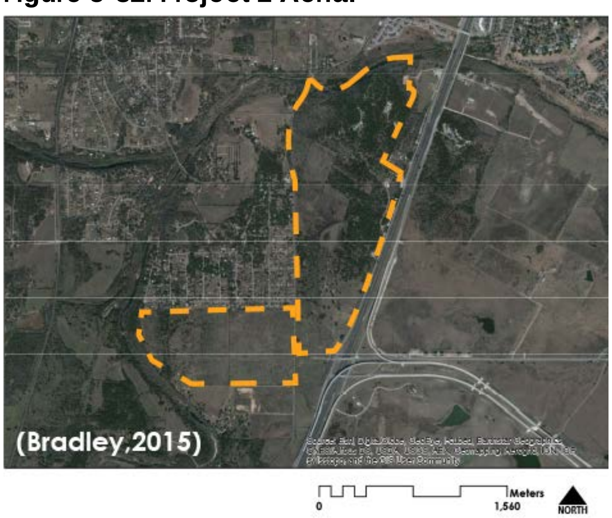
A view off I-35 looking west. This view looks over the north branch site. This image gives a good understanding of the northern portion of the site. It consists mainly of grasslands with scattered vegetation and a few areas of dense mature vegetation.

Figure 5-31: Old San Antonio Rd

A view at the intersection of Old San Antonio Rd and Puryear Rd looking west. The west branch of the development is almost completely grasslands. There is little to no tall vegetation on this portion of the site, and it is almost completely open space. The vast amount of open space could provide foraging areas but with the lack of vegetation, only the furthest west areas near the creek should provide high quality foraging opportunities.

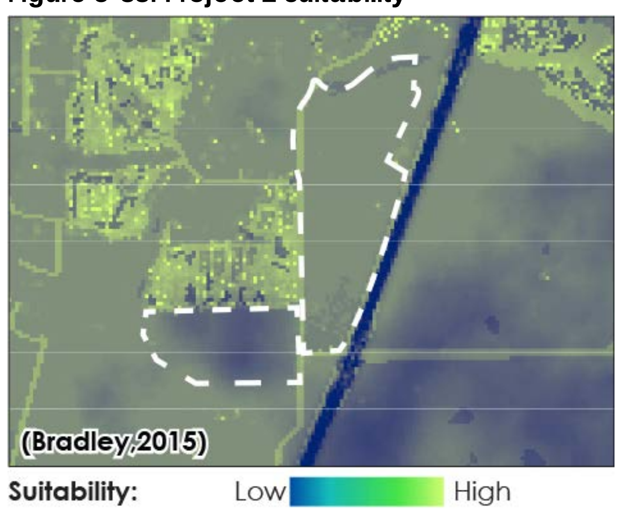
5.4.2.1.1 Site Scale

Figure 5-32: Project 2 Aerial



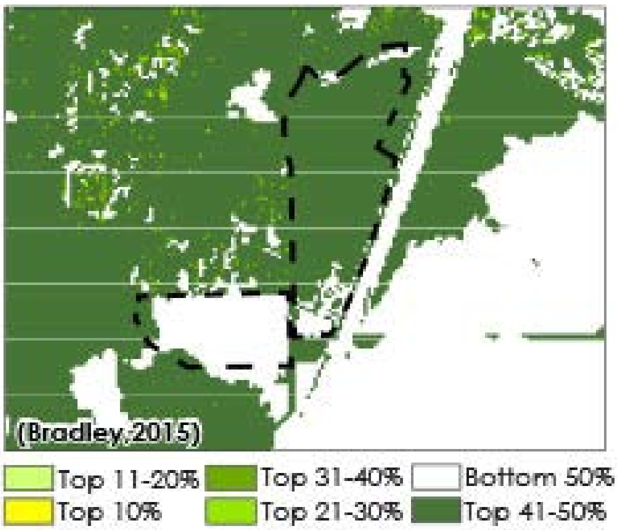
A site scale aerial helps to locate the site

Figure 5-33: Project 2 Suitability



The suitability from the model output is while understanding the types of development surrounding the site.

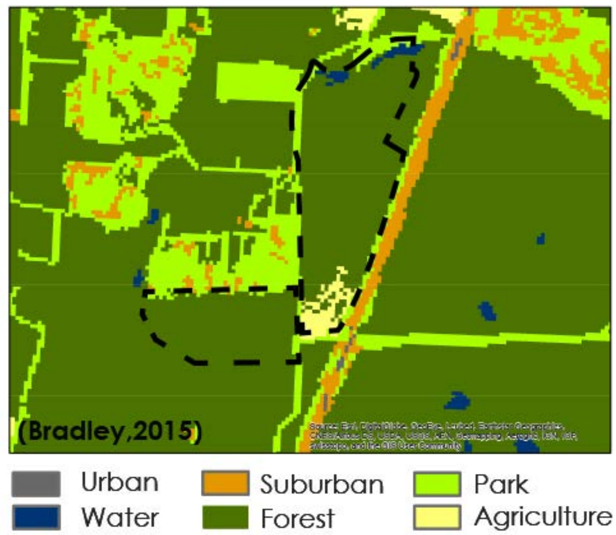
Figure 5-34: Project 2 Top 50% Suitability



The top 50% suitability from the model output. The northern branch of the site is almost completely in the top 50% suitability in the Austin Metropolitan Area. The greatest suitability near the site is to the northwest across Onion Creek.

shown over a site scale aerial. I-35 offers the lowest areas of suitability for Mexican Free-Tailed Bats. The areas of highest suitability are to the north and west of the site.

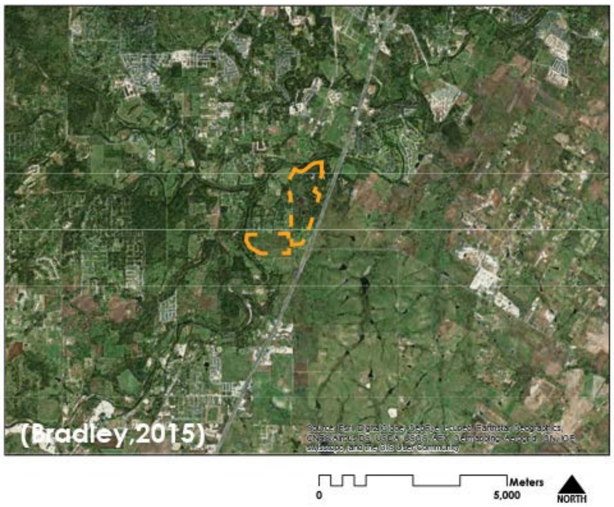
Figure 5-35: Project 2 Land Cover



The simplified land cover helps to understand the composition of the landscape for Mexican Free-Tailed Bats. Much of this landscape in the area is forest. The development is low density and contains little impervious surfaces, which creates a park land cover classification. These areas coincide with much of the highest suitability in the area.

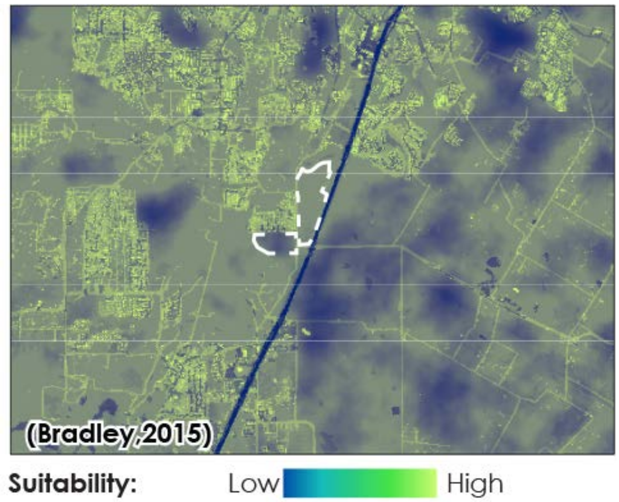
5.4.2.1.2 Regional Scale

Figure 5-36: Project 2 Aerial



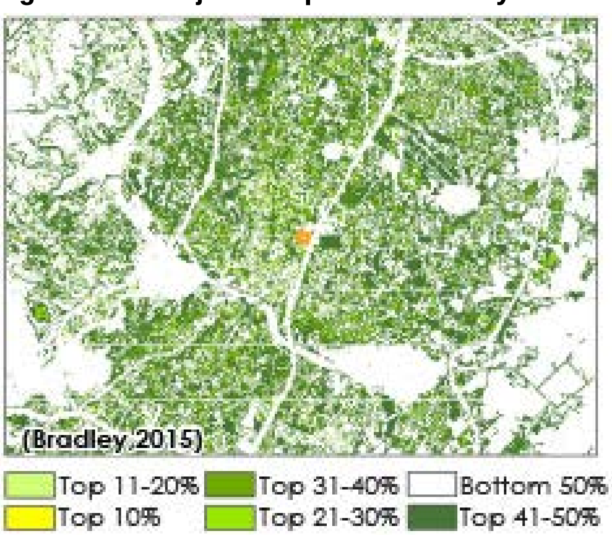
A site aerial helps to locate the site while showing the broader context.

Figure 5-37: Project 2 Suitability



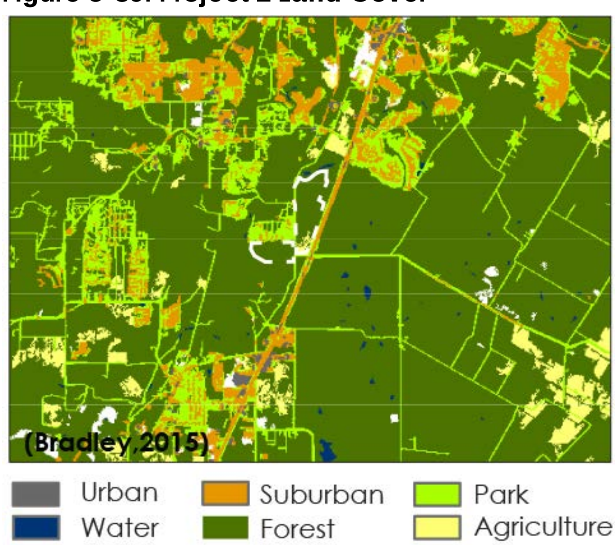
The suitability for the model output is shown over the broader scale aerial. The areas of lowest suitability are to the southeast. The areas of highest suitability are to the northwest on this view shed.

Figure 5-38: Project 2 Top 50% Suitability



The top 50% suitability from the model output is shown at a broader scale. The

Figure 5-39: Project 2 Land Cover



The simplified land cover helps to understand the broader scale composition site is located in the middle of some of the most suitable habitat in the area. Thus, maintaining or improving Mexican Free-Tailed Bat habitat in the area could support the surrounding suitable areas to the north and west.

of the landscape. Since the site and much of its surroundings are undeveloped and mostly naturalized much of the area is forest. Since much of the area is forest the site could help improve diversity in spaces and land cover types.

5.4.2.2 Proposed Development

Figure 5-40: Project 2 Proposed Development

5.4.2.3 Proposed Development Analysis

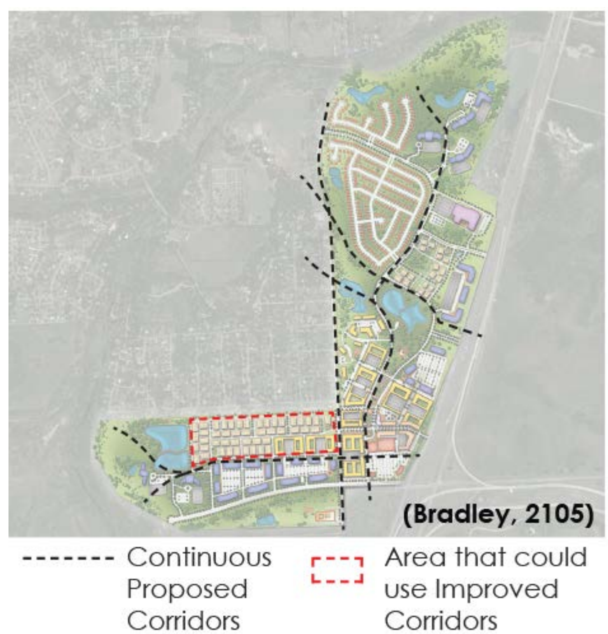
5.4.2.3.1 Open Space

The main effect the proposed development has on the existing site is reducing the amount of open space on site with the proposed development. Although the site is being developed, a generous amount of open space is maintained in the multiple proposed parks throughout the site (see Figure 5-41).

At a finer scale there is open space throughout much of the residential development on the north branch of the site. This space connects into much of the larger open space parks, which help to create opportunities for connections throughout the site.

Figure 5-41: Proposed Open Space

Figure 5-42: Proposed Continuous Corridors



5.4.2.3.2 Proposed Corridors

A major effect of developing the entire site besides the loss of open space is changing the way bats traverse the site. Mexican Free-Tailed bats have developed to fast flights with less maneuverability so continuous corridors would better support the species flight abilities.

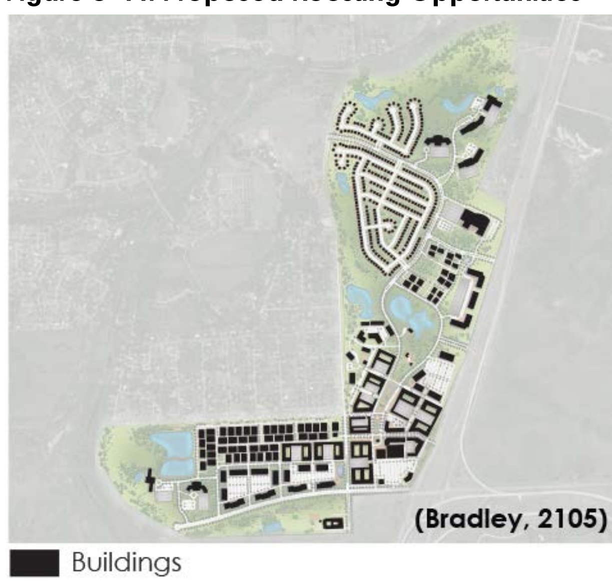
The continuous proposed corridors can be seen in Figure 5-42. Much of the proposed open space is well connected with park spaces extending into developed areas. The proposed townhomes on the west branch of the site could be better connected to the surrounding context.

5.4.2.3.3 Water

The existing site has a water features on site but the proposal increases the access to water with many proposed ponds in the park spaces (see Figure 5-43). These ponds will help to increase insect abundance in the area and with the proposed vegetation and open space surrounding many of the ponds this site will provide many quality foraging opportunities.

Figure 5-43: Proposed Pond

Figure 5-44: Proposed Roosting Opportunities



5.4.2.3.4 Roosting Opportunities

The existing site offered little roosting opportunities for Mexican Free-Tailed Bats. The proposed design increases overall vegetation and drastically increases the number of structures on site. Buildings on site can be seen in Figure 5-44. The larger multiuse buildings would provide more suitable roosting opportunities than the smaller residential or townhome buildings. Overall the proposed development increases the opportunities for roosting on site while providing many suitable opportunities in the larger taller structures.

5.4.2.4 Summary of Relevant Proposed Policies

The proposed development in located on a plot of land that would be considered open space character which is addressed in the proposed Mexican Free-Tailed Bat policy 1. Although the proposal is developing a large percentage of the site, the proposal maintains a lot of the open space with the many proposed parks. In addition, the proposal further supports policy 1 by proposing open space along Onion Creek, which supports the priority of maintaining these open spaces along waterway corridors. The proposal calls for a wealth of well-connected open spaces that helps to define and separate development centers on site. Overall the proposed development already closely follows the proposed Mexican Free-Tailed Bat policy 1.

The proposed development creates a well-connected environment that does not drastically interrupt the existing connectivity in the area, which closely follows the proposed Mexican Free-Tailed Bat policy 2. Parks and vegetated street corridors proposed for this site further supports policy 2's priorities by creating connections between proposed development and open space. Overall the proposed development already closely follows the proposed Mexican Free-Tailed Bat policy 2.

The proposed development looks to maintain much of the existing on site vegetation, which supports the proposed Mexican Free-Tailed Bat policy 5. Although there is not large amounts of existing vegetation on site the proposal looks to enhance the current environment with more vegetated corridors while maintaining areas of naturalized vegetation along Onion Creek. Overall the proposed development already closely follows the proposed Mexican Free-Tailed Bat policy 5.

The proposed development is already employing three of the seven proposed Mexican Free-Tailed Bat policies. This shows that the development may not need many adjustments to meet more of the policies and is already providing many quality habitat opportunities for Mexican Free-Tailed Bats.

5.4.2.5 Changes to Proposed Development to Support Mexican Free-Tailed Bats

This section addresses how the proposed design can better follow the Mexican Free-Tailed Bat proposed policies and discusses site related opportunities that could further support Mexican Free-Tailed Bats.

Figure 5-45: Changes to Proposed Development with MFTB Policy

Buildings to be Relocated to Increase Connectivity:
These structures should be relocated or combined with other structures to increase connectivity through the proposed design. These should be replaced by more open space including parks, plazas, corridors, or streets.

Possible Areas to Increase Density:
These areas offer the good opportunities to increase density. Increasing density can be done by increasing the number of stories or by rearranging development to allow for more buildings in the area.

Areas to Consider an Eco-Passage:
This site is very large so the use of an eco-passage to assist bats or other wildlife to cross I-35 would help to reduce the effect I-35 has on the landscape connectivity. A wildlife bridge would provide the highest quality crossing points but a simple hop over could allow for increased opportunities for bats to cross I-35.

Figure 5-46: Changes to Proposed Development Explanation 1

Buildings to be Relocated to Increase Connectivity:
These structures interrupt connectivity through the site. These areas have enough vehicular circulation so replacing these buildings with small green spaces, plaza spaces, or recreational space would allow the community more gathering or recreational spaces while helping to create better flight corridors through the site. Also if development was shifted around these townhome/apartment areas the proposed developments street corridors could better align with the existing corridors in the development to the north. This shift would not need to change the proposed design drastically but would allow for better north to south connectivity through the proposed development.

Possible Areas to Increase Density:
These areas are located closer to the mixed use and retail development which offer better opportunities for increased density because it would allow people to more easily walk to the town center development. With the large amount of space that exists in the proposed design there are also opportunities for locating structures in alternate locations.

Figure 5-47: Other Site Considerations for Proposed Development

- - - **Existing Corridors to Align Proposed Development Corridors**:
The proposed development could better support connectivity if the proposed corridors lined up with some of the existing corridors.

Highway Buffer:
I-35 runs along the east side of the site and highways have shown to reduce Mexican Free Tailed Bat activity. This can be improved by increasing the trees along the east side of the site in the areas shown. This would help to reduce sound and vision lines to the highway which could help to reduce the highways effect on Mexican Free Tailed Bats.

5.4.2.6 Project Summary

With a few adjustments Estancia Hill Country Station can better support Mexican Free-Tailed Bats by supporting more of the proposed policies. Although not every projects site in Austin allows for support of every proposed policy, the proposed changes to development will allow Estancia Hills Country to support six of the proposed policies. These changes allow the development to support policies 6 (Street Easements), 7(Highway Connectivity Disruption Mitigation), and 8 (High Density Urban Development). These changes help to further support connectivity on and through the site, increases the density to allow for better connectivity, increases the opportunities to support the management of street easements, and provides opportunities for crossing points over I-35 highway.

5.4.3 Project 3: The Dell Medical School at The University of Texas

Project Type: Civic

Project Location: Between Martin Luther King Jr Blvd/5th St and Trinity St/N I-35 Frontage Rd

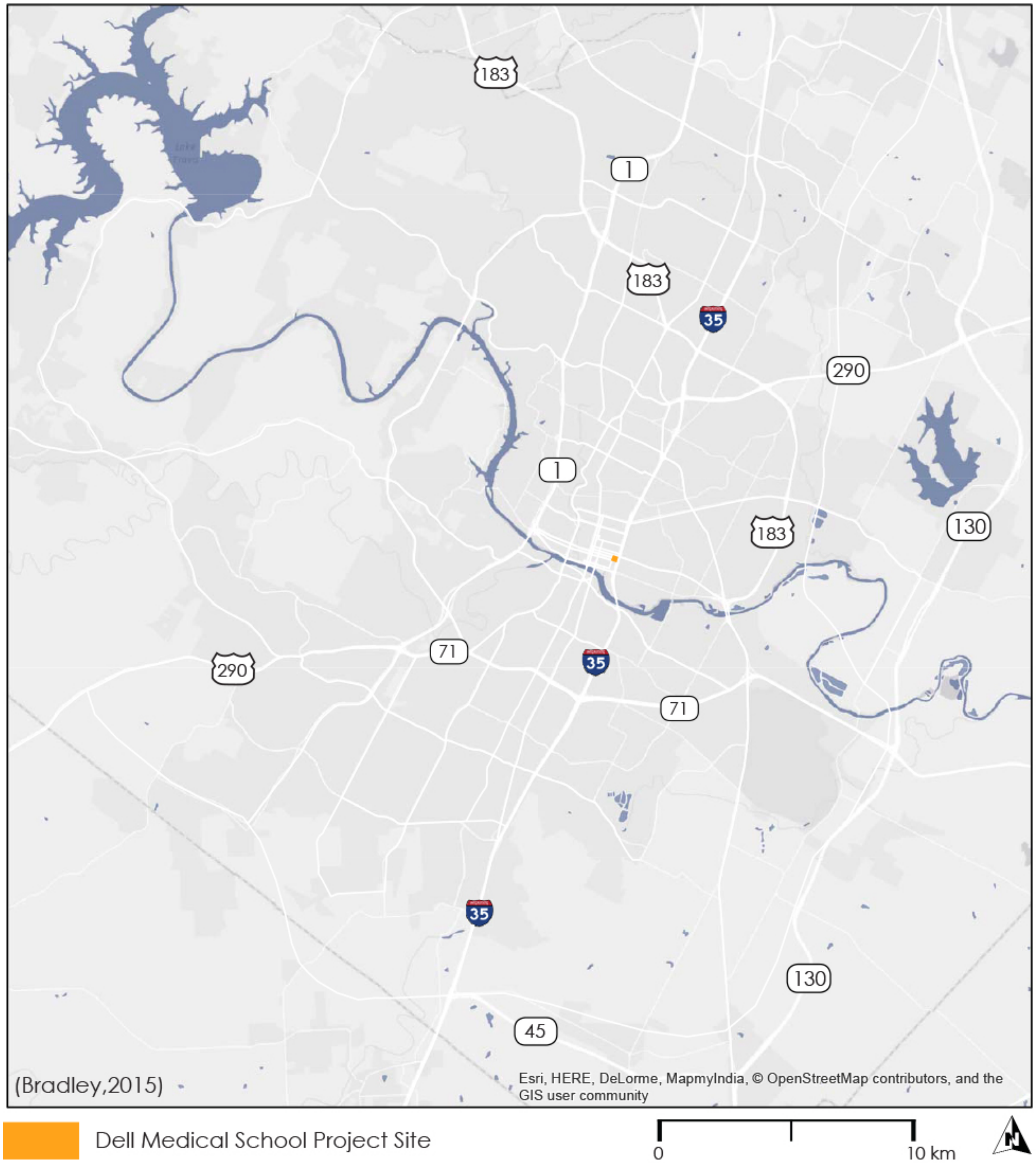
Project Size: 40 Acres

Project Plans: 515,000 Total Square Feet Consisting of an Academic Building, a Research Building, a Medical Office Building and a Parking Garage.

Project Website:

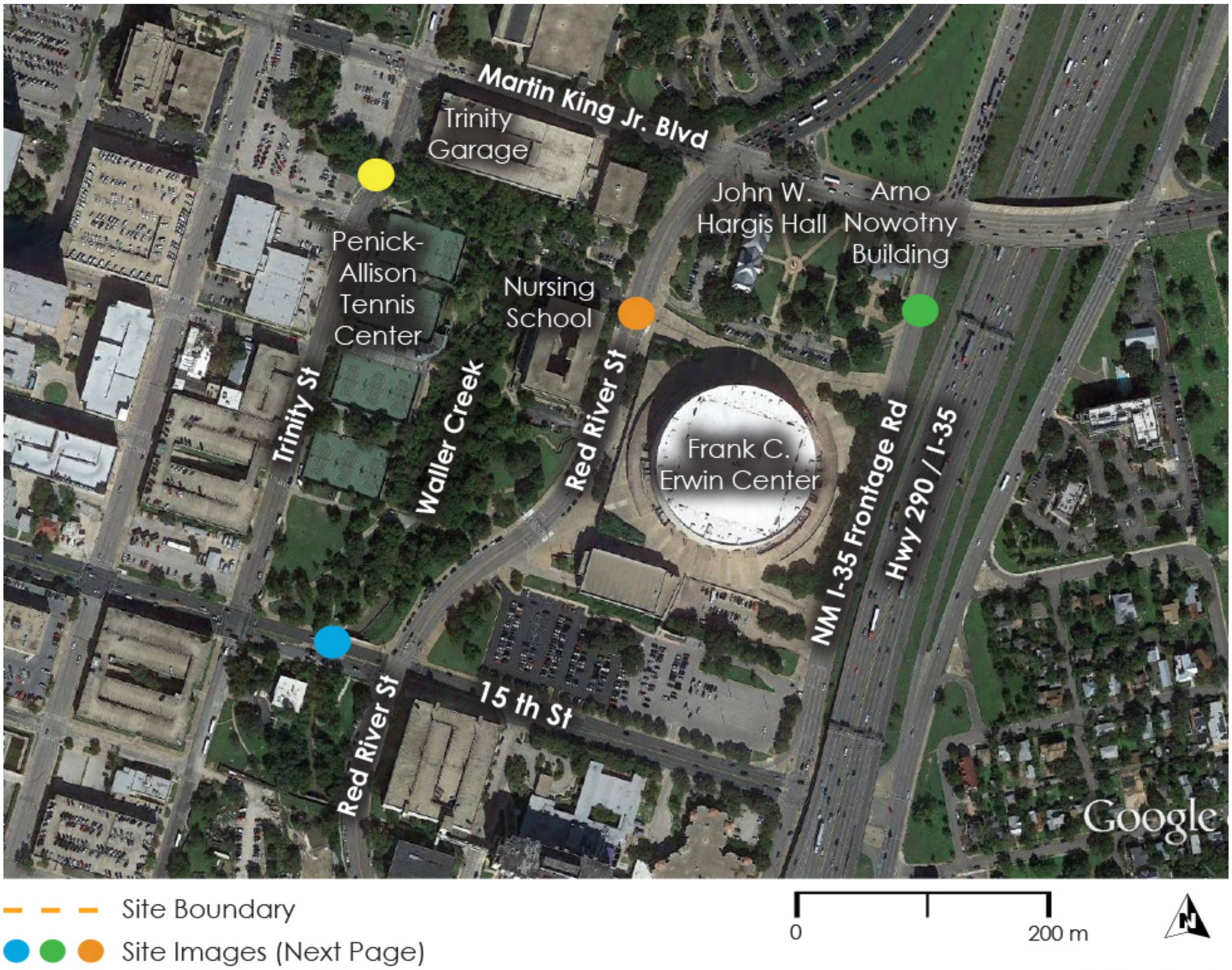
https://www.utexas.edu/operations/masterplan/documents/MedicalDistrict20130509.pdf

Figure 5-48: Project 3 The Dell Medical Campus at The University of Texas



5.4.3.1 Site Existing

Figure 5-49: Project 3 Site Existing



(Bradley,2015)

Site Overview: The site is currently a part of The University of Texas campus. The University of Texas Campus is located on the edge of downtown Austin in a highly urbanized area. The site is one block located at the far south of the campus. The block is divided by Red River St which divides the Frank C. Erwin Center and the Nursing School. There are 7 existing buildings and the Penick-Allison Tennis Center on site.

The surrounding urban development provides less open space and vegetation. The site however, provides a wealth of open space and vegetation along Waller Creek. On site is the one of the most naturalized areas of Waller Creek with much of the creek to the south being underground or highly controlled with concrete. Waller Creek to the north is more naturalized than the south but it runs through The University of Texas Campus where there is a lack of open space near the creek.

Figure 5-50: Waller Creek

A view over Waller Creek. The vegetation through much of Waller Creek is mature with areas of naturalized, unmanaged vegetation. There are many quality foraging opportunities because of the mix of mature and unmanaged vegetation, open space, and Waller Creek's water. These provide an areas that would support high insect abundance while provide the needed open space for foraging.

Figure 5-51: I-35 N Frontage Rd

A view down N I-35 Frontage Rd toward the Frank C. Edwin Center. Frontage Rd has a good mix of vegetation and open space along the street. The vegetation is mostly mature, providing better support for a high insect abundance. This vegetation will be important to maintain to help support quality flight paths through and around the site.

Figure 5-52: Red River St

A view down Red River Street looking south. The view shows the Frank C. Edwin

Figure 5-53: Trinity St

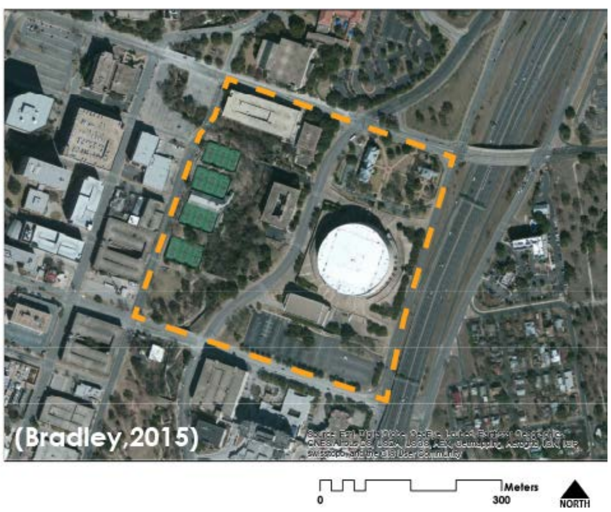
A view of Trinity St looking southeast. This view looks along Waller Creek toward the

Center and The University of Texas School Of Nursing building, which are two of largest structures existing on site. Red River Street has a mix of open space with a few street trees alternating on each side of the street. This street could provide a good open corridor for commuting bats while providing foraging opportunities along the street.

Penick-Allison Tennis Center. This area has a combination of open space over the tennis courts and along Waller Creek, and vegetation. The area is made up of mainly mature vegetation but there are some scattered saplings along the tennis courts. The open space, creek and vegetation support high insect abundance while providing the space needed for foraging which creates an area that provides high quality foraging opportunities.

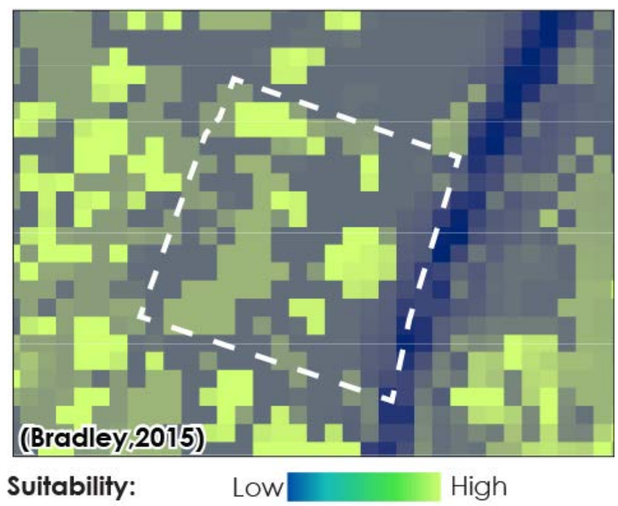
5.4.3.1.1 Site Scale

Figure 5-54: Project 3 Aerial



A site scale aerial helps to locate the site while understanding the types of development surrounding the site.

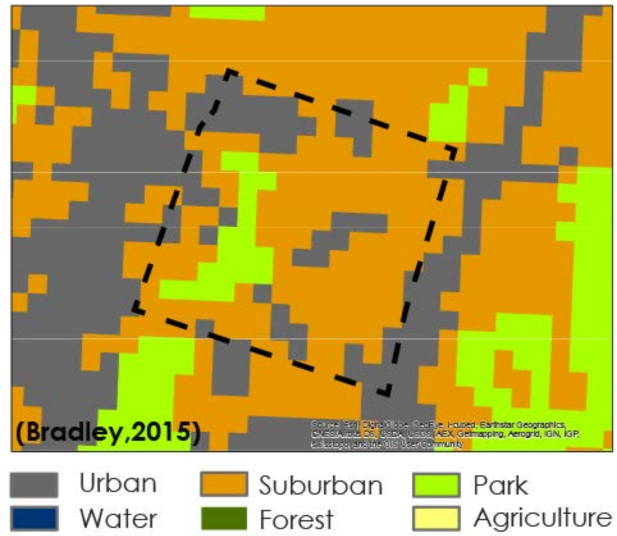
Figure 5-55: Project 3 Suitability



The suitability from the model output is shown over a site scale aerial. I-35 offers the lowest areas of suitability for Mexican Free-Tailed Bats. Most of the highest suitable areas are to the west and south of the site.

Figure 5-56: Project 3 Top 50% Suitability

Figure 5-57: Project 3 Land Cover



The top 50% suitability from the model output. Over half the site is in the top 50% suitability or higher for all of the Austin Metropolitan Area. This site has a few areas of top 21-30% suitability scattered toward the north of the site.

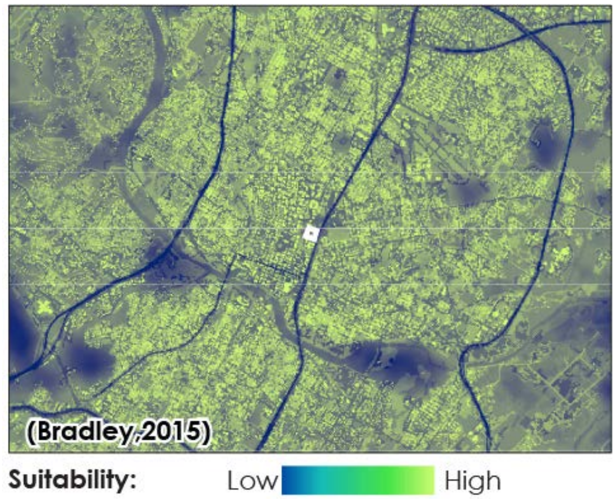
The simplified land cover helps to understand the composition of the landscape for Mexican Free-Tailed Bats. The site provides one of the greatest open space in the area which could be important for providing foraging space. The area is made up of mainly suburban and urban areas with a few small open parks spaces.

5.4.3.1.2 Regional Scale

Figure 5-58: Project 3 Aerial

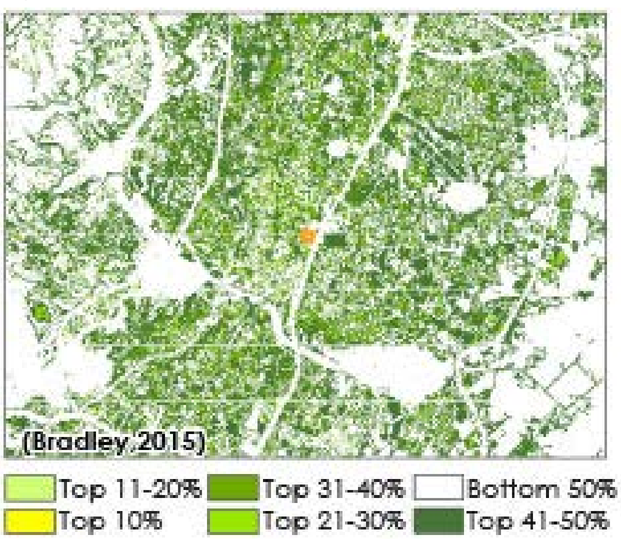
A site aerial helps to locate the site while showing the broader context.

