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16. Abstract
This report consists of two parts. The first summarizes key details of the Suitability Analysis (SA) model, while the second illustrates the implementation details of the Gravity Land-Use Model (G-LUM). Both modeling approaches have been applied to the Austin region of Texas, but for different case study examples.

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# DESIGN AND APPLICATION OF ACCESSIBLE LAND-USE MODELING TOOLS FOR TEXAS REGIONS

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# PROJECT 5-5667: FINAL IMPLEMENTATION REPORT

This report consists of two parts. The first summarizes key details of the Suitability Analysis (SA) Model, while the second illustrates the implementation details of the Gravity Land-Use Model (G-LUM). Both modeling approaches have been applied to the Austin region of Texas, but for different case study examples.

# PART 1: SUITABILITY ANALYSIS

## 1.1 INTRODUCTION

The focus of the SA project, as managed by the University of Texas at Arlington (UTA) team, was the development of a prototype model application. The implementation process allowed the UTA team to fine-tune the process and present an executed example. The resulting model spatially allocated all projected employment types and household categories across the region's undeveloped grid cells in 5-year intervals/time steps. This allocation was based on the built environment through the application of buffers for proximity and access to attractions (such as activity sites, urban centers, and highways) and on natural environmental factors (e.g., soil, slope, and flood plains), via a series of cell ratings and attribute weightings.

## 1.2 LAND-USE FORECASTING FOR AUSTIN

The Austin region was selected as the study area thanks to the availability of demographic and geospatial data needed for SA application in ArcGIS, and this interesting mid-size region's continuing growth pressures.

### 1.2.1 Process

As a necessary part of realizing this task, the local natural and built environmental factors for the application of the SA were identified. Several agencies such as the Capital Area Council of Governments (CAPCOG), Capital Area Metropolitan Planning Organization (CAMPO), and the Texas Workforce Commission (TWC) were contacted to acquire appropriate information and data on these factors and other required variables (including employment types and household demographics). As is common in this type of project, data preparation and manipulation were necessary. For example, some of the collected data needed to be adjusted for consistency in terms of time spans as well as zonal configuration of the data. The unique application of this process needed data analyzed in smaller zones, such as 50 x 50 meter (0.62 acre) grids. These were later aggregated to larger zones, such as Traffic Analysis Zones (TAZs), which can be used as inputs for Transportation Demand Modeling (TDM).

Based on the team's analysis, the model process included four steps: 1) projection of employment and households, 2) calculation of required land, 3) suitability analysis for all grid cells, and 4) spatial allocation of employment and households to cells (Appendix A, Figure A.1). Each step required a specific set of data. The first step used past and current employment and household data (by job and household type) to project future values for the region. The second step used these results to calculate the required land for each job and household category in the study area. In the third step, SA considered both natural factors (e.g., presence of wetlands, water bodies, and other environmentally sensitive areas) and built environmental factors based on proximity/accessibility variables (e.g., time/distance to major highways or intersections and proximities to major activity centers) to provide suitability indices for different uses in each of the zones. The fourth step distributes the projected employment and households based on suitability indices of each land use into cells. The results were then aggregated into the TAZs, providing figures of various employment types and household categories (as potential inputs for a TDM, for example).

### 1.2.2 Determining Uses

The essential requirements of a land-use model (LUM) for integration with a TDM are employment and household projections. For this LUM, these projections were derived from the two-digit North American Industrial Classification System (NAICS) employment types and Census household income categories. Employment data was divided into two categories: basic and service sectors.

To convert employment activities into land-use categories, a use matrix (Freilich & White, 2008) was utilized as a reference. This task required a more detailed description of employment categories at the three-digit NAICS level to determine more specific types of activities that occur in land-use scenarios (Appendix A, Table A.1). Meanwhile, households are divided based on income categories into single family or multifamily residential uses. Land-use categories considered for the Austin region are provided in the Appendix A, Table A.2.

## 1.3 PROJECTION

The main purpose of this LUM is to project employment and population changes for each zone of the study area. The projection process involved the collection of available data, specifying the needed variables based on the case study and projecting employment into the basic and service sectors (see Appendix A, Figure A.2). The required data included the following:

- total population, household income, and total employment for the base year (2005) and the six projected intervals (5-year periods);
- number of households and employees per area (density);
- average parcel size for each household income (required land); and
- average area per worker (required land).

### 1.3.1 Employment Projection Data and Methodology

Employment data for each county in the Austin area was compared with employment data of the State of Texas to identify which industries can be categorized as basic and service sectors. The variables required for employment projection were:

- Base year and projected interval employment data–The total employment projections for the study area were collected from Austin's CAMPO. More detailed employment data was provided by the Texas Comptroller of Public Accounts, which included employment in year 2009 with two-digit NAICS classification and the average four-year annual growth. Data for 2006 employment estimation and 2016 projection in four-digit NAICS was derived from the Texas Workforce

Commission. Additional data for 2008 estimation and 2013 projection in two-digit NAICS of Census block groups was obtained from the ESRI Business Analyst suite.

- Average area per worker: The data was obtained from business listings provided by ESRI Business Analyst suite.
- Percentage of workers in each two-digit NAICS category: The percentage of workers in each two-digit NAICS category was needed to break down the total employment projections from CAMPO so that in every projected interval, the data would consist of these categories. The percentage of workers in each category was obtained from detailed employment data provided by the Texas Comptroller of Public Accounts, the TWC, and ESRI Business Analyst suite.
- Floor area ratio (FAR): FAR equals total area (sq.ft.) of building(s) divided by area (sq.ft.) of the accompanying parcel lot.

There are several methods to identify which industries fall into the basic or service sectors. This study used the *location quotient technique* to estimate the basic employment in each industry (Appendix A).

### 1.3.2 Household Projection

Household data for the base and projection intervals are divided into the three income categories of low income, medium income, and high income, and are allocated into single family (SF) and multifamily (MF).

The following describes the population data collected:

- Base year (2005) population and household data (2040) was collected from the U.S. Census Bureau. Future-year projects were developed using ArcGIS ESRI estimates for year 2014 and the Texas State Data Center for population estimates across 2005–2040. This available data served as a measure to apply trend extrapolation and the ratio share method to provide data needed for year 2015 until the final projection year.
- Average parcel size for each residential land use (SF, MF) was derived from existing parcel data provided by the CAPCOG data clearinghouse
- Household percentages. The population was categorized into three household types by income level–low income, medium income, and high income. These categories were used to allocate single family (SF) and multifamily (MF) residential uses. The percentage of each category in the base year was used to obtain the percentage for the projected intervals.

## 1.4 REQUIRED LAND CALCULATION

Required land is defined as the amount of land that is needed to accommodate future projections of households and jobs. Calculation of required land starts with obtaining the existing residential and non-residential land area and the growth between the base year and future years. CAPCOG provided GIS parcel-level data, including parcel size and categories of use for Travis, Williamson, and Hays Counties.

Required residential land was estimated by reviewing the base-year (2005) parcel data and simply computing the percentage or ratio of the acreage used for single family (SF) and multifamily (MF) uses. Non-residential required land was calculated by multiplying the average area per worker in the base year with the projected number of employees in every two-digit NAICS category.

## 1.5 SUITABILITY ANALYSIS IN AUSTIN

### 1.5.1 Identification of Suitability Factors

Identification of the key factors causing land-use changes was a very important step in this research because these factors are assumed to be the ones that drive changes in urban development. Another essential step was determining how to represent these factors in the analysis so that it is simple enough to model—but not too simple to lose its applicability to practice. Developing a realistic modeling of land-use change required first identifying the most important factors that drive changes and then representing these factors in the model (Veldkamp and Lambin 2001). The tools in ArcGIS enabled these factors to be represented and analyzed simultaneously to produce a suitability map of every land use.

The factors considered in this SA were divided into two categories: *natural environmental* and *built environmental* factors. The natural environmental factors included water resources, wildlife or endangered species habitats, karst zones (acquifers), and other sensitive ecological areas (e.g., Texas Ecological Assessment Protocol or TEAP zones). Several natural environmental factors (such as floodplains and sensitive habitats) are masked due to safety and environmental concerns. In most cases, the proximity of development to these areas is regulated by federal, state, or local governments and agencies. The built environment areas were selected based on how accessibility and/or proximity can affect locational choice of activities. These areas typically included (but are not limited to) employment centers, airports, highways, major road intersections, and shopping centers.

Selection of the suitability factors depended on the characteristics of the planning area and categories of land use considered. Every region had its own specific natural and built environmental features. A complete list of all the factors considered in SA for the Austin region is provided in Appendix B, Table B.1.

### 1.5.2 Rating

The rating process in SA assessed both natural and built environmental factors based on how much they impacted development. Suitability of location *i* for land use *j*, $S_{ij}$, can be represented as follow:

$$S_{ij} = b_1 F_{1ij} + b_2 F_{2ij} + b_3 F_{3ij} + ..... + b_k F_{kij}$$

*or*

$$S_{ij} = \sum_{k=1}^{k} b_k F_{kij}$$

where the *F*'s are ratings of each factor according to the degree of its effects, positive or negative, on each of the selected land uses, *j*; and *b's* are coefficients, measuring importance (weight) of the *k* selected factors, *F's*, in determining suitability of location *i* for land use *j*.

The nature of the rating process is subjective because the rating used assumptions based on the degree of importance of accessibility and/or proximity to these factors in impacting land-use development. The rating process included determining distance known as *buffering*, in which a certain rate number (ranging from -10 to +10) was assigned to areas within every buffer distance. Figure B.1 in Appendix B shows the proposed zones to preserve wetlands and streams (Semlitsch & Bodie, 2003), which can be used as the base for setting the buffer distance for the ratings. Detailed buffer distance categories and accessibility/proximity analysis for all the suitability factors considered in this project are provided in the Appendix B, Table B.1.

### 1.5.3 Weighting

After all factors were rated, the next step was to assign weights to each factor under consideration for each land use. The determination of weights was based on the relative importance of the factors compared to each other for development suitability of a given use. Some factors may be considered more important to determine the suitability for the respective land use. There are several ways to achieve these weighted-ratings such as the Delphi technique[1] and the Analytical Hierarchy Process (AHP)[2] or a combination of them. AHP is based on pair-wise comparison, which compares two factors against each other to weigh the importance of their value in urban development.

### 1.5.4 Suitability Map

The weighted-rating process produced a suitability map for each land use that showed a range of values indicating a suitability score for each respective land use. Figure B.3 in Appendix B shows an example of a suitability map for single-family (SF) use (for 2005 and 2010). In this map, the highest suitability score is +3.42 and lowest suitability score is -4.66. These scores indicate the range of suitability for SF to be allocated in the projected year.

After the suitability map for each land use was obtained, the next step was the allocation process, where the required land for projected number of employment and population was distributed spatially into the most suitable location.

### 1.5.5 Allocation

The allocation process is where space required for projected numbers of households and jobs is allocated spatially, across developable sites. Once the household and employment data for the base year and the projected 5-year period was determined and required land was calculated, the next step was to allocate them into developable sites based on the suitability score for each use.

Developable land is defined as the amount of land on which additional and new development can take place within the constraints of the environmentally sensitive areas, and in accordance to local plan and policy (Berke, et al., 2006). Developable land does not include environmentally sensitive areas, existing developed land uses, or other pre-defined constraints (local regulation that does not allow development).

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[1] The Delphi method is a systematic, iterative process to acquire experts' opinion on a particular topic and is particularly useful if there are no standard criteria for evaluation (see, e.g., Khorramshahgol & Moustakis, 1988; Taleai & Mansourian, 2008).

[2] The AHP process is based on the premise that a complex issue can be evaluated by hierarchically examining its parts.

Allocation of the projected employment and households into developable land (supply) was based on how much required land (demand) was needed to accommodate them. The allocation process involved determining the order of allocation into the most suitable developable land in the region. Because LUM essentially allocates projected employment and household growth, the order for allocation in this prototype application was based on economic base theory (Appendix B, Figure B.4). Once the basic employment is allocated into the most suitable land, the next step is to allocate the households into single-family or multifamily residential uses. The projected service sector employment growth was then allocated into service commercial, light industrial, and heavy industrial. Because all the environmentally sensitive areas have been masked and removed prior to the allocation process, the remaining open space to be allocated was mainly recreational uses. The result of the allocation process created a final land-use allocation composite map (Appendix B, Figure B.5).

## 1.6 DERIVING NUMBER OF PROJECTED EMPLOYMENT AND HOUSEHOLD

TDM requires employment and household numbers within a specific zone of analysis. Because the final composite suitability map showed the locations of future employment types and household categories in a raster format of 50 x 50 m (0.62 acre) cell size, data was merged to the level of TAZs. Every allocated cell represented land area occupied by each employment type or household category.

To obtain the total number of employment in each TAZ, the original raster cell data was converted into TAZ geography. The result was a TAZ shape file that contained the area of land allocated for each employment and household categories (Appendix C, Figure C.1). The number of households was obtained by dividing the total allocated area by average area per residential units (for both single family and multifamily). The TAZ shape file showed the range of employment and household numbers in the TAZ level for the projected year 2010 (Appendix C, Figure C.2 and Figure C.3).

Figure C.4 in Appendix C shows the region's projected densities (in jobs per acre). Such density is projected to have higher concentrations in northern, western, and southern areas, outside downtown Austin. Most of the projected developments are next to or near freeways.

Meanwhile, households are projected to be mostly concentrated within and in close proximity to the city of Austin. Figure C.5 shows that projections of household density are higher in downtown Austin and the surrounding neighborhoods. This indicates higher concentrations of multi-family housing in these areas, including high-rise apartments/condominiums.

## 1.7 SCENARIOS

Based on the four-step application of the processes discussed above, the model was run for two different scenarios: 1) projecting the land-use effects *with* State Highway (SH) 130 and the Ronald Reagan extension, and 2) projecting the land-use effects *without* SH130 and the Ronald Reagan extension. The result of comparing these two scenarios estimated the effects of building (or not building) the new highway in the Austin region and the shifts (and losses and gains) of development across the study area.

Scenario one's projected results (*with* SH 130) allowed us to compare it to the actual effects of the built highway (Appendix D, Figure D.1). It appears that the development patterns, especially in vicinity of the new highway, closely match the actual observed effects of the highway. The results also confirm that the projected development was/is more concentrated around SH 130.

Figures D.2 and D.3 in Appendix D show the different distribution of employment and households *without* and *with* SH 130 and the Ronald Reagan extension. In general, developments were more distributed around and along SH 130 and the Ronald Reagan extension, as compared to the scenario *without* them. The SA model considers suitability for household and jobs allocation based simply on access to freeways, and does not consider the transportation system's capacity, travel times, or congestion levels.

## 1.8 CONCLUSIONS (TO PART 1)

The SA model developed in this project allows identification of real factors or variables and their data sources for Texas applications, specifically for a medium-sized metropolitan area such as Austin. The model uses four key steps to simply project employment and household numbers, calculate required land, assess the suitability of various cells, and spatially allocate new/added jobs and households by type. This SA model in ArcGIS also provides a way to compare different scenarios if distinctive plans or policies (e.g., with versus without SH 130) are of interest for analysis. Overall, the scenario analysis results appear to support this prototype application model's projection ability and reliability.

Detailed descriptions of the ArcGIS application of the SA model process is provided in the project's SA guidebook, including a user-friendly step by step guide for metropolitan planning organizations (MPOs) to follow.

# PART 2. IMPLEMENTATION OF ACCESSIBLE LAND-USE MODELING TOOLS FOR TEXAS APPLICATIONS

## 2.1 INTRODUCTION

As described at length in the final report of the accompanying, earlier research project, the G-LUM is a land-use forecasting tool modeled on Putman's DRAM-EMPAL equations and developed for use by Texas MPOs (and provided via http://www.ce.utexas.edu/prof/kockelman/g-lum_Website/homepage.htm). It consists of three main components, or sub-models: RESLOC, EMPLOC, and LUDENSITY. The RESLOC and EMPLOC components estimate the parameters associated with residential and employment location choice based on user-provided lag and base year data. Similarly, the LUDENSITY component estimates all parameters associated with the land consumption model based on the base year data given. Finally, the PREDICTION module forecasts the household and employment counts and land consumption variables for each of the zones for the user-entered time periods, while holding the travel cost matrix constant.

Under this implementation project, G-LUM was implemented for the Austin, San Antonio, Waco, and El Paso regions, and all results were evaluated. Run times for the RESLOC and EMPLOC components were around 70 minutes for each of these regions (with zone counts ranging from 283 to 1,074), and run times were just 5 minutes for LUDENSITY and PREDICTION module applications. The results of the implementation for the Austin region are discussed below, and results for other regions are summarized in Appendices F through J.

## 2.2 AUSTIN RESULTS

The Austin data was provided by CAMPO for the region's 1,074 traffic analysis zones (TAZs). Year 2005 data was used as the base-year data set, and Year 2000 data was used as the lag year.

The population and employment growth were obtained from control totals provided by CAMPO, with number of households increasing from 546,692 in 2005 to 1,095,198 in 2030, while the total number of jobs increased from 699,447 in 2005 to 1,388,330 in 2030 (almost doubling). G-LUM requires that users input a travel time or generalized travel cost matrix (rather than running a travel demand model endogenously). In these Texas simulations, inter-zonal travel times were unchanged across time steps, though, in reality, they will generally rise (due to added congestion from population and employment growth in the region). Ideally, users will run their own travel demand model after each time step using that period's population and job forecasts as key inputs.

Figures 1 and 2 illustrate the employment density in the base year (2005) and the final forecast year (2030) based on a series of five 5-year forecasts (for years 2010, 2015, 2020, 2025, and 2030). Images are shown in two-dimensional (2D) and three-dimensional (3D) formats. In the final forecast year 2030, employment density peaked at around 400 jobs per acre (from 250 jobs per acre in 2005) in Austin's downtown (in TAZ #379). If a building footprint comprises 50% of land area in a commercial zone and each worker gets 400 square feet of office space, then a job density of 400 jobs per acre will result in an average building height of 7.3 stories.


*Figure 1: 2D Employment Density (Jobs per Acre) in Base and Forecast Years (2005 & 2030)*

*Figure 2: 3D Employment Density (Jobs per Acre) in Base and Forecast Years (2005 & 2030)*

Figures 3 and 4 summarize household densities in the base and forecast years. A peak household density of 163 households per acre was observed in TAZ #358 in the final forecast year (increasing from a maximum zone density of 47 households per acre in 2005). Because simple regional density numbers (gross and averaged across zones) obscure variations in density, as experienced by Austin's residents and workers, count-weighted averages of household and employment densities were calculated. Also, accessibility indices were calculated as measures of accessibility of jobs and households from CBD zones. Table 1 lists the count-weighted densities and accessibility indices for the base year (2005) and forecasted year (2030)

.


*Figure 3: 2D Household Density (HHs per Acre) in Base and Forecasted Years (2005 & 2030)*

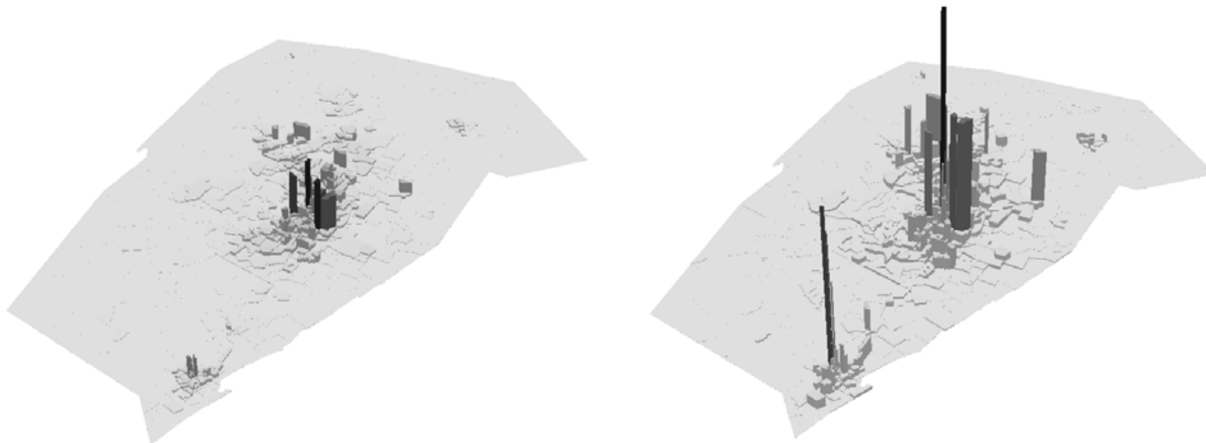


*Figure 4: 3D Household Density (HHs per Acre) in Base and Forecasted Years (2005 & 2030)*

**Table 1: Numerical Results in Base and Forecast Years for Austin**

| | Job Density (jobs/acre) | HH Density (HHs/acre) | AI for jobs (from CBD) (counts/mile) | AI for HHs (from CBD) (count/mile) |
|---|---|---|---|---|
| Base (2005) | 26.49 | 4.84 | 223,620 | 172,332 |
| Trend (2030) | 21.05 | 13.84 | 360,224 | 299,783 |

$AI = \sum_i \frac{count}{(distance\ to\ CBD)}$ Count weighted density = $\sum \frac{HH_i \times HHDens_i}{TotalHouseholds}$

As shown in Table 1, even though total jobs rise over time, the count-weighted job density falls, suggesting continuing suburbanization or greater sprawl. A look at the lag and base year data reveals that between 2000 and 2005 Austin's job total increased from 602,399 to 699,447, but count-weighted density fell from 28.81 to 26.49 jobs/acre (see Appendix F). Such decentralization of jobs from lag to base year is captured by the G-LUM parameters, resulting in a similar behavior under the TREND (business-as-usual) scenario.

Kneebone (2009) reported Austin to be among the metropolitan areas that experienced rapid decentralization between 1998 and 2006. Many other organizations, like the Coalition on Sustainable Transport (COST), have also reported acceleration in employment decentralization in Austin between 2000 and 2006. The centralization or decentralization behavior might result from a lot of temporary factors (rapid construction, etc.) that might not be present in future years. Utmost care must be taken while assembling the data for lag and base years. The household density increased in the forecasted year as expected. The increase in household density indicates densification of households. Also, the accessibility indices corresponding to both jobs and households increases as a result of the increase in number of households and densification.

## 2.3 SCENARIOS

Implementation in Austin, San Antonio, Waco, and El Paso tested G-LUM for its ability to appropriately capture the trends and make reasonable forecasts. G-LUM was found to perform quite well in terms of applicability to different data sets. G-LUM was then tested for its sensitivity to changes applied to the various inputs which might reflect changes as a result of regional changes. Employment totals, population control totals, and inter-zonal travel times were increased by 50% to appreciate variations in model outputs. The results of these changes were compared to the results of the TREND scenario. The effect of increased job totals was readily observed in the increased number of jobs and count-weighted job densities in each of the regions. As expected, the job accessibility indices to CBD also increased due to centralization. Boosting of the household control totals resulted in an anticipated increase in the number of households and household density. It was noted that the count-weighted job densities decreased for each of the regions. Also, the job accessibility indices were found to decrease for all the regions which indicate a sprawling job density.

Generally, as travel times increase, tone finds greater (predicted) clustering of households and jobs. Count-weighted job density was found to decrease slightly across all the modeled regions. Such low responsiveness could be attributed to either lack of representation of the actual costs experienced by the users or inability of the model to capture the effect of overall increase in network impedance. Nevertheless, some evidence of clustering was found in the increase of job and household accessibility indices for all four regions. In the case of Austin, for example, the job accessibility index increased from 360,224 to 390,079 jobs per mile. Detailed results of all the scenarios are presented in Appendices F through J.

## 2.4 CONCLUSIONS (TO PART 2)

G-LUM was developed in light of the various modeling needs and abilities of Texas' twenty-five MPOs. G-LUM uses entropy maximization principles to estimate parameters from lag and base year data. Its straightforward structure and MATLAB-based graphical user interface (GUI) makes G-LUM very user-friendly. G-LUM was implemented for the Austin, San Antonio, Waco, and El Paso regions under several scenarios (where jobs, population, and travel times increase) and found to perform quite well in terms of running time and reasonableness of predictions. G-LUM mimics the trends in the lag and base year data quite well. So care needs to be taken to ensure that data inputs are proper and trends reasonable. Data may best be filtered to offset extreme events or other effects of unusual short-term trends.

The scenario runs illustrate the sensitivity of G-LUM to several key inputs and assumptions. However, at times downtown zones were predicted to have very high job and/or household densities. These can be avoided by applying caps on counts after each time period forecast, and re-starting the prediction mid-stream (e.g., time step by time step, rather than five steps and 25 years all at once). Updates on travel costs and times can also be introduced in intermediate years for more informed prediction. Overall, G-LUM provides policymakers, planners, and planning organizations with a valuable open-source, transparent, and user-friendly tool for estimating future land-use patterns, in concert with travel conditions and reflections of competing locational accessibilities. More details can be found in the research report that preceded this implementation project, and at the G-LUM website (http://www.ce.utexas.edu/prof/kockelman/G-LUM_Website/homepage.htm).