Figure 5-59: Project 3 Suitability



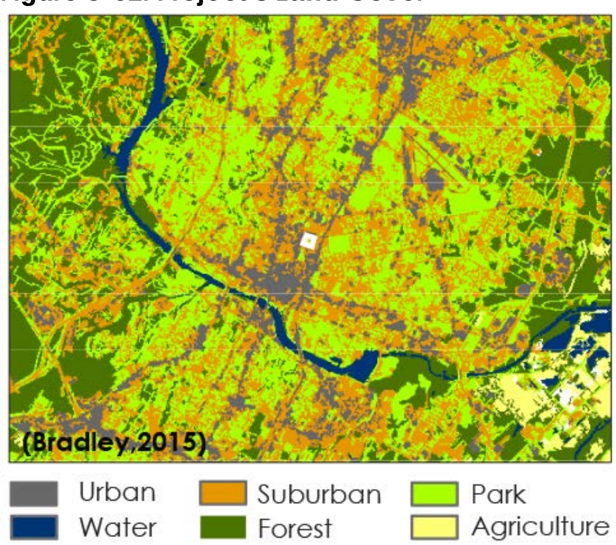
The suitability for the model output is shown over the broader scale aerial.

Figure 5-60: Project 3 Top 50% Suitability



The top 50% suitability from the model output at a broader scale. The largest groupings of highly suitable habit is to the west with a large grouping of top 21-30% suitability is to the northwest of the site.

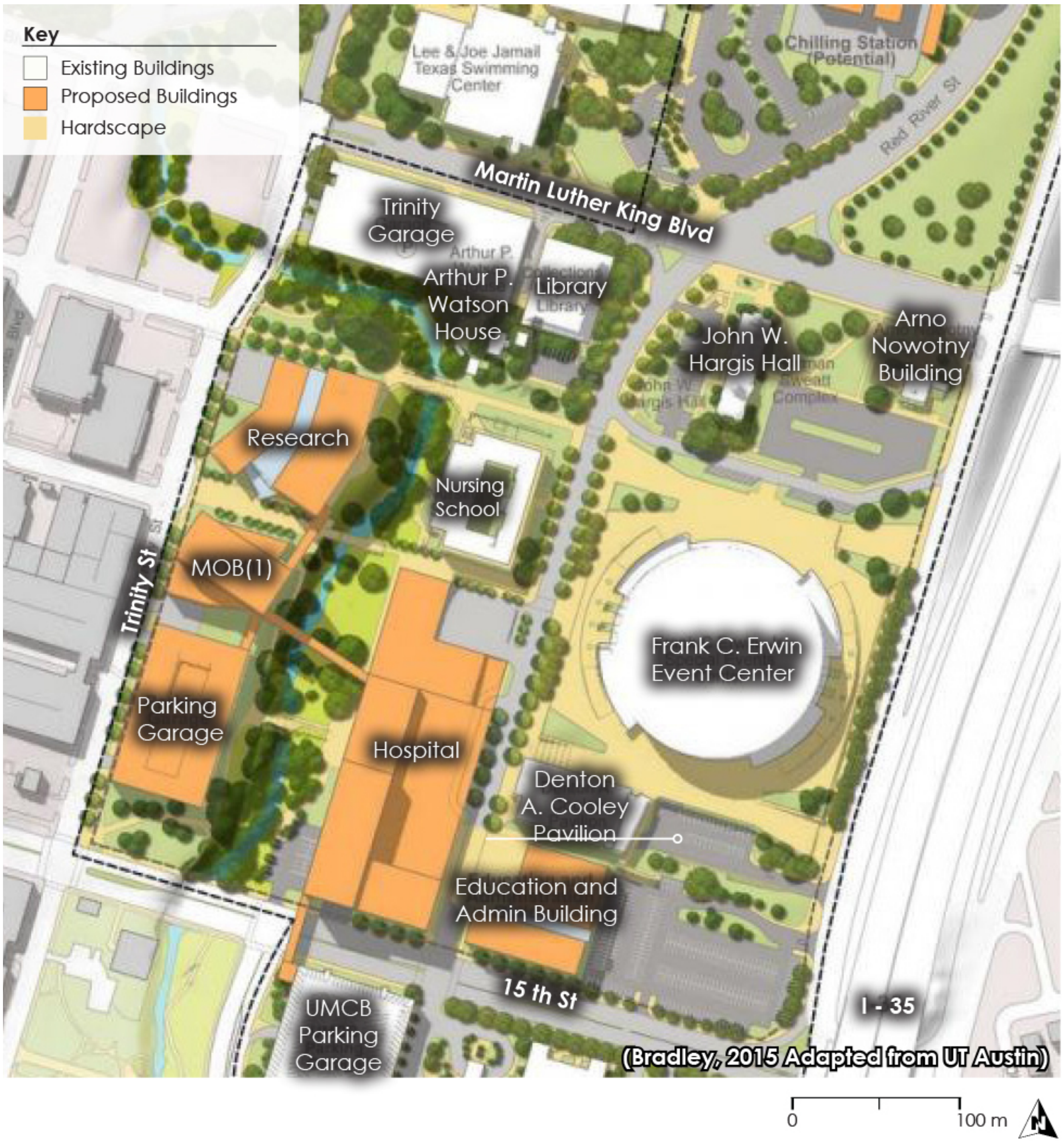
Figure 5-61: Project 3 Land Cover



The simplified land cover helps to understand the broader scale composition of the landscape. At the broader scale the sites open space is not as substantial as some of the available open park space surrounding the area.

5.4.3.2 Proposed Development

Figure 5-62: Project 3 Proposed Development



5.4.3.3 Proposed Development Analysis

5.4.3.3.1 Open Space

The main effect the proposed development has on the existing site is eliminating a large portion of the open space by developing along Waller Creek (see Figure 5-63. Although the development is on the southwest portion of the site it is concentrated along Waller Creek which in this area is one of the most naturalized areas along the creek. The wealth of existing open space along Waller Creek and over the Penick-Allison Tennis Center combined with the mature naturalized vegetation creates an area that should be maintained for the benefit of Mexican Free-Tailed Bats.

Developing along Waller Creek not only reduces the amount of open space but will drastically reduce the vegetation along the creek. With the site being located near downtown Austin there is little vegetation to the west so the site provides some of the best spaces for foraging in the area. The reduction in vegetation and open space with the proposed design will reduce the areas overall ability to support high quality foraging habitat.

Figure 5-63: Proposed Open Space

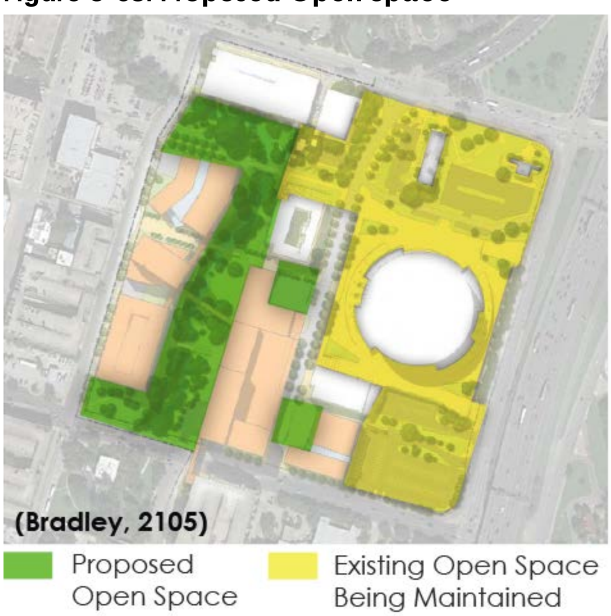


Figure 5-64: Proposed Continuous Corridors

5.4.3.3.2 Proposed Corridors

Mexican Free-Tailed bats have developed to fast flights with less maneuverability so continuous corridors would better support the species flight abilities. Therefore continuous corridors are important for connectivity and foraging (see Figure 5-64).

One major effect of developing most of the site besides the loss of open space is changing the way bats can traverse the site. The proposed development does not drastically change the corridors through the site but it does reduce the overall size and connectivity through the area. East to west corridors have been almost completely removed by proposing large buildings along Waller Creek, especially the new proposed hospital building. Also the main corridor along Waller Creek has been narrowed and vegetation has been reduced creating an overall less suitable flight corridor. The proposed bridges between the new hospital building and the Medical Office Building create another obstacle for flight along Waller Creek.

5.4.3.3.3 Water

The existing site has Waller Creek as the only access to water on site. The proposed development maintains Waller Creek but may reduce the overall insect abundance in the area by reducing the vegetation along the creek. In addition, since much of the existing open space along Waller Creek is being developed the access to water will not be as important for Mexican Free-Tailed Bats with the major reduction in open space. Waller Creek currently provides one of the highest quality access to water and support for insect abundance in the area so development along the creek needs to be carefully considered.

Figure 5-65: Creek Water Access

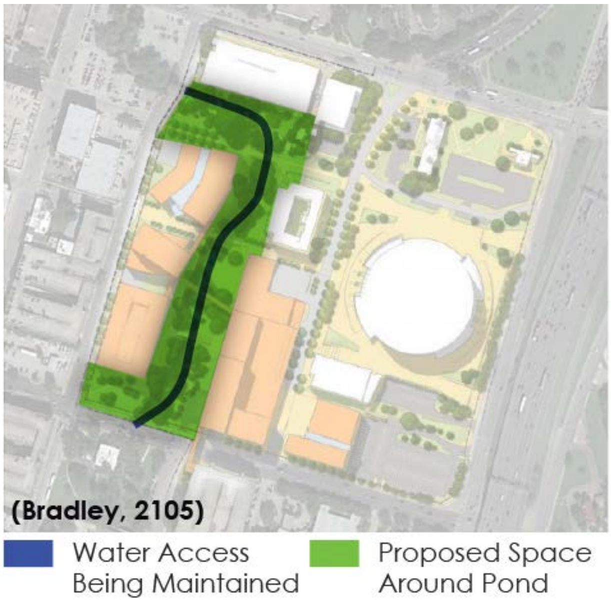
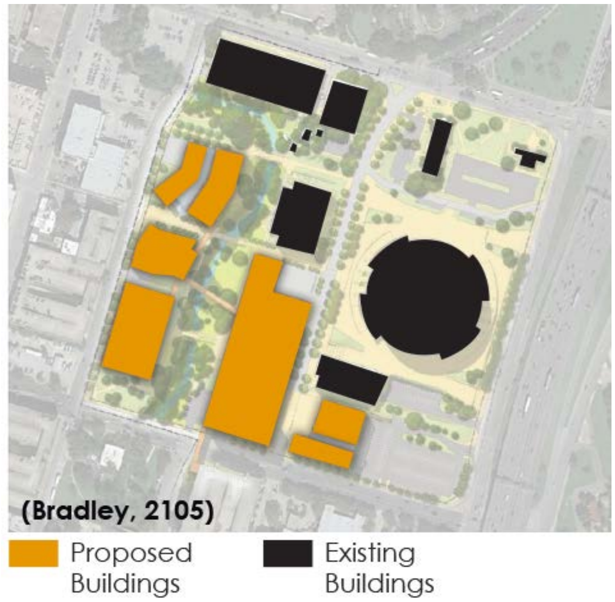


Figure 5-66: Roosting Opportunities



5.4.3.3.4 Roosting Opportunities

The existing site offered few roosting opportunities for Mexican Free-Tailed Bats. Although there are buildings on site, most of the buildings would not provide a great number of roosting opportunities. The Frank C. Erwin Center and the Trinity Parking Garage are large tall structures but because of the buildings construction there are little to no roosting opportunities. The other buildings on site could offer some opportunities for small roosts (see Figure 5-66). The proposed development reduces opportunities for small day roosts with the loss of mature vegetation along Waller Creek. Overall the proposed design will increase opportunities for roosting but will depend on the construction of the new buildings.

5.4.3.4 Summary of Relevant Proposed Policies

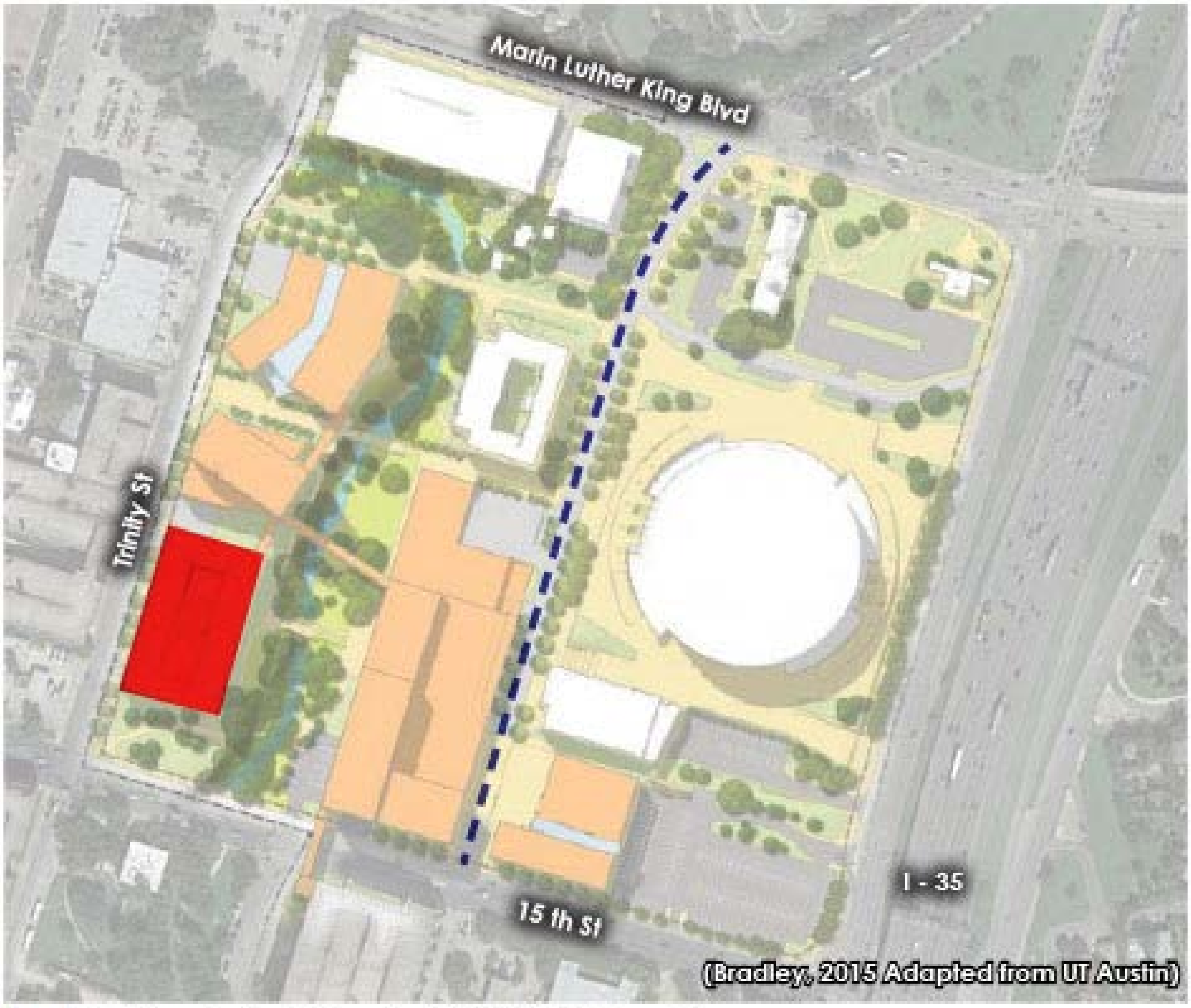
The proposed site does not currently support any of the proposed Mexican Free-Tailed Bat policies. In fact, the proposed development directly opposes some of the proposed

Mexican Free-Tailed Bat policies. The development along Waller Creek opposes policy 1 (Open Space Character) while opposing the policies priorities of maintain open space along waterways. This shows that this site has many opportunities to improve the proposed development to better support Mexican Free-Tailed Bat habitat.

5.4.3.5 Changes to Proposed Development to Support Mexican Free-Tailed Bats

This section addresses how the proposed design can better follow the Mexican Free-Tailed Bat proposed policies and discusses site related opportunities that could further support Mexican Free-Tailed Bats.

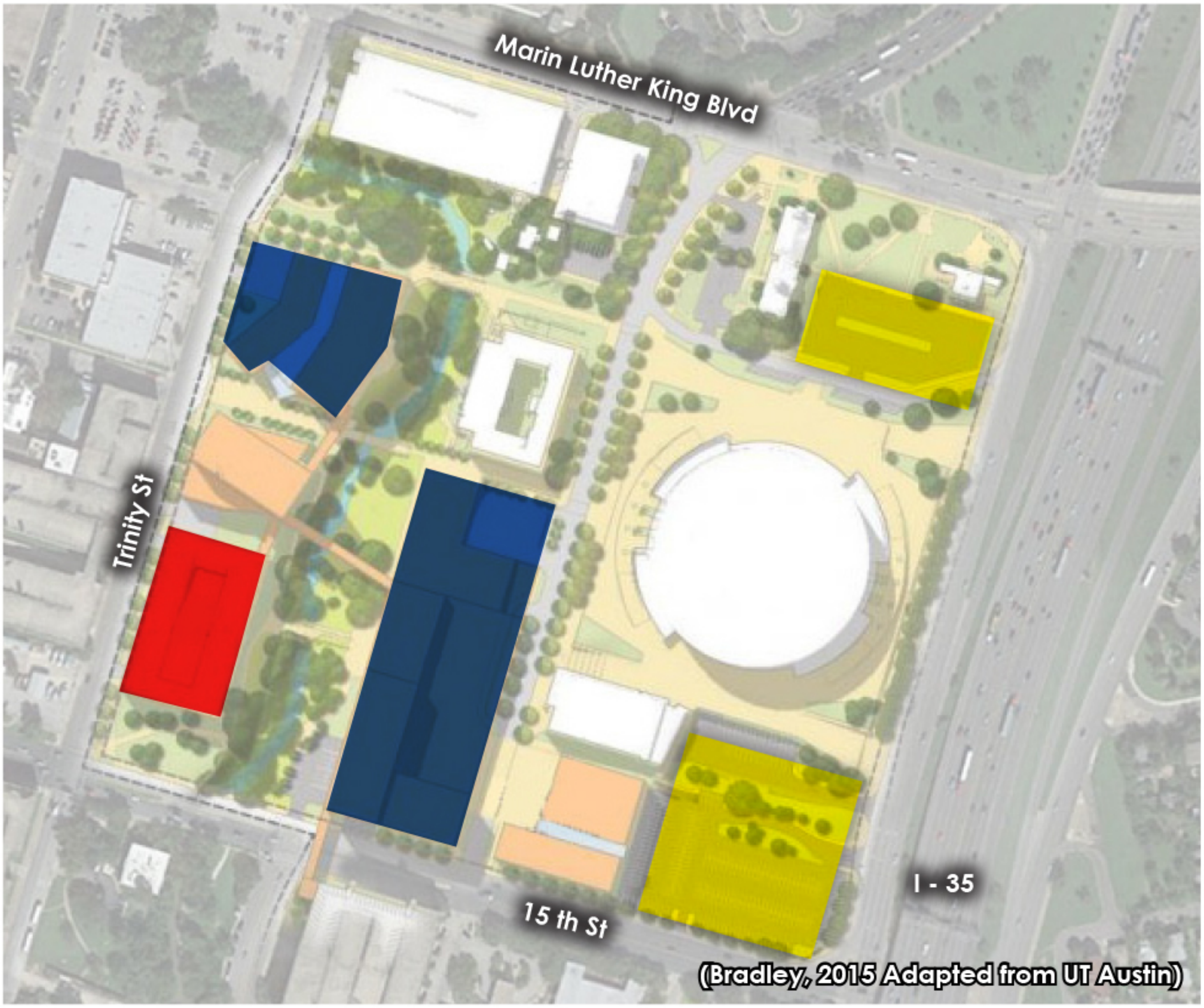
Figure 5-67: Changes to Proposed Development with MFTB Policy



Buildings to be Relocated to Maintain Open Space:
These structures should be relocated or combined with other structures to maintain larger open spaces. These should be replaced by additional open space, especially to increase the size of other proposed open spaces.

Areas to Concentrate Green Water Management Infrastructure:
These areas with increased impervious surfaces offer less vegetation. Therefore, using green street water management, rain gardens, and naturalized swales in these areas will help to increase insect abundance.

Figure 5-68: Changes to Proposed Development Explanation 1

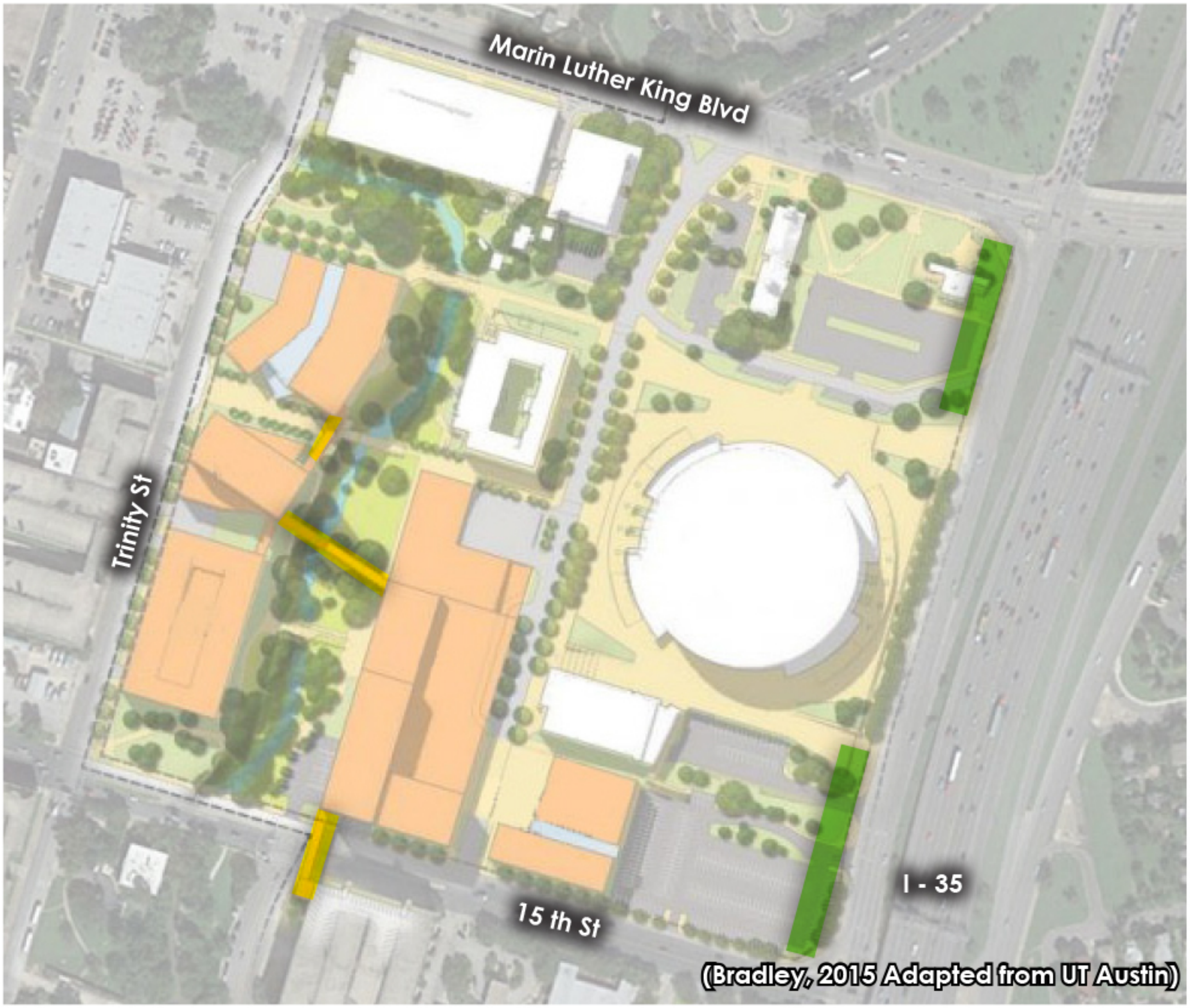


Buildings to be Relocated to Maintain Open Space:
This structures is a parking garage that should be relocated or rethought. This is the second large parking garage on site and the third large parking garage that could service the hospital, because the hospital is proposed to be connected to the parking garage to the south on the other side of 15th street.

Possible Locations for Relocating Parking Garage:
These areas offer better locations for the parking garage. Although this relocation would not change to overall amount of open space maintained it would however maintain higher priority open space near Waller Creek. The creek helps support high insect abundance which helps to create an overall better foraging space of bats, where the other two spaces are currently parking lots which does not offer the same quality of open foraging space.

Buildings to Consider Underground Parking:
These proposed structures offer the opportunity to replace the proposed garage with underground parking. This would allow for the project to maintain or increase the proposed amount of parking spots while still maintaining the sites open space.

Figure 5-69: Other Site Considerations for Proposed Development



Bridges that Could Interrupt Connectivity:
These proposed bridges could interrupt the connectivity on 15th St, along Waller Creek, and through the center of the site. It will be important to maintain or plant more trees along the edges of the bridge to help soften the transition under the bridge.

Highway Buffer:
I-35 runs along the east side of the site and highways have shown to reduce Mexican Free Tailed Bat activity. This can be improved by increasing the trees along the east side of the site in the areas shown. This would help to reduce sound and vision lines to the highway which could help to reduce the highways effect on Mexican Free Tailed Bats.

5.4.3.6 Project Summary

With a few adjustments, The Dell Medical Campus at The University of Texas can better support Mexican Free-Tailed Bats by supporting the proposed policies. Although not every projects site in Austin allows for support of every proposed policy, the proposed changes to development will allow The Dell Medical Campus to support five of the proposed policies well. These changes allow the development to support policies 1 (Open Space Character), 2 (Connectivity), 3 (Waterfront), 5 (Maintaining Vegetation), and 6 (Street Easements). These changes increase the amount of vegetation that will be maintained, maintains higher priority open space, creates opportunities for management of street trees and the support of green water management in a highly impervious areas.

6 Conclusion

6.1 Project Summary

This project creates an understanding of Mexican Free-Tailed Bats' habitat relationships to inform the design of built environments that better support Mexican Free-Tailed Bat habitat. This understanding was used to create a spatial suitability model for Mexican Free-Tailed Bat habitat in the Austin Metropolitan area. The model output was used to explore the most suitable areas to provide a better understanding of Mexican Free-Tailed Bat habitat in and around Austin, Texas. The analysis and model output indicated that maintaining unprotected open space, building higher density, maintaining and establishing vegetation, and supporting landscape connectivity, especially to mitigate the effect highways have on Mexican Free-Tailed Bat habitat, should be incorporated into planning policies to help protect and support Mexican Free-Tailed Bat habitat. Austin's future goals and literature on supporting bats habitat needs furthered the proposed planning policies to include protection of natural resources, waterfront properties, and the support of green water management.

6.2 Challenges

One of the most significant challenges of this project has been expanding my knowledge and understanding of ecology to create a suitability model for Mexican Free-Tailed Bats in a limited amount of time. The creation of wildlife models can be a very complex process that can create a basic understanding of a species relationship or a much deeper understanding that is based off species locational data. Although Mexican Free-Tailed Bats are a well-studied species, wide spread detailed data still does not exist of the species concentrations or movement throughout the Austin area so the understanding created in this project is based off empirical data from other studies that create a basic understanding of different habitat relationships.

Learning the modelling processes in ArcGIS further increased the challenges of creating a suitability model. ArcGIS is a powerful program that has many nuisances to creating and running models. There are many different methods to arrive at the same outcome so choosing the most suitable process was a challenge. In addition anomalies in the program or data can create situations where it is unknown as to why some pieces do not match up. For example an anomaly in the data or program causes the results for the model outcome in land cover areas to come up under 100% accuracy. When breaking up each land cover area into the specific ranges of suitability in each area the results came up to within 0.0001% of the total area but a very small area of the total Austin Metropolitan area was lost to an anomaly. Many things could cause this but after checking and running the calculations multiple times the values never came out to 100%.

6.3 Limitations

One of the most significant limitations of this study is the lack of knowledge and distribution data that exists for Mexican Free-Tailed Bats. Although studies relating to the species relationships exist, they have not yet been fully explored or tested in multiple situations. This allows for a basic understanding of Mexican Free-Tailed Bats but specifics on elements or habitats metrics are not fully understood. With more time or money collecting any amount of base line Mexican Free-Tailed Bat location data would help to confirm or guide the suitability model to further the projects findings.

The most significant limitation on this project was time. The amount of analyses and understanding that had to be created to get a basic understanding of large scale policy interventions to support Mexican Free-Tailed Bats created a very focused project that was based off of current understandings of Mexican Free-Tailed Bats. In addition, when creating the suitability model, habitat suitability indexes were assumed to have linear relationships without enough data to suggest otherwise. This is only one way to create suitability relationships and thresholds for Mexican Free-Tailed Bats habitat relationships may exist, but the full understanding of the species and these thresholds do not exist with the current research on Mexican Free-Tailed Bats. Further research on Mexican Free-Tailed Bats can help to confirm or expand on the projects findings.

6.4 Implications

This project begins to bring together knowledge from multiple disciplines that allows for a better understanding of how urban development patterns can better support Mexican Free-Tailed Bats. It also helps to begin to visualize the types of policies and relationships that would help support Mexican Free-Tailed Bats habitat needs in urban areas. This begins to create an understanding of how and why wildlife's habitat needs could and should be integrated into future development. Using Mexican Free-Tailed Bats as a base for this study, it helps to show how supporting habitat needs can directly benefit urban environments through direct income from ecotourism and indirect income from natural control of insect populations.

6.5 Future Research

Further research into planning and designing for Mexican Free-Tailed Bats should explore increasing the base of knowledge about Mexican Free-Tailed Bats to further the suitability model while exploring ways to collect and organize spatial data that may be missing. Important spatial data that do not exist that would help to further the suitability model include: data related to the construction of urban infrastructure (buildings, bridges, tunnels, etc.) that could offer roosting opportunities for Mexican Free-Tailed Bats, data related to the distribution of Mexican Free-Tailed Bats in the Austin area, and lighting data (location, type, and intensity). There exists significant opportunity for multiple professions to work together to allow ecologists, conservationists, planners and designers to be a part of master planning and site design for places where key wildlife species are of concern. This would allow urban environments to be better integrated within the natural ecosystems in order to better support wildlife's habitat and needs.

Another area of further research are performance evaluations to test the effect new development has on Mexican Free-Tailed Bats. This would involve collecting detailed data on the species distribution and movement in the Austin Area allowing areas of new construction to have base levels of Mexican Free-Tailed Bat activity to understand new developments effects on Mexican Free-Tailed Bats. These performance evaluations would provide a deeper understanding of Mexican Free-Tailed Bats use of different habitats while creating an overall better understanding of the species and how different types of development affect Mexican Free-Tailed Bats.

The model output revealed suburban land cover areas to make up almost 90% of the bottom 20% of suitability. This could be caused by the fact that highways offer the lowest suitability in the area and most highways are classified as suburban land cover because it is considered developed area but is a lower percent of impervious surfaces. If the study were to be conducted again, removing the land cover within highways or creating a new highway land cover would allow for a better understanding of suburban land cover areas. This is important because suburban land cover made up almost 30% of the total area that was in the top 21-40% of suitable areas in the Austin Metropolitan area.

6.6 Conclusion

The methodology employed in this project led to a solution of proposed policies for the City of Austin to support Mexican Free-Tailed Bats. Through the creation of a typology, spatial suitability model, and finer scale landscape analysis this project envisions a city of Austin that not only better supports Mexican Free-Tailed Bat habitat but begins to show that designing for wildlife can be currently integrated in urban planning and design.

This project has made the case for integrating Mexican Free-Tailed Bats needs into urban planning and design policies in Austin, Texas. The consideration of Mexican Free-Tailed Bats habitat needs can contribute to Austin's greater economic and cultural goals and opportunities. By supporting Mexican Free-Tailed Bat habitat in Austin, Texas the city can hope to increase ecotourism revenue from people coming to observe urban bat colonies and increasing the city's natural insect control while reducing the need for harmful pesticide use throughout the area. In addition, these proposed policies could help to support a declining Mexican Free-Tailed Bat population and hope to increase the species population in the area.

7 References

1) Figure Citations

Figure 1-1: Bradley, Dale. 2015. Project Design Methodology Diagram. Adobe Indesign.

Figure 2-1: USFWS/Ann Froschauer. (2012). *Mexican free-tailed bat* [Photo]. Retrieved from https://www.flickr.com/photos/usfwshq/8006856842/

Figure 2-2: Bradley, Dale. 2015. Mexican Free-Tailed Bat Range. Adobe Photoshop and ArcGIS. Source data: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors. Source data: The IUCN Red List of Threatened Species: Tadarida brasiliensis. Retrieved from http://www.iucnredlist.org/details/summary/21314/0.

Figure 2-3: Gunnell, K., Grant, G., & Williams, C. U (2012). Residential Biodiversity Enhancements [Image]. Landscape and urban design for bats and biodiversity pg. 6. London: Bat Conservation Trust. Retrieved from http://www.bats.org.uk/download_info.php?id=1180&file=Landscape_and_urban_design_for_bats_and_biodiversityweb.pdf&referer=http%3A%2F%2Fwww.bats.org.uk%2Fpages%2Flandscapedesign.html.

Figure 2-4: Gunnell, K., Grant, G., & Williams, C. U (2012). Urban Biodiversity Enhancements [Image]. Landscape and urban design for bats and biodiversity pg. 22. London: Bat Conservation Trust. Retrieved from http://www.bats.org.uk/download_info.php?id=1180&file=Landscape_and_urban_design_for_bats_and_biodiversityweb.pdf&referer=http%3A%2F%2Fwww.bats.org.uk%2Fpages%2Flandscapedesign.html.

Figure 2-5: Gunnell, K., Grant, G., & Williams, C. U (2012). Ecological Networks [Image]. Landscape and urban design for bats and biodiversity pg. 30. London: Bat Conservation Trust. Retrieved from http://www.bats.org.uk/download_info.php?id=1180&file=Landscape_and_urban_design_for_bats_and_biodiversityweb.pdf&referer=http%3A%2F%2Fwww.bats.org.uk%2Fpages%2Flandscapedesign.html.

Figure 2-6: Gunnell, K., Grant, G., & Williams, C. U (2012). Underpasses, Hop-overs, Green bridge [Images]. Landscape and urban design for bats and biodiversity pgs. 26-27. London: Bat Conservation Trust. Retrieved from http://www.bats.org.uk/download_info.php?id=1180&file=Landscape_and_urban_desi

gn_for_bats_and_biodiversityweb.pdf&referer=http%3A%2F%2Fwww.bats.org.uk%2Fpages%2Flandscapedesign.html.