# APPENDIX A: EMPLOYMENT AND HOUSEHOLD PROJECTION

## Use Matrix

**Table A.1: Example of Use Matrix (Freilich & White, 2008, p. 73)**

| Use/Activity | RP | RE, NS | NU | CN | O | CG | CL | D | IL | IH | Variable |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Research-and-development services (scientific, medical, and technology) | — | — | — | C | P | P | P | P | P | P | Function |
| Car rental and leasing | — | — | — | — | — | — | — | — | — | P | Function |
| Leasing trucks, trailers, recreational vehicles, etc. | — | — | — | — | — | — | — | — | — | P | Function |
| Services to buildings and dwellings (pest control, janitorial, landscaping, carpet/upholstery cleaning, parking, and crating) | — | — | — | — | — | P | P | P | P | P | Function |
| Bars, taverns, and nightclubs | — | — | — | — | — | — | P | P | — | — | |
| Camps, camping, and related establishments | P | C | — | — | — | P | P | — | — | — | Function |
| Tattoo parlors | — | — | — | — | — | P | P | P | — | — | |
| ***Industrial buildings and structures*** | | | | | | | | | | | Structure |
| Light industrial structures and facilities (not enumerated in Codes 2611-2615, below) | — | — | — | — | C | — | — | — | P | P | Structure |
| Loft building | — | — | — | — | P | — | — | P | P | P | Structure |
| Mill-type factory structures | — | — | — | — | — | — | — | — | C | P | Structure |
| Manufacturing plants | — | — | — | — | — | — | — | — | — | P | Structure |
| Industrial parks | — | — | — | — | P | — | — | — | P | P | Structure |
| Laboratory or specialized industrial facility | — | — | — | — | P | — | — | P | P | P | Structure |

**Land-Use Categories**

Table A.2 illustrates the land uses and the example of activities that fall within each category. It is important to note that what activities fall on which categories may change, depending on the policy of the region.

**Table A.2: Land-Use Categories**

| Use Categories | Activities |
|---|---|
| Single Family (SF) | Single Family residential |
| Multi Family (MF) | Multi Family residential |
| Basic Low Commercial (BLC)<br>Service Low Commercial (SLC) | Office, assisted living, day care, retail sales and services, restaurants, banks, nursery or greenhouse, grocery sales, pharmacies, fitness centers, dance and music academies, artist studio, colleges and universities, bed and breakfast. |
| Basic High Commercial (BHC)<br>Service High Commercial (SHC) | Any use in Low Commercial plus bar, nightclub, entertainment venues, hospital, hotel, liquor store, office/warehouse, vehicle and equipment sales, leasing and repair, furniture sales, pet shop, wholesale activities. |
| Basic Light Industrial (BLI)<br>Service Light Industrial (SLI) | Any use in HC plus commercial laundry, contractor storage yard, lumber yards, indoor manufacture, assembly and processing, mini-warehouse, RV, trailer and boat storage, SOB's, testing and research, warehouse and distribution, wholesale, wrecker impoundment. |
| Basic Heavy Industrial (BHI)<br>Service Heavy Industrial (SHI) | Any use in LI plus outdoor manufacture, assembly and processing. |
| Open Space (OS) | City parks, pocket parks , community gardens, outdoor recreational areas, natural areas, environmentally sensitive areas, greenways |

**General Process**

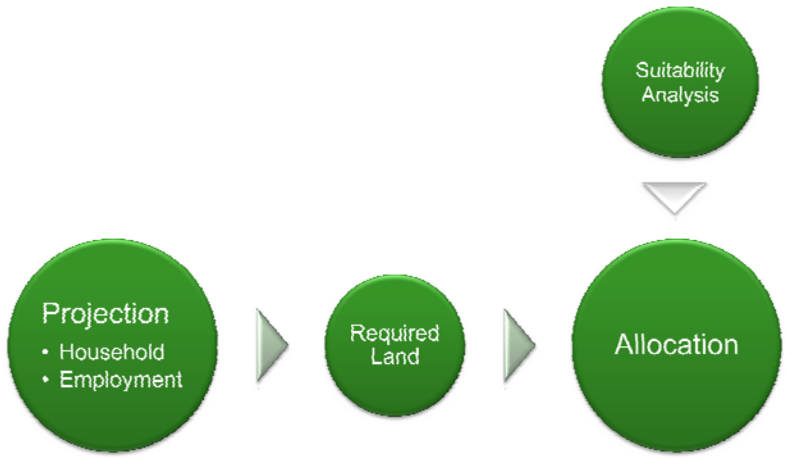



*Figure A.1: Diagram of the Process*

**Projection Methods**

The following diagram shows the projection methods used for both employment and households.

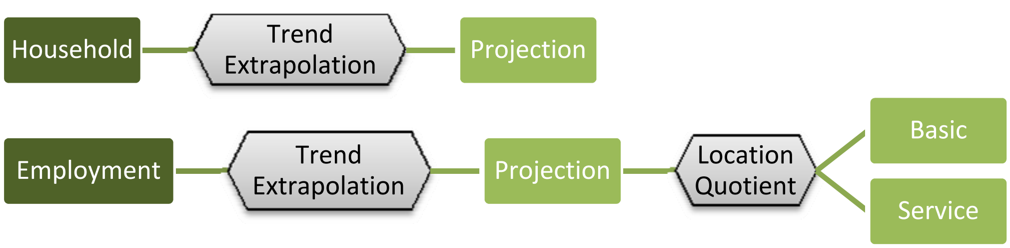



*Figure A.2: Diagram of Projection Methods for Employment and Households (Source: TxDOT Presentation).*

**Location Quotient Technique**

The location quotient technique is the most commonly utilized economic base analysis method for dividing the employment into basic and service sectors, by relating an industry's local employment share to its state or national employment share, based on NAICS 2 digit categories. The following is a formula for determining the basic sector employment using the location quotient technique:

$$\text{Basic Sector Employment} = \frac{\text{Regional Employment Industry } i}{\text{National Employment Industri } i} - \frac{\text{Total Regional Employment}}{\text{Total National Employment}} \times \text{National Employment Industri } i$$

# APPENDIX B: SUITABILITY ANALYSIS

## Rating

For Austin, the accessibility/proximity factors and the ratings used are summarized into the following table:

**Table B.1: Suitability Factors, Proximity/Accessibility Analysis, and Buffer Distance**

| Factors | Analysis | Distance (Buffer) Categories |
|---|---|---|
| Highway | Proximity | 50, 200, 500, 1000, 2000, 10000 feet |
| Intersection | Accessibility | 0.5, 1, 2, 3 miles |
| Employment Centers | Accessibility | 1000, 5000, 10000, 15000, 20000 feet |
| Shopping Centers | Accessibility | 1000, 5000, 10000, 15000, 20000 feet |
| Airport | Accessibility | 1000, 5000, 10000, 15000, 20000 feet |
| Karst | Assignment Features | Zone 1, zone 2, zone 3 |
| Endangered Species | Proximity | 328, 984, 2296, 4921 feet |
| Water Bodies | Proximity | 98, 328, 656, 3280 feet |
| Wetlands | Proximity | 98, 328, 918, 3280 feet |
| TEAP | Assignment Raster | 1, 10, 25, 50 (in percent of the total area) |
| Existing Land Use | Assignment | Vacant Lots and Tracts, Qualified Agricultural Land, Farm and Ranch Improvements (because we want to focus on undeveloped areas) |

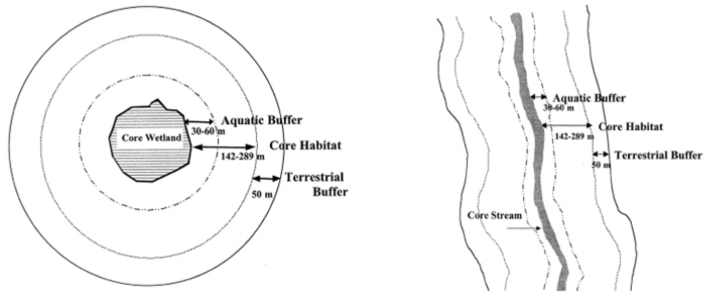
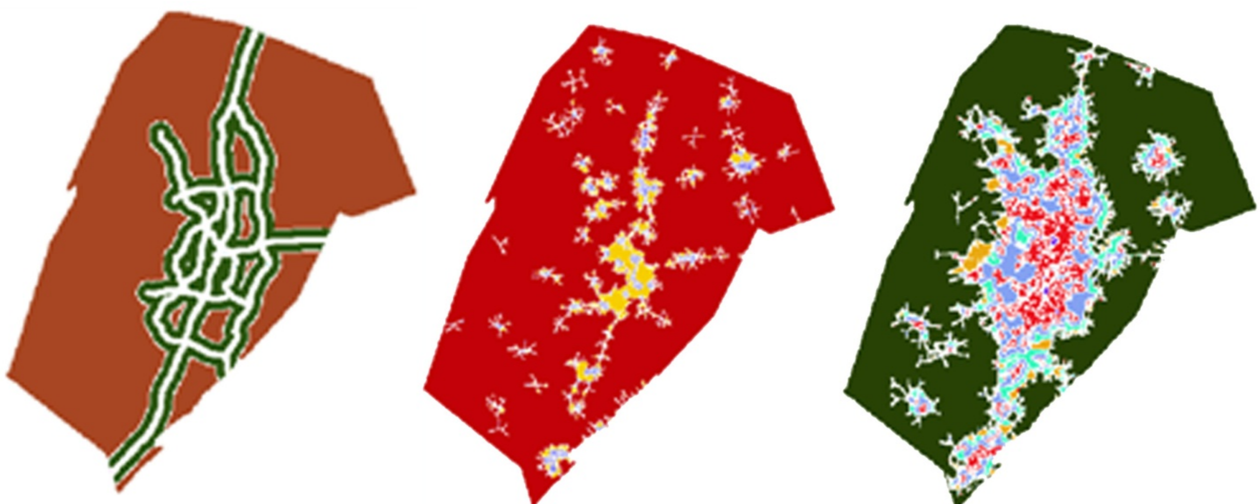



*Figure B.1: Proposed Zones to Preserve Wetlands and Streams*
*Source: (Semlitsch & Bodie, 2003)*



a. Proximity to Highway

b. Accessibility to Major Road Intersections

c. Accessibility to Employment Centers

d. Accessibility to Airports

e. Proximity to Endangered Species

e. Proximity to Water Bodies

*Figure B.2: Example of Suitability Factors Buffering (Proximity/Accessibility)*

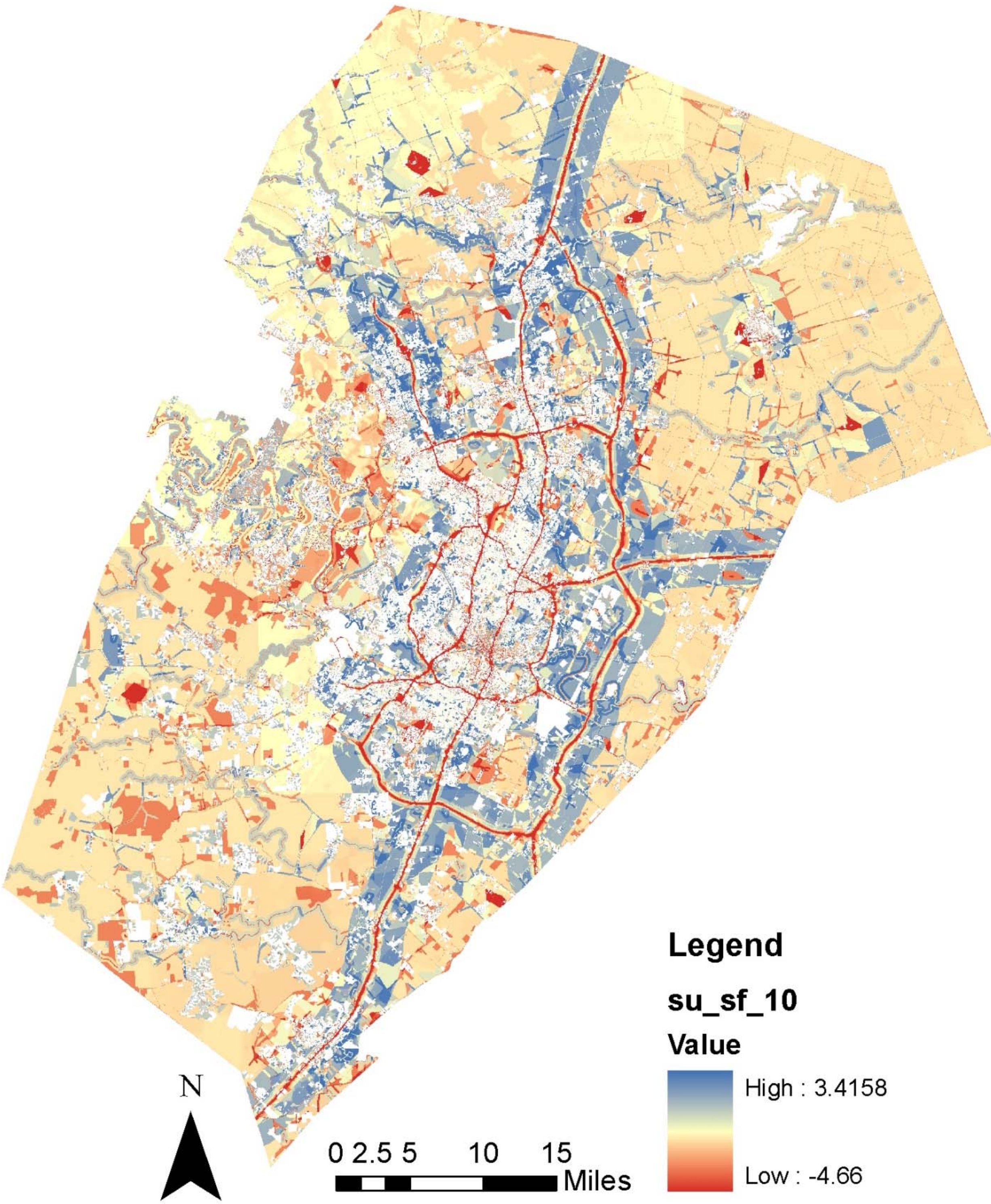



*Figure B.3: Suitability Map for Single Family (2005–2010)*

**Allocation Order**

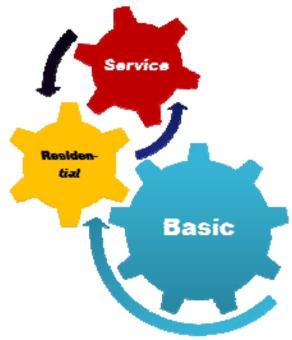



*Figure B.4: Allocation Order*

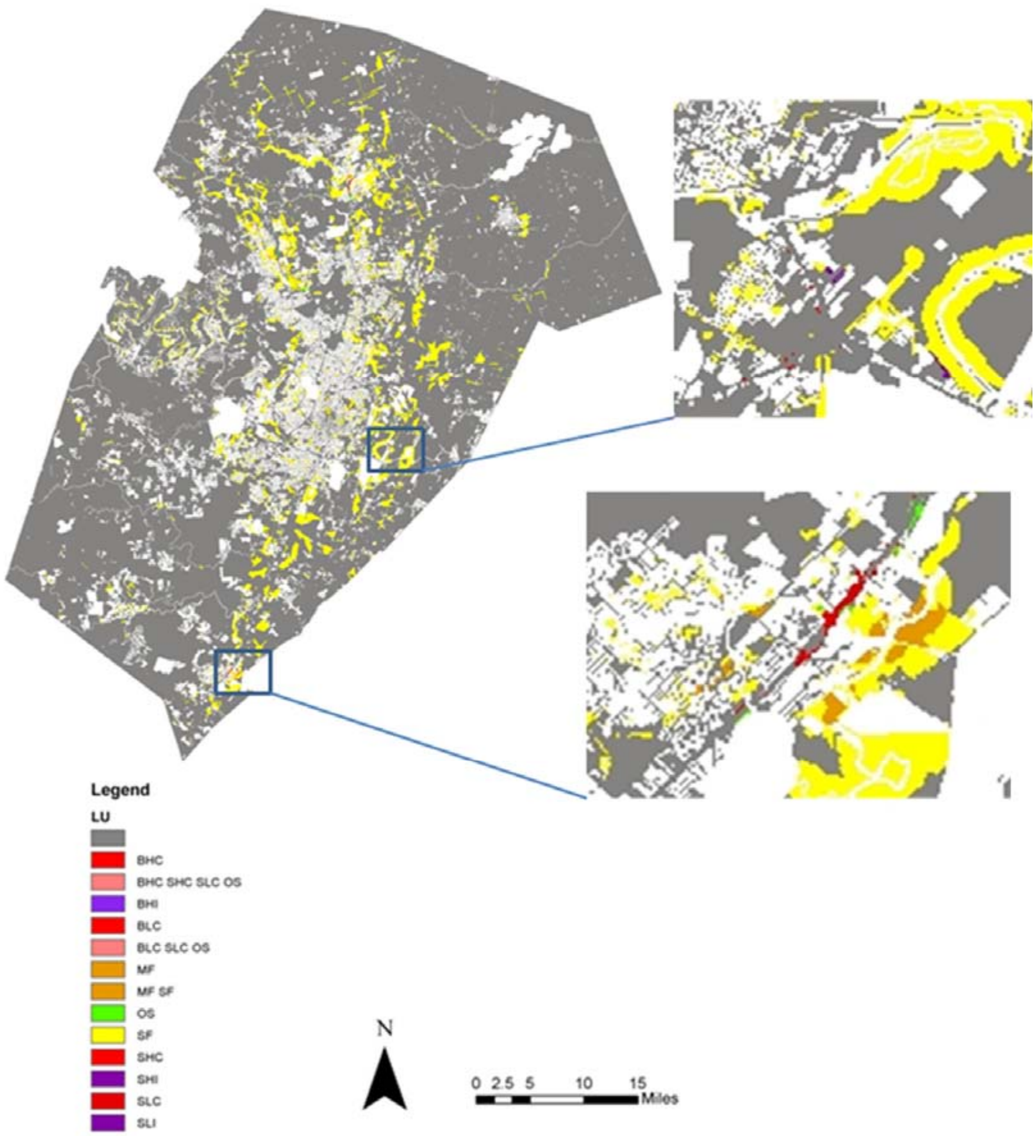