Figure 3-2: Bradley, Dale. 2015. Mexican Free-Tailed Bat Spatial Suitability Model Diagram. Adobe Indesign.

Figure 3-3: Bradley, Dale. 2015. Distance to Water GIS Methods. Adobe Indesign.

Figure 3-4: Bradley, Dale. 2015. Distance to Water GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source data: "Bastrop_Rivers_TIGER", "Williamson_Rivers_TIGER", "Travis_Rivers_TIGER", "Caldwell_Rivers_TIGER", "Hays_Rivers_TIGER", "Bastrop_Lakes_TIGER", "Williamson_Lakes_TIGER", "Travis_Lakes_TIGER", "Caldwell_Lakes_TIGER", "Hays_Lakes_TIGER," http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. Accessed 12 November 2015.

Figure 3-5: Bradley, Dale. 2015. Distance to Highways GIS Methods. Adobe Indesign.

Figure 3-6: Bradley, Dale. 2015. Distance to Highways GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source data:"NHPNLine." http://www.fhwa.dot.gov/planning/processes/tools/nhpn/.

Figure 3-7: Bradley, Dale. 2015. Edge Habitat GIS Methods. Adobe Indesign.

Figure 3-8: Bradley, Dale. 2015. Edge Habitat GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source data: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1. Accessed 12 November 2015.

Figure 3-9: Bradley, Dale. 2015. Building Height GIS Methods. Adobe Indesign.

Figure 3-10: Bradley, Dale. 2015. Building Height GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User

Community. Source data: “building_footprints_2013,” ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html. Accessed 12 November 2015.

Figure 3-11: Bradley, Dale. 2015. Building Density GIS Methods. Adobe Indesign.

Figure 3-12: Bradley, Dale. 2015. Building Density GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source data: “building_footprints_2013,” ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html. Accessed 12 November 2015.

Figure 3-13: Bradley, Dale. 2015. Foraging Preferences GIS Methods. Adobe Indesign.

Figure 3-14: Bradley, Dale. 2015. Foraging Preferences GIS Layers. Adobe Indesign and ArcGIS. Source image: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source data: “NLCD06_TX_landcover,” http://www.tnris.org/get-data?quicktabs_maps_data=1. Accessed 12 November 2015.

Figure 3-15: Bradley, Dale. 2015. Suitability Modelling Process. Adobe Indesign and Photoshop.

Figure 3-16: Bradley, Dale. 2015. Final Suitability Model Equation Adobe Indesign.

Figure 3-17: Bradley, Dale. Model Output - Spatial Analysis Locator Map [map]. 1:750,000. “Personal GIS” Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. ”NHPNLine.” http://www.fhwa.dot.gov/planning/processes/tools/nhpn/. “Bastrop_Rivers_TIGER”, “Williamson_Rivers_TIGER”, “Travis_Rivers_TIGER”, “Caldwell_Rivers_TIGER”, “Hays_Rivers_TIGER”, “Bastrop_Lakes_TIGER”, “Williamson_Lakes_TIGER”, “Travis_Lakes_TIGER”, “Caldwell_Lakes_TIGER”, “Hays_Lakes_TIGER.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. Accessed 12 November 2015. Modified from Model Output.

Figure 3-18: Bradley, Dale. 2015. Spatial Analysis 1. Adobe Indesign, ArcGIS, and Google Maps. Source Data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Google Maps. (2015). [St Edwards University, Austin, Texas][Street View Image]. Retreived from https://www.google.com/maps/@30.22904,-97.752988,3a,75y,71.31h,85.38t/data=!3m4!1e1!3m2!1sQGxPAZgcmvGLRdIAzqBJUg!2e0.

Google Maps. (2015). [Blunn Creek Nature Preserve, Austin, Texas][Street View Image]. Retreived from https://www.google.com/maps/@30.233511,-97.748589,3a,90y,120.94h,82.55t/data=!3m4!1e1!3m2!1sUectE-umY3-ScyO9bScKeA!2e0.
Google Maps. (2015). [El Paso St, Austin, Texas][Street View Image]. Retreived from https://www.google.com/maps/@30.234818,-97.758866,3a,90y,300.28h,69.13t/data=!3m4!1e1!3m2!1sskMjUumE0fKkjyW4B9pLkQ!2e0. Modified from Model Output.

Figure 4-1: Dale Bradley. Austin Metro Area Mexican Free-Tailed Bat Suitability [map]. 1:750,000. Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. “Bastrop_Bndry_ESRI”, “Williamson_Bndry_ESRI”, “Travis_Bndry_ESRI”, “Caldwell_Bndry_ESRI”, “Hays_Bndry_ESRI.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. Modified from Model Output.

Figure 4-2: Bradley, Dale. 2015. Cities with Over 25,000 People and Suitability Comparison. Adobe Indesign and ArcGIS. Source data: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community. "capcop_city_limits." http://www.capcog.org/data-maps-and-reports/geospatial-data/. Modified from Model Output.

Figure 4-3: Dale Bradley. Suitability and Land Cover Comparison. Adobe Indesign and ArcGIS. Source data: Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. “Bastrop_Bndry_ESRI”, “Williamson_Bndry_ESRI”, “Travis_Bndry_ESRI”, “Caldwell_Bndry_ESRI”, “Hays_Bndry_ESRI.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. “NLCD06_TX_landcover,” http://www.tnris.org/get-data?quicktabs_maps_data=1. Modified from Model Output.

Figure 4-4: Dale Bradley. Suitability and Water Body Comparison. Adobe Indesign and ArcGIS. Source data: . Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community. “Bastrop_Bndry_ESRI”, “Williamson_Bndry_ESRI”, “Travis_Bndry_ESRI”, “Caldwell_Bndry_ESRI”, “Hays_Bndry_ESRI.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. “Bastrop_Rivers_TIGER”, “Williamson_Rivers_TIGER”, “Travis_Rivers_TIGER”, “Caldwell_Rivers_TIGER”, “Hays_Rivers_TIGER”, “Bastrop_Lakes_TIGER”,

“Williamson_Lakes_TIGER”, “Travis_Lakes_TIGER”, “Caldwell_Lakes_TIGER”, “Hays_Lakes_TIGER.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php.. Modified from Model Output.

Figure 4-5: Bradley, Dale. 2015. Top 40% Suitable Areas [map]. 1:750,000. Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. “Bastrop_Bndry_ESRI”, “Williamson_Bndry_ESRI”, “Travis_Bndry_ESRI”, “Caldwell_Bndry_ESRI”, “Hays_Bndry_ESRI.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. “Bastrop_Rivers_TIGER”, “Williamson_Rivers_TIGER”, “Travis_Rivers_TIGER”, “Caldwell_Rivers_TIGER”, “Hays_Rivers_TIGER”, “Bastrop_Lakes_TIGER”, “Williamson_Lakes_TIGER”, “Travis_Lakes_TIGER”, “Caldwell_Lakes_TIGER”, “Hays_Lakes_TIGER.” http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. Modified from Model Output.

Figure 5-1: City of Austin. (2012, June 15). Imagine Austin Comprehensive Plan Growth Concept Map. Retrieved from ftp://ftp.ci.austin.tx.us/GIS-Data/planning/maps/Fig_4.5_Growth_Concept_Map_24x36-2_Map.jpg.

Figure 5-2: Bradley, Dale. 2015. Austin Emerging Projects. Adobe Photoshop. Source data: Austin Planning and Development Review Department. (2015, March 2). Emerging Projects. Retrieved from http://www.austintexas.gov/page/emerging-projects.

Figure 5-3: Bradley, Dale.2015. Austin Emerging Projects and Suitability Comparison. Adobe Indesign and ArcGIS. Source data: Austin Planning and Development Review Department. (2015, March 2). Emerging Projects. Retrieved from http://www.austintexas.gov/page/emerging-projects.

Figure 5-4: Bradley, Dale. 2015. Project 1 Crestview Station. Adobe Indesign and ArcGIS. Source data: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community.

Figure 5-5: Bradley, Dale. 2015. Project 1 Site Exiting. Adobe Indesign and Google Maps. Source data: Google Earth V. 7.1.2.2041. (November 28, 2003). [Lamar Blvd x Airport Blvd Austin, Texas]. 30° 20’ 32.86” N 97° 48’ 36.58” W. Eye alt 7003 feet. DigitalGlobe 2015. Google Earth Desktop [March 15, 2015].

Figure 5-6: Google Maps. (2015). [Metro Rail Red Line, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.347208,-97.72187,3a,75y,350.98h,81.13t/data=!3m4!1e1!3m2!1sJYOVo8VtI-bJM-C8Y8j2lQ!2e0

Figure 5-7: Google Maps. (2015). [Morrow St, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.346889,-97.72098,3a,75y,112.7h,81.11t/data=!3m4!1e1!3m2!1sToTTQHIKzWELH5IIQjQ1tA!2e0

Figure 5-8: Google Maps. (2015). [Lamar Blvd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.338992,-97.718093,3a,75y,225.56h,98.15t/data=!3m5!1e1!3m3!1spyCDqQUQRfsT50WABpgxTQ!2e0!5s20071001T000000

Figure 5-9: Bradley, Dale. 2015. Project 1 Site Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-10: Bradley, Dale. 2015. Project 1 Site Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-11: Bradley, Dale. 2015. Project 1 Site Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-12: Bradley, Dale. 2015. Project 1 Site Scale Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-13: Bradley, Dale. 2015. Project 1 Regional Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-14: Bradley, Dale. 2015. Project 1 Regional Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-15: Bradley, Dale. 2015. Project 1 Regional Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-16: Bradley, Dale. 2015. Project 1 Regional Scale Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-17: Bradley, Dale. 2015. Project 1 Proposed Development. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image}. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-18: Bradley, Dale. 2015. Project 1 Proposed Open Space. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-19: Bradley, Dale. 2015. Project 1 Proposed Continuous Corridors. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-20: Bradley, Dale. 2015. Project 1 Proposed Pond. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-21: Bradley, Dale. 2015. Project 1 Proposed Roosting Opportunities. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-22: Bradley, Dale. 2015. Project 1 Changes to Proposed Development with MFTB Policy. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-23: Bradley, Dale. 2015. Project 1 Changes to Proposed Development Explanation 1. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-24: Bradley, Dale. 2015. Project 1 Changes to Proposed Development Explanation 2. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-25: Bradley, Dale. 2015. Project 1 Changes to Proposed Development Explanation 3. Adobe Photoshop and Indesign. Adapted from: JHP Architecture. (2007), Midtown Commons Master Plan [Image]. Retrieved March 2, 2015 from JHP http://jhparch.com/index.php/recognition.

Figure 5-26: Bradley, Dale. 2015. Project 2 Estancia Hills Country. Adobe Indesign and ArcGIS. Source data: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community.

Figure 5-27: Bradley, Dale. 2015. Project 2 Site Exiting. Adobe Indesign and Google Maps. Source data: Google Earth V. 7.1.2.2041. (August 1, 2012). [I-35 x TX-45 Austin, Texas]. 30° 07' 17.14" N 97° 48' 36.58" W. Eye alt 19287 feet. Google Earth Desktop [March 15, 2015].

Figure 5-28: Google Maps. (2015). [Puryear Rd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.112446,-97.809398,3a,65y,291.75h,82.32t/data=!3m4!1e1!3m2!1sYHtVnxJTpOqUAXCMx9N5QQ!2e0.

Figure 5-29: Google Maps. (2015). [Onion Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.13574,-97.79824,3a,90y,275.78h,77.44t/data=!3m4!1e1!3m2!1sH2qVEMHlCMAYT5zCP5kUnw!2e0

Figure 5-30: Google Maps. (2015). [I-35, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.133629,-97.798718,3a,75y,254.72h,82.26t/data=!3m4!1e1!3m2!1sWTSRWymWQUETjQAaewFJZg!2e0

Figure 5-31: Google Maps. (2015). [Old San Antonio Rd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.112424,-97.81131,3a,75y,249.22h,89.19t/data=!3m4!1e1!3m2!1s9OBTtnTsD8wOp46OQ0bhvg!2e0

Figure 5-32: Bradley, Dale. 2015. Project 2 Site Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-33: Bradley, Dale. 2015. Project 2 Site Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-34: Bradley, Dale. 2015. Project 2 Site Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-35: Bradley, Dale. 2015. Project 2 Site Scale Existing Reclassified Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-36: Bradley, Dale. 2015. Project 2 Regional Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-37: Bradley, Dale. 2015. Project 2 Regional Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-38: Bradley, Dale. 2015. Project 2 Regional Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-39: Bradley, Dale. 2015. Project 2 Regional Scale Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-40: Bradley, Dale. 2015. Project 2 Proposed Development. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image]. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-41: Bradley, Dale. 2015. Project 2 Proposed Open Space. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image]. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-42: Bradley, Dale. 2015. Project 2 Proposed Continuous Development. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image]. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-43: Bradley, Dale. 2015. Project 2 Proposed Pond. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image]. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-44: Bradley, Dale. 2015. Project 2 Proposed Roosting Opportunities. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image]. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-45: Bradley, Dale. 2015. Project 2 Changes to Proposed Development with MFTB Policy. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image}. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-46: Bradley, Dale. 2015. Project 2 Changes to Proposed Development Explanation 1. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image}. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-47: Bradley, Dale. 2015. Project 2 Other Site Considerations for Proposed Development. Adobe Photoshop and Indesign. Adapted from: Stratford Land. (n.d.), Interactive Site Map [Image}. Retrieved March 2, 2015 from Estancia Hill Country http://estanciahillcountry.com/vision_map.html.

Figure 5-48: Bradley, Dale. 2015. Project 3 The Dell Medical Campus at The University of Texas. Adobe Indesign and ArcGIS. Source data: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community.

Figure 5-49: Bradley, Dale. 2015. Project 3 Site Exiting. Adobe Indesign and Google Maps. Source data: Google Earth V. 7.1.2.2041. (October 31, 2013). [Frank C. Erwin Center Austin, Texas]. 30° 16' 38.03" N 97° 44' 00.48" W. Eye alt 2819 feet. Google Earth Desktop [March 15, 2015].

Figure 5-50: Google Maps. (2015). [Waller Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.275763,-97.735147,3a,75y,36.06h,90.22t/data=!3m4!1e1!3m2!1svwcaZH5XZzkSI6xVNzbXLg!2e0

Figure 5-51: Google Maps. (2015). [I-35 N Frontage Rd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.277884,-97.730763,3a,75y,223.04h,75.04t/data=!3m4!1e1!3m2!1sM0vgUf6UnZjPchu1AakAAQ!2e0

Figure 5-52: Google Maps. (2015). [Red River Street, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.277829,-97.732967,3a,75y,197.6h,93.44t/data=!3m4!1e1!3m2!1sRA8oqyRCMwq4FVPQnhrr2Q!2e0

Figure 5-53: Google Maps. (2015). [Trinity St, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.278859,-97.734844,3a,75y,162.75h,82.58t/data=!3m4!1e1!3m2!1sw98fzgs0eyaQIZGoqpibHQ!2e0

Figure 5-54: Bradley, Dale. 2015. Project 3 Site Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-55: Bradley, Dale. 2015. Project 3 Site Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-56: Bradley, Dale. 2015. Project 3 Site Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-57: Bradley, Dale. 2015. Project 3 Site Scale Existing Reclassified Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-58: Bradley, Dale. 2015. Project 3 Broad Scale Aerial. Adobe Indesign and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 5-59: Bradley, Dale. 2015. Project 3 Regional Scale Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-60: Bradley, Dale. 2015. Project 3 Regional Scale Top 50% Suitability. Adobe Indesign and ArcGIS. Modified from Model Output.

Figure 5-61: Bradley, Dale. 2015. Project 3 Regional Scale Existing Reclassified Land Cover. Adobe Indesign and ArcGIS. Source: "NLCD06_TX_landcover," http://www.tnris.org/get-data?quicktabs_maps_data=1.

Figure 5-62: Bradley, Dale. 2015. Project 3 Proposed Development. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-63: Bradley, Dale. 2015. Project 3 Open Space. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image}. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-64: Bradley, Dale. 2015. Project 3 Continuous Proposed Corridors. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-65: Bradley, Dale. 2015. Project 3 Water Access. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-66: Bradley, Dale. 2015. Project 3 Roosting Opportunities. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-67: Bradley, Dale. 2015. Project 3 Changes to Proposed Development with MFTB Policy. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-68: Bradley, Dale. 2015. Project 3 Changes to Proposed Development Explanation 1. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

Figure 5-69: Bradley, Dale. 2015. Project 3 Other Site Considerations for Proposed Development. Adobe Photoshop and Indesign. Adapted from: The University of Texas at Austin. (2013), Dell Medical School Construction Plan [Image]. Retrieved March 2, 2015 from The University of Texas http://www.utexas.edu/news/2013/05/08/dell-medical-school-construction-plans-unveiled/.

2) Appendices Figures Citations

Figure 7-1: Bradley, Dale. 2015. Roost Density HSI. Microsoft Excel and Adobe Indesign.

Figure 7-2: Bradley, Dale. 2015. Building Density GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-3: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Roost Density – Buildings [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-4: Bradley, Dale. 2015. Building Height HSI. Microsoft Excel and Adobe Indesign.

Figure 7-5: Bradley, Dale. 2015. Building Height GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-6: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Building Height [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-7: Bradley, Dale. 2015. Distance to Highways HSI. Microsoft Excel and Adobe Indesign.

Figure 7-8: Bradley, Dale. 2015. Distance to Highways GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-9: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Distance to Highways [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-10: Bradley, Dale. 2015. Edge Density HSI. Microsoft Excel and Adobe Indesign.

Figure 7-11: Bradley, Dale. 2015. Edge Density GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-12: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Edge Density [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-13: Bradley, Dale. 2015. Foraging Preferences GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-14: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Foraging Preferences [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-15: Bradley, Dale. 2015. Distance to Water HSI. Microsoft Excel and Adobe Indesign.

Figure 7-16: Bradley, Dale. 2015. Distance to Water GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-17: Bradley, Dale. 2015. Mexican Free-Tailed Bat Suitability Distance to Water [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-18: Bradley, Dale. 2015. Final Suitability Equation. Adobe Indesign.

Figure 7-19: Bradley, Dale. 2015. Final Mexican Free-Tailed Bat Suitability Combination GIS Model Structure. Adobe Indesign and ArcGIS.

Figure 7-20: Bradley, Dale. 2015. Austin Metro Area Mexican Free-Tailed Bat Suitability [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Adapted from Model Output.

Figure 7-21: Bradley, Dale. Model Output - Spatial Analysis Locator Map [map]. 1:750,000. "Personal GIS" Using: ArcMap [GIS software]. Version 10.2. Redlands, CA: Environmental Systems Research Institute,Inc., 2010. "NHPNLine." http://www.fhwa.dot.gov/planning/processes/tools/nhpn/. "Bastrop_Rivers_TIGER", "Williamson_Rivers_TIGER", "Travis_Rivers_TIGER", "Caldwell_Rivers_TIGER", "Hays_Rivers_TIGER", "Bastrop_Lakes_TIGER", "Williamson_Lakes_TIGER", "Travis_Lakes_TIGER", "Caldwell_Lakes_TIGER", "Hays_Lakes_TIGER."

http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php. Accessed 12 November 2015. Modified from Model Output.

Figure 7-22: Bradley, Dale. 2015. Spatial Analysis 1. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Bouldin Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.256912,-97.750933,3a,90y,106.89h,67.79t/data=!3m4!1e1!3m2!1suiybPueqLJIlkOo3rr76yw!2e0. Google Maps. (2015). [Auditorium Shores at Town Lake Metro Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.261974,-97.751288,3a,75y,23.82h,79.89t/data=!3m4!1e1!3m2!1sldDIX0RwjNT6NuzjqSXh4A!2e0. Google Maps. (2015). [Colorado River, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.262601,-97.748259,3a,90y,280.67h,72.49t/data=!3m4!1e1!3m2!1s1SehXo2j5r8JclqWngVr9A!2e0

Figure 7-23: Bradley, Dale. 2015. Spatial Analysis 2. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Williamson Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.226239,-97.841614,3a,85.8y,29.06h,73.67t/data=!3m4!1e1!3m2!1s9-qIdO7fYfmwBvkjSzMv7A!2e0. Google Maps. (2015). [Brodie Ln, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.223211,-97.82443,3a,75y,7.53h,86.13t/data=!3m4!1e1!3m2!1sCu9slVmCgpz_f_9mecBxrw!2e0. Google Maps. (2015). [Monterey Oaks Blvd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.230926,-97.837727,3a,75y,112.18h,85.32t/data=!3m4!1e1!3m2!1sh7WiLRrrmiFERcwLgArKcQ!2e0.

Figure 7-24: Bradley, Dale. 2015. Spatial Analysis 3. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Barton Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.274039,-97.844402,3a,75y,324.75h,94.4t/data=!3m4!1e1!3m2!1sj1G-VqWMcIe85GKXZez73w!2e0. Google Maps. (2015). [Barton Creek Wilderness Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.274154,-97.844208,3a,90y,111.58h,85.28t/data=!3m4!1e1!3m2!1skibMq4ZlMEV1fPoZrWwkFw!2e0. Google Maps. (2015). [Barton Creek Country Club, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.292455,-97.862326,3a,72.2y,51.26h,86.26t/data=!3m4!1e1!3m2!1swoGzfnKRwenvgWLjUP86bA!2e0.

Figure 7-25: Bradley, Dale. 2015. Spatial Analysis 4. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [St Edwards University, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.22904,-97.752988,3a,75y,71.31h,85.38t/data=!3m4!1e1!3m2!1sQGxPAZgcmvGLRdIAzqBJUg!2e0. Google Maps. (2015). [Blunn Creek Nature Preserve, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.233511,-97.748589,3a,90y,120.94h,82.55t/data=!3m4!1e1!3m2!1sUectE-umY3-ScyO9bScKeA!2e0. Google Maps. (2015). [El Paso St, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.234818,-97.758866,3a,90y,300.28h,69.13t/data=!3m4!1e1!3m2!1sskMjUumE0fKkjyW4B9pLkQ!2e0.

Figure 7-26: Bradley, Dale. 2015. Spatial Analysis 5. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Hancock Creek, Austin, Texas][Street View Image]. Retrieved from

https://www.google.com/maps/@30.318886,-97.749223,3a,75y,4.16h,91.53t/data=!3m4!1e1!3m2!1s8-zORqfDOfCmYHFAhq5__w!2e0. Google Maps. (2015). [Austin Memorial Park Cemetery, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.328118,-97.750153,3a,75y,337.26h,79.38t/data=!3m4!1e1!3m2!1sFwo6g3gZLhcHt_TfjbllRQ!2e0. Google Maps. (2015). [Park Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.327788,-97.753123,3a,75y,353.01h,82.89t/data=!3m4!1e1!3m2!1sAmPmuhOplak8i3Dfs7xxWg!2e0.

Figure 7-27: Bradley, Dale. 2015. Spatial Analysis 6. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Shinoak Valley Greenbelt, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.350566,-97.768397,3a,75y,102.31h,81.94t/data=!3m4!1e1!3m2!1s107ruowofgbYqdT3_F6yMQ!2e0. Google Maps. (2015). [Austin Memorial County Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.344954,-97.75501,3a,90y,130.82h,85.47t/data=!3m4!1e1!3m2!1sIvXJszuQanMPUYBHQKtYXA!2e0. Google Maps. (2015). [Highland Hills Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.34849,-97.758688,3a,75y,148.93h,78.21t/data=!3m4!1e1!3m2!1s-gjOyUtlcO7sadTcA6inWQ!2e0.

Figure 7-28: Bradley, Dale. 2015. Spatial Analysis 7. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Yett Creek Neighborhood Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.430874,-97.734458,3a,75y,163.56h,92.66t/data=!3m4!1e1!3m2!1sLBw8q7dhTmvFuRpDxMI37w!2e0. Google Maps. (2015). [Riatta Neighborhood Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.431003,-

97.739761,3a,75y,156.73h,93.53t/data=!3m4!1e1!3m2!1sMQFCQEhjoA_bHefQxiUcgQ!2e0. Google Maps. (2015). [Mustang Chase, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.422264,-97.736571,3a,90y,20.98h,83.69t/data=!3m4!1e1!3m2!1sxvmv_pRegUvb6w665GS3Rw!2e0.

Figure 7-29: Bradley, Dale. 2015. Spatial Analysis 8. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Round Rock West Greenbelt, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.500568,-97.698967,3a,75y,178.14h,89.4t/data=!3m4!1e1!3m2!1sd6Ht2BmxBG3bCSLgrjxmfg!2e0. Google Maps. (2015). [Round Rock West Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.503591,-97.691537,3a,75y,232h,83.85t/data=!3m4!1e1!3m2!1s49Xc_b2odm4g5g5rmXZ8QQ!2e0. Google Maps. (2015). [Bluff Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.497111,-97.693921,3a,90y,202.23h,70.14t/data=!3m4!1e1!3m2!1s5KEulWcDtmxuIT2FR8KcGg!2e0.

Figure 7-30: Bradley, Dale. 2015. Spatial Analysis 9. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Big Snady Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.488714,-97.920994,3a,75y,138.16h,84.15t/data=!3m4!1e1!3m2!1sZUxEswRYD4AgcZ96oJNVmQ!2e0. Google Maps. (2015). [Johnson Rd, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.493627,-97.909131,3a,75y,40.61h,77.94t/data=!3m4!1e1!3m2!1sHzDQcjeO37nS8gKs2pJwfQ!2e0.

Google Maps. (2015). [Lake Oaks Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.499196,-97.916342,3a,90y,260.54h,73.42t/data=!3m4!1e1!3m2!1sGvoikjbKirGi3ZqtXlRBHQ!2e0.

Figure 7-31: Bradley, Dale. 2015. Spatial Analysis 10. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Blanco River, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/place/Wimberley,+TX/@29.993557,-98.088596,3a,90y,246.3h,69.42t/data=!3m4!1e1!3m2!1sBayqTFFytZOuNiSVWvG7dA!2e0!4m2!3m1!1s0x865b5828209ccdc3:0xf6d81b4d14131fa4. Google Maps. (2015). [Cypress Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@29.996756,-98.097424,3a,90y,215.8h,86.18t/data=!3m4!1e1!3m2!1s0X-ys9zuPHwIBmtEqz4eAQ!2e0. Google Maps. (2015). [Oak Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@29.99432,-98.095795,3a,90y,332.1h,79.25t/data=!3m4!1e1!3m2!1sJND1X7mHE1DpKunGm8TPfA!2e0.

Figure 7-32: Bradley, Dale. 2015. Spatial Analysis 11. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Meridian Ln, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@29.729084,-97.725631,3a,75y,325.22h,94.29t/data=!3m4!1e1!3m2!1sv2woMxFiGNFsG6lz-6uFow!2e0. Google Maps. (2015). [Luling Gas Plant, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@29.735472,-97.73186,3a,75y,164.82h,78.53t/data=!3m4!1e1!3m2!1sigIwrDfhkEbdBvcO1qSjow!2e0. Google Maps. (2015). [FM 671, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@29.729278,-97.717294,3a,75y,225.49h,76.35t/data=!3m4!1e1!3m2!1sZEPfPbuUtBxAyjAHPPp6nQ!2e0.

Figure 7-33: Bradley, Dale. 2015. Spatial Analysis 12. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Pine Forest Golf Club, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.067934,-97.293897,3a,75y,136.22h,79.13t/data=!3m4!1e1!3m2!1stT_Xqa2EVt-00-RH-dnonQ!2e0. Google Maps. (2015). [Akoloa Dr, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.075775,-97.29464,3a,75y,43.95h,89.92t/data=!3m4!1e1!3m2!1s_c5AmoNPOOapgc_SovGi_A!2e0. Google Maps. (2015). [Colorado River, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.069266,-97.298148,3a,75y,151.71h,88.56t/data=!3m4!1e1!3m2!1s7sG6CpYBwnVoNximv4_WFA!2e0.

Figure 7-34: Bradley, Dale. 2015. Spatial Analysis 13. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [San Gabriel River, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/search/San+Gabriel,+TX/@30.645204,-97.678222,3a,75y,75.55h,90.12t/data=!3m4!1e1!3m2!1s7e85PLqxzhSrhgi8fif0Tg!2e0. Google Maps. (2015). [San Gabriel Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/search/San+Gabriel,+TX/@30.649294,-97.672253,3a,90y,34.8h,85.48t/data=!3m4!1e1!3m2!1sYpjpNrG-ifDGpFn-_c2cLw!2e0. Google Maps. (2015). [2nd St, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.641637,-97.676925,3a,90y,90.81h,81.78t/data=!3m4!1e1!3m2!1su86VfHwMy9TYxymdQA411w!2e0.

Figure 7-35: Bradley, Dale. 2015. Spatial Analysis 14. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar

Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Murphy Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.579039,-97.412885,3a,90y,10.93h,80.26t/data=!3m4!1e1!3m2!1s9J-lYyz4kGaLd-uOcBrR8A!2e0. Google Maps. (2015). [Bull Branch Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.575063,-97.405699,3a,75y,285.25h,85.36t/data=!3m4!1e1!3m2!1sS4w1Al9oNL4aDm8uBSGNtw!2e0. Google Maps. (2015). [10th St, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.576095,-97.411651,3a,75y,272.63h,83.9t/data=!3m4!1e1!3m2!1s7NibqxNqlCrA8nnNLlx5fg!2e0.

Figure 7-36: Bradley, Dale. 2015. Spatial Analysis 15. Adobe Indesign and Photoshop, Google Maps, and ArcGIS. Source data: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Modified from Model Output. Google Maps. (2015). [Slaughter Creek, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.169119,-97.859775,3a,75y,105.81h,77.42t/data=!3m4!1e1!3m2!1sbPDxrlD4YcDqlbhVcEu2xQ!2e0. Google Maps. (2015). [Bauerle Ranch Park, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.164763,-97.849707,3a,90y,29.66h,76.4t/data=!3m4!1e1!3m2!1seOZokQ7lkHJTltzMnSdLiA!2e0. Google Maps. (2015). [Capistrano Trail, Austin, Texas][Street View Image]. Retrieved from https://www.google.com/maps/@30.168481,-97.862291,3a,75y,280.19h,78.91t/data=!3m4!1e1!3m2!1sCz_b1YxjQfXIbU5NaoBzrw!2e0.

3) Table Citations

Table 3-1: Bradley, Dale. 2015. Full Typology Structure. Adobe Indesign and Microsoft Excel.

Table 3-2: Bradley, Dale. 2015. Spatial Modelling Typology Structure. Adobe Indesign and Microsoft Excel.

Table 3-3: Bradley, Dale. 2015. Study Data Areas Reclassification Table. Adobe Indesign and Microsoft Excel.

Table 3-4: Bradley, Dale. 2015. Land Cover Reclassification Table. Adobe Indesign and Microsoft Excel.

Table 3-5: Bradley, Dale. 2015. Land Cover Suitability Value Table. Adobe Indesign and Microsoft Excel.

Table 4-1: Bradley, Dale. 2015. Mexican Free-Tailed Bat Spatial Modelling Typology. Adobe Indesign and Microsoft Excel.

Table 4-2: Bradley, Dale. 2015. Mexican Free-Tailed Bat Typology. Adobe Indesign and Microsoft Excel.

Table 4-3: Bradley, Dale. 2015. Simplified Land Cover Located in Suitable Areas. Adobe Indesign and Microsoft Excel.

Table 4-4: Bradley, Dale. 2015. Suitability Results within 300m from Water. Adobe Indesign and Microsoft Excel.

Table 4-5: Bradley, Dale. 2015. Spatial Analysis Results. Adobe Indesign and Microsoft Excel.

Table 5-1: Bradley, Dale. 2015. Austin Development in Highly Suitable Areas. Adobe Indesign and Microsoft Excel.

4) Appendices Table Citations

Table 7-1: Bradley, Dale. 2015. Spatial Analysis Results. Microsoft Excel and Adobe Indesign.

Table 7-2: Bradley, Dale. 2015. GIS References. Microsoft Excel and Adobe Indesign.

5) References

Allen, L. C., Turmelle, A. S., Mendonça, M. T., Navara, K. J., Kunz, T. H., & McCracken, G. F. (2009). Roosting ecology and variation in adaptive and innate immune system function in the Brazilian free-tailed bat (Tadarida brasiliensis). *Journal of Comparative Physiology B*, *179*(3), 315–323. http://doi.org/10.1007/s00360-008-0315-3

Altringham, J. (1998). *Bats: Biology and Behaviour*. Oxford England; New York: Oxford University Press.

America's Fastest-Growing Cities - In Photos: America's Fastest-Growing Cities. (2015). Retrieved March 23, 2015, from http://www.forbes.com/pictures/mlj45hfdf/americas-fastest-growing-cities/

Anthony M. Hutson, Simon P. Mickleburgh, & Paul A. Racey. (2001). Global Status Survey and Conservation Action Plan Microchiropteran Bats. IUCN, Gland, Switzerland and Cambridge, UK. Retrieved from https://portals.iucn.org/library/efiles/documents/2001-008.pdf

Austin Planning and Development Review Department. (2015, March 2). Emerging Projects. Retrieved from http://www.austintexas.gov/page/emerging-projects

Austin Planning and Development Review Department. (n.d.). City of Austin Master Plans. Retrieved from http://www.austintexas.gov/page/city-austin-master-plans

Avila-Flores, R., & Fenton, M. B. (2005). USE OF SPATIAL FEATURES BY FORAGING INSECTIVOROUS BATS IN A LARGE URBAN LANDSCAPE. *Journal of Mammalogy*, *86*(6), 1193–1204. http://doi.org/10.1644/04-MAMM-A-085R1.1

Basham, R., Law, B., & Banks, P. (2011). Microbats in a "leafy" urban landscape: are they persisting, and what factors influence their presence? *Austral Ecology*, *36*(6), 663–678. http://doi.org/10.1111/j.1442-9993.2010.02202.x

Bat Conservation International. (2008, March). Facts on the Fly: Answers to Questions About Bats and Public Health. Retrieved from http://www.batcon.org/pdfs/education/fof_public.pdf

Bat Conservation International. (2014). USA-Canada. Retrieved from http://www.batcon.org/index.php/our-work/regions/usa-canada?tmpl=component

Bat Conservation International (1). (n.d.). Austin's Bridge Bats. Retrieved from http://www.batcon.org/pdfs/cab/BridgeBatsBrochure.pdf

Bat Conservation International (2). (n.d.). Congress Avenue Bridge. Retrieved from http://www.batcon.org/index.php/our-work/regions/usa-canada/protect-mega-populations/cab-intro

BBC Nature - Mexican free-tailed bat videos, news and facts. (2014). Retrieved December 11, 2014, from http://www.bbc.co.uk/nature/life/Mexican_Free-tailed_Bat

Bellamy, C., Scott, C., Altringham, J., & Minderman, J. (2013). Multiscale, presence-only habitat suitability models: fine-resolution maps for eight bat species. *Journal of Applied Ecology*, *50*(4), 892–901. http://doi.org/10.1111/1365-2664.12117

Bell, G. P. (1980). Habitat use and response to patches of prey by desert insectivorous bats. *Canadian Journal of Zoology*, *58*(10), 1876–1883. http://doi.org/10.1139/z80-256

Bennett, V. J., & Zurcher, A. A. (2013). When corridors collide: Road-related disturbance in commuting bats. *The Journal of Wildlife Management*, *77*(1), 93–101. http://doi.org/10.1002/jwmg.467

Berthinussen, A., & Altringham, J. (2012). The effect of a major road on bat activity and diversity. *Journal of Applied Ecology*, *49*(1), 82–89. http://doi.org/10.1111/j.1365-2664.2011.02068.x

Best, T. L., Geluso, K. N., & Ammerman, L. K. (2003). SUMMER FORAGING RANGE OF MEXICAN FREE-TAILED BATS (TADARIDA BRASILIENSIS MEXICANA) FROM CARLSBAD CAVERN, NEW MEXICO. *The Southwestern Naturalist*, *48*(4), 590–596. http://doi.org/10.1894/0038-4909(2003)048<0590:SFROMF>2.0.CO;2

Bollmann, K., Graf, R. F., & Suter, W. (2011). Quantitative predictions for patch occupancy of capercaillie in fragmented habitats. *Ecography*, *34*(2), 276–286. http://doi.org/10.1111/j.1600-0587.2010.06314.x

Brenner, N. J. (Ed.). (2014). *Implosions/Explosions: Towards a Study of Planetary Urbanization*. Jovis.

Bridgeland, W., & States, H. S. of the U. (1991). *Pocket guide to the humane control of wildlife in cities & towns*. Humane Society of the U.S.

Buckland, S. T., & Elston, D. A. (1993). Empirical Models for the Spatial Distribution of Wildlife. *Journal of Applied Ecology*, *30*(3), 478–495. http://doi.org/10.2307/2404188

Buckman-Sewald, J., Whorton, C., & Root, K. (2014). Developing macrohabitat models for bats in parks using maxent and testing them with data collected by citizen scientists. *International Journal of Biodiversity and Conservation*, *6*(2), 171–183. http://doi.org/10.5897/IJBC2013.0647

Burdett, R., Sudjic, D., London School of Economics and Political Science, & Alfred Herrhausen Gesellschaft für Internationalen Dialog. (2007). *The endless city: the urban age project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society*. London: Phaidon.

Catherine Rich, & Travis Longcore. (2006). *Ecological consequences of artificial night lighting*. Washington, DC: Island Press.

CBRE Inc. (n.d.). Estancia Hill Country. Retrieved from http://www.loopnet.com/xNet/Looplink/Profile/Profile.aspx?LID=17664744&STID=CB0003&LL=true

City of Austin. (2012, June 15). Imagine Austin Comprehensive Plan. Retrieved from http://www.austintexas.gov/sites/default/files/files/Planning/ImagineAustin/webiacpreduced.pdf

Clark, D. R. (1996). Dead and Dying Brazilian Free-Tailed Bats (Tadarida brasiliensis) from Texas: Rabies and Pesticide Exposure. *The Southwestern Naturalist*, *41*(3), 275–278.

Clark, D. R. (2001). DDT and the Decline of Free-Tailed Bats (Tadarida brasiliensis) at Carlsbad Cavern, New Mexico. *Archives of Environmental Contamination and Toxicology*, *40*(4), 537–543. http://doi.org/10.1007/s002440010207

Clark, D. R., Martin, C. O., & Swineford, D. M. (1975). Organochlorine Insecticide Residues in the Free-Tailed Bat (Tadarida brasiliensis) at Bracken Cave, Texas. *Journal of Mammalogy*, *56*(2), 429. http://doi.org/10.2307/1379372

Cleveland, C. J., Betke, M., Federico, P., Frank, J. D., Hallam, T. G., Horn, J., … Kunz, T. H. (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the Environment*, *4*(5), 238–243. http://doi.org/10.1890/1540-9295(2006)004[0238:EVOTPC]2.0.CO;2

Davis, R. B., Herreid, C. F., & Short, H. L. (1962). Mexican Free-Tailed Bats in Texas. *Ecological Monographs*, *32*(4), 311. http://doi.org/10.2307/1942378

Davis, R., & Cockrum, E. L. (1963). Bridges Utilized as Day-Roosts by Bats. *Journal of Mammalogy*, *44*(3), 428–430. http://doi.org/10.2307/1377225

Dixon, M. D. (2012). Relationship between land cover and insectivorous bat activity in an urban landscape. *Urban Ecosystems*, *15*(3), 683–695. http://doi.org/10.1007/s11252-011-0219-y

Duff, A. A., & Morrell, T. E. (2007). Predictive Occurrence Models for Bat Species in California. *The Journal of Wildlife Management*, *71*(3), 693–700. http://doi.org/10.2193/2005-692

Englert, A. C., & Greene, M. J. (2009). Chemically-Mediated Roostmate Recognition and Roost Selection by Brazilian Free-Tailed Bats (Tadarida brasiliensis). *PLOS ONE*, *4*(11). http://doi.org/10.1371/journal.pone.0007781

Evelyn, M. J., Stiles, D. A., & Young, R. A. (2004). Conservation of bats in suburban landscapes: roost selection by Myotis yumanensis in a residential area in California. *Biological Conservation*, *115*(3), 463–473. http://doi.org/10.1016/S0006-3207(03)00163-0

Gehrt, S. D., & Chelsvig, J. E. (2004). SPECIES-SPECIFIC PATTERNS OF BAT ACTIVITY IN AN URBAN LANDSCAPE. *Ecological Applications*, *14*(2), 625–635. http://doi.org/10.1890/03-5013

Geluso, K. (2008). Winter Activity of Brazilian Free-Tailed Bats (Tadarida brasiliensis) at Carlsbad Cavern, New Mexico. *The Southwestern Naturalist*, *53*(2), 243–247.

Ghanem, S. J., & Voigt, C. C. (2012). Chapter 7 - Increasing Awareness of Ecosystem Services Provided by Bats. In T. J. R., Marc Naguib, John C. Mitani and Leigh W. Simmons H. Jane Brockmann (Ed.), *Advances in the Study of Behavior* (Vol. Volume 44, pp. 279–302). Academic Press. Retrieved from http://www.sciencedirect.com/science/article/pii/B9780123942883000071

Gillam, E. H., & McCracken, G. F. (2007). Variability in the echolocation of Tadarida brasiliensis: effects of geography and local acoustic environment. *Animal Behaviour*, *74*(2), 277–286. http://doi.org/10.1016/j.anbehav.2006.12.006

Gretchen C Daily. (1997). *Nature's services : societal dependence on natural ecosystems*. Washington, DC: Island Press.

Gunnell, K., Grant, G., & Williams, C. (2012). *Landscape and urban design for bats and biodiversity*. London: Bat Conservation Trust.

Hall, E. R. (1981). *The mammals of North America* (2d edition..). New York: Wiley.

Hill, J. E. (1984). *Bats: A natural history* (1st edition). Austin: University of Texas Press.

Hirzel, A. H., & Le Lay, G. (2008). Habitat suitability modelling and niche theory. *Journal of Applied Ecology*, *45*(5), 1372–1381. http://doi.org/10.1111/j.1365-2664.2008.01524.x

Hoyle, Z. (2009). Urban Parks Provide Bats Needed Refuge. *Compass : Recent Publications of the Southern Research Station*, *2009 Sept., issue 14*. Retrieved from http://hdl.handle.net/10113/40011

Imagine Austin Partnership. (2012, June 15). Imagine Austin Vision. Retrieved February 14, 2015, from https://austintexas.gov/page/imagine-austin-vision

Jackrel, S. L., & Matlack, R. S. (2010). Influence of surface area, water level and adjacent vegetation on bat use of artificial water sources.(Report). *The American Midland Naturalist*, *164*(1), 74.

Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R., Racey, P. A., & others. (2009). Carpe noctem: the importance of bats as bioindicators. *Endangered Species Research*, *8*(1-2), 93–115.

Jyrki Kangas, J. K. (1993). A method for estimating the suitability function of wildlife habitat for forest planning on the basis of expertise. *Silva Fennica. 1993. 27(4): 259-268.*

Kemp, S. J., & Spotila, J. R. (1997). Effects of Urbanization on Brown Trout Salmo trutta, Other Fishes and Macroinvertebrates in Valley Creek, Valley Forge, Pennsylvania. *American Midland Naturalist*, *138*(1), 55–68. http://doi.org/10.2307/2426654

Kitzes, J., & Merenlender, A. (2014). Large Roads Reduce Bat Activity across Multiple Species. *PLoS ONE*, *9*(5), e96341. http://doi.org/10.1371/journal.pone.0096341

Klinkenborg. (2008). Our Vanishing Night. *National Geographic*. Retrieved from http://ngm.nationalgeographic.com/2008/11/light-pollution/klinkenborg-text

Krutzsch, P. H. (1955). Observations on the Mexican Free-Tailed Bat, Tadarida mexicana. *Journal of Mammalogy*, *36*(2), 236. http://doi.org/10.2307/1375882

Kunz, T. H. (1982). Roosting Ecology of Bats. In T. H. Kunz (Ed.), *Ecology of Bats* (pp. 1–55). Springer US. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4613-3421-7_1

Kunz, T. H., Braun de Torrez, E., Bauer, D., Lobova, T., & Fleming, T. H. (2011). Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, *1223*(1), 1–38. http://doi.org/10.1111/j.1749-6632.2011.06004.x

Kunz, T. H., Jr, J. O. W., & Wadanoli, M. D. (1995). Dietary energetics of the insectivorous Mexican free-tailed bat (Tadarida brasiliensis) during pregnancy and lactation. *Oecologia*, *101*(4), 407–415. http://doi.org/10.1007/BF00329419

Larson, M. A., Dijak, W. D., Thompson, F. R., & Millspaugh, J. J. (2003). *Landscape-level habitat suitability models for twelve wildlife species in southern Missouri*. North Central Forest Experiment Station, Forest Service, US Department of Agriculture. Retrieved from http://www.researchgate.net/publication/257984488_Landscape-level_habitat_suitability_models_for_twelve_species_in_southern_Missouri/file/72e7e520e551e148d1.pdf

LaVal, R. K. (1973). Observations on the Biology of Tadarida brasiliensis cynocephala in Southeastern Louisiana. *American Midland Naturalist*, *89*(1), 112. http://doi.org/10.2307/2424140

Lee, Y.-F., & McCracken, G. F. (2005). DIETARY VARIATION OF BRAZILIAN FREE-TAILED BATS LINKS TO MIGRATORY POPULATIONS OF PEST INSECTS. *Journal of Mammalogy*, *86*(1), 67–76. http://doi.org/10.1644/1545-1542(2005)086<0067:DVOBFB>2.0.CO;2

Lesiński, G. (2007). Bat road casualties and factors determining their number. *Mammalia*, *71*(3), 138–142. http://doi.org/10.1515/MAMM.2007.020

Li, H., & Wilkins, K. T. (2014). Patch or mosaic: bat activity responds to fine-scale urban heterogeneity in a medium-sized city in the United States. *Urban Ecosystems*, 1–19. http://doi.org/10.1007/s11252-014-0369-9

Loeb, S. C., Post, C. J., & Hall, S. T. (2009). Relationship between urbanization and bat community structure in national parks of the southeastern U.S. *Urban Ecosystems*, *12*(2), 197–214. http://doi.org/10.1007/s11252-008-0075-6

Mazurska, K., & Ruczyński, I. (2008). Bats select buildings in clearings in Białowieża Primeval Forest. *Acta Chiropterologica*, *10*(2), 331–338. http://doi.org/10.3161/150811008X414908

McCracken, G. F. (1986). Why Are We Losing Our Mexican Free-tailed Bats? *BATS Magazine*, *3*(3). Retrieved from http://www.batcon.org/index.php/resources/media-education/bats-magazine/bat_article/253

McCracken, G. F., Gillam, E. H., Westbrook, J. K., Lee, Y.-F., Jensen, M. L., & Balsley, B. B. (2008). Brazilian free-tailed bats (Tadarida brasiliensis: Molossidae, Chiroptera) at high altitude: links to migratory insect populations. *Integrative and Comparative Biology*, *48*(1), 107–118. http://doi.org/10.1093/icb/icn033

McCracken, G. F., McCracken, M. K., & Vawter, A. T. (1994). Genetic Structure in Migratory Populations of the Bat Tadarida brasiliensis mexicana. *Journal of Mammalogy*, *75*(2), 500. http://doi.org/10.2307/1382574

McHarg, I. L. (1995). *Design with Nature* (1 edition). New York: Wiley.

Mcintyre, N. E., Knowles-Yánez, K., & Hope, D. (2000). Urban ecology as an interdisciplinary field: differences in the use of "urban" between the social and natural sciences. *Urban Ecosystems*, *4*(1), 5–24. http://doi.org/10.1023/A:1009540018553

McKinney, M. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, *11*(2), 161–176. http://doi.org/10.1007/s11252-007-0045-4

McKinney, M. L. (2002). Urbanization, Biodiversity, and Conservation. *BioScience*, *52*(10), 883–890. http://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, *127*(3), 247–260. http://doi.org/10.1016/j.biocon.2005.09.005

McWilliams, L. A. (2005). VARIATION IN DIET OF THE MEXICAN FREE-TAILED BAT (TADARIDA BRASILIENSIS MEXICANA). *Journal of Mammalogy*, *86*(3), 599–605. http://doi.org/10.1644/1545-1542(2005)86[599:VIDOTM]2.0.CO;2

Meineke, E. K., Dunn, R. R., Sexton, J. O., & Frank, S. D. (2013). Urban Warming Drives Insect Pest Abundance on Street Trees. *PLoS ONE*, *8*(3), e59687. http://doi.org/10.1371/journal.pone.0059687

Meyer, C. F. J., Aguiar, L. M. S., Aguirre, L. F., Baumgarten, J., Clarke, F. M., Cosson, J.-F., … Kalko, E. K. V. (2010). Long-term monitoring of tropical bats for anthropogenic impact assessment: Gauging the statistical power to detect population change. *Biological Conservation*, *143*(11), 2797–2807. http://doi.org/10.1016/j.biocon.2010.07.029

Mickleburgh, S. P., Hutson, A. M., & Racey, P. A. (2002). A review of the global conservation status of bats. *Oryx*, *36*(1). http://doi.org/10.1017/S0030605302000054

Mistry, S. (1990). Characteristics of the visually guided escape response of the Mexican free-tailed bat, Tadarida brasiliensis mexicana. *Animal Behaviour*, *39*(2), 314–320. http://doi.org/10.1016/S0003-3472(05)80876-0

Mistry, S., & McCracken, G. F. (1990). Behavioural response of the Mexican free-tailed bat, Tadarida brasiliensis mexicana, to visible and infra-red light. *Animal Behaviour*, *39*(3), 598–599.

Nichols, L. (2006, October 6). Crestview at the Crossroads. Retrieved March 23, 2015, from http://www.austinchronicle.com/news/2006-10-06/408210/

OFF! Insect Repellents. (2012). Bug Bites are No.1 Factor for Ruining Summer Vacations. Retrieved from http://www.scjohnson.com/Libraries/Download_Documents/OFF_Buggiest_Cities_Survey.sflb.ashx

O’Shea, T. A., & Bogan, M. A. (2003). *Monitoring trends in bat populations of the United States and territories : problems and prospects* (No. ITR - 2003-0003). United States Geological Survey. Retrieved from http://www.fort.usgs.gov/Products/Publications/21329/21329.pdf

Papouchis, C. M., Singer, F. J., & Sloan, W. B. (2001). Responses of Desert Bighorn Sheep to Increased Human Recreation. *The Journal of Wildlife Management*, *65*(3), 573–582. http://doi.org/10.2307/3803110

Pauchard, A., Aguayo, M., Peña, E., & Urrutia, R. (2006). Multiple effects of urbanization on the biodiversity of developing countries: The case of a fast-growing metropolitan area (Concepción, Chile). *Biological Conservation*, *127*(3), 272–281. http://doi.org/10.1016/j.biocon.2005.05.015

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). URBAN ECOLOGICAL SYSTEMS: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. *Annual Review of Ecology & Systematics*, *32*, 127.

Pimentel, C., Krummel, J., Gallahan, D., Hough, J., Merrill, A., Schreiner, I., … Fiance, S. (1978). Benefits and costs of pesticide use in U.S. food production. *BioScience*, *28*, 772.

Rainho, A., & Palmeirim, J. M. (2011). The Importance of Distance to Resources in the Spatial Modelling of Bat Foraging Habitat. *PLoS ONE*, *6*(4), e19227. http://doi.org/10.1371/journal.pone.0019227

Rees, W. (1996). Revisiting carrying capacity: Area-based indicators of sustainability. *Population and Environment*, *17*(3), 195–215. http://doi.org/10.1007/BF02208489

Rittenhouse, C. D., Dijak, W. D., Thompson III, F. R., & Millspaugh, J. J. (2007). Development of landscape-level habitat suitability models for ten wildlife species in the central hardwoods region. Retrieved from http://training.fws.gov/courses/roadmaps/shc/FSHSILandscape.pdf

Scales, J. A., & Wilkins, K. T. (2007). SEASONALITY AND FIDELITY IN ROOST USE OF THE MEXICAN FREE-TAILED BAT, TADARIDA BRASILIENSIS , IN AN URBAN SETTING. *Western North American Naturalist*, *67*(3), 402–408. http://doi.org/10.3398/1527-0904(2007)67[402:SAFIRU]2.0.CO;2

Schmidly, D. and D. (1994). *The Mammals of Texas* (Revised edition edition). Austin, Tex.: TX Parks and Wildlife. Retrieved from http://www.nsrl.ttu.edu/tmot1/Default.htm

Schwind, R. (1989). A variety of insects are attracted to water by reflected polarized light. *Naturwissenschaften*, *76*(8), 377–378. http://doi.org/10.1007/BF00366211

Seto, K. C., Snchez-Rodrguez, R., & Fragkias, M. (2010). The New Geography of Contemporary Urbanization and the Environment.

Sgro, M. P., & Wilkins, K. T. (2003). Roosting behavior of the Mexican free-tailed bat (Tadarida brasiliensis) in a highway overpass. *Western North American Naturalist*, *63*(3), 366–373.

Simmons, J. A., Lavender, W. A., Lavender, B. A., Childs, J. E., Hulebak, K., Rigden, M. R., … O'Farrell, M. J. (1978). Echolocation by free-tailed bats (Tadarida). *Journal of Comparative Physiology □ A*, *125*(4), 291–299. http://doi.org/10.1007/BF00656863

Sosnicki, J. (2012). Tadarida brasiliensis. Retrieved September 25, 2014, from http://animaldiversity.ummz.umich.edu/accounts/Tadarida_brasiliensis/

Stone, E. L., Jones, G., & Harris, S. (2009). Street Lighting Disturbs Commuting Bats. *Current Biology*, *19*(13), 1123–1127. http://doi.org/10.1016/j.cub.2009.05.058

Store, R., & Kangas, J. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. *Landscape and Urban Planning*, *55*(2), 79–93. http://doi.org/10.1016/S0169-2046(01)00120-7

Svoboda, P. L., & Choate, J. R. (1987). Natural History of the Brazilian Free-Tailed Bat in the San Luis Valley of Colorado. *Journal of Mammalogy*, *68*(2), 224. http://doi.org/10.2307/1381461

Texas Parks & Wildlife. (2007). Bat Watching Sites of Texas. Texas Parks & Wildlife. Retrieved from http://www.tpwd.texas.gov/publications/pwdpubs/media/pwd_bk_w7000_1411.pdf

Texas Parks & Wildlife. (n.d.). Brazilian Free-tailed Bat (Tadarida brasiliensis). Retrieved from https://tpwd.texas.gov/huntwild/wild/species/brazilfreetailbat/

The IUCN Red List. (2014). The IUCN Red List of Threatened Species: Tadarida brasiliensis. Retrieved from http://www.iucnredlist.org/details/summary/21314/0

Thomsen, D. E. (1973). Light Pollution. *Science News*, *104*(24), 381–382. http://doi.org/10.2307/3958540

Threlfall, C. G., Law, B., & Banks, P. B. (2012). Influence of Landscape Structure and Human Modifications on Insect Biomass and Bat Foraging Activity in an Urban Landscape. *PLoS ONE*, *7*(6), e38800. http://doi.org/10.1371/journal.pone.0038800

Threlfall, C. G., Law, B., & Banks, P. B. (2013). Roost selection in suburban bushland by the urban sensitive bat Nyctophilus gouldi. *Journal of Mammalogy*, *94*(2), 307–319. http://doi.org/10.1644/11-MAMM-A-393.1

University of Calgary. (2011, March). Fewer bats carry rabies than thought. Retrieved October 21, 2014, from http://www.sciencedaily.com/releases/2011/01/110131133323.htm

US EPA, O. of P. P. (2007). 2006-2007 Pesticide Market Estimates: Table of Contents (Sections) | Pesticides | US EPA. Retrieved October 21, 2014, from http://www.epa.gov/opp00001/pestsales/07pestsales/table_of_contents2007.htm

U. S. Fish and Wildlife Service. Division of Ecological Services. (1981). *Standards for the development of habitat suitability index models : 103 ESM.* Washington, DC: Division of Ecological Services, USFish and Wildlife Service, Deptof the Interior.

U. S. Fish And Wildlife Service, D. O. E. S. (1980). *Habitat evaluation procedures (HEP)*. Washington: Deptof the Interior, Fish and Wildlife Service ; Springfield, Va: NTIS.

U.S. Geological Survey (USGS). (2006). National Land Cover Database 2006 (NLCD2006). Retrieved from http://www.mrlc.gov/nlcd06_leg.php

USGS. (2014, September 10). White-Nose Syndrome (WNS). Retrieved from http://www.nwhc.usgs.gov/disease_information/white-nose_syndrome/

Vander Pol, R. (2012). *Characteristics of urban constructions occupied by bats* (Thesis). Retrieved from https://beardocs.baylor.edu:8443/xmlui/handle/2104/8403

Van der Ree, R., & McCarthy, M. A. (2005). Inferring persistence of indigenous mammals in response to urbanisation. *Animal Conservation*, *8*(3), 309–319. http://doi.org/10.1017/S1367943005002258

Vindigni, M. A., Morris, A. D., Miller, D. A., & Kalcounis-Rueppell, M. C. (2009). Use of modified water sources by bats in a managed pine landscape. *Forest Ecology and Management*, *258*(9), 2056–2061. http://doi.org/10.1016/j.foreco.2009.07.058

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human Domination of Earth's Ecosystems. *Science*, *277*(5325), 494–499.

Washington Habitat Guidelines. (2014). Retrieved from http://wdfw.wa.gov/publications/search.php?Cat=Habitat&SubCat=Guidelines

Weigl, R. (2005). Brazilian free-tailed bat videos, photos and facts - Tadarida brasiliensis. Retrieved October 14, 2014, from http://www.arkive.org/brazilian-free-tailed-bat/tadarida-brasiliensis/

Wilkins, K. T. (1989). Tadarida brasiliensis. *Mammalian Species*, (331), 1–10. http://doi.org/10.2307/3504148

Williams, K. (2012, May 1). *Bat Foraging Activity and Insect Abundance in Relation to Foraging Activity on Baylor University Campus* (Thesis). Retrieved from https://beardocs.baylor.edu:8443/xmlui/handle/2104/8336

Williams, T. C., Ireland, L. C., & Williams, J. M. (1973). High Altitude Flights of the Free-Tailed Bat, Tadarida brasiliensis, Observed with Radar. *Journal of Mammalogy*, *54*(4), 807. http://doi.org/10.2307/1379076

World Wildlife Fund. (2014). Living Planet Report 2014. Retrieved October 18, 2014, from http://wwf.panda.org/about_our_earth/all_publications/living_planet_report/

Yamada, K., Elith, J., McCarthy, M., & Zerger, A. (2003). Eliciting and integrating expert knowledge for wildlife habitat modelling. *Ecological Modelling*, *165*(2), 251–264. http://doi.org/10.1016/S0304-3800(03)00077-2

Zubaid, A., McCracken, G. F., & Kunz, T. (Eds.). (2006). *Functional and Evolutionary Ecology of Bats*. Oxford ; New York: Oxford University Press.

A. Appendix - Bat Information

6) Importance

Bats are important wildlife species because of their ability to act as bioindicators (Jones et al., 2009) and the important ecosystem services bats provide such as pollination services, control of insect populations, and seed dispersal (Kunz, Braun de Torrez, Bauer, Lobova, & Fleming, 2011; Ghanem & Voigt, 2012). Changes in bat populations or activity can be related to climate change, deterioration of water quality, land use changes related to agriculture, fragmentation of forests, fatalities by human infrastructure, disease, pesticide use and overhunting (Jones et al., 2009). Since bats can be sensitive to many elements of the environment and anthropocentric changes bats are important species to monitor and preserve for the future wellbeing of ecosystems (Meyer et al., 2010), including urban ecosystems.

7) General Biology

Bats are the only mammal capable of flight and are of the order Chiroptera with two sub orders, the *Megachiroptera* and *Microchiroptera*. These sub orders are commonly referred to as microbats and megabats (Altringham, 1998). Megabats are large (20-1500 g) old world fruit eating bats that are exclusively plant eating and are confined to Africa, tropical Asia, and Indo-Australia (Altringham, 1998). Microbats are smaller than megabats (1.5-150 g) and are distributed throughout the world on every continent except Antarctica. Microbats have a range of diet requirements from insects to plant eating species. There is approximately 790 species of micro bats distributed among 17 families. Bats are the most wide spread and second most numerous group of mammals in the world. (Altringham, 1998)

Most bats use echolocation for navigation during flight and foraging but some bats use only vision. Although bats are not the only wildlife species to use echolocation it is said that bats have taken echolocation to the peak of evolutionary process (Altringham, 1998). Echolocation has evolved alongside individual bat species wings to combine to create different types of flight and echolocation. As an example bats feeding in and around dense vegetation evolved broad wings with a low wing loading to allow for better maneuverability in a cluttered environment. Echolocation in bats foraging in dense areas also evolved to use higher frequency calls in most cases which allow for better location of insects against heavy background clutter. (Altringham, 1998)

Many bats are nocturnal and tend to conserve energy through the use of daily torpor or hibernation. States of torpor allow for bats to conserve energy and body warmth when not active. Many insectivorous bats hibernate when prey becomes unavailable during winter months but some species migrate, similar to birds. These states of torpor are important for bat species to conserve energy and are what have allowed bats to live the way they do and access resources more efficiently than many other mammals. (Altringham, 1998)

Bats spend most of their lives in roosts although roosting habits range greatly for individual species. Roosts are important for hibernation, reproduction, and safety. The range of suitable roosts are dependent on individual species but bats have been found to roost in caves, crevices, trees, foliage, tents or nests, and manmade structures such as buildings, bridges, and other built infrastructure. (Altringham, 1998)

There are 47 species of bats in the United States and Canada (Bat Conservation International, 2014). The greatest species richness for bats in North America is located in the southwestern United States (Bat Conservation International, 2014).

8) Conservation Status

Out of the 1,001 bat species worldwide there are twelve species that are confirmed to be extinct while there are 238 species that are threatened. For species at lower risk, 212 species are categorized as Near Threatened, 479 as Least Concern, and 60 species that are Data Deficient. These numbers are usually generalizations that are based off of limited information because few bat species have been studied in detail across their whole range. Although bats are a highly evolved species it is concerning that almost half of the world's bats species are extinct, threatened or near threatened, therefore future management for bat species will be important for bats conservation. (Mickleburgh, Hutson, & Racey, 2002)

9) Threats to Bat Species

Bats are subject to many threats in today's world with many of the threats directly related to anthropocentric activities. These human modifications of environments put strains on habitat, habitat quality, habitat connectivity, food, health, roosting, and overexploitation. Bats also have had problems with disease. (Mickleburgh, Hutson, & Racey, 2002)

10) Habitat Loss or Change

Forests and woodlands are one of the most important habitats for bats and with the loss or fragmentation of such areas from anthropocentric activities, wooded areas are becoming less suitable to sustain many bat species (Mickleburgh, Hutson, & Racey, 2002). Also the loss or separation of linear landscape elements such as hedgerows, tree lines, or canals can be harmful to many bat species (Mickleburgh, Hutson, & Racey, 2002). Linear landscape elements provide important connections between roosting and foraging sites (Mickleburgh, Hutson, & Racey, 2002) the loss or modification of linear elements cause some species of bats to choose less suitable commuting routes, foraging sites, or roosts (Stone, Jones, & Harris, 2009). Disruptions in normal behavior caused by landscape modification can cause an increased energy cost by increasing flight time and stress which may cause a reduced survival rate or reduced reproductive success while increasing the chances of predation (Papouchis, Singer, & Sloan, 2001). Overall the loss or modification of linear landscape elements that are important for bats safe commuting routes can cause reductions in populations.

Current management practices for wooded areas can also stress bat populations. Removing dead trees or decaying branches has the potential to reduce the availability of available roosting sites for some bat species. Also abandoned underground mines are potential roosting sites for many bat species which are often disturbed by human activity. Abandoned mines are threatened with resumption of activity or being sealed for safety reasons introduce more challenges for bat species roosting and can be the cause of death for bat species. (Mickleburgh, Hutson, & Racey, 2002)

A. Persecution

With many bat species roosting in or around urban areas the chances that bats roost in places that people do not deem fit such as people's homes or businesses increase. When bats roost in areas that such as people's homes the removal of bats become necessary in most cases, which at a broader scale can put strain on some bat populations. When a bat species is not thought to be harmful the removal of bats from human structures is usually done humanely (Bridgeland & States, 1991) but still can cause extra stress on the bats to relocate and find new roosting locations which are not always successful. Bats have also been used as food sources in some areas such as Indian and Pacific Ocean islands (Mickleburgh, Hutson, & Racey, 2002). Although the number of bats being consumed by humans worldwide is very low it is just another challenge bats face with growing anthropocentric changes.

B. Pesticides

Agricultural practices involving the use of pesticides can have negative effects on bat species (Clark 1996, Pimentel et al. 1978, Clark 2001). Although effects of pesticides on bat species are not well understood (Pimentel et al., 1978) pesticides have shown to be fatal to bats (Clark, 1996; Clark, 2001). Even though the effects on bats are not well understood the 1.1 billion pounds of pesticide used in the United States along each year (US EPA, 2007) will continue to have impacts on bat species. Though the trend of using fewer pesticides and less harmful pesticides in the United States is likely to continue (US EPA, 2007) it is clear that pesticide use can play an important role in future considerations for bat habitats.

C. Disease

Disease has not been a major issue for most bat species throughout history, although more recently a disease called White-Nose Syndrome (WNS) has become a major concern for hibernating bat species (USGS, 2014). White-Nose Syndrome is a fungal disease that infects the muzzle, ears, and wings of hibernating bat species causing abnormal behaviors during hibernation which lead to over consumption of fat reserves leading to death in many bat species. Although White-Nose Syndrome has emerged recently White-Nose Syndrome has caused an 80% decline in bat populations in the northeastern United States in less than a decade. (USGS, 2014)

11) Public Perception and Safety

Many cultures view bats with fear or distrust (Mickleburgh, Hutson, & Racey, 2002). This fear causes many people to overreact to the danger of situations that involve bats (Texas Parks & Wildlife, 2007). The danger of bats living closely with people is often over exaggerated. Bats are not accustomed to human interaction and avoid any conflicts with humans (University of Calgary, 2011). Being nocturnal bats natural decrease the time that it is possible for interaction with humans. While bats are carriers for rabies less than one percent of bats are infected with the disease (University of Calgary, 2011). In fact bat rabies only accounts for about one human death each year in the United States (Bat Conservation International, 2008). To put bat rabies deaths in perspective, dogs kill more people each year than bats from rabies in a decade (Bat Conservation International, 2008). Since bats are feared and often misunderstood it becomes important to educate people about bats benefits.

Education becomes an important part of keeping people and bats safe when there is a large number of bats roosting or foraging closely to where people are located (Texas Parks & Wildlife, 2007) such as an urban area. When people are not educated on why bats are important and how to live alongside them people tend to overreact or take distorted media reporting as the truth. When people overreact and are uneducated it causes people to employ methods of keeping bats out of their homes or area that may actually put them in more consistent contact with bats than a person would normally have on a daily basis therefore actually increasing the chances of a bat related problem or encounter(Texas Parks & Wildlife, 2007). An example of putting oneself at unneeded risk because of lack of education is when someone may try to cover an exterior hole in their attic to not allow bats entry, which puts the person in close contact with the bats and may cause trapped bats to find other ways out of the home usually through the house itself.

12) Literature Review

D. Mexican Free-Tailed Bat

Mexican Free-Tailed Bats are one of the most widely distributed species of bats in North and South America (Hall, 1981). Although extensive studies on their range have yet to be completed they are found throughout much of southern North America, Mexico, and northern South America (Sosnicki 2012; International Union for Conservation, 2014) (See **Error! Reference source not found.**). It becomes important to understand the general biology of the Mexican Free-Tailed Bat as well as the individual relationships Mexican Free-Tailed Bats have with urban areas to better understand how the species lives.

E. Importance

Mexican Free-Tailed Bats are an important part of the ecosystems they are a part of, providing important insect control services (Cleveland et al., 2006) and creating large amounts of guano that can be harvested for use as fertilizer (Wilkins, 1989). It has been estimated that a single female Mexican Free-Tailed Bat will consume up from 39.4% to 73.4% (about 4.7 – 8.6 g) of their pre feeding body mass in insects each night during different stages of lactation (Kunz, Jr, & Wadanoli, 1995). A study conducted in south central Texas to estimate the value of Mexican Free-Tailed Bats to the agriculture in the area found that the populations of Mexican Free-Tailed Bats provided an annual value of $741,000 per year on average but up to $1,725,000 depending on insect populations in a given year (Cleveland et al., 2006). These values seem high but with a total harvest value of $4.6-$6.4 million a year Mexican Free-Tailed Bats can provide great economic value to agricultural areas. Urban areas can benefit from the same type of insect control but for different reasons. Insects are often more abundant in urban areas (Meineke, Dunn, Sexton, & Frank, 2013) and can carry diseases and cause stress on vegetation (Meineke, Dunn, Sexton, & Frank, 2013). The insect control provided by Mexican Free-Tailed Bats can also reduce the need for harmful pesticide which can save money and is less harmful than chemical pesticides (Cleveland et al., 2006).

F. General Biology

Mexican Free-Tailed Bats are small brown furred mammals with large dark ears, short snouts and a wrinkled upper lip that are capable of flight. The name "Free-Tailed" comes from the easy recognizable tail that extends beyond the uropatagium which is not common among bat species (Sosnicki, 2012). Mexican Free-Tailed Bats are wells suited for rapid long distance flight because they possess long narrow pointed wings (Anthony M. Hutson, Simon P. Mickleburgh, & Paul A. Racey, 2001).

Tadarida brasiliensis are nocturnal and spend much of the daytime in a state of torpor (LaVal 1973). Adults range in size from 79 to 98 mm in length with a 31 to 41mm tail. The typical weight of adult *Tadarida brasiliensis* is 11 to 15 g but seasonal changes affect their weight (Anthony M. Hutson, Simon P. Mickleburgh, & Paul A. Racey, 2001).

Tadarida brasiliensis ears range from 8 to 15 mm and their forearm length ranges from 36 to 46 mm (Anthony M. Hutson, Simon P. Mickleburgh, & Paul A. Racey, 2001).