*Figure B.5: Final Composite Land-Use Allocation Map*

# APPENDIX C: PROJECTED EMPLOYMENT AND HOUSEHOLD IN TAZ

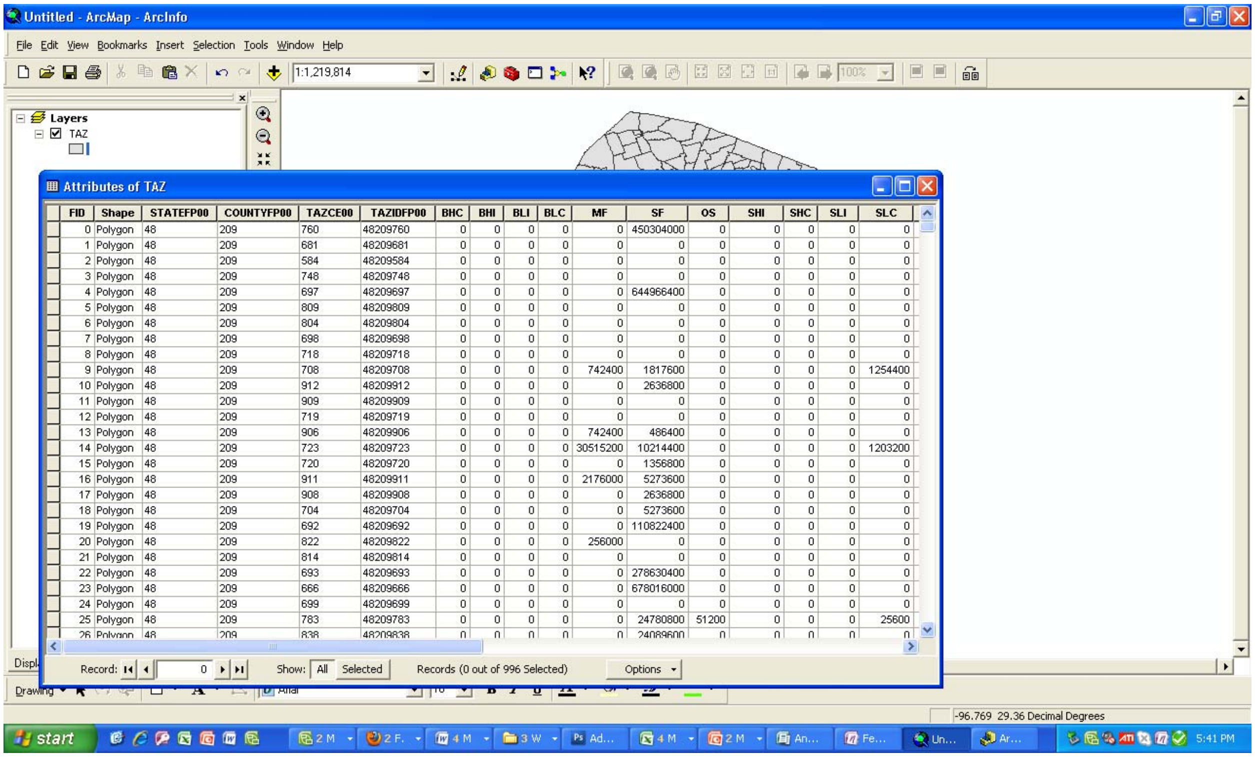



*Figure C.1: Screen Capture of TAZ Shapefile Attribute Table*

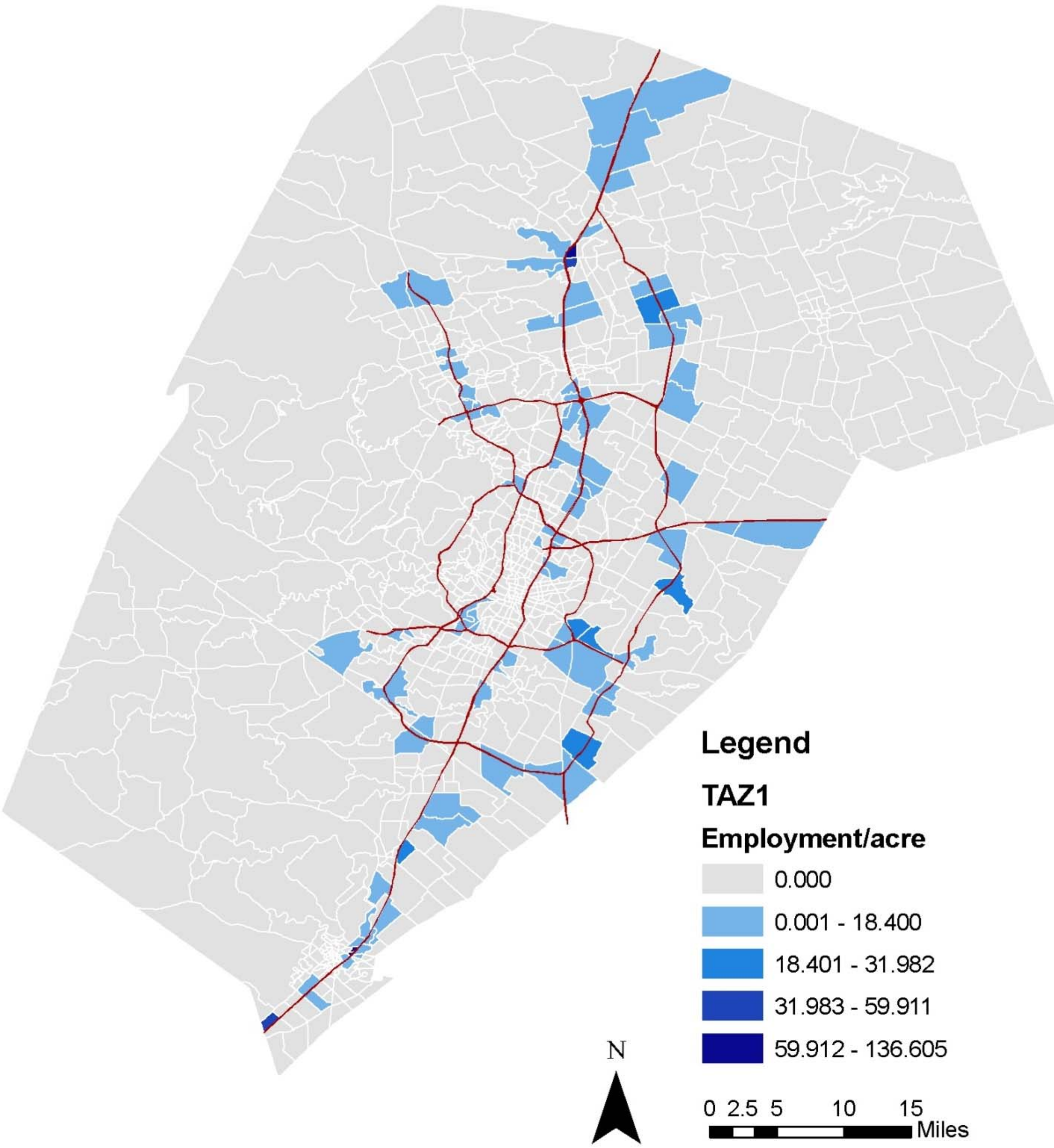



*Figure C.2: Employment Density in TAZ (2005–2010)*

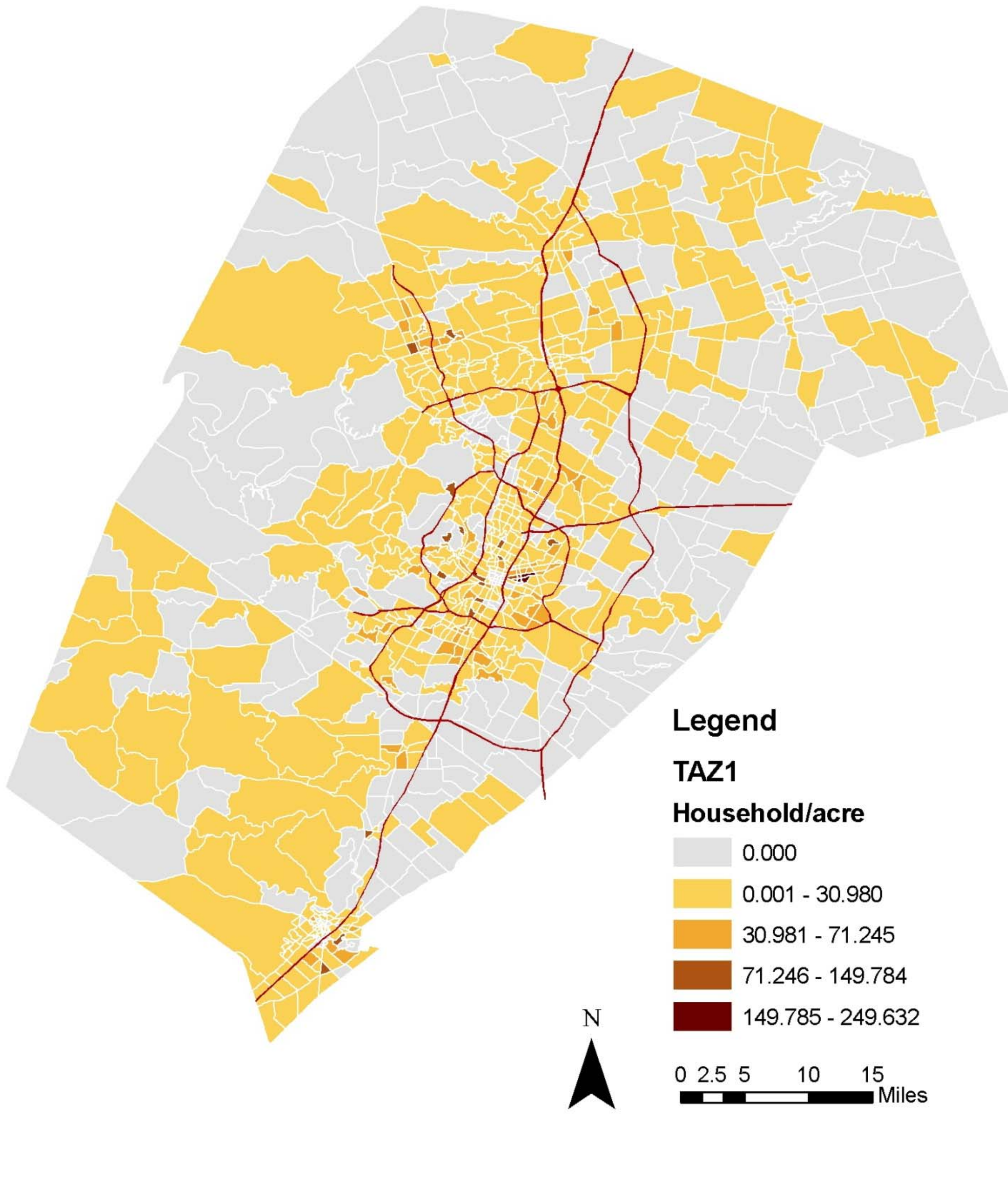



*Figure C.3: Household Density in TAZ (2005–2010)*

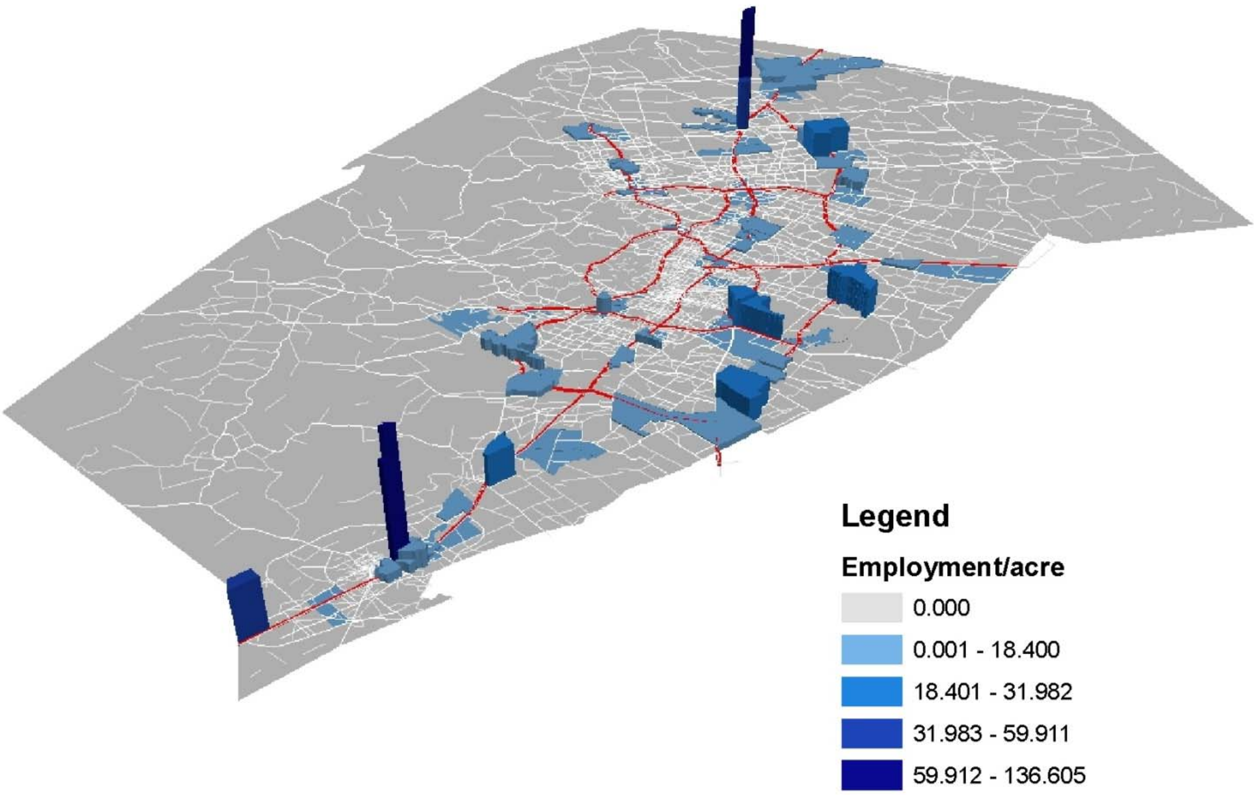



*Figure C.4: Projected Densities of Employment per Acre (2005–2010)*