Male and female *Tadarida brasiliensis* live roughly the same amount of time with the longest living to over eight years old. The longest recorded living species in captivity is 12 years old (Weigl, 2005).

Tadarida brasiliensis do not suffer from much predation but its predators consist of red-tailed hawks (Buteo jamaicensis), American kestrals (Falco sparverius), great horned owls (Bubo virinianus), barn owls (Tyto alba), Mississippi kites (Ictinia mississippiensis), Virginia opossum (Didelphis virginiana), striped skunks (Mephitis mephitis), raccoons (Procyon lotor), eastern coachwisps (Masticophis flagellum), and eastern coral snakes (Micrurus fulviusprey). (Sosnicki, 2012)

G. Echolocation

A. Bats

Microchiroptera use echolocation primary for navigation and locating prey. Megachiroptera do not use echolocation and rely almost completely on sight to navigate and locate plants, fruit, and nectar. Although a behavior similar to echolocation is found in some species of megachiroptera but is produced using the tongue and is used primarily for orientation. The ability to echolocate is accomplished through an adept hearing ability and the ability to produce vibrations in the larynx. For these reasons bats tend to have large ears and a large larynx. Although bats are not the only mammals to use echolocation it has arguably reached the peak of its evolution in bats (Altringham, 1998). Echolocation is the reason bats are so adaptable allowing bats to take advantage of the night and dark roosts that many animals are not able to use. (Hill, 1984; Altringham, 1998)

B. Mexican Free-Tailed Bat

Mexican Free-Tailed Bats use echolocation as their primary mode of navigation and for detecting prey (Gillam & McCracken, 2007; Simmons et al., 1978). Mexican Free-Tailed Bats have a well-developed echolocation process that may be one of the most versatile in species of bats (Hill, 1984). Studies have shown that Mexican Free-Tailed Bats are able to adjust their frequencies of echolocation for different situations (Hill, 1984) allowing them to prevent overlap with other bats calls or avoid any environmental noise overlap (Gillam & McCracken, 2007; Simmons et al., 1978). Although bats have been shown to avoid foraging where noise may interfere with echolocation calls (Frenckell & Barclay, 1987) or avoid anthropocentric noise (Hage & Metzner, 2013) the Mexican Free-Tailed Bat's ability to adjust echolocation call frequencies could reduce the avoidance of noise clutter or anthropocentric noise.

H. Important Habitat Elements

1) Roosting

C. Bats

Bats spend most of their lives in their roosts therefore finding the most suitable roost can be important for mating, hibernation, rearing young, protection, and digestion (Kunz, 1982; Altringham, 1998). The roosting habits of bat species are a complex interaction of physiological, behavioral, and morphological adaptations and demographic response (Kunz, 1982). There are many variables for why bats choose a particular roost but the abundance and availability of food, risk of predation, social organization, and energy requirements (Kunz, 1982; Altringham, 1998).

Bats inhabit a wide range of roosts that are dependent on the individual species of bat (Altringham, 1998). Roosts locations and structures vary greatly but caves and crevices, trees, foliage, tent making, and manmade roosts are the most widely used structures (Altringham, 1998). Manmade structures occupied by bats include buildings, mines, bridges, tunnels, tombs, and attics (Altringham, 1998). With such a wide range of roosts bats have adapted to inhabit some bats actually prefer manmade roosts over natural roosts when both are present (Mazurska & Ruczyński, 2008).

D. Mexican Free-Tailed Bat

A variety of different habitats are of importance for Mexican Free-Tailed Bats roosting needs. Some roosting sites include caves (Allen et al. 2009, Geluso 2008) and man-made structures like bridges (Davis & Cockrum, 1963; Allen et al., 2009), buildings (Vander Pol, 2012). Roosts are important for safety (Sgro & Wilkins 2003), breeding (Sgro & Wilkins 2003) and social interaction (Englert & Greene, 2009). Mexican Free-Tailed Bats prefer temperate climates (Sosnicki, 2012) and are found throughout almost all environments such as urban (Avila-Flores & Fenton 2005, Scales & Wilkins 2007, Li & Wilkins, 2014), suburban (Avila-Flores & Fenton, 2005; Scales & Wilkins, 2007; Li & Wilkins, 2014) and natural environments (Loeb, Post, & Hall, 2009).

Mexican Free-Tailed Bats tend to roost in large groups but breeding seasons can change group sizes and compositions (Zubaid, McCracken, & Kunz, 2006). Mexican Free-Tailed Bat colonies are some of the largest congregations of mammals in the world (Wilkins, 1989) reaching totals of up to tens of millions (Zubaid, McCracken, & Kunz, 2006). Females gather in large maternity roosts usually in caves while smaller groups can be found in trees, bridges, buildings, and other man-made structures. Some Mexican Free-Tailed Bats mate multiple times with multiple mates. Most mating activity takes place in the spring when females have their one yearly estrous cycle which lasts approximately five weeks. Females usually give birth to a single offspring after a 11 to 12 week gestation period (Sosnicki, 2012). After birth mothers do not roost with their young but leave them in large groupings of pups so young are identified by scent and calls produced by the pups (Englert & Greene, 2009).

2) Food Habits and Feeding

E. Bats

Bat species exhibit a wide range of food habits. Bats have evolved to take advantage of an incredible range of food habits such as insectivory, carnivory, piscivory, sanguivory, frugivory and nectarivory (Hill, 1984; Altringham, 1998). These wide ranges of feeding habits have allowed bats to take advantage of resources more efficiently while avoiding possible hazards. Feeding ecology of bat species as a whole ranges so much that a comprehensive review would be lengthy (Altringham, 1998) but a general understanding of how and what bats feed on is important for the understanding of bat species.

Feeding times of bat have been shown to range depending on the species but most bats start foraging a little before or at dusk (Hill, 1984). Many species are most active at dusk and dawn where as some species prefer to forage later in the evening (Hill, 1984). Nightly activity varies for different species but nightly activity may be influenced by abiotic factors, meaning some bats tend to be more active on dark nights with little to no moonlight and change their activity levels based on weather patterns such as wind and rain (Hill, 1984).

F. Mexican Free-Tailed Bat

Mexican Free-Tailed Bats are insectivorous and have a relatively diverse diet compared to most other bat species (Lee & McCracken, 2005; McWilliams, 2005). Lee and McCraken (2005) found that Mexican Free-Tailed Bats have a diet that consisted of 12 insect orders and 35 families of insects, which is the highest diversity recorded in a single study for any bat species. The diverse diet of Tadarida brasiliensis was also shown in McWilliams (2005) study which found similar ranges in insect diet diversity (11 orders and 38 families). McCracken et al. (2008) found that the distribution of bats when feeding followed that of the moths that made up an important part of Mexican Free-Tailed Bats diet. Feeding on these moths were recorded at altitudes of 400-600m which shown that Mexican Free-Tailed Bats are not only adapted to a wide range of insect prey but have the ability to exploit food sources at relatively high altitudes. Also because the Mexican Free-Tailed Bat followed important dietary species it can be assumed that availability of insects plays an important role in the Mexican Free-Tailed Bats habits. Long term dietary data is important for the conservation and understanding of Tadarida brasiliensis role in the ecosystem but the data is does not exist because of migratory trends in the species (McWilliams, 2005).

Mexican Free-Tailed Bats usually start forging after sunset, and feed throughout the night, and can fly over 50 km to find a foraging area (Best et al., 2003). Observations of Mexican Free Tail Bats from the Orient Mine in the San Luis Valley, California showed that bats on average emerged 15 minutes after sunset (ranging from 25 minutes before to 46 minutes after sunset) (Svoboda & Choate, 1987). Mexican Free-Tailed Bats diverse diet can be partially attributed to their ability to fly long distances (Best et al., 2003; Williams et al., 1973). Best et al (2003) found the nightly foraging range of Mexican Free-Tailed Bats at Carlsbad Cavern in New Mexico to be at least 56 km from the cave. The entire colony had a forging space nearly 4,000 km3 with individual bats being recorded at altitudes of 750m (Best et al.,2003). Williams et al. (1973) found that the high altitude flight patterns of Mexican Free-Tailed Bats at up to 1300m suggests that the species is capable of high long distance flights similar to many species of birds during migration. This high altitude long distance flight allows Mexican Free-Tailed Bats to access distant resources for foraging also allowing them to migrate seasonally (Lee & McCracken, 2005; McCracken et al., 2008).

Studies on the effects of weather on the emergence of Mexican Free-Tailed Bats have shown that cloud cover can delay the time Mexican Free-Tailed Bats emerge from their roosts (Krutzsch, 1955). Other studies have shown that cloud cover was not a significant factor in the time of emergence and that only serve storms played a role in the delay of emergence from roosts (Svoboda & Choate, 1987). Although weather can affect the time of emergence from roosts for the Mexican Free-Tailed Bat the time at which they choose to emerge is dependent on many factors and is a complicated and misunderstood behavior.

3) Migration and Torpor

G. Bats

The daily cycle of bats can be looked at in two stages: diurnal and nocturnal (Hill, 1984). Since bats are nocturnal most bats spend a the greatest amount of the nocturnal cycle foraging for food or taking part in reproductive activities (Hill, 1984). The diurnal cycle is spent mostly sleeping but activities such as grooming, taking care of young, social behavior and reproductive activities have been observed in most species of bat (Hill, 1984). This process of daily inactivity is a part of torpor. Bats use forms of torpor to regulate body temperatures and conserve energy. The two main forms of torpor many bat species employ are daily sleeping and hibernating. Bats sleep daily because they are nocturnal and are conserving energy for the evening and night hours. Bats hibernate when temperatures drop below individual species temperature ranges and food supplies are not as abundant. Hibernation occurs at different times and for different periods both of which range greatly for individual species of bats. (Hill, 1984; Altringham, 1998)

Some bats use migration as a method for regulating body temperatures and finding food. While migration is not as common as hibernation many bat species are known to migrate in winter months. Most migration is between summer foraging areas and winter hibernation sites and do not always involve north-south movement. Tree roosting bats are the most common species to migrate as trees do not offer suitable hibernation sites because of poor temperature regulation in the coldest climates. Long distance migratory flights require immense amounts of energy and for that reason the process must be accurate. The accuracy of migrating and daily foraging leading to the homing ability of bats to return to their individual roosts repeatedly. (Hill, 1984; Altringham, 1998)

Bat species have shown the ability to find their way back to roosts daily and yearly after migrations (Davis & Cockrum, 1962). Many studies have observed how bats have a homing ability but a complete understanding of how bats continually return to their roosts does not exist. Although we may not know exactly how bats use homing it is understood that vision and light sources could play important roles in bats homing ability (Hill, 1984; Altringham, 1998)

H. Mexican Free-Tailed Bat

Mexican Free-Tailed Bats employ a daily state of torpor to regulate body temperature and conserve energy (Wilkins, 1989; Krutzsch, 1955) like most bat species. Mexican Free-Tailed Bats are a migratory species that have been shown to hibernate with individual migratory groupings with each group having different migratory routes and roosts (McCracken, McCracken, & Vawter, 1994; Davis, Herreid, & Short, 1962).

Studies on Mexican Free Tails Bats have shown the ability to return to their roosts on a daily and yearly basis (Sgro & Wilkins, 2003; Schmidly, 1994; Scales & Wilkins, 2007). In fact the largest urban population of Mexican Free Tail Bats in the Congress Avenue Bridge in Austin, Texas have been around since shortly after the bridges construction in 1984 (Bat Conservation International, n.d.). The tendency to return to roosts day after day and year after year shows that large roosts are important to preserve for the benefit of Mexican Free-Tailed Bats.

4) Road Networks

I. Bats

With the massive increase in urbanization (Burdett et al., 2007) the number of roads will likely continue to increase. Roads can act as barriers for bats restricting access to vital resources (Bennett & Zurcher, 2013; Kitzes & Merenlender, 2014). Roads tend to act as barriers because they create large gaps in commuting routes causing bats to turn and use other route (Bennett & Zurcher, 2013). Also bats tend to avoid roads with increased noise levels causing large roads act as even greater barriers for some bat species (Bennett & Zurcher, 2013). Overall many studies have shown a negative relationship with distance to roads and activity levels for bat species (Berthinussen & Altringham, 2012; Bennett & Zurcher, 2013; Kitzes & Merenlender, 2014) meaning activity levels are lower near roads for some bat species.

Roads also create a dangerous situation for bat because of possible collisions with vehicles. Mortality rates are species related depending on foraging strategies and height of flight for individual species. It was also found that young bats were significantly more likely to be killed by vehicles than adults. (Lesiński, 2007) Given the number of different negative effects on bats it can be seen that roads offer a great boundary or danger for many bat species.

J. Mexican Free-Tailed Bat

Mexican Free-Tailed Bats have been shown to have a negative relationship with their activity related to distance to large roads in more natural environments (Kitzes & Merenlender, 2014). Kitzes and Merenlender (2014) studied bat activity levels near highways and found that Mexican Free-Tailed Bat numbers were twice as much for a distance of 300m from a large highway road as compared to 0m from the road. This would seem to show that Mexican Free-Tailed Bats would not be very active around a great number of roads such as in urbanized areas but a study by Avila-Flores & Fenton (2005) showed that Mexican Free-Tailed Bats tend to favor large urban parks and illuminated areas such as plazas, monuments, temples, parking lots, or similar areas over small urban parks, residential areas, or natural forest areas. This could mean that although bat activity is lower near large roads only the largest roads, such as highways, present a major obstacle for Mexican Free-Tailed Bats.

5) Artificial Light

K. Bats

Artificial lighting at night has species specific impacts on bat species (Avila-Flores & Fenton, 2005; Stone, Jones, & Harris, 2009). Since urban areas are becoming brighter at night with increases artificial lighting we are losing places with darkness and light pollution has become a major problem (Catherine Rich & Travis Longcore, 2006; Klinkenborg, 2008; Thomsen, 1973). Anthropocentric artificial lighting can have varied effects on different bat species (Threlfall, Law, & Banks, 2013; Avila-Flores & Fenton, 2005). Negative effects of lighting has been studied where some species were found to use lit areas significantly less than unlit areas, with some species almost completely avoided lit areas (Avila-Flores & Fenton, 2005; Threlfall, Law, & Banks, 2013; Stone, Jones, & Harris, 2009). While some species of bat are negatively affected by lighting other species actually find artificial lighting as an advantage because light tends to attract insects, which makes feeding extremely easy (Avila-Flores & Fenton, 2005; Rydell, 1991; Threlfall, Law, & Banks, 2013). Overall species of bats are affected differently by the presence of artificial lighting but it is clear that lighting plays a major role in the abundance of bat species.

L. Mexican Free-Tailed Bat

Mexican Free Tail Bats have been observed feeding around artificial lights at night (Bell, 1980). In fact Mexican Free-Tailed Bats tend to actually favor illuminated areas over other sites such as small parks, residential areas and natural forests (Avila-Flores & Fenton, 2005). Studies have shown that not only will Mexican Free-Tailed Bats feed around light they will not avoid light and light may actually play an important role in Mexican Free-Tailed Bats visual navigation (Mistry, 1990; Mistry & McCracken, 1990). While it can be seen that light plays an important role in the feeding and navigation of the Mexican Free-Tailed Bat dark areas are still needed for roosting.
A study conducted by Krutzsch (1955) found that light intensity could play an important role in when Mexican Free-Tailed Bats decide to leave their roosts for the night to begin foraging. Therefore artificial lighting near occupied roosts could play a role in delaying Mexican Free-Tailed Bats time of emergence. Delaying the time of emergence in Mexican Free-Tailed Bats allows less time for foraging and could affect the Mexica Free-Tailed Bats foraging success.

6) Water Sources

M. Bats

Water sources are important to bat species for different reasons but foraging, reproductive and basic physiological requirements are reasons bats typically rely on water sources (Jackrel & Matlack, 2010). Foraging is the main driver behind bats needs for water. Water helps to attract insects for food as well as provides a source of water for drinking. For piscivorous bats water also plays a vital role by providing habitat where fish are found for food sources. (Hill, 1984; Altringham, 1998)

Studies have shown for many species proximity to water is one of the most important variables in locating the distribution of the species (Le Roux, Le Roux, & Waas, 2013; Dixon, 2012; Evelyn, Stiles, & Young, 2004). One study by Rainho & Palmeirim (2011) showed that for *M. schreibersii* and *R. mehelyi*, distance to roost and distance to water explained 86% and 73% of the use of space by the species respectively which shows just how important water can be for some species of bats. Overall it can be seen that water is an important resource for bat species.

N. Mexican Free-Tailed Bat

Like most other bat species Mexican Free Tail Bats use water sources for foraging (Vindigni, Morris, Miller, & Kalcounis-Rueppell, 2009; Best, Geluso, & Ammerman, 2003; Kunz, Jr, & Wadanoli, 1995). Observations on the dietary energetics of the Mexican Free-Tailed Bat show it is unclear if Mexican Free-Tailed Bats actually drink water at all. However it is clear that Mexican Free-Tailed Bats are highly evolved to a relatively low daily water intake. The low to no intake of water by Mexican Free-Tailed Bats may be attributed to the species high dietary fat intake, from their insect prey, which provides an important source of metabolic water while possibly reducing the water lost from the skin during prolonged foraging or migratory flights. (Kunz, Jr, & Wadanoli, 1995) Although Mexican Free-Tailed Bats may not be as dependent on water as some bat species water still attracts insects (Schwind, 1989) providing important opportunities for foraging. Mexican Free-Tailed Bats ability to fly long distances (Best et al., 2003) may reduce the need for a water source near roosts. Being able to fly long distances may explain why Mexican Free-Tailed Bats actually seemed to favor urban spaces, which may offer less opportunities for water, to natural ones in a study conducted by Avila-Flores and Fenton (2005).

B. Appendix - GIS Modelling

The following Appendix is a collection of the GIS modelling structure used to create the Mexican Free-Tailed Bat Suitability Model. Tools used throughout the modeling process can be seen in each of the following diagrams as square yellow rectangles. The final (furthest right) outputs are used in the final model structure (see).

13) Roost Density - Building Density

Figure 7-1: Roost Density HSI

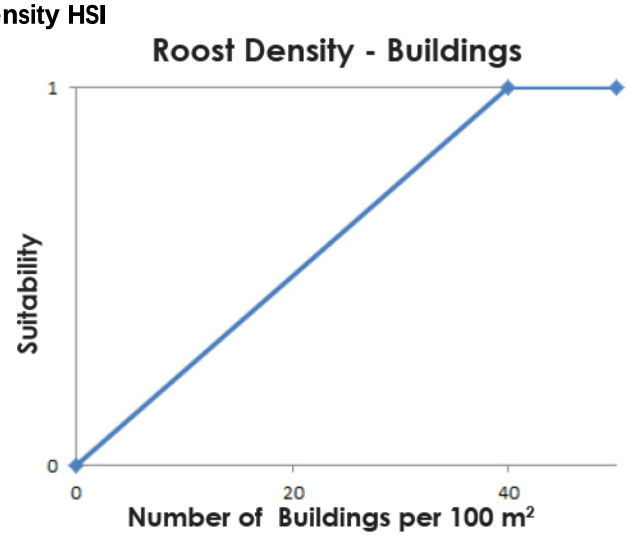
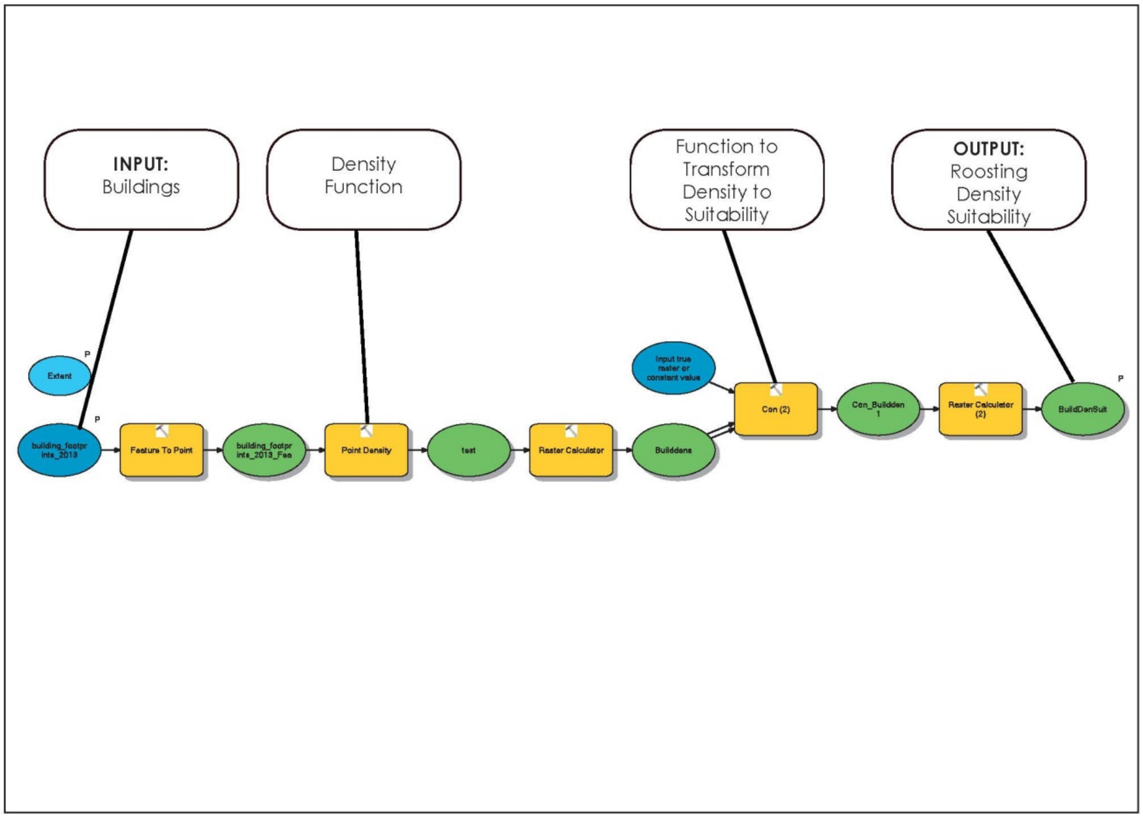
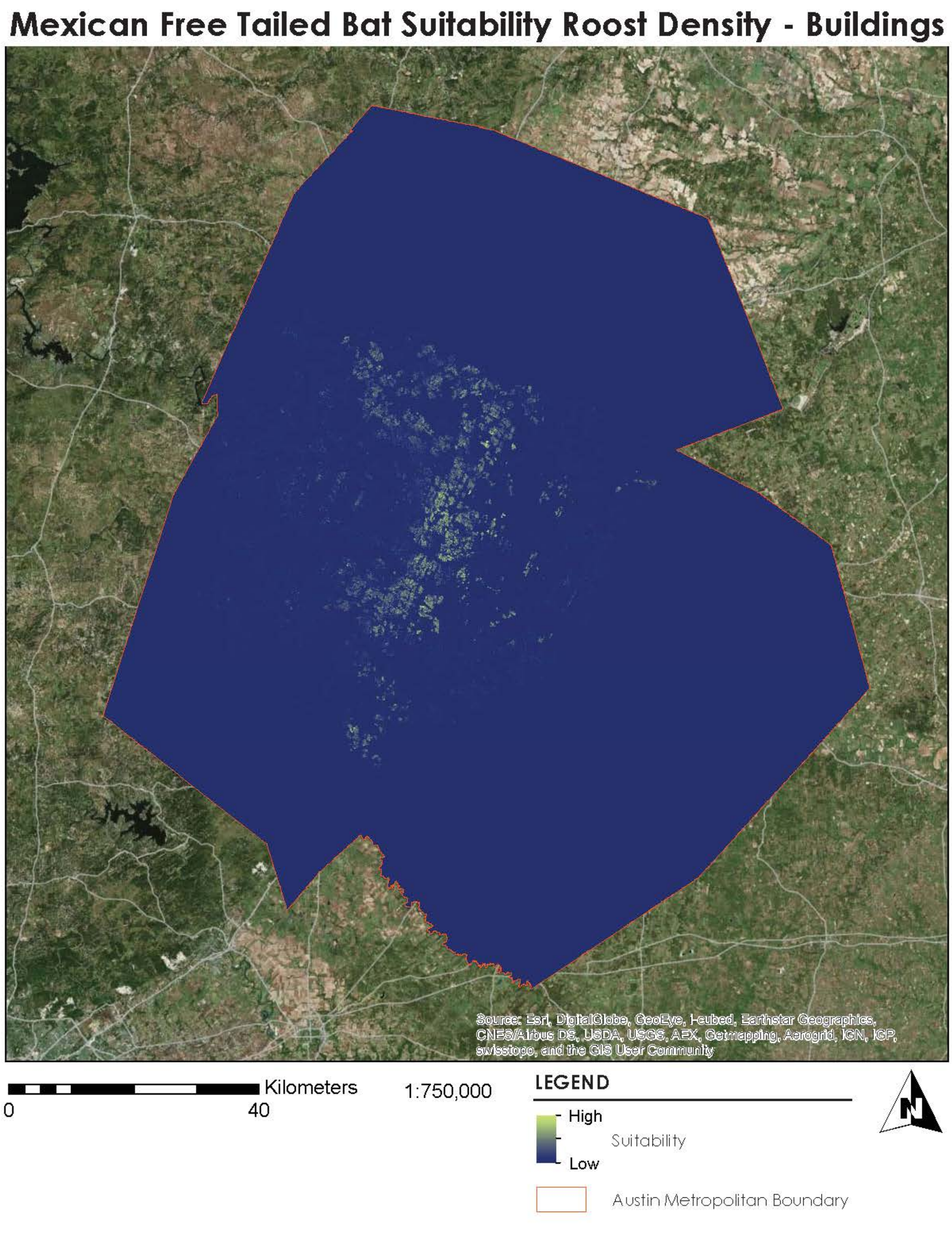


Figure 7-2: Building Density GIS Model Structure



Building Density

Figure 7-3: Building Density Suitability



14) Building Height

Figure 7-4: Building Height HSI

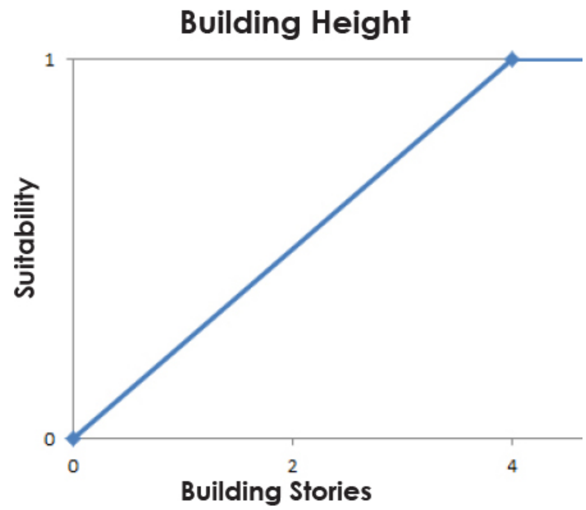
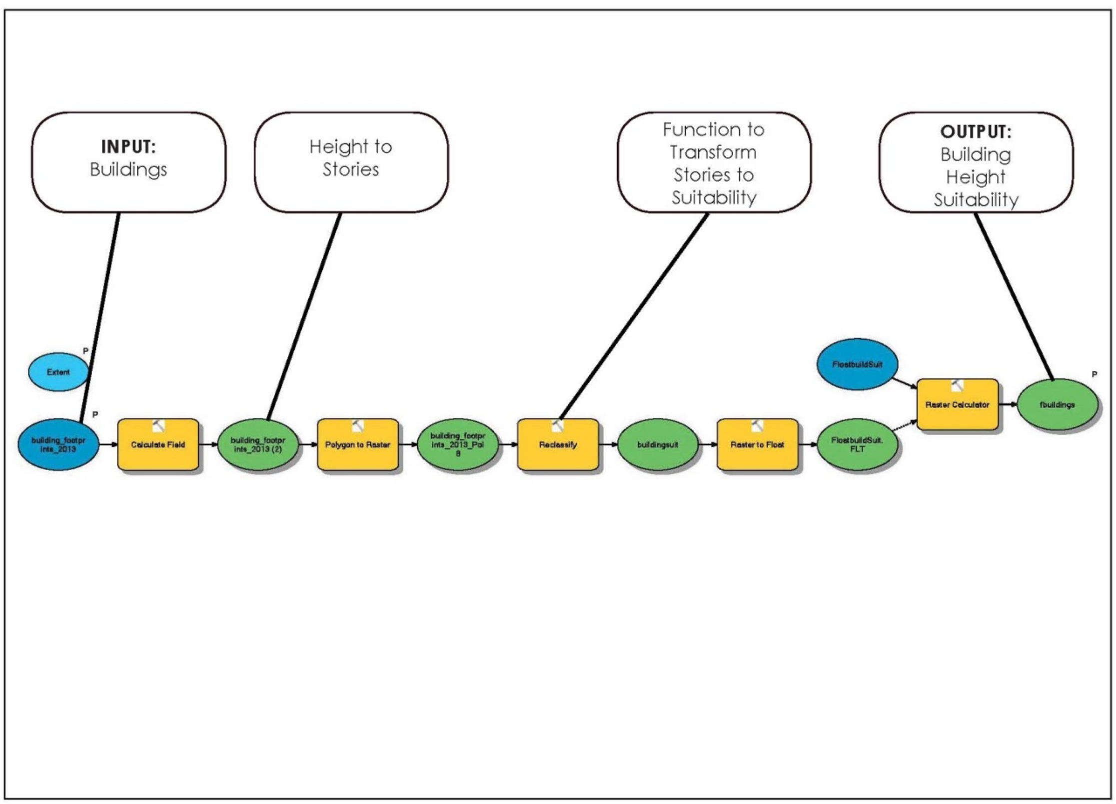
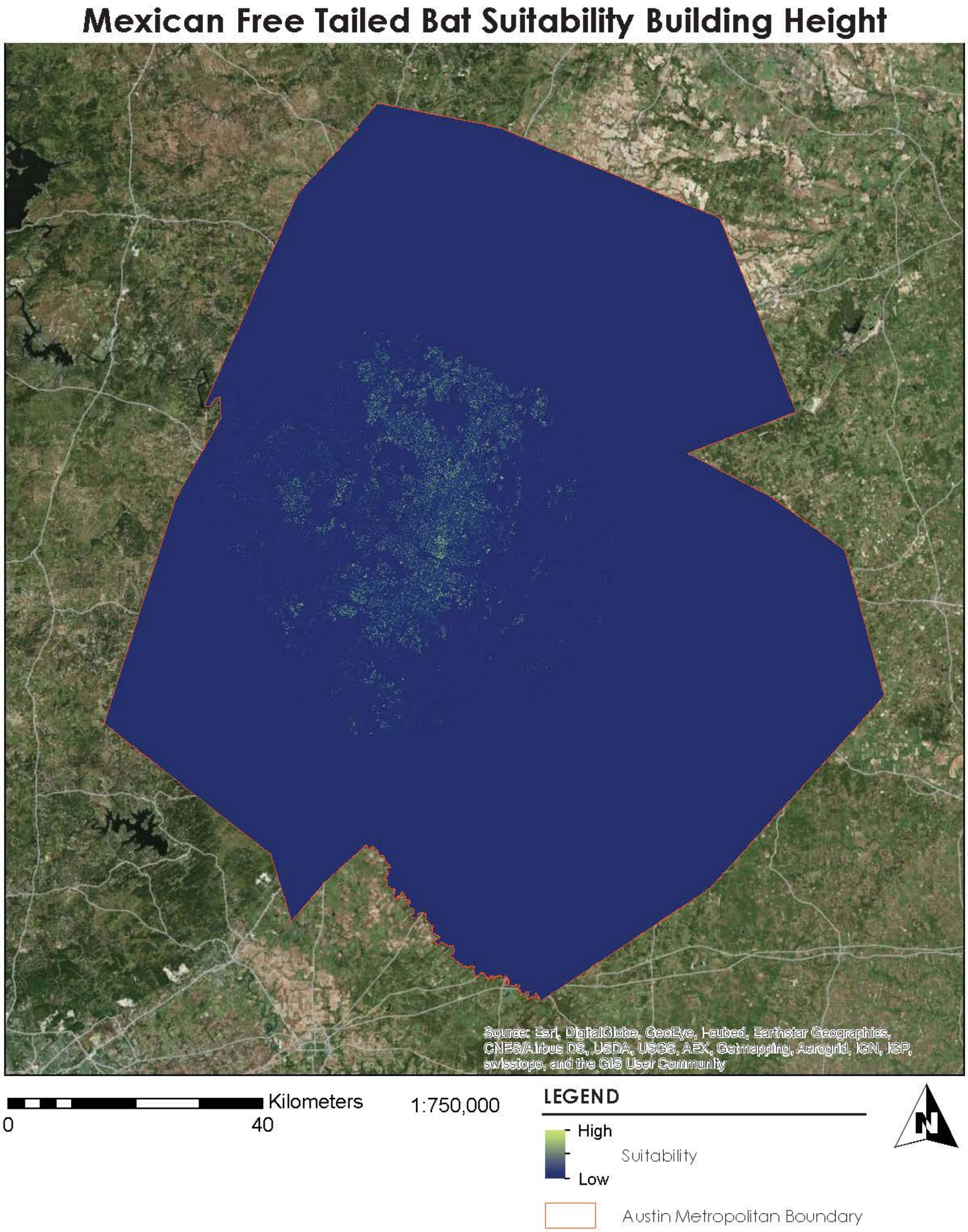


Figure 7-5: Building Height GIS Model Structure



Building Height

Figure 7-6: Building Height Suitability



15) Distance to Highways

Figure 7-7: Distance to Highways HSI

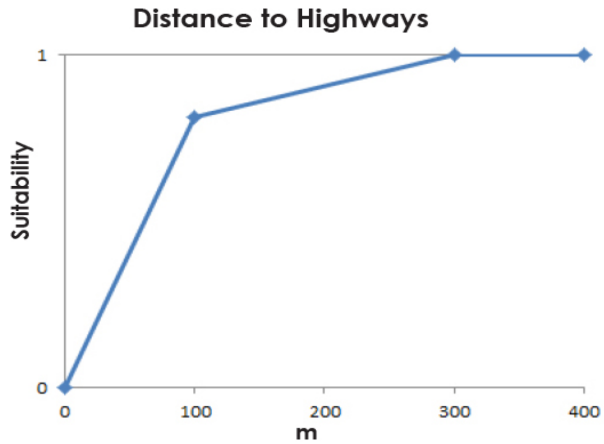
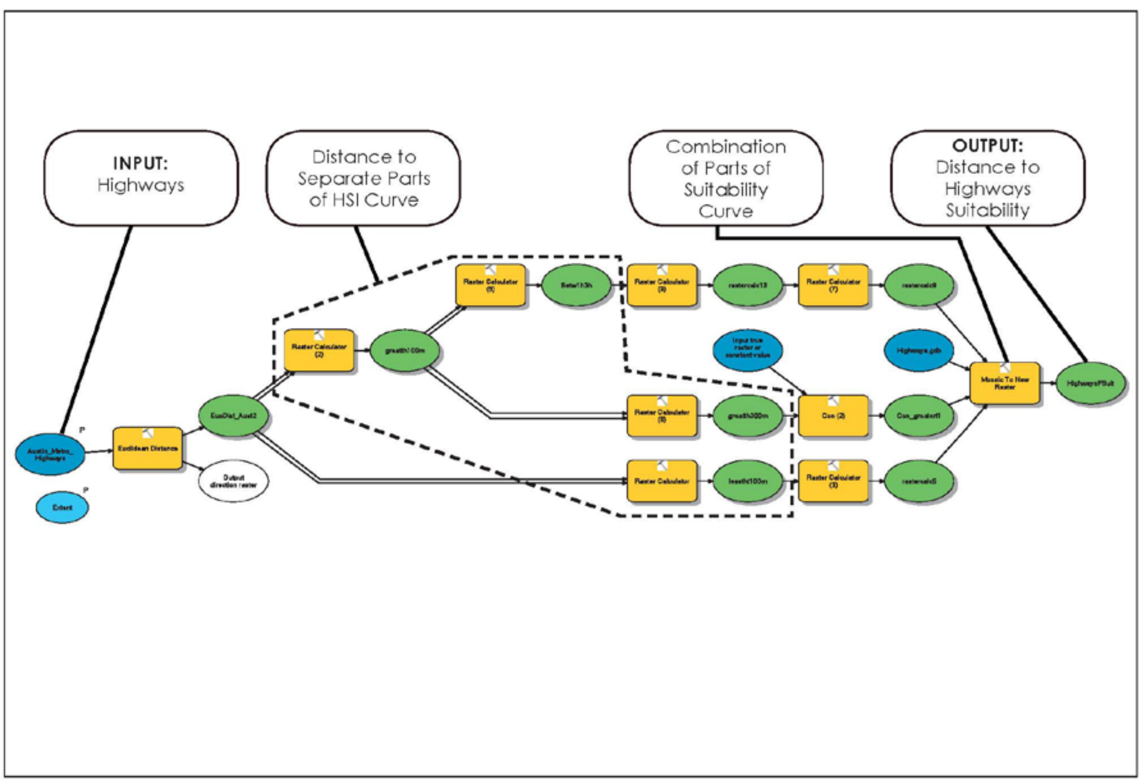
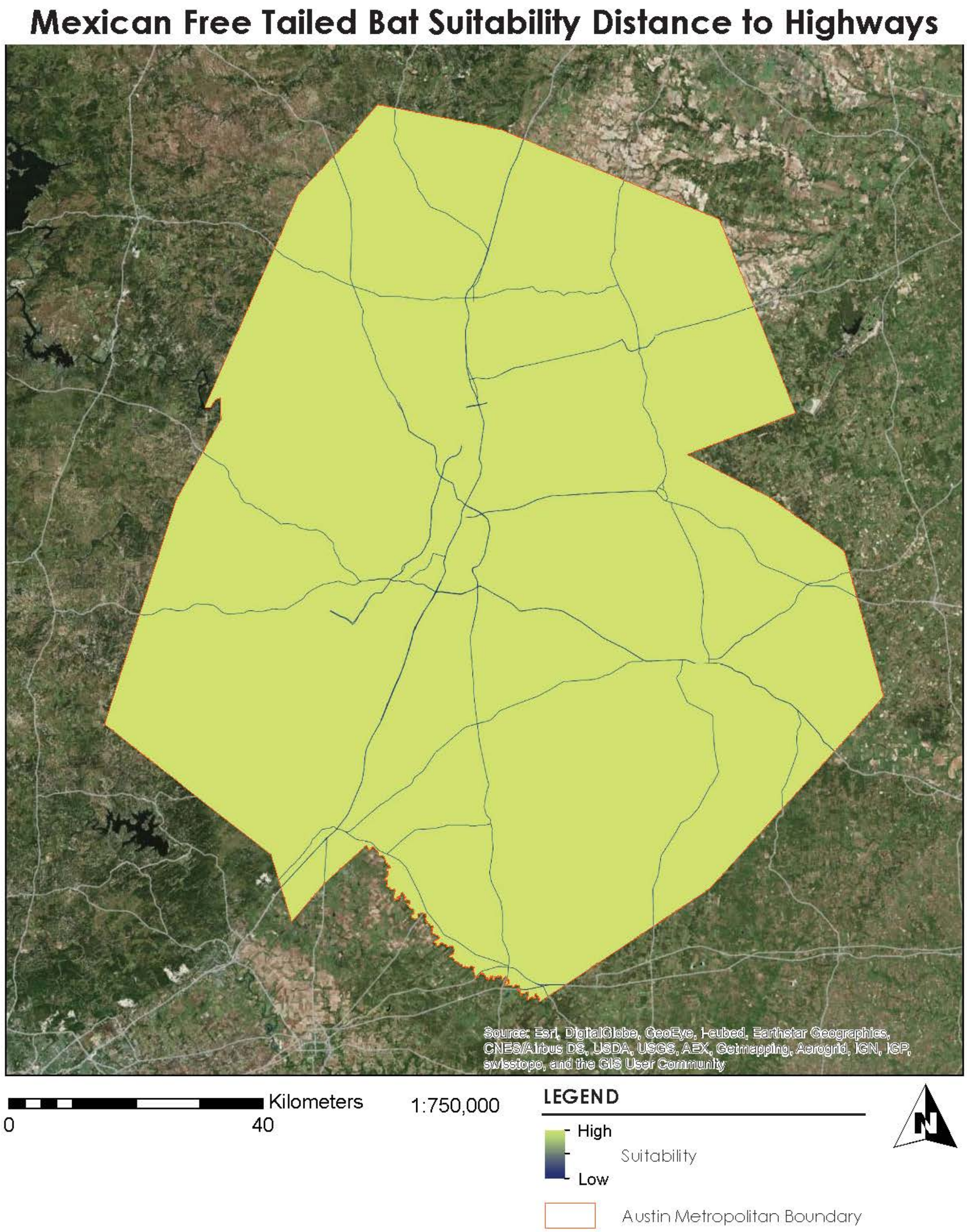


Figure 7-8: Distance to Highways GIS Model Structure



Distance to Highways

Figure 7-9: Distance to Highways Suitability



16) Edge Habitat

Figure 7-10: Edge Density HSI

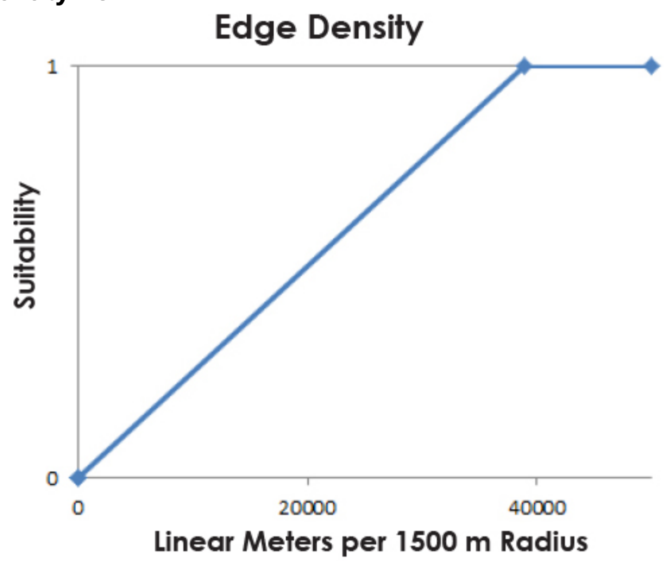
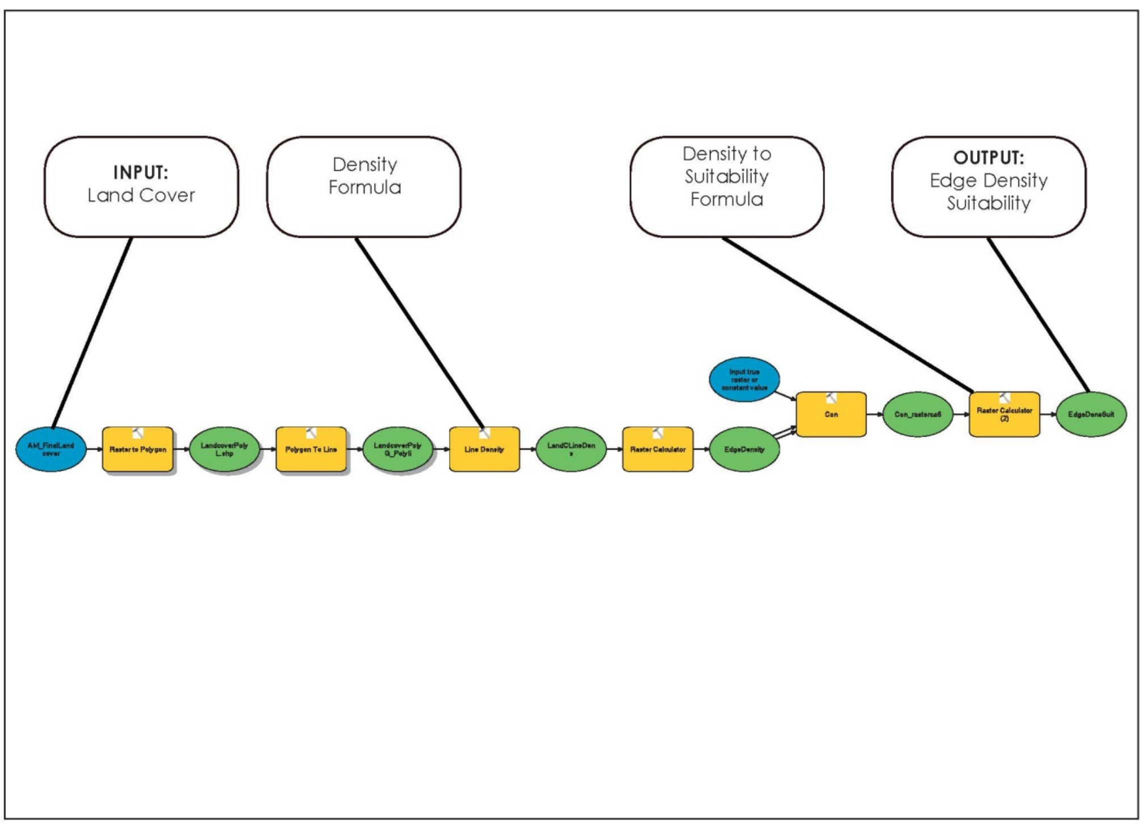
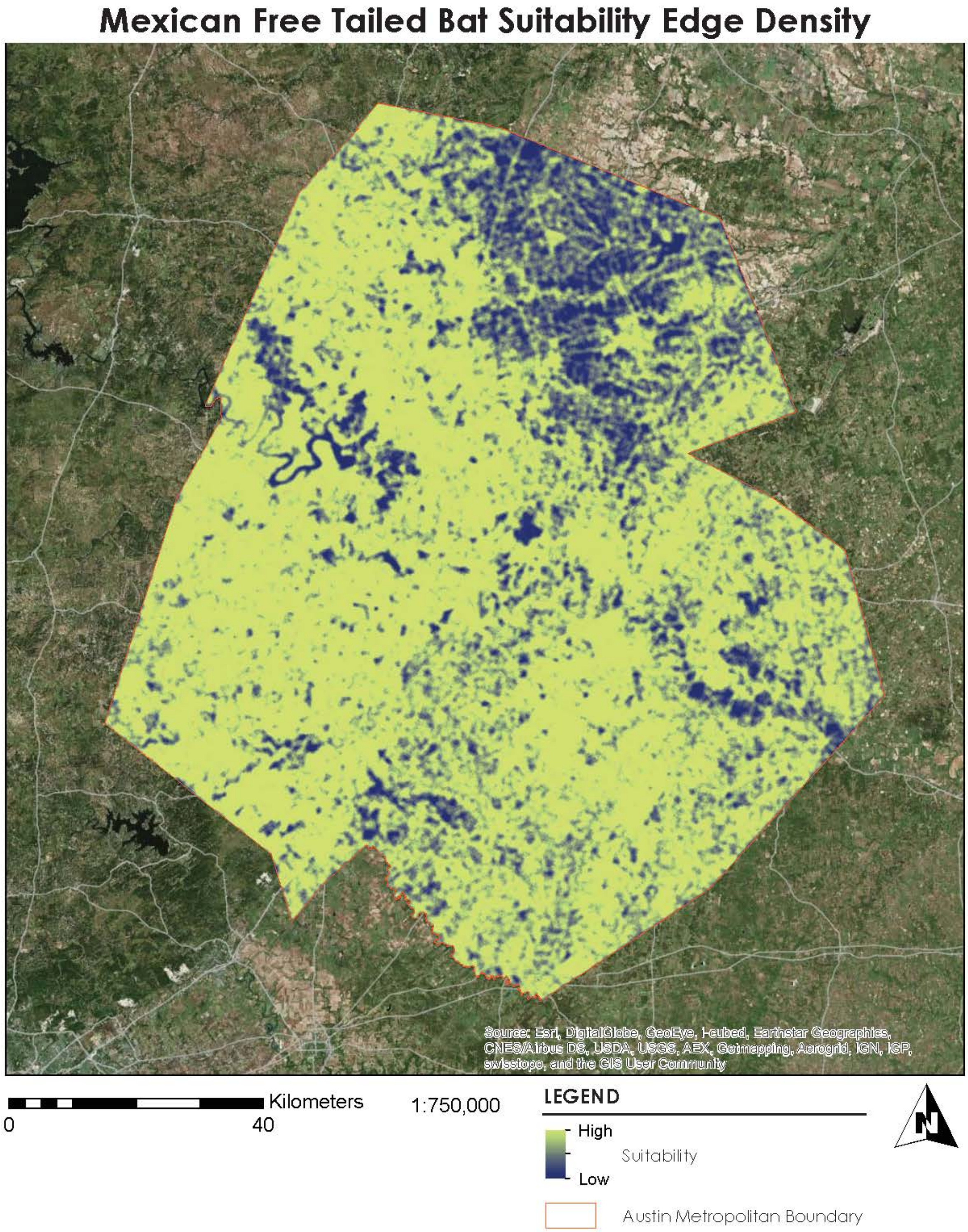


Figure 7-11: Edge Density GIS Model Structure



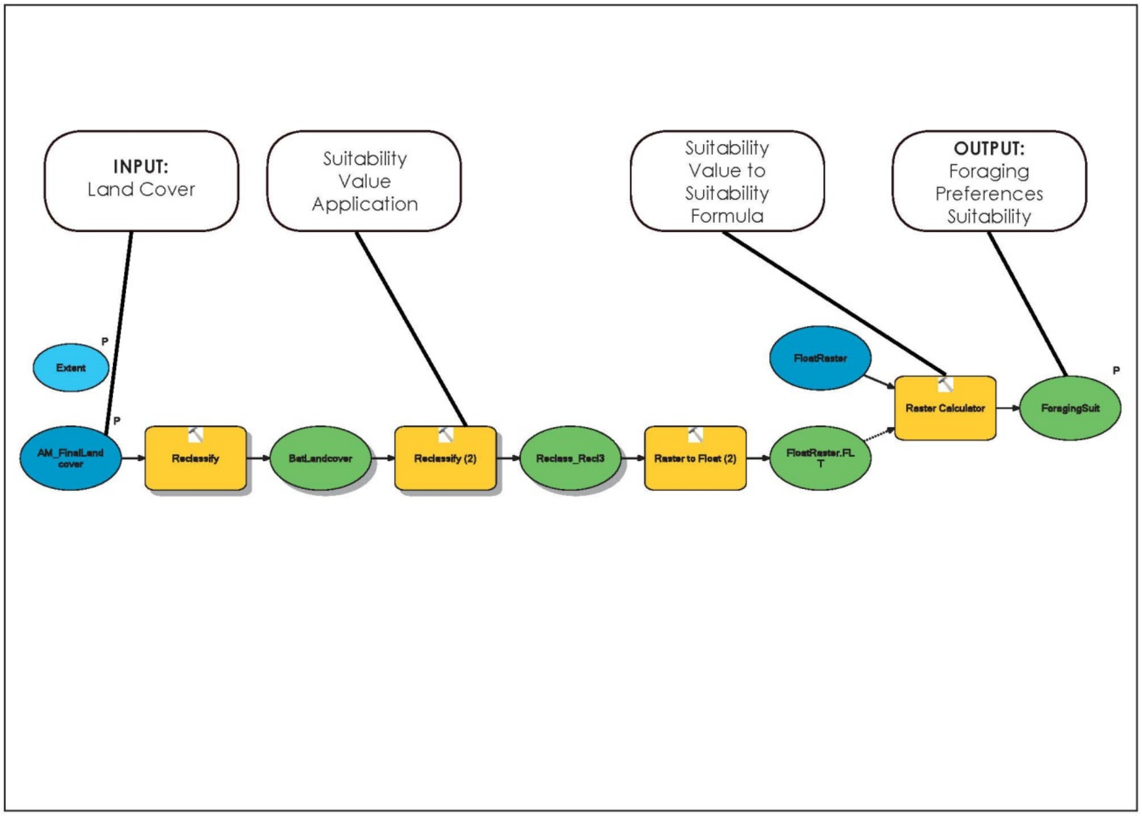
Edge Density

Figure 7-12: Edge Density Suitability



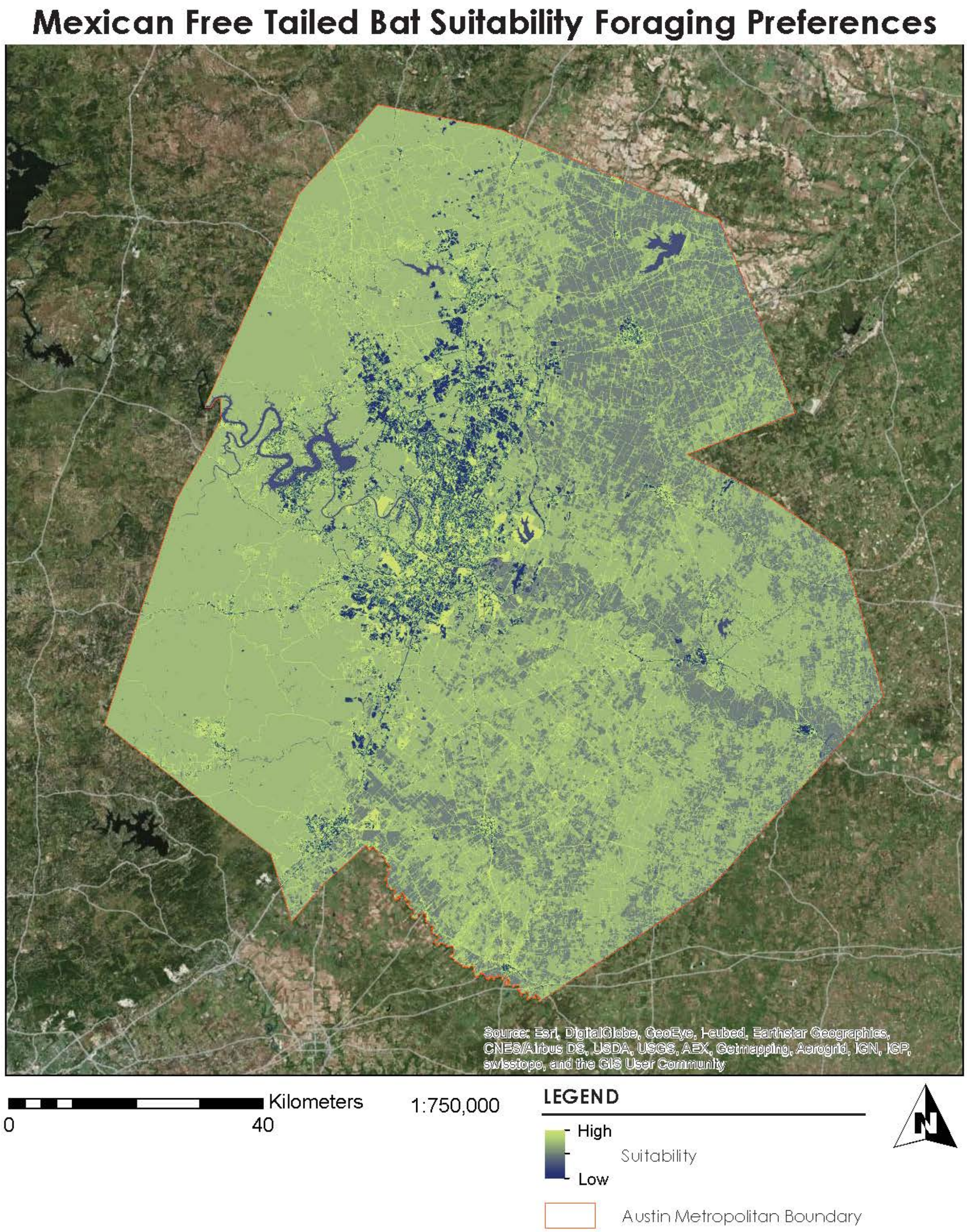
17) Foraging Preferences

Figure 7-13: Foraging Preferences GIS Model Structure



Foraging Preferences

Figure 7-14: Foraging Preferences Suitability



18) Distance to Water

Figure 7-15: Distance to Water HSI

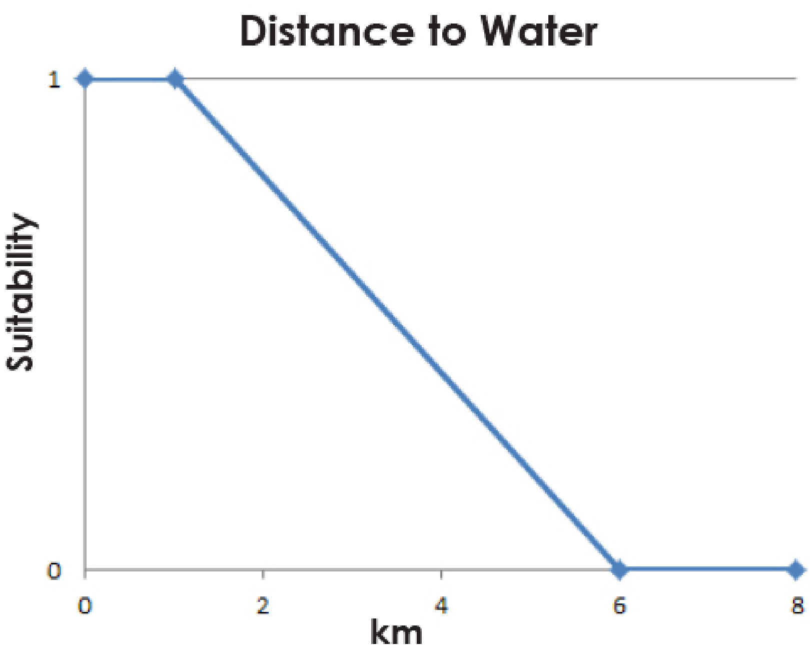
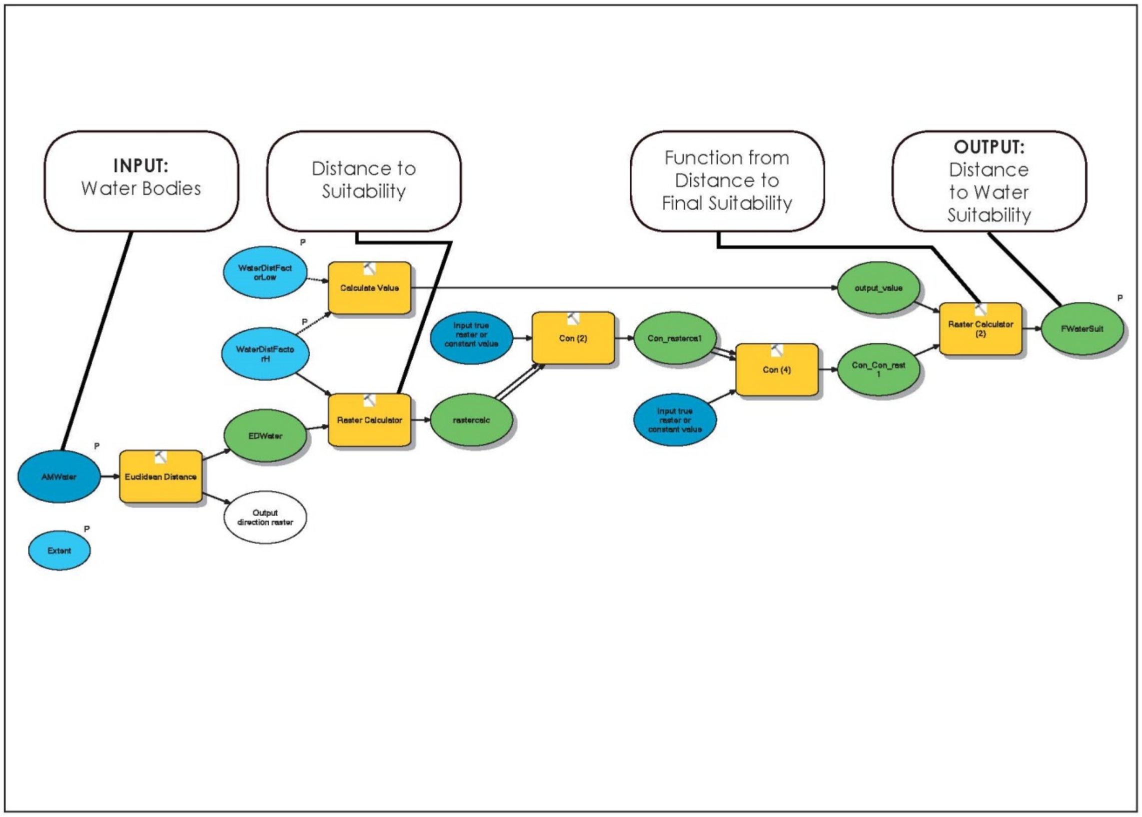
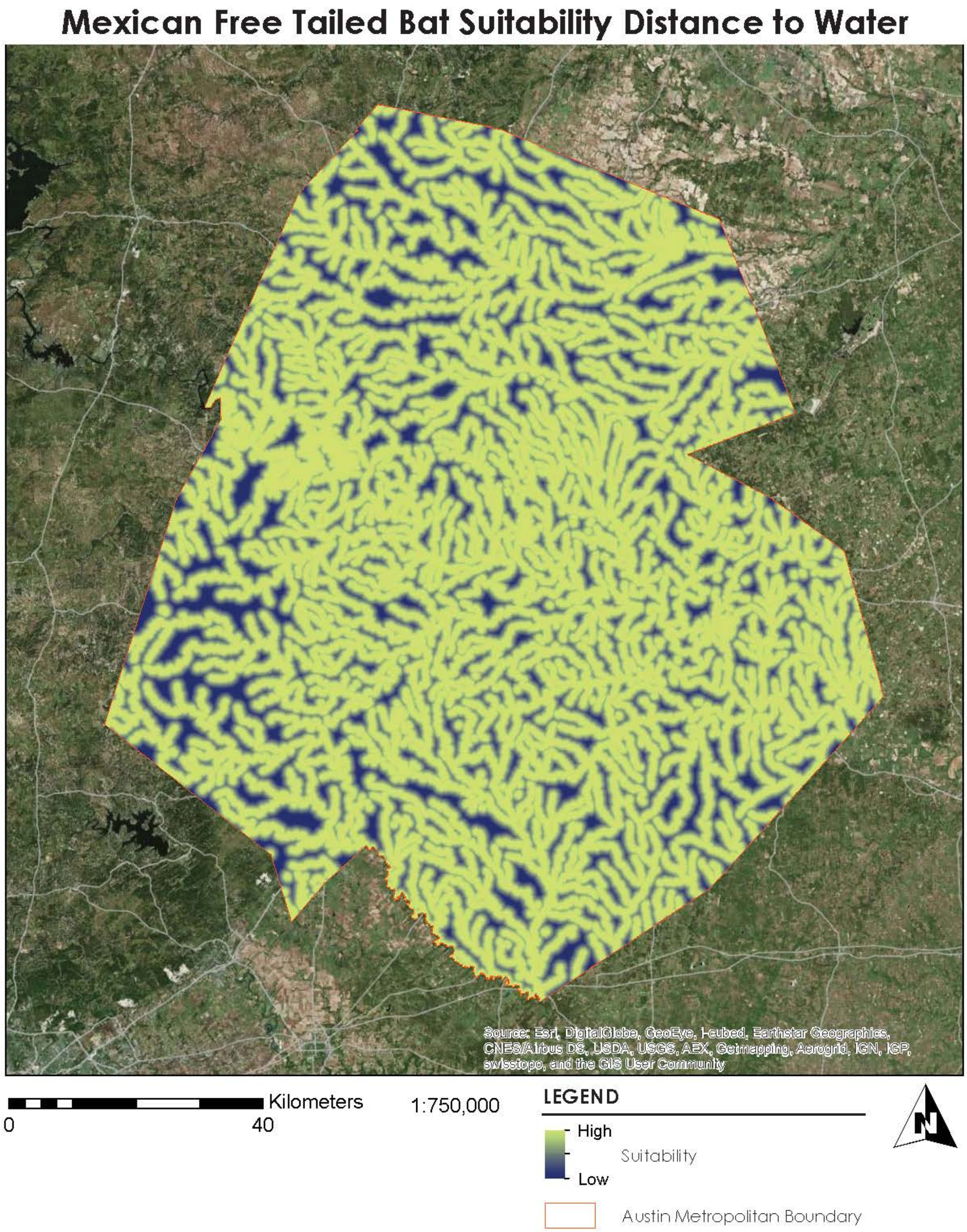


Figure 7-16: Distance to Water GIS Model Structure



Distance to Water

Figure 7-17: Distance to Water Suitability



19) Final Model Combination

Figure 7-18: Final Suitability Equation

$$Suit_i = \left(\sum_{n}^{i} V_n \right) / n$$

i=pixel value
V=habitat variables
n=number of variables

Figure 7-19: Final Mexican Free-Tailed Bat Suitability Combination GIS Model Structure

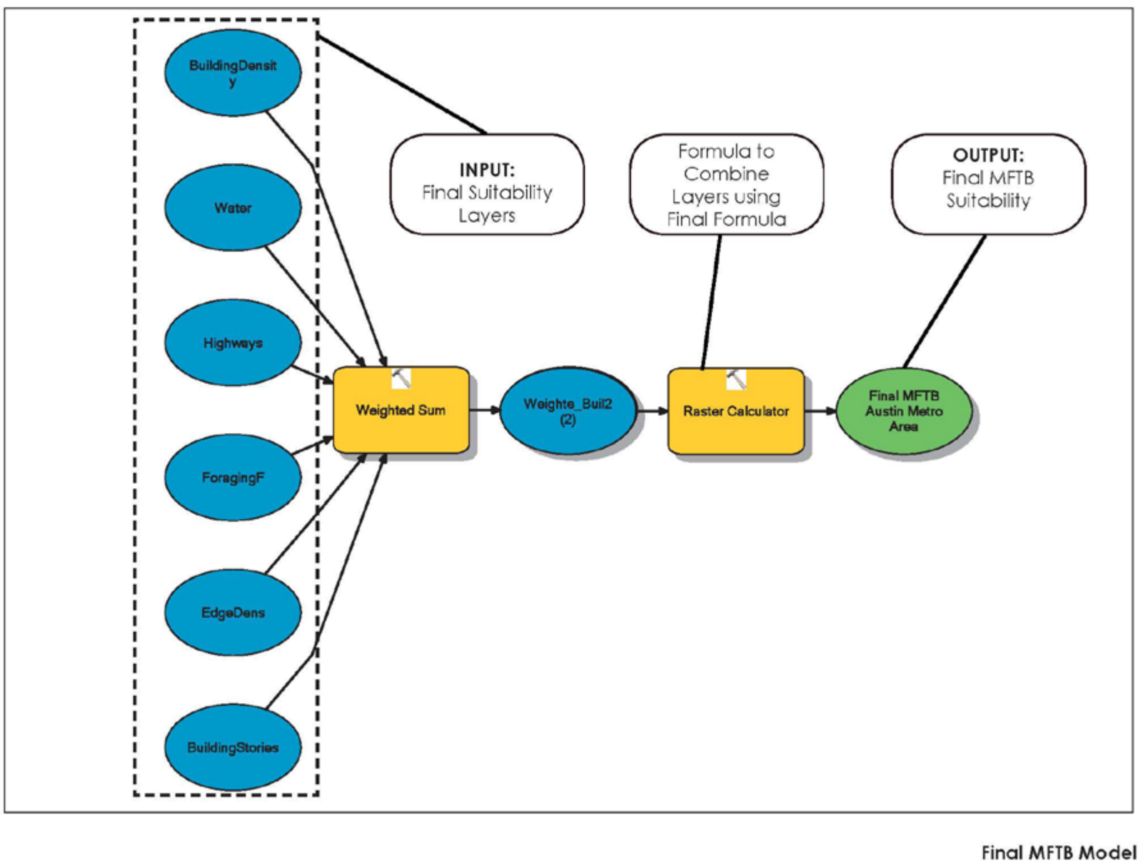
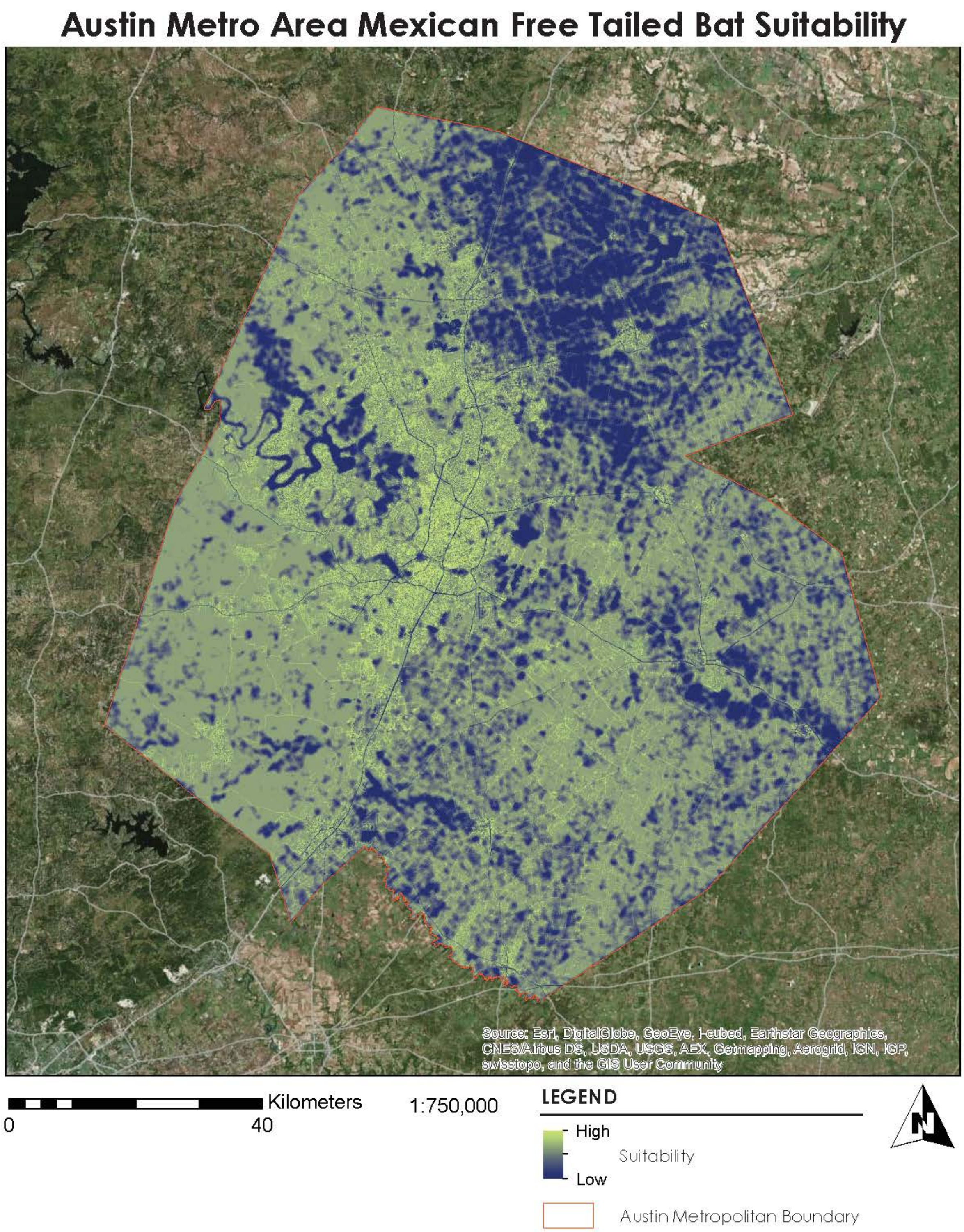