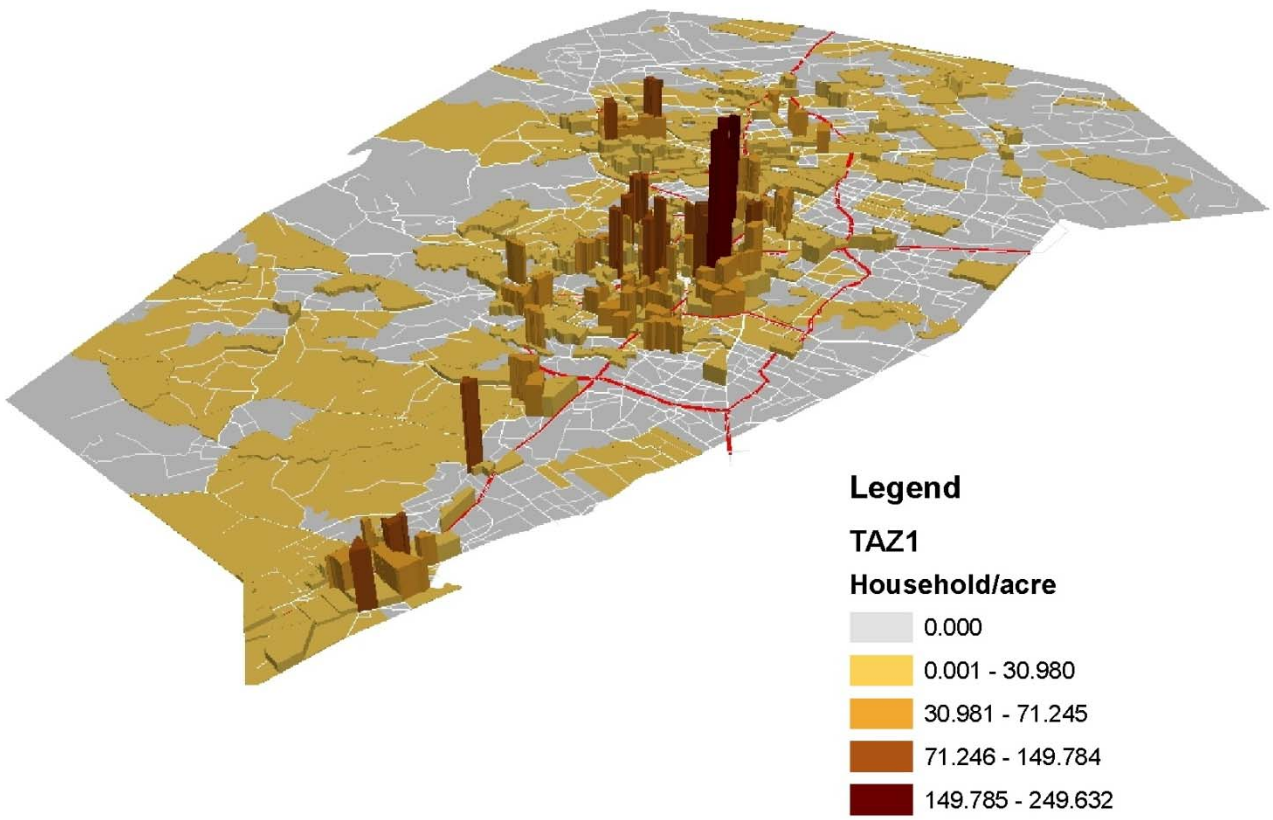



*Figure C.5: Projected Densities of Household per Acre (2005–2010)*

# APPENDIX D: SCENARIOS

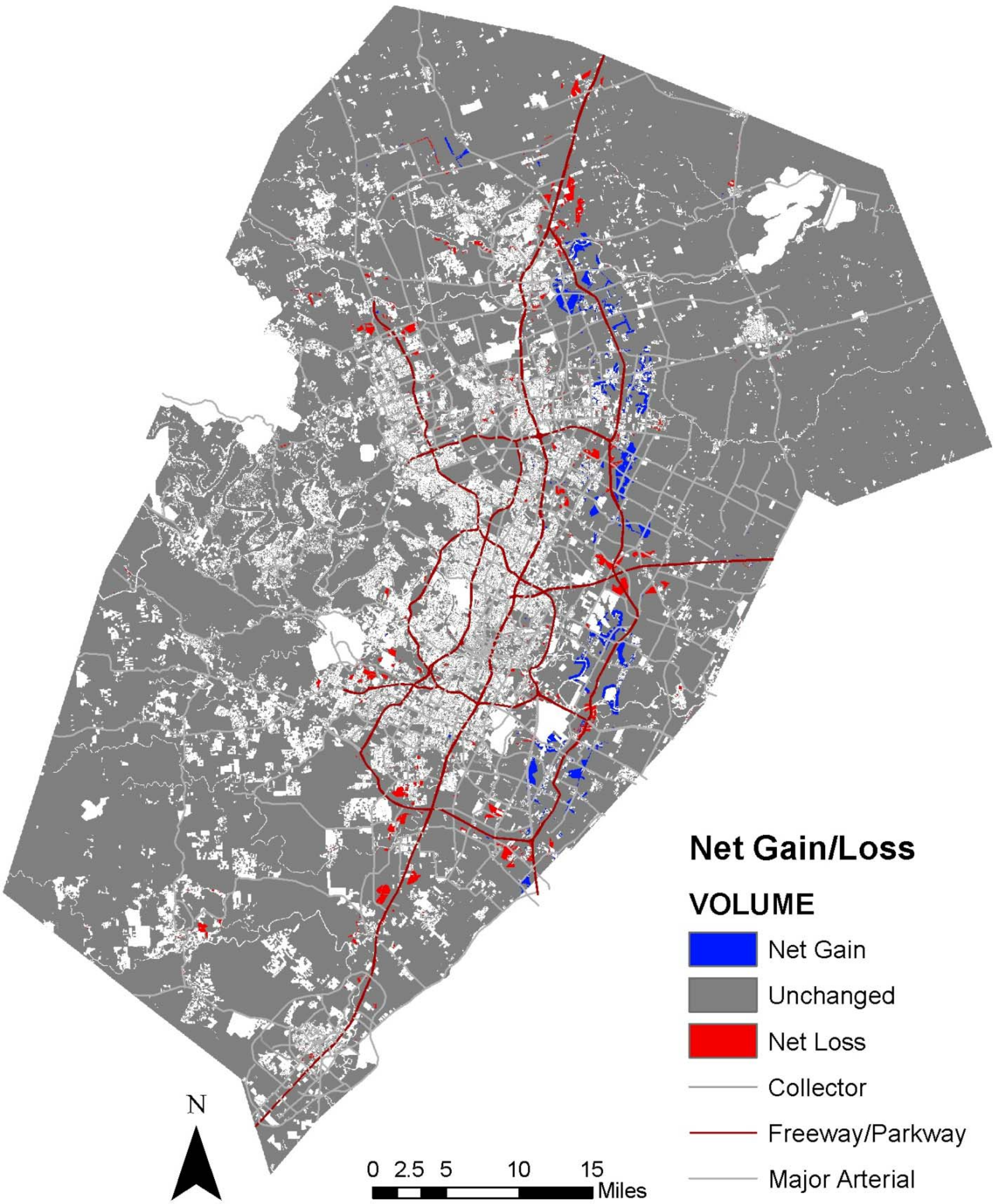



*Figure D.1: Net Gain and Loss Due to SH 130 and Ronald Reagan Extension (2005–2010)*

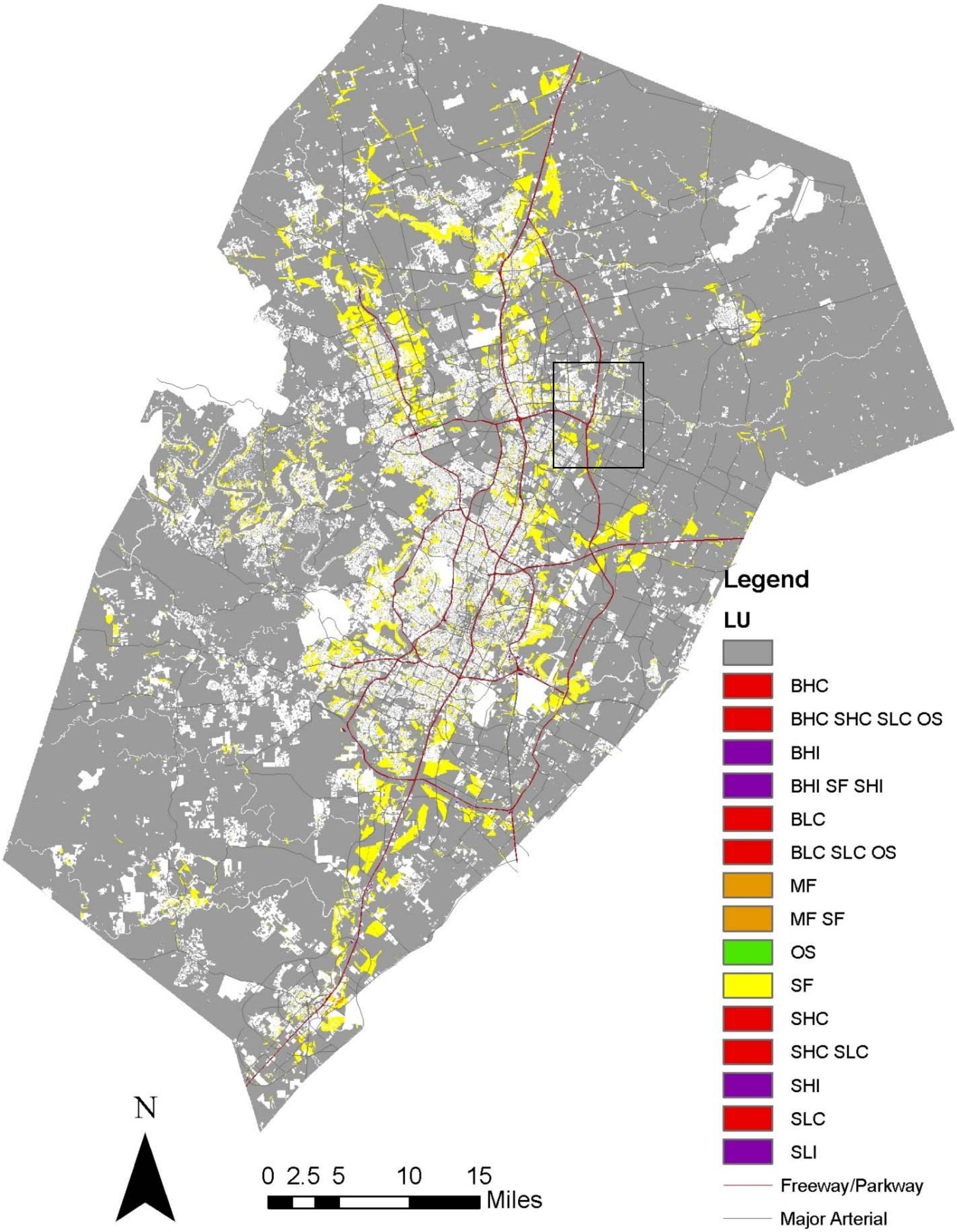



*Figure D.2: Without SH 130 and Ronald Reagan Extension (2005–2010)*

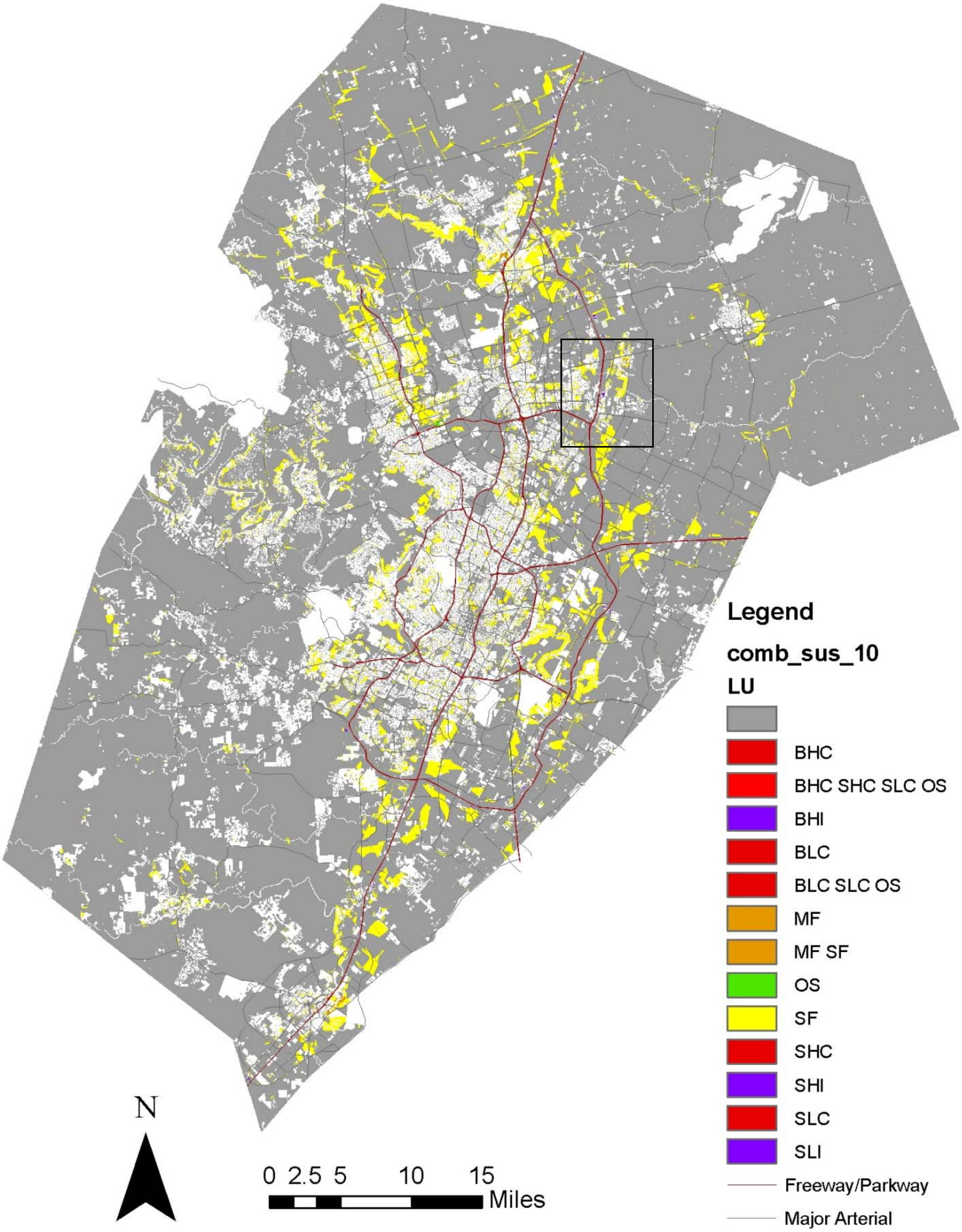
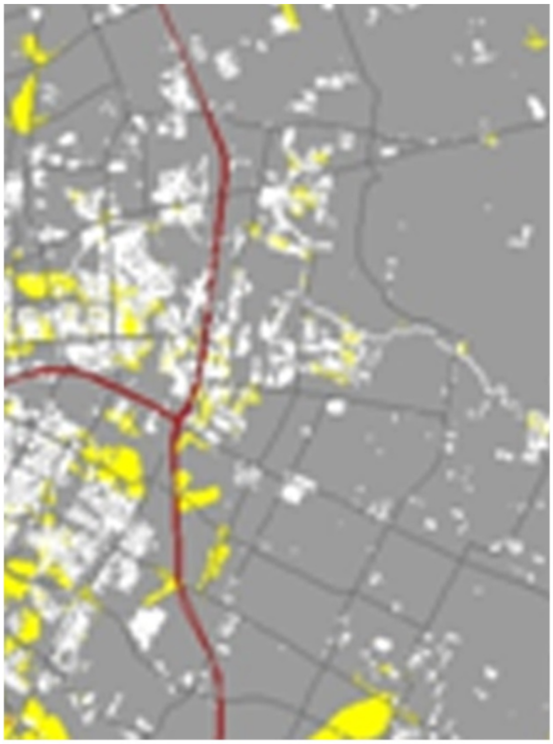
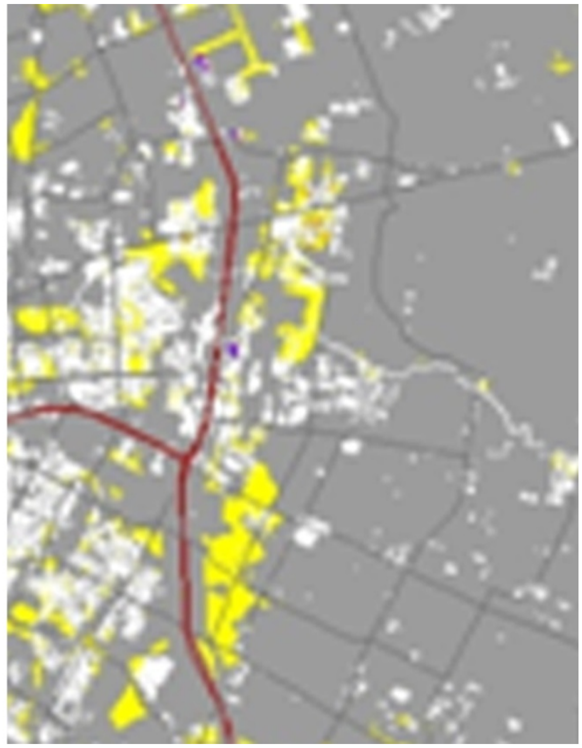