Figure 7-20: Final Mexican Free-Tailed Bat Suitability for Austin Metropolitan Area

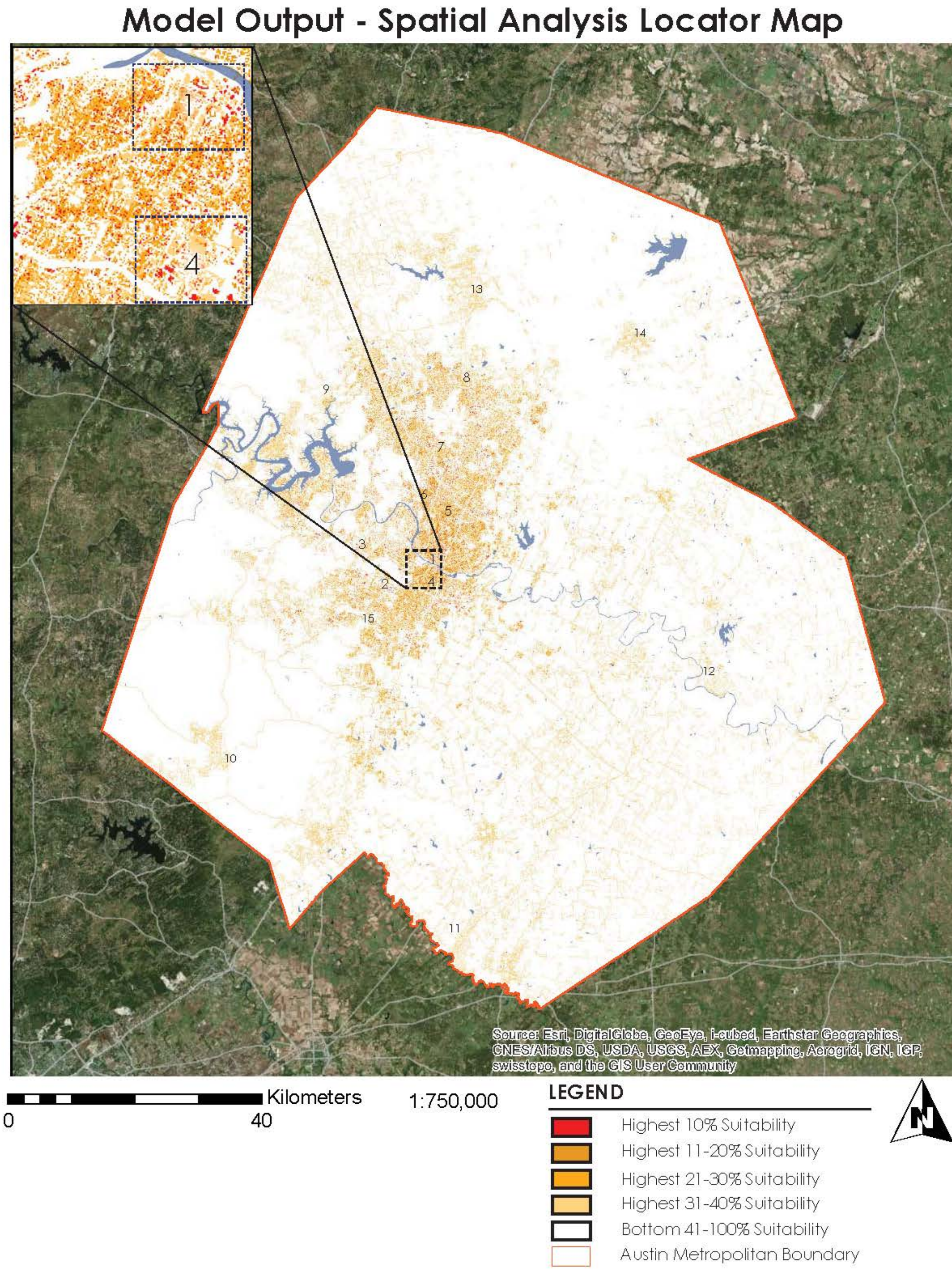


C. Appendix - Spatial Analysis

The following Appendix is a collection of the spatial analysis results for each area. Each area is located on Figure 7-21 and the following pages are each areas analysis. The results from the analysis can be seen in Table 7-1.

20) Model Output – Spatial Analysis Locator Map

Figure 7-21: Spatial Analysis Locator Map

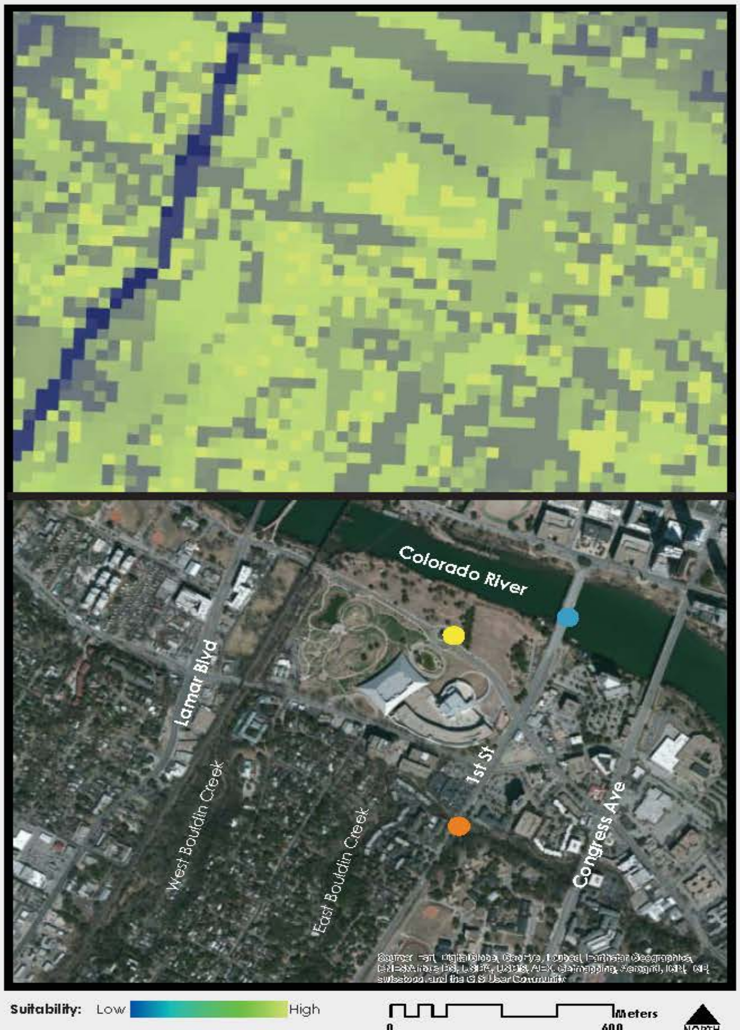


21) Spatial Analysis Individual Area Results

Figure 7-22: Spatial Analysis 1

Spatial Analysis 1

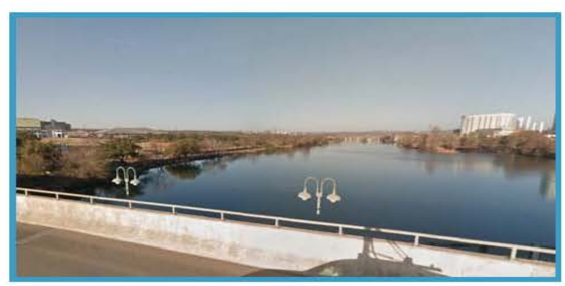
Location: 30°15'36.34" N 97°45'08.76" W
near The Long Center for Performing Arts



Overall Area Description:
The area is on the south side of the Colorado River adjacent to the Austin downtown area. Within this area is the Congress Ave Bridge which is the home of the largest urban Mexican Free Tailed Bat colony in the world. This area provides abundant high quality Mexican Free Tailed Bat habitat because of easy access to lit urban areas, which have shown to be important for the species, and high quality open space along the Colorado River. The area provides many opportunities for roosting as well. With the high density development comes more opportunities for small groupings or day roosts. In addition, the bridges in the area provide high quality large grouping or maternity roost opportunities.

East and West Bouldin Creek
Two large, seemingly unmanaged, creeks that weave through much of the single family low density housing that is in the area. East Bouldin Creek creates a boundary between highly developed urban areas and the low density single family housing in the area. The unmanaged nature of the creeks could create good foraging areas where open space permits and most likely provides good flight paths through the urban areas.

Auditorium Shores at Town Lake Metropolitan Park
A large open green space along the Colorado River that could provide high quality foraging areas because of the open space and proximity to the Colorado River. The close proximity to the Austin downtown area, seen in the background, provides both urban and more natural foraging opportunities.

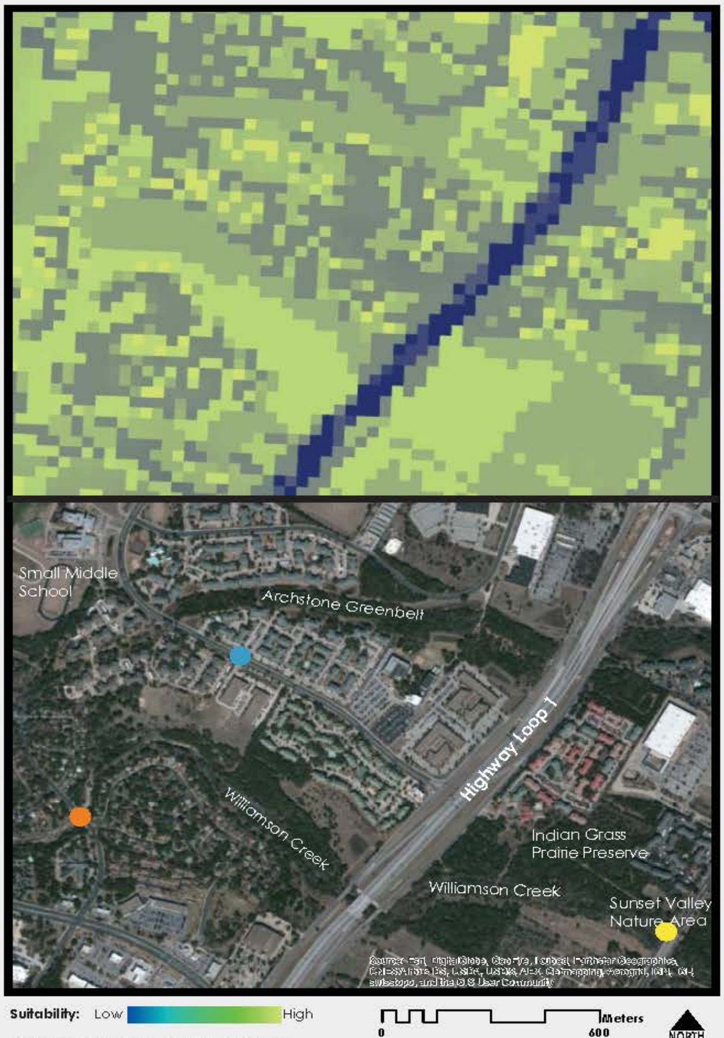


Colorado River
A large river that runs almost directly through the center of downtown Austin. Although development is concentrated along the river in this area much of the vegetation along the river is maintained. The Colorado River provides a large safe flight path through downtown while most likely providing a wealth of high quality foraging areas along or above the river.

Figure 7-23: Spatial Analysis 2

Spatial Analysis 2

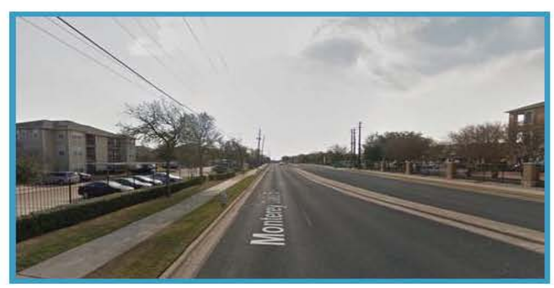
Location: 30°13'37.68" N 97°49'45.66" W
near Sunset Valley Market Fair



Overall Area Description:
The area is located near the intersection of highway loop 1 and highway 290. The development in the area is a mix of typical low density suburban and higher density apartment complexes. Although much of the area is developed a large portion of the area is more natural vegetation. These areas include a large, seemingly unmanaged, creek, a prairie preserve and a small neighborhood greenbelt. A common attribute with all these areas are they are more natural or unmanaged over much of the area. The more natural vegetation these areas off could provide high quality foraging grounds because of the abundance of insects. Another key observation is the open areas adjacent to these more natural areas providing adequate space to forage. This area is divided by highway loop 1, a three lane highway, which interrupts Williamson Creek and the Archstone Greenbelt. The large gap in connectivity combined with the traffic could cause highway loop 1 to be an obstacle in the area.

Williamson Creek
A very large creek that seems to divide the higher and low density development. The large open nature of the creek in the area provides high quality flight paths and foraging areas. Although it seems the creek is rarely full of water the unmanaged mix of vegetation combined with the off and on appearance of water would provide high insect abundance.

Brodie Ln near Indian Grass Prairie Preserve
Brodie Ln runs through the Sunset Valley Nature Area and an Indian Grass Prairie Preserve. Both areas provide high quality naturalized areas which most likely provide high insect abundance.

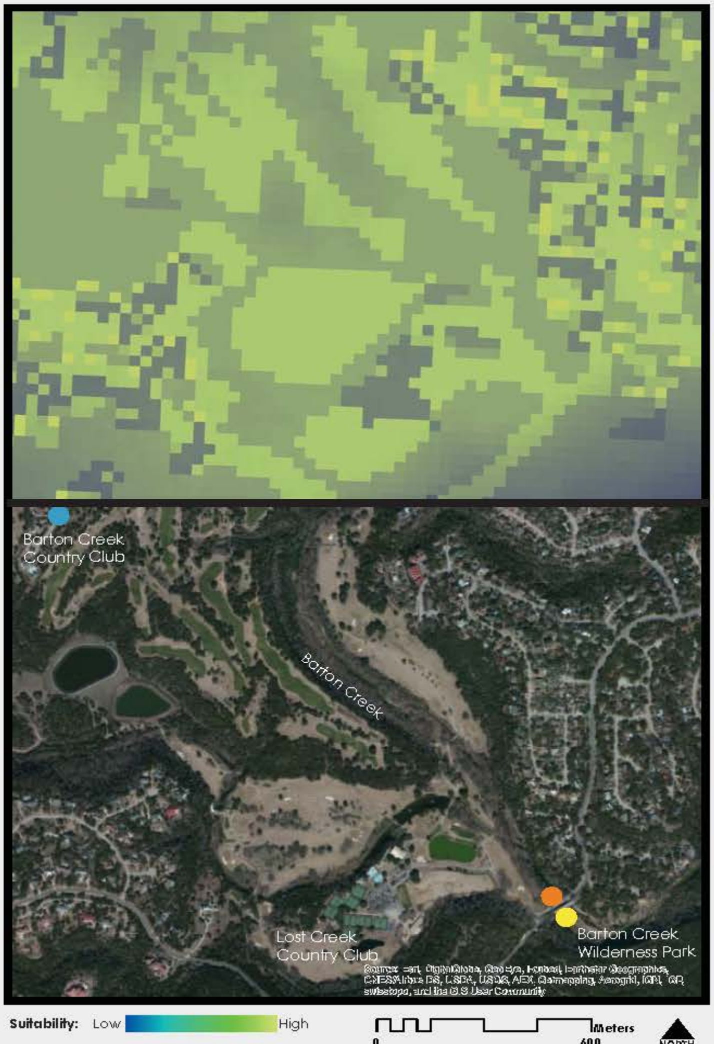


Monterey Oaks Blvd
Monterey Oaks Blvd provides a typical example of the higher density development spread throughout this area. Large groupings of apartment complexes make up much of the higher density development in the area. These buildings could provide many reasonable opportunities for roosting. The larger and taller buildings most likely provide good opportunities for small group or day roosts.

Figure 7-24: Spatial Analysis 3

Spatial Analysis 3

Location: 30°16'59.21" N 97°51'07.75" W
near Barton Creek Country Club



Overall Area Description:
Located about 6 miles west of downtown Austin this area is made up of mostly high end, low density suburban development surrounding the Barton Creek County Club. The mix of vegetated areas and adjacent open space provides many opportunities for high quality foraging spaces. This area has access to multiple water bodies in the form of a large creek and small man made water bodies throughout the area. This area does not offer many opportunities for roosting because of the lack of development in the area and the spread out low density development that makes up most of the development in the area.

Barton Creek
A large seemingly unmanaged creek that is adjacent to a golf course at the Barton Creek Country Club. The mix of water, unmanaged vegetation, and adjacent open space creates many high quality foraging opportunities.

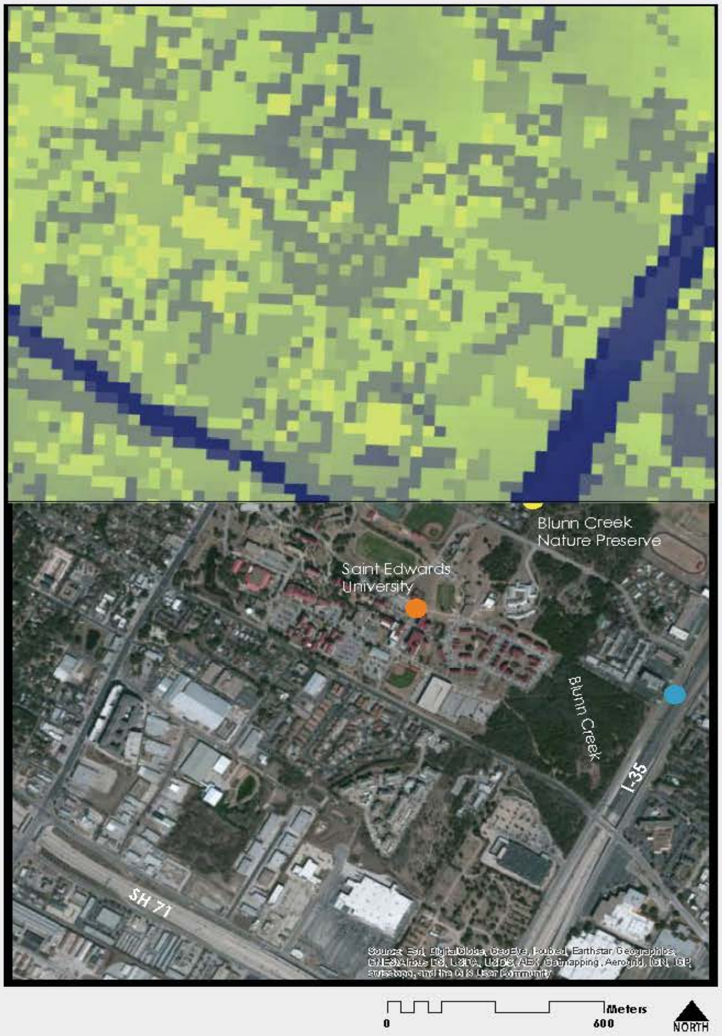
Barton Creek Wilderness Park
A large wilderness park that surrounds Barton Creek and continues to the east until the urban edge of Austin. This space provides a large naturalized area away from much of the Austin's development that could provide relief from urbanized areas while providing high quality foraging opportunities.

Barton Creek Country Club
The Barton Creek Country Club is sited along Barton Creek and consists of mainly of a golf course in this area. The golf course provides a wealth of open space for foraging and access to water. The highly managed nature of the area could reduce the overall insect abundance but the area still provides good quality foraging space.

Figure 7-25: Spatial Analysis 4

Spatial Analysis 4

Location: 30°13'29.54" N 97°45'14.84" W
near Saint Edwards University



Overall Area Description:
This area is located around Saint Edwards University west of I-35. Much of this area consists of Saint Edwards campus, a warehouse district, and a large shopping area. Adjacent to these areas is the Blunn Creek Nature Preserve which runs along much of Blunn Creek in this area. The development in this area is sprawled out along SH 71 between SH 71 and Saint Edwards Campus. Two large highways intersect near this area and could inhibit flight paths and overall connectivity in the area. Overall the area is mostly developed but vegetation throughout the area is more mature which could help support better insect abundance.

Saint Edwards University
Saint Edwards University Campus provides abundant open space adjacent to a naturalized area and urbanized development that offers high quality foraging space. The campus buildings and surrounding development offers opportunities for roosting in the area.

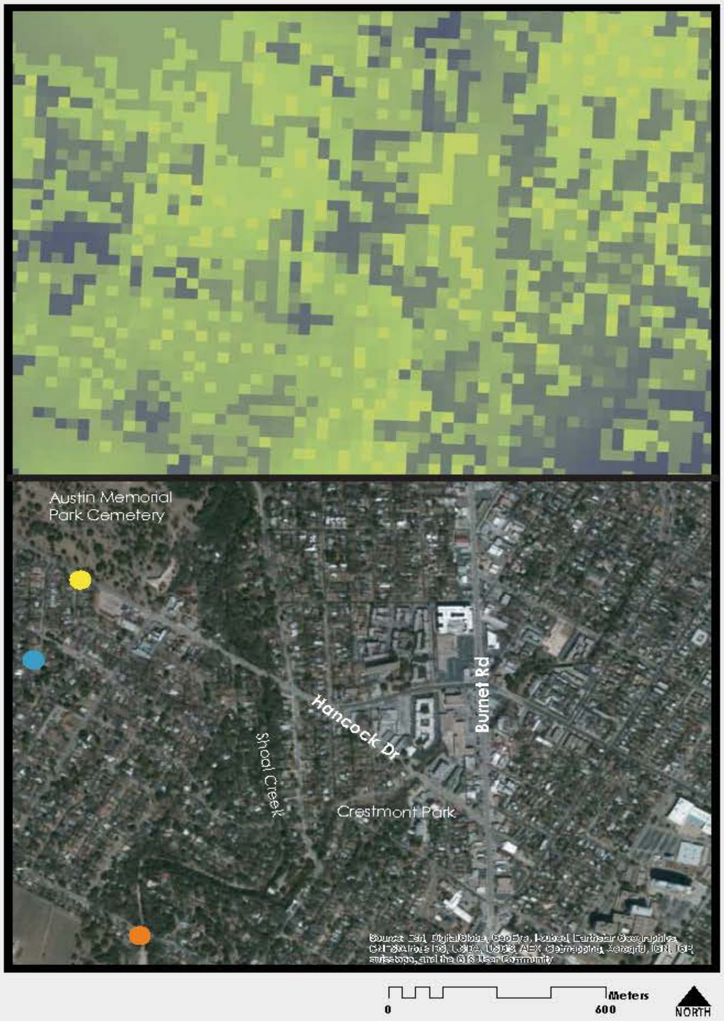
Blunn Creek Nature Preserve
A naturalized area surrounded by suburban development. The unmanaged nature of the vegetation and access to the creek supports insect abundance which should provide high quality opportunities for foraging. The preserve is highly vegetated so the preserve can act as safe flight routes for commuting bats while helping to support the surrounding areas insect abundance.

Royal Hill Dr - Typical Residential Development
Much of the development surrounding Saint Edwards campus consists of a mixture of low density suburban development and higher density apartment complexes. While much of the area is not housing the housing in the area seems to have mature vegetation which could help to support better flight paths through the area while providing better conditions for insect prey in the area.

Figure 7-26: Spatial Analysis 5

Spatial Analysis 5

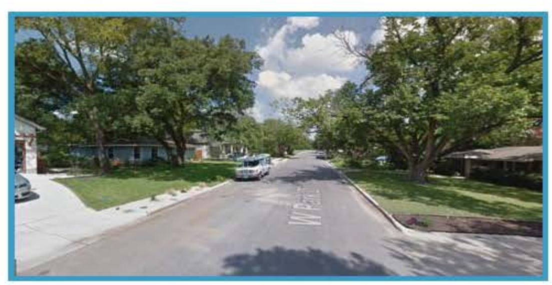
Location: 30°19'31.64" N 97°44'31.02" W
near McCallum High School



Overall Area Description:
This area is located around the intersection of Hancock Dr and Burnet Rd and consists mainly of low density suburban development with sprawled shopping districts mostly along Burnet Rd. Much of the open foraging space in the area is integrated throughout the development or is park space. Shoal Creek and the overall mature vegetation in the area provides support for insect abundance. The combination of mature vegetation and roads create good flight paths through the area without creating many disturbances for Mexican Free Tailed Bats.

Shoal Creek
Shoal Creek provides a large seemingly unmanaged corridor that winds through the development in the area. The creek provides high quality flight paths through the area that could be used as safe commuting routes for nightly foraging activity.

Austin Memorial Park Cemetery
Austin Memorial Park Cemetery is located along Shoal Creek and provides most of the open space in the area. The cemeteries adjacency to Shoal Creek provides high quality foraging areas.

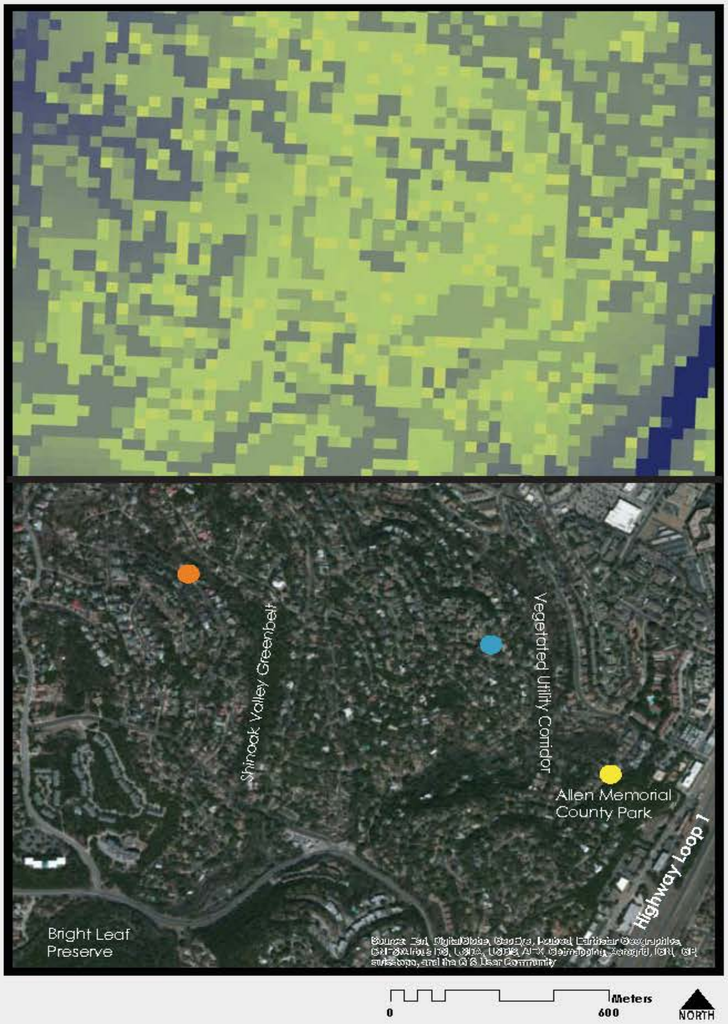


Park St - Typical Development
A large portion of this area consists of single family, low density suburban development. The vegetation in the area is mature helping to support insect abundance. The large number of buildings provide many opportunities for small roosts but because most of the structures are single family houses the roosting opportunities in this area may be limited.

Figure 7-27: Spatial Analysis 6

Spatial Analysis 6

Location: 30°19'35.65" N 97°44'30.71" W
near Murchison Middle School



Overall Area Description:
The area is located about 5 miles north of downtown Austin just west of highway loop 1. Much of the area consists of low density suburban development with some higher density apartment complexes to the northwest. This area is highly vegetated and includes many high quality flight paths through the area such as the Shinoak Valley Greenbelt and a vegetated utility corridor. The mixture of unmanaged vegetation spaces throughout the area should help support a high insect abundance in the area. This area has little direct access to water bodies but is located near the Colorado River.

Shinoak Valley Greenbelt
Shinoak Valley Greenbelt is a small naturalized vegetated corridor that could provide safe flight paths through the area. The naturalized nature of the vegetation helps support better insect abundance in the area.

Allen Memorial County Park
Allen Memorial County Park is a naturalized park that surrounded by development. The unmanaged natural vegetation helps support insect abundance and supports foraging areas nearby or in the park. The park is highly naturalized and lacking in open space for foraging.

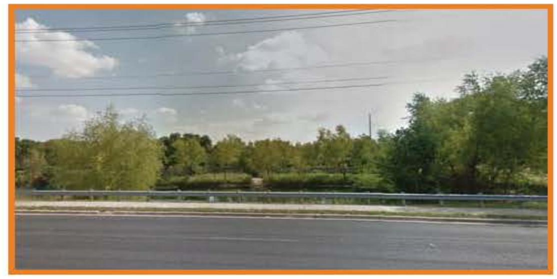
Highland Hills Dr - Typical Development
Highland Hills Dr provides a good understanding of the single family low density development that makes up much of this area. Some higher density living areas can be seen in the northwestern portion of this area. The mature vegetation along the small streets helps to create quality flight paths through the area.

Figure 7-28: Spatial Analysis 7

Spatial Analysis 7

Location: 30°25'21.60" N 97°44'08.09" W
near Davis Elementary School

Overall Area Description:
The area is located about 9 miles north of downtown Austin. Low density, sparsely vegetated single family housing makes up most of this area. The mature vegetation mixed with areas of naturalized vegetation support insect abundance and the open space throughout the area could provide quality forging areas. There are two small ponds in the area but are both small and should provide some quality opportunities for foraging. The sparse nature of vegetation in the residential areas are a cause for concern because it creates connectivity issues in the area. The low amount of consistent cover could create problems for bats trying to commute through and around the area. The area also has very little immediate access to water.



Yet Creek Neighborhood Park
Yet Creek Neighborhood Park is a highly vegetated small park in the area. The park has access to a small water feature on the northern side but is almost completely covered with trees. The vegetation provides quality insect habitat but without the needed open space in the park this park provides little in terms of foraging opportunities.

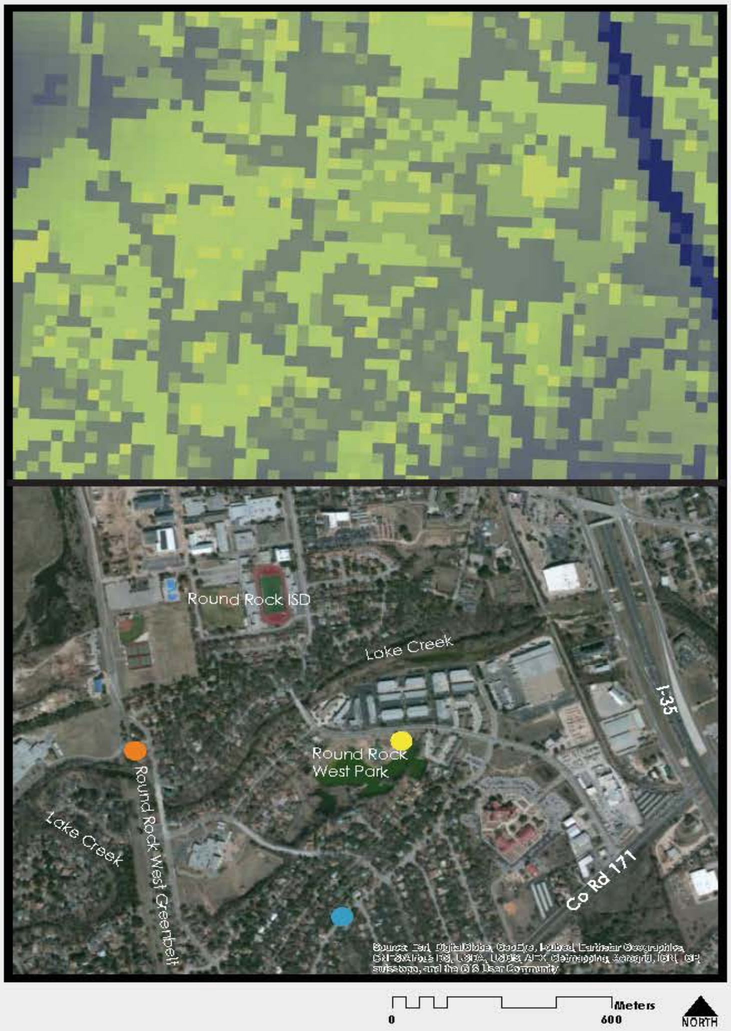
Riata Neighborhood Park
Riata Neighborhood Park is small park that consists of a small pond and highly vegetated wooded area. Riata Park is near Yett Creek Park and is connected with vegetation and footpaths. The pond in the park provides good foraging habitat by supporting both Mexican Free Tailed Bats and their insect prey.

Mustang Chase - Typical Development
Mustang Chase provides a good understanding of the low density single family housing in the area. Much of this area consists of this type of development. The vegetation in these areas are mature but are sparse in areas. The open space created could provide good foraging opportunities throughout the neighborhood areas while the lack of vegetation may not provide many high quality fliight routes through the area.

Figure 7-29: Spatial Analysis 8

Spatial Analysis 8

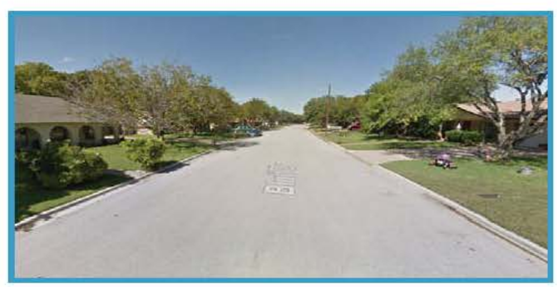
Location: 30°29'57.96" N 97°41'34.73" W
near Round Rock ISD



Overall Area Description:
The area is located about 9 miles north of downtown Austin. The combination of vegetated areas, open space, good flight paths, and immediate access to water show this areas ability to provide quality foraging areas for Mexican Free Tailed Bats. The overall connectivity in the area is good with many quality flight paths such as Lake Creek, Round Rock West Greenbelt, and vegetated streets in the area. The mix of residential buildings and larger business/institutional buildings provide many opportunities for roosting within the area. This area is bounded by I-35 to the east and the highway itself causes breaks in connectivity and could be an obstacle when moving through the landscape. Although I-35 may cause an obstacle for Mexican Free Tailed Bats the area along Lake Creek is still vegetated around I-35 making it easier and safer for bats to cross in this area.