*Figure D.3: With SH 130 and Ronald Reagan Extension (2005–2010)*



*(a) without SH 130 and Ronald Reagan extension*



*(b) with SH 130 and Ronald Reagan extension*

*Figure D.4: Comparison of Two Scenarios (with and without SH 130 and Ronald Reagan Extension)*

# APPENDIX E: EQUATIONS AND NOTATIONS

Equations Used:

Accessibility Index (AI): $I = \sum_i \frac{Count}{(Distance\ to\ CBD)}$ ,

Density Values: $Count\text{-}\ weighted\ HH\ density = \sum \frac{HH_i \times HHDens_i}{TotalHouseholds}$

$Count\text{-}\ weighted\ job\ density = \sum \frac{Job_i \times JobDens_i}{TotalJobs}$

Notations:

| ***Scenario*** | |
|---|---|
| Lag | The lag year. |
| Base | Base or starting year. |
| Trend | Business as usual (BAU) or TREND scenario. |
| Emp150 | Scenario with employment control totals boosted by 50% throughout the forecasting period. |
| HH150 | Scenario with household control totals boosted by 50% throughout the forecasting period. |
| TT150 | Scenario with travel times boosted by 50% throughout the forecasting period. |

# APPENDIX F: AUSTIN RESULTS

## Austin: Numerical Results

**Table F.1: Numerical Results in Base and Forecast Years for Austin**

| | Total Jobs | Job Density* (count-weighted) | Total HHs | HH Density* (count-weighted) | Job AI (from CBD) | HH AI(from CBD) |
|---|---|---|---|---|---|---|
| Lag (2000) | 602,399 | 28.81 | 444,953 | 4.59 | 202,351 | 142,161 |
| Base (2005) | 699,447 | 26.49 | 546,692 | 4.84 | 223,620 | 172,332 |
| Trend[1] | 1,388,330 | 21.05 | 1,095,198 | 13.84 | 360,224 | 299,783 |
| Emp150[1] | 2,082,496 | 35.93 | 1,095,197 | 14 | 562,757 | 296,166 |
| HH150[1] | 1,388,330 | 16.32 | 1,642,796 | 20.06 | 345,195 | 446,100 |
| TT150[1] | 1,388,330 | 21.53 | 1,095,196 | 14.64 | 390,079 | 303,866 |

*All densities are shown in counts per acre. [1]Results are for final forecast year (2030).

**Table F.2: Peak Densities (count-weighted) in Base and Forecast Years for Austin**

| | Base | Trend | EMP150 | HH150 | TT150 |
|---|---|---|---|---|---|
| Peak Job Density (jobs/acre) | 246 | 397 | 614 | 331 | 395 |
| Peak HH Density (HHs/acre) | 47 | 172 | 173 | 249 | 180 |