Round Rock West Greenbelt
Rock round West Greenbelt is a linear green space that runs through the southwest part of this area. It is a sparsely vegetated corridor with vegetation along the edges. This corridor provides a quality flight path through the area while being open enough throughout the corridor to provide foraging areas.

Round Rock West Park
Round Rock West Park is a large park that consists of a pond, open space, and vegetated areas. The combination of these show that Round Rock West Park can provide many opportunities for high quality foraging.

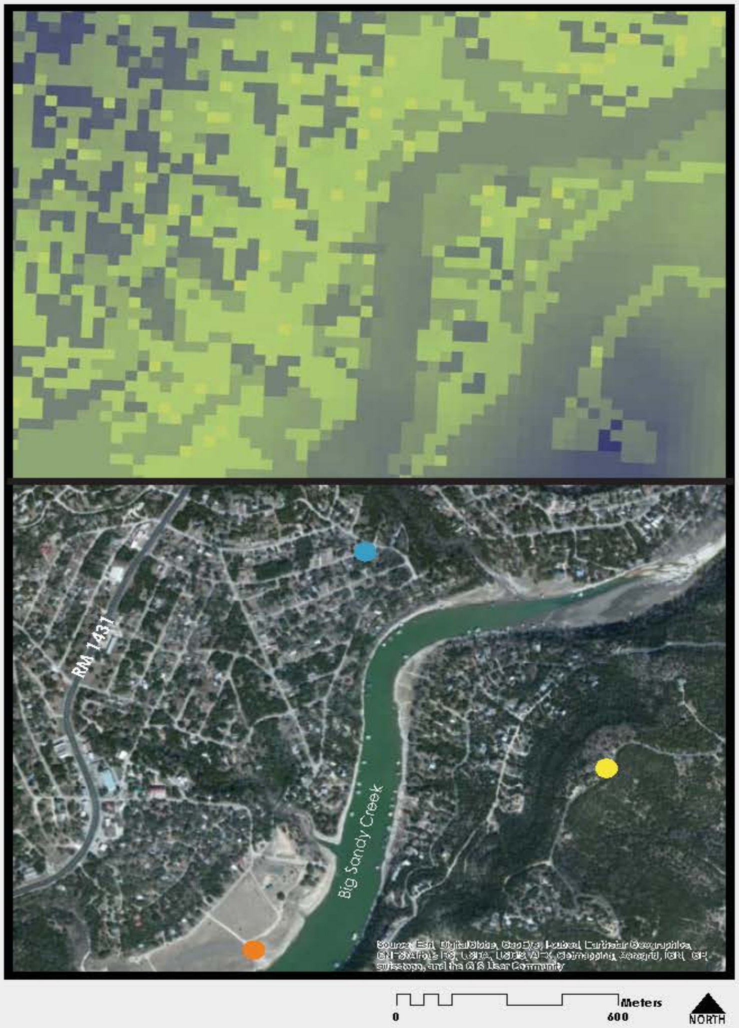


Bluff Dr - Typical Development
Bluff Dr provides a good understanding of the low density single family housing in the area. The areas vegetation is mature helping to support insect abundance and providing quality flight paths through the area.

Figure 7-30: Spatial Analysis 9

Spatial Analysis 9

Location: 30°29'42.58" N 97°54'52.92" W
near Big Sandy Creek



Overall Area Description:
The area is located about 18 miles northwest of downtown Austin off a direct creek branch of Travis Lake. Most of the development in the area consists of low density single family housing with a large portion of the area being undeveloped vegetated areas. Big Sandy Creek and the pattern of vegetation in the area provide many quality flight routes throughout the area making the area easy to navigate and easy to reach other important resources. The access to water in the immediate area may not exist as the creek has dried up recently, but the area is close to Lake Travis so the area should maintain easy access to water. The area does not provide many good opportunities for roosting as most of the buildings are small, short and more sparse than other urbanized areas.

Big Sandy Creek
Big Sandy Creek is a direct creek branch off the north of Travis Lake. Although development is centered around the creek, Big Sandy Creek is large enough to create many opportunities for quality flight paths along the creeks edges. The access to water in this area may not be as quality as the images show. Recent droughts have caused water levels to decrease to the point of being almost completely dry in this area.

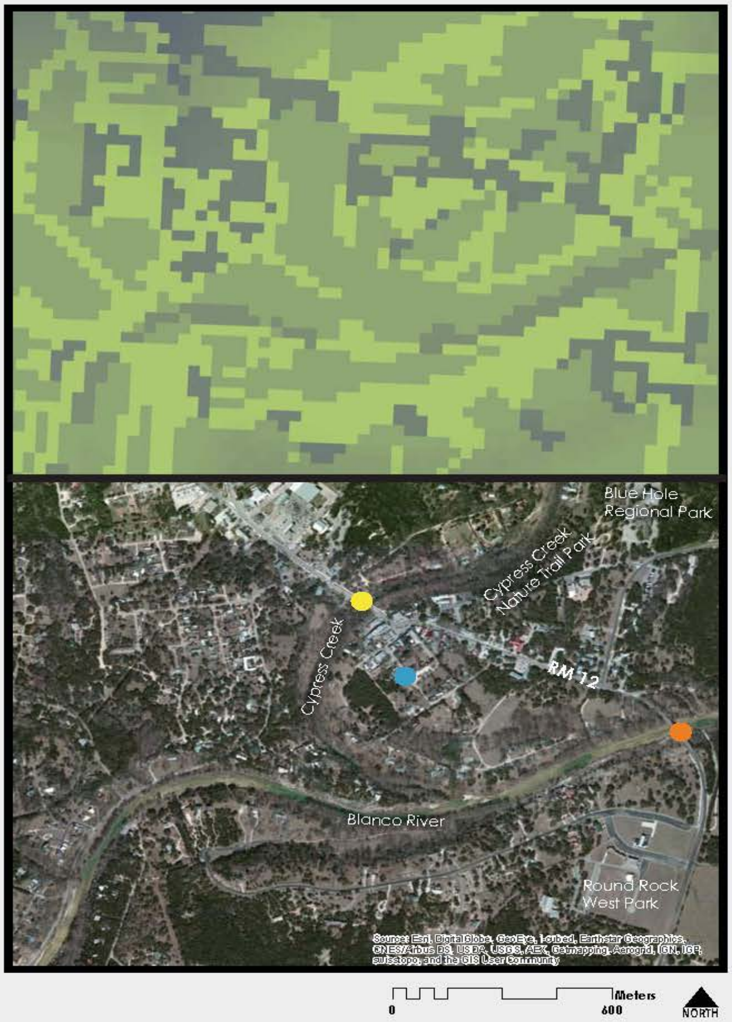
Johnson Rd - Naturalized Area
A large portion of the area is undeveloped naturalized area, which can be seen off of Johnson Rd. Much of the naturalized area is vegetated similar to what is seen off of Johnson Rd with a mixture of unmanaged mature trees and shrublands. The vegetation in the area provides good habitat for a rich insect abundance but the lack of open space limits the areas opportunities for foraging.

Lake Oaks Dr - Typical Development
Lake Oaks Dr provides a good understanding of the low density single family housing in the area. The areas vegetation is mature providing quality flight routes through the area. The pattern of sparsely vegetated areas mixed with densely vegetated areas create adequate open space for foraging while supporting good insect abundance.

Figure 7-31: Spatial Analysis 10

Spatial Analysis 10

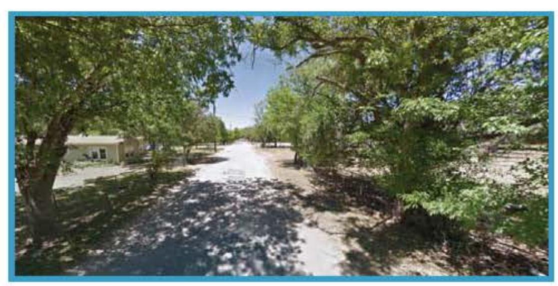
Location: 29°59'37.60" N 98°05'42.51" W
near Wimberley



Overall Area Description:
This area is located in Wimberley which is southwest of Austin. The development in this area is mainly low density single family housing which creates quality open space for foraging because the open space is interspersed among naturalized wooded areas. The area provides some opportunities for roosts but because many of the buildings are small, short and sparse the opportunities for roosting could be better elsewhere. The Blanco River and Cypress Creek provide great opportunities for quality flight routes and foraging areas along and adjacent to the water bodies.

Blanco River
The Blanco River is a densely vegetated corridor that provides high quality flight routes while supporting high quality foraging areas along the river and adjacent open spaces. Through this area the river is more naturalized with little development near the river and dense bank vegetation.

Cypress Creek
Cypress Creek is a densely vegetated creek that branches off the Blanco River which create high quality flight routes throughout the area. The vegetation and water create good foraging areas. The creek is so densely vegetated that it does not provide much open space for foraging.

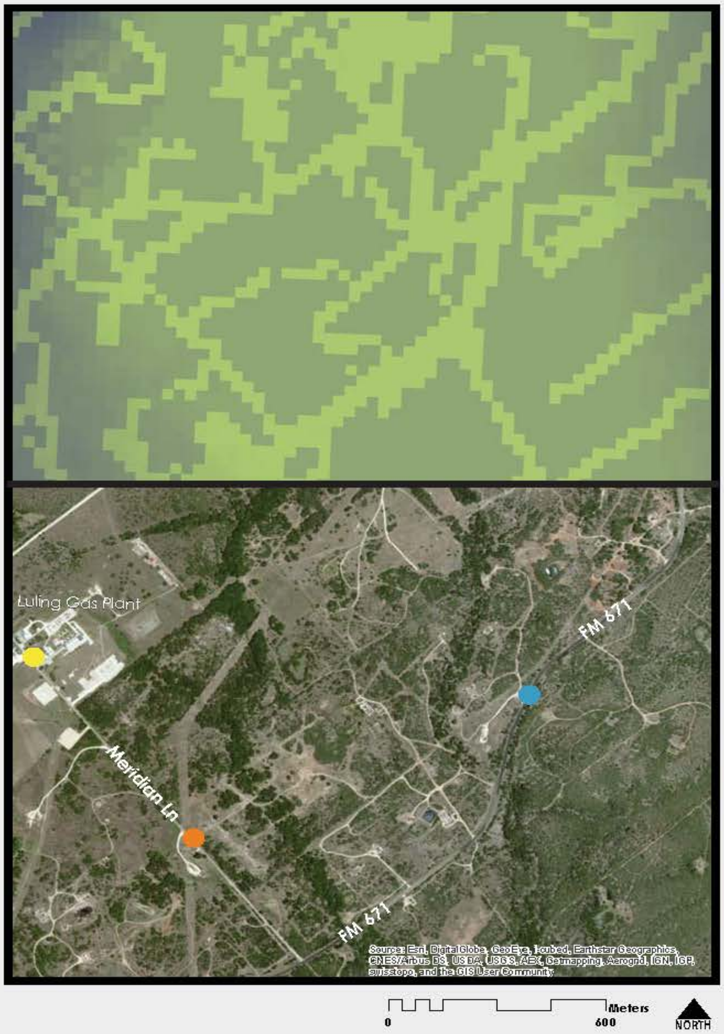


Oak Dr - Typical Development
Oak Dr provides a good understanding of the low density single family housing in the area. Much of this area consists of this type of development which are which is interspersed among wooded areas. The open space created by development among the naturalized wooded areas creates many high quality foraging areas.

Figure 7-32: Spatial Analysis 11

Spatial Analysis 11

Location: 29°43'57.28" N 97°43'28.42" W
near Luling Gas Plant



Overall Area Description:
This area is located northwest of Luling which is about 45 miles south of Austin. Much of the area is undeveloped grasslands with gas pumping stations throughout the area. There is little road infrastructure and few housing units in the area. The area is very sparsely vegetated with few patches of woodlands. There are many small ponds in the area providing better insect abundance. The Luling Gas plant dominates the landscape in this area and daily operation and pollution from the plant could cause bats to completely avoid this area. This area may provide quality flight paths to surrounding areas with some of the continuous vegetated corridors. Overall this area offers reasonable habitat opportunities but becuase of the finer scale use of the area, the area may not offer highly suitable habitat.

Meridian Ln
Meridian Ln shows some of the infrastructure that exists in the area. The electric utility corridor seen off of Meridian Ln could provide quality flight routes through the area. Much of this space could be used for foraging but is not high quality foraging space.

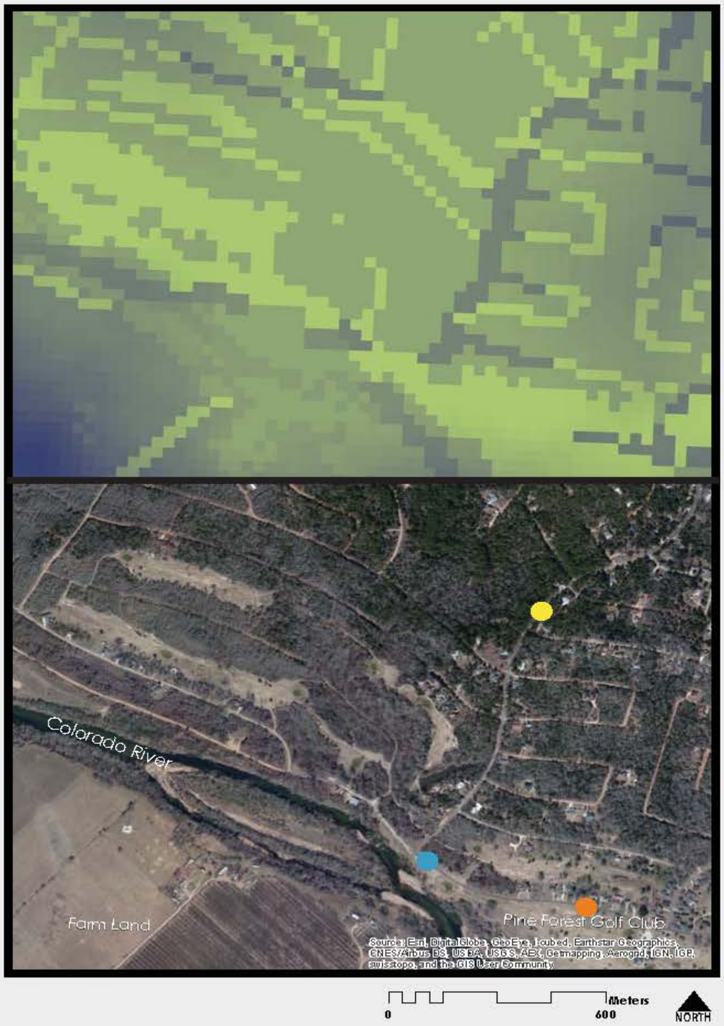
Luling Gas Plant
The Luling Gas Plant dominates much of landscape this area. The actual plant can be seen above and many of the winding roads seen in the aerial are gas pumping stations. The operation of the plant or pollution from the plant could cause a disruption to commuting or foraging bats.

FM 671
FM 671 provides a good understanding of the undeveloped grass and shrublands that make up most of this area. This area could provide adequate foraging opportunities but is not of high quality foraging habitat.

Figure 7-33: Spatial Analysis 12

Spatial Analysis 12

Location: 30°05'03.23" N 97°18'04.67" W
near Pine Forest Golf Club



Overall Area Description:
This area is located in southern Bastrop which is about 30 miles south of Austin. The area consists of a mixture of very low density single family housing, farm land, and densely vegetated areas. Much of this area is densely vegetated with small areas carved out for sparse housing and road infrastructure. There are little roosting opportunities in this area with the sparse buildings throughout the area and densely wooded areas taking up much of the area. The streets and Colorado River provide good flight routes through the area. The Colorado River and densely wooded areas provide good habitat for insect abundance and open space especially along the river should provide high quality foraging areas. The farm land on the south side of the Colorado River should provide high levels of insect abundance and being open space along the river should serve as very high quality foraging areas.

Pine Forest Golf Club
The Pine Forest Golf Club is located along the Colorado River. Although the area is highly managed the golf course provides open space along the river that help create high quality foraging areas.

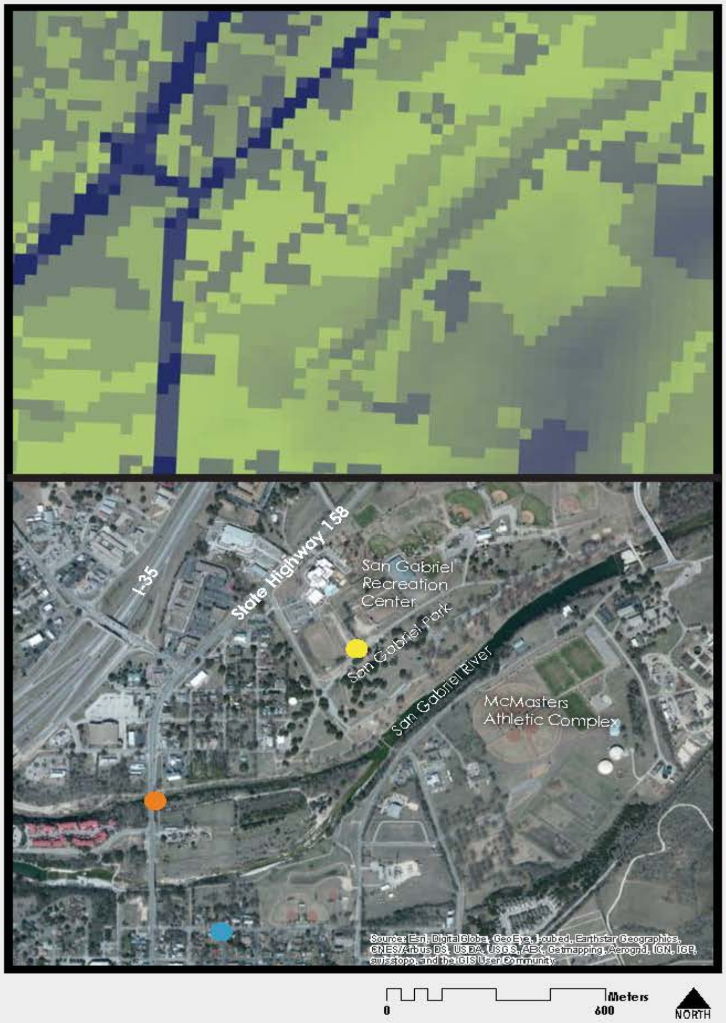
Akaloa Dr
Akaloa Dr provides a good understanding of the low density residential development in the area. The development is sparse and cut into the densely vegetated areas. The buildings in the area could provide roosting opportunities but there are too few buildings to provide a good number of suitable roosts. The streets provide high qaulity flight paths with little to no obsticles

Colorado River
In this area the Colorado River is mostly naturalized with little development near the river and a mostly unmanaged densely vegetated bank line. The river should support high levels of insect abundance while providing high quality foraging areas and flight routes.

Figure 7-34: Spatial Analysis 13

Spatial Analysis 13

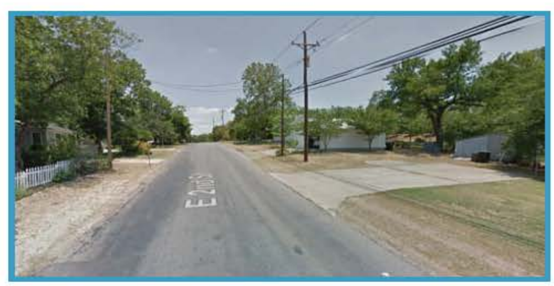
Location: 30°38'50.82" N 97°40'19.17" W
near San Gabriel Recreation Center



Overall Area Description:
The area is located in northern Georgetown which is about 25 miles north of Austin. The area consists mainly of park and open space, from sport and recreation complexes, along the San Gabriel River. The combination of open space along the river with well vegetated areas lining the river and throughout much of the park space creates many opportunities for quality foraging areas. The lighting from night recreation actually could increase the areas usability and create higher quality foraging areas along the river. I-35 could create a break in connectivity and be an obstacle for bats, but where I-35 crosses the San Gabriel River, one of the main corridors in the area, the highway is suspended high above the river to create quality flight paths under the highway along the river. There are opportunities for roosting in the area but are few total buildings in the area and most of the buildings are small and would not provide quality roosts. There are a few bridges in the area that could offer roosting opportunities but depends on construction.

San Gabriel River
The San Gabriel River is vegetated corridor that divides the area. The river provides quality foraging opportunities along and adjacent to the river because of the easy access to water and support for high insect abundance. The river also provides a quality flight route through the area helping to improve connectivity to surrounding areas.

San Gabriel Park
San Gabriel Park is a part of the San Gabriel Recreation Complex which sits along the San Gabriel River. The park provides open space along the river that can provide quality opportunities for foraging. The complexes lighting could further improve opportunities for easy and quality foraging.

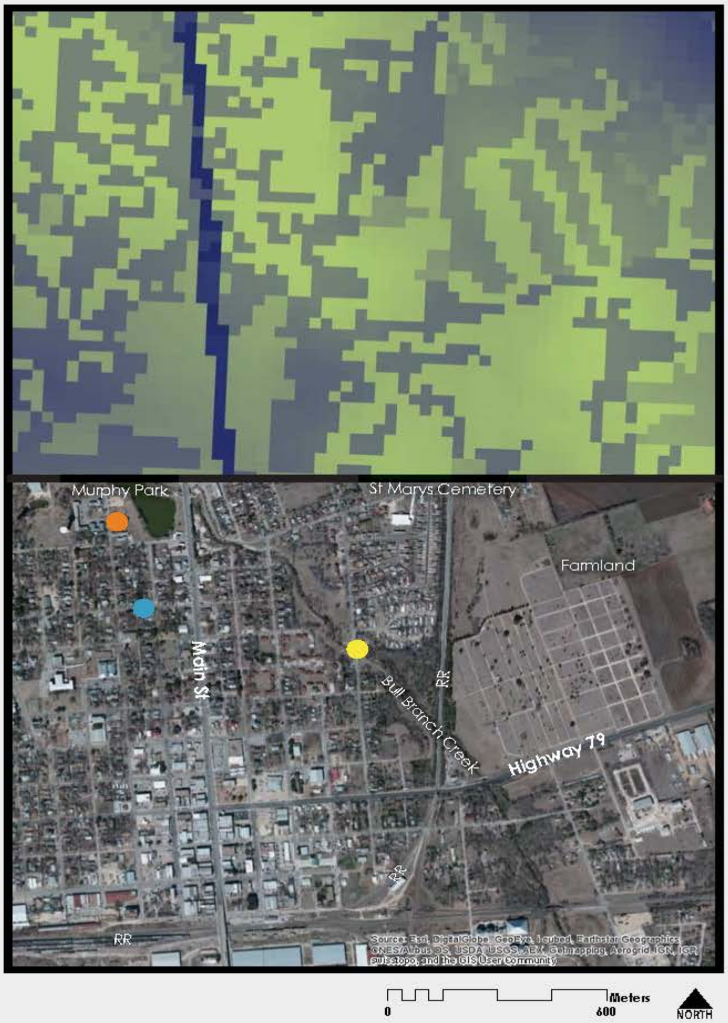


2nd St - Typical Residential Development
2nd St provides a good understanding of low density single family residential development that makes up a major portion of the area. The area provides reasonable flight routes and foraging areas with combinations of mature vegetation along streets and open spaces throughout.

Figure 7-35: Spatial Analysis 14

Spatial Analysis 14

Location: 30°34'24.08" N 97°24'19.04" W
near Taylor



Overall Area Description:
The area is located in Taylor which is about 30 miles northeast of Austin. The area consists of mainly low density single family housing areas with a more developed low density area off Main Street. Areas to the east change to mainly farmland. There is access to water at the Murphy Park pond and the Bull Branch Creek which runs through Murphy Park and creates a quality flight route through the area and to surrounding areas. There is a connection to the farmland to the east along the Bull Ranch Creek where it intersects highway 79. The farmland can provide an abundance of insects for foraging so adjacencies and connections to those areas can be important. The developed areas with vegetation create many quality flight routes through the area while open space scattered throughout provides many opportunities for foraging. The buildings in the area do not provide quality roosting opportunities because buildings are too sparse and the buildings are too small to provide enough quality roosting space.

Murphy Park
Murphy Park is a large park in the northern part of this area. The park consists of open space, sparsely vegetated areas, and a pond. The open space around the pond provides quality forging space while supporting high insect abundance. There is little vegetation in and around the park though which reduces possible flight routes to and from the park.

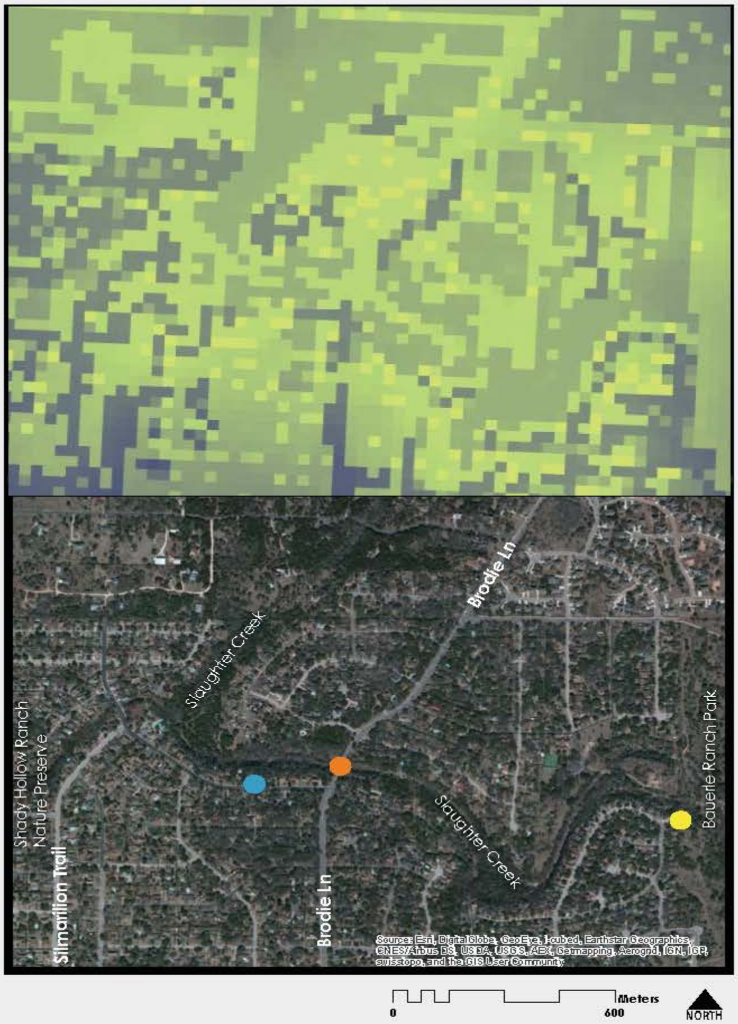
Bull Branch Creek
A densely vegetated creek that runs along an open space that bisects this area. The mature unmanaged vegetation along the open space provides quality foraging space while supporting high insect abundance. The creek also provides quality flights paths through the area and to its surroundings.

10th St - Typical Development
10th St provides a good understanding of low density single family residential development that makes up the greatest portion of the area. The mature vegetation lining the streets combined with the open space throughout the area provides well connected high quality foraging space. Some more vegetated streets provide high quality flight routes through the area.

Figure 7-36: Spatial Analysis 15

Spatial Analysis 15

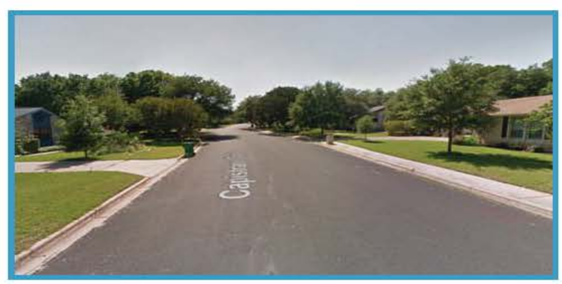
Location: 30°10'08.40" N 97°51'34.07" W
near Shady Hallow



Overall Area Description:
The area is located near Shady Hallow about 10 miles southwest of Austin. The area consists almost entirely of low density single family development with some highly vegetated areas throughout. Slaughter Creek provides a high quality flight route that helps connect some of the areas that offer high quality foraging opportunities such as, Bauerle Ranch Park and scatters open space throughout the developed areas. Much of the areas vegetation is mature helping to support insect abundance but a few new subdivided areas can be seen in the northeast of the area which has little to no mature vegetation and is mostly open space. This area provides some roosting opportunities but the small single family nature of most of the buildings restrict the quality and size of roosting opportunities.

Slaughter Creek
Slaughter Creek is a vegetated corridor that twists through the area. It seems that the creek rarely holds water but it is a large unmanaged corridor that provides high quality flight paths and foraging space along and in the creek corridor. The vegetation alone supports high insect abundance so when the creek does hold water or shortly after rains the area has the ability to provide very high quality foraging opportunities.

Bauerle Ranch Park
Bauerle Ranch Park is a large naturalized park that surrounds a new low density subdivided development on the eastern most edge of the area. The park provides open space and vegetated corridors that would support high quality flight routes and high quality foraging areas.



Capistrano Trail - Typical Development
Capistrano Trail provides a good understanding of low density single family residential development that makes up a major portion of the area. The mature vegetation that consists of areas of dense vegetation and sparsely vegetated open space provides very high quality well connected foraging opportunities.

Table 7-1: Spatial Analysis Results

Spatial Analysis Area	Unprotected Open Space	Water Source	Urban	Suburban	Highway
1	Y	Y	Y	Y	N
2	Y	Y	Y	Y	Y
3	Y	Y	N	Y	N
4	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	N
6	N	N	Y	Y	Y
7	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y
9	Y	Y	Y	Y	N
10	Y	Y	Y	Y	N
11	Y	Y	N	N	N
12	Y	Y	N	Y	N
13	Y	Y	Y	Y	Y
14	Y	Y	Y	Y	Y
15	Y	Y	N	Y	N

22) GIS References

Table 7-2: GIS References

Theme	Layer Name	Descriprion	Date	Source
Landcover	NLCD06_TX_landcover nlcd2006_TX_Impervious	National Land Cover Database 2006 (NLCD 2006) is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters. NLCD 2006 is based primarily on a decision-tree classification of circa 2006 Landsat satellite data. NLCD 2006 also quantifies land cover change between the years 2001 to 2006. The NLCD2006 land cover change product was generated by comparing spectral characteristics of Landsat imagery between	2011	http://www.tnris.org/get-data?quicktabs_maps_data=1
County Boundaries	Bastrop_Bndry_ESRI Williamson_Bndry_ESRI Travis_Bndry_ESRI Caldwell_Bndry_ESRI Hays_Bndry_ESRI	The county boundaries. Data is vector locating the boundary for each county in the Austin Metro area. Each layer is found within its resepective county search.	n.d.	http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php
County Water	Bastrop_Rivers_TIGER Williamson_Rivers_TIGER Travis_Rivers_TIGER Caldwell_Rivers_TIGER Hays_Rivers_TIGER Bastrop_Lakes_TIGER Williamson_Lakes_TIGER Travis_Lakes_TI-	Water layers are made up of two classes. The rivers/streams and the lakes/reserviors. Data is vector lines and polygons locating rivers and bodies of water in the Austin Metro area. Each layer is found within its respective county search.	n.d.	http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php
County Roads	Bastrop_Roads_StratMap Williamson_Bndry_StratMap Travis_Bndry_StratMap Caldwell_Bndry_StratMap Hays_Bndry_StratMap	Roads in each county. Data is vector lines referencing the locaiton of road networks in the area. Each layer is found within its respective county search.	n.d.	http://www.gis.ttu.edu/center/DataCatalog/CntyDownload.php
Building Footprints	building_footprints_2013	Building data for the city of Austin incuding LiDAR data for heights of buildings. Data is vector locating buidlings in Austin.	2013	ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html
Parks	city_of_austin_parks	Park data within the City of Austin including size, location, name, type of park, and address. Data is vector polygons locaitng parks.	2013	ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

Tree Cover	layer 1 (a GIS layer package named: ff946d025fb	This dataset portrays percent tree canopy coverage for NLCD mapping superzone ten (south), covering parts of Texas and Louisiana	2011	http://www.arcgis.com/home/item.html?id=35f11e098c6c4e4c8902374558a7827c
Bridges	bridges	Bridges connecting paved roadways for the CAPCOG region.	n.d.	http://www.capcog.org/data-maps-and-reports/geospatial-data/
Highways				http://www.fhwa.dot.gov/planning/processes/tools/nhpn/
City Limits		"capcop_city_limits"		http://www.capcog.org/data-maps-and-reports/geospatial-data/
Hydrography				http://www.capcog.org/data-maps-and-reports/geospatial-data/
Land use				ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

D. Image Permission

Lisa Hundt <LHundt@bats.org.uk>
Wed 4/8/2015 4:28 AM
To:
Dale Bradley;
Cc:
Keiron Brown <kbrown@bats.org.uk>;
You replied on 4/8/2015 1:40 PM.
Hi Dale,

We are happy for you to use the images as part of your publication with the appropriate credits.

Best wishes

Lisa

-----Original Message-----
From: Keiron Brown
Sent: 08 April 2015 10:21
To: Lisa Hundt
Subject: FW: Other

Hi Lisa,

Request below for the use of images from one of the biodiversity team's publications.

-----Original Message-----
From: BCT [mailto:noreply@bats.org.uk]
Sent: 02 April 2015 23:29
To: helplinetodo
Subject: Other

Email from: Dale Bradley

County: United States

Email: supra@ksu.edu

Telephone: 9139070450

Greetings,

Hi, my name is Dale Bradley and I am in the Master of Landscape Architecture program at Kansas State University. I am looking for permission to use images from \\\"Landscape and Urban Design for Bats and Biodiversity\\\" in my Master\\\'s report. The report will not be distributed but is required to be posted to Kansas State University\\\'s website as a part of my graduation, https://krex.k-state.edu/dspace/.

My project explores how urban planning and design can support bat\\\'s habitat and needs. I would really appreciate it, if it is possible to use some of the images because they do a very good job at visually providing a lot of important information. The images I would like permission to include in my report are:
1) Residential Biodiversity Enhancements - pg. 6
2) Woodland Patches and Buffer Trees - pg. 16
3) Urban Biodiversity Enhancements - pg. 22
4) Underpasses - pg. 26
5) Hop-Overs - pg. 27
6) Green Bridge - pg. 27
7) Ecological Networks - pg. 30

If it is possible to use these all of some of these images please let me know. If you have any other questions don\\\'t hesitate to ask. Thank you for your time.

All the Best,
Dale Bradley