**Austin: Job and Household Density Comparison**

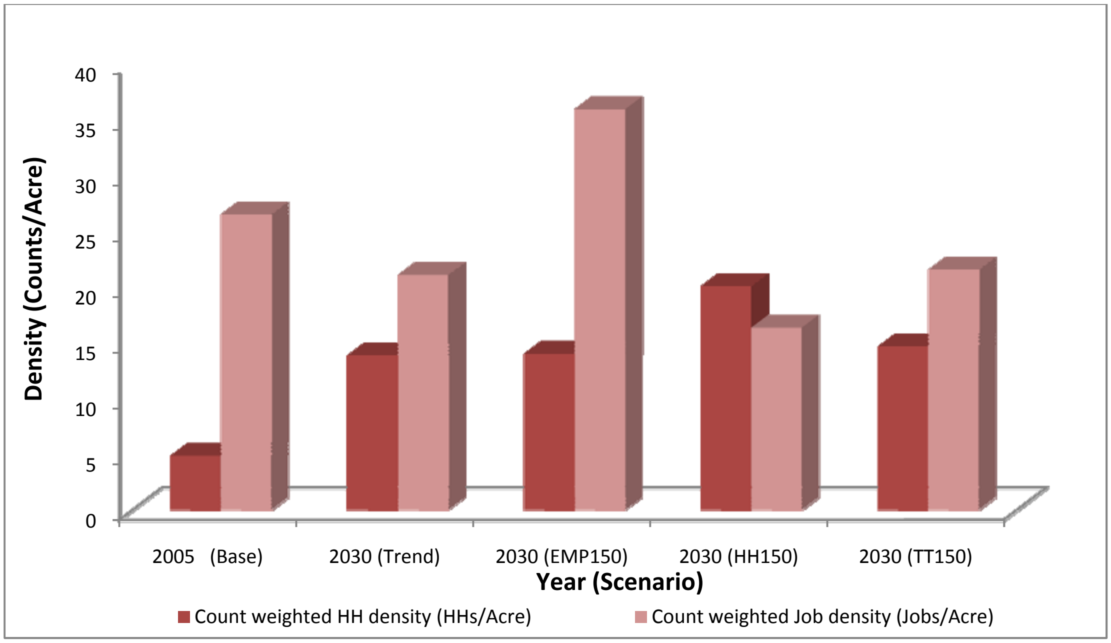



*Figure F.1: Count-Weighted HH & Job Density (Counts/Acre)*

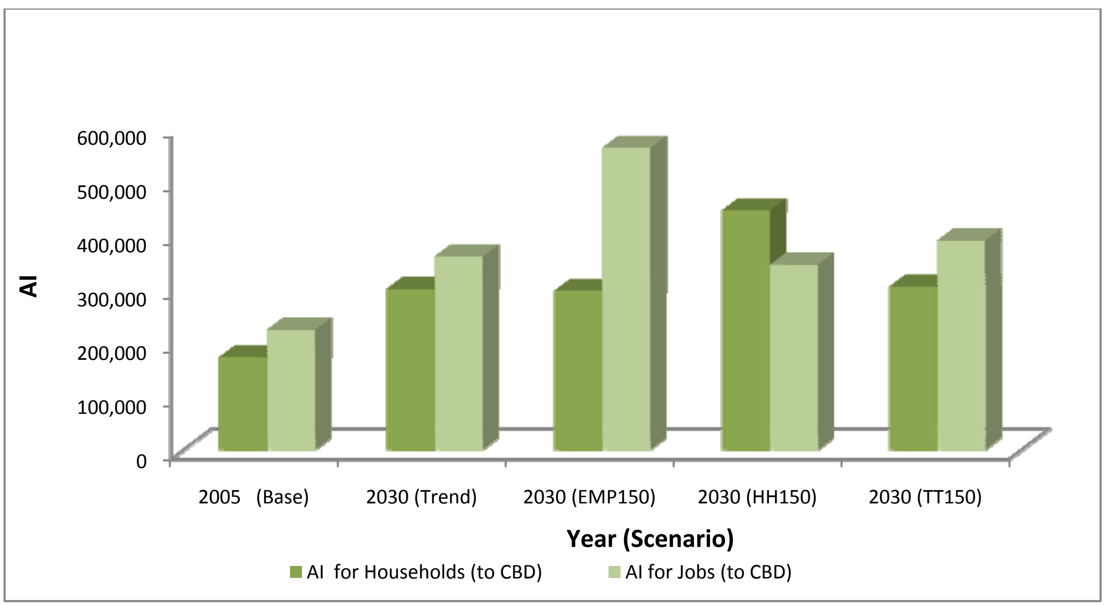



*Figure F.2: CBD AI to Households & Jobs*

**Austin Scenario Results**

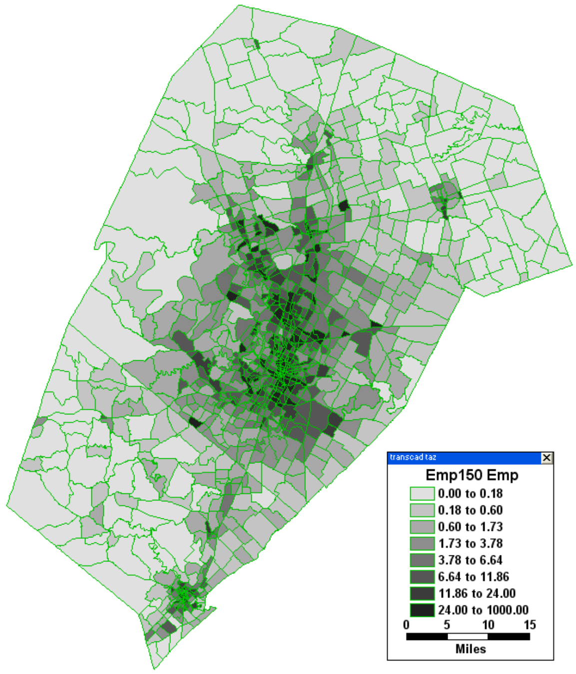



*Figure F.3: Job Density (EMP150) in 2030 for Austin*

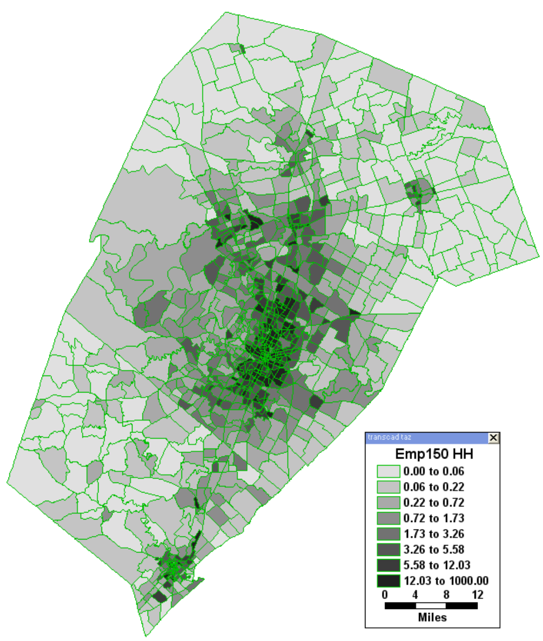



*Figure F.4: Household Density (EMP150) in 2030 for Austin*

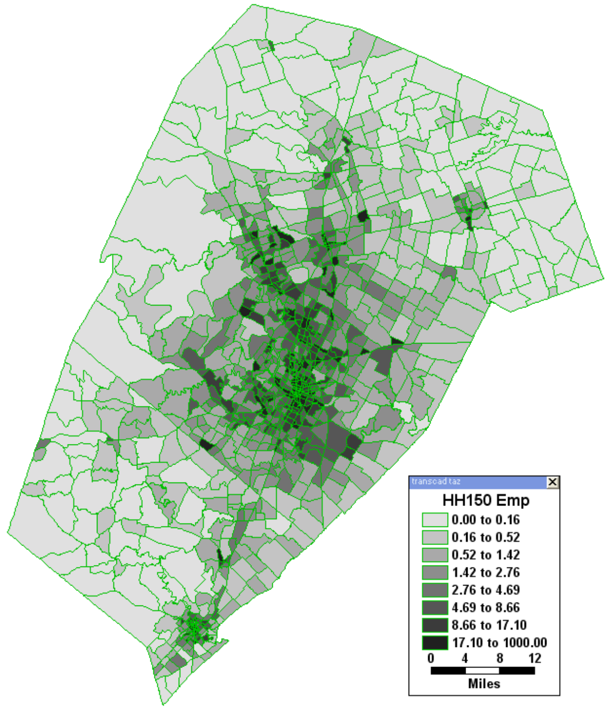



*Figure F.5: Job Density (HH150) in 2030 for Austin*

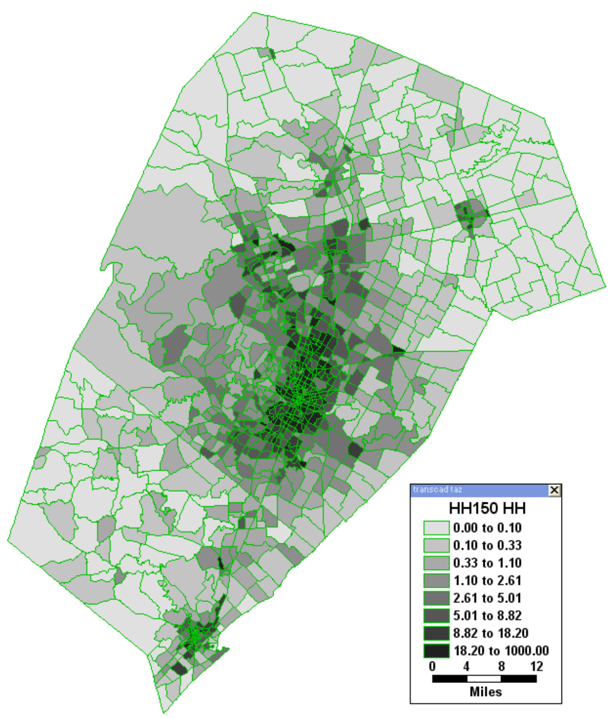



*Figure F.6: Household Density (HH150) in 2030 for Austin*

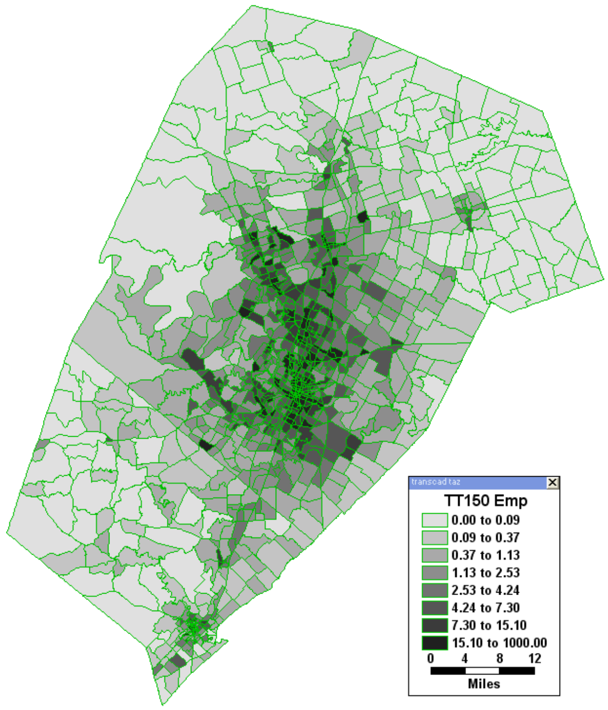



*Figure F.7: Job Density (TT150) in 2030 for Austin*

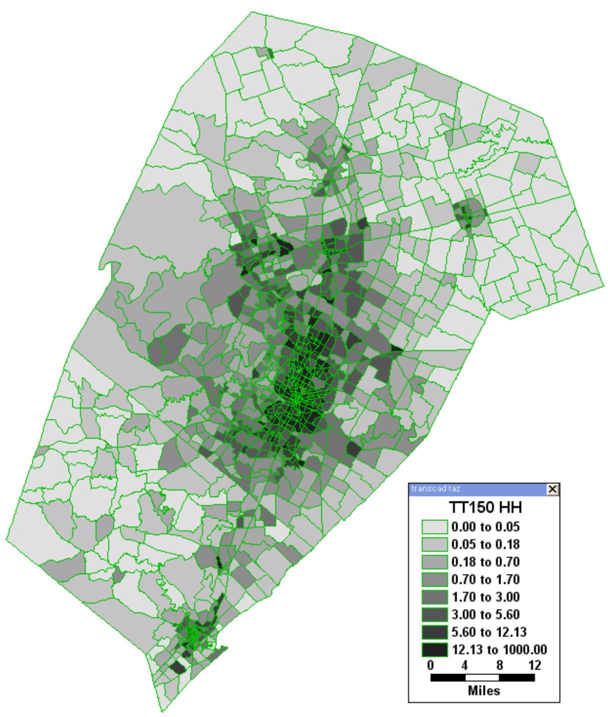



*Figure F.8: Household Density (TT150) in 2030 for Austin*

# APPENDIX G: SAN ANTONIO RESULTS

Data for the San Antonio region was provided partially by the San Antonio MPO and the remainder was collected by the research team at The University of Texas at Austin. The five-county San Antonio region contains 1,069 TAZs, and the base and lag years were chosen to be 2008 and 2005, based on data availability. Data on land use for jobs was missing and estimates of these values were made for all zones based on exponential relationships between net job density and distance to CBD, estimated using Austin and Waco data.

Figure G.1 and G.2 show San Antonio job densities in the base and forecast years (2008 and 2023, respectively). San Antonio is also among the U.S. metro areas that have experienced rapid decentralization between 1998 and 2006, according to Kneebone's (2009) report. But the lag and base year data do not provide much evidence of decentralization in the short 2005 to 2008 window. The count-weighted job density was estimated to decrease from 13.86 in 2008 to 10.05 jobs/acre in 2023; this indicates a decentralizing trend in jobs. A peak job density of 159 jobs/acre was predicted in 2023 in TAZ# 535 in downtown San Antonio, decreasing from 196 jobs/acre in 2008.

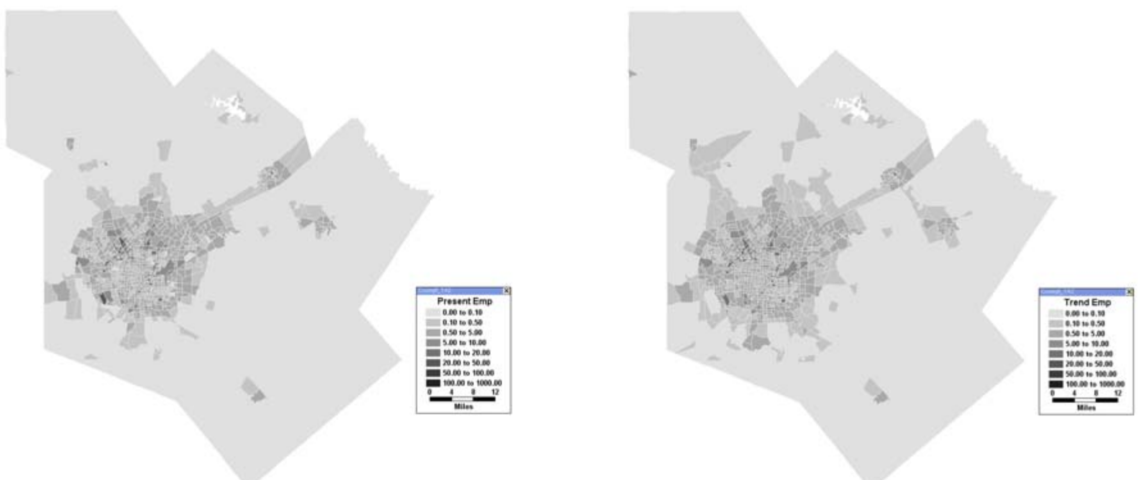



*Figure G.1: 2D Job Density (Jobs per Acre) in Base and Forecasted Years (2008 & 2023)*

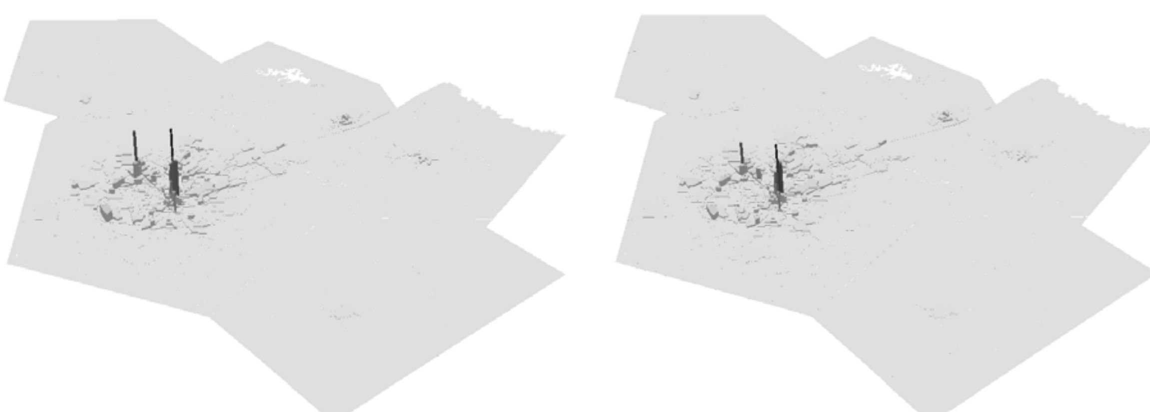


*Figure G.2: 3D Job Density (Jobs per Acre) in Base and Forecasted Years (2008 & 2023)*

Figure G.3 and G.4 show household density in base and forecast years. The control totals for total number of households were increased from 679,930 in 2008 to 863,584 in 2023 and the count-weighted HH density was predicted to increase from 2.56 to 2.96 HHs per acre (see appendix C). A peak density of 15.6 HHs per acre was estimated in the downtown region (TAZ# 218) in the forecast year.

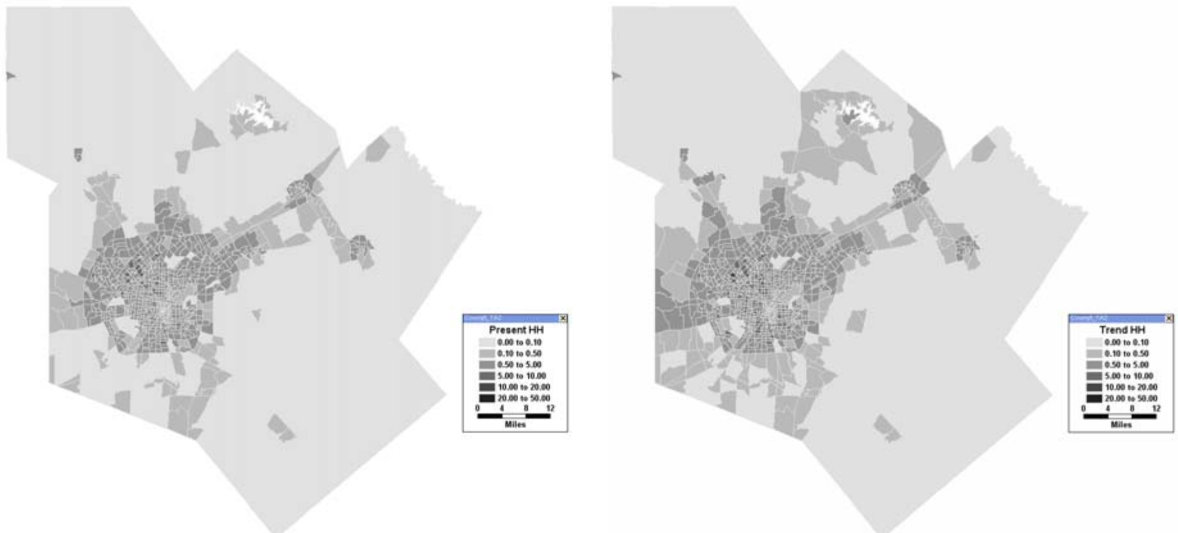



*Figure G.3: 2D Household Density (HHs per Acre) in Base and Forecasted Years (2008 & 2023)*

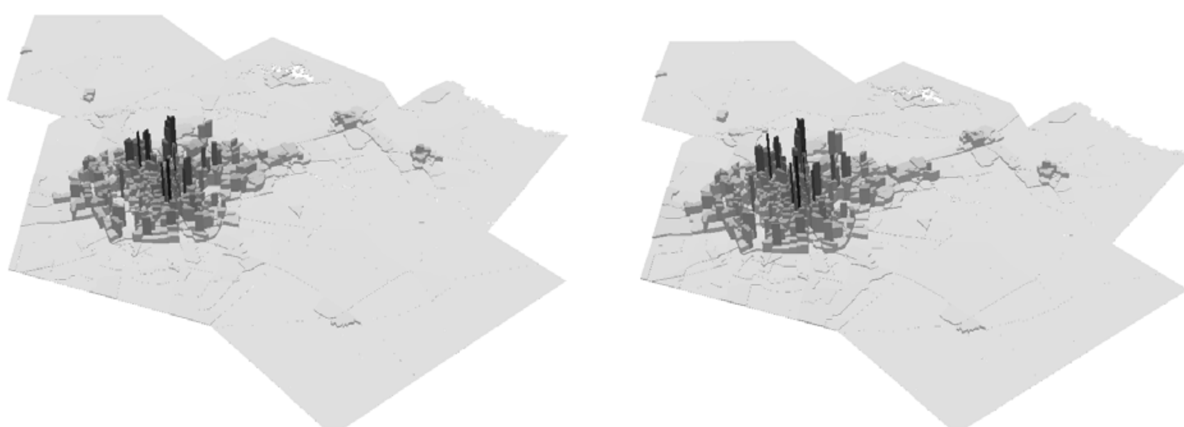


*Figure G.4: 3D Household Density (HHs per Acre) in Base and Forecasted Years (2008 & 2023)*

The years 2005 and 2008 were selected as the lag and base year for San Antonio implementation, resulting in a time period of 3 years. Sometimes, a gap of 3 years might not provide the real picture in terms of movement of households and jobs and is very sensitive to various short-term changes. Changes in property taxes and other land-use legislations influence the dynamics of household or job movement. Since 2000, the city of San Antonio has annexed various corridors along the outlying areas and plans to annex even more. G-LUM users must be very careful with such developments and appropriately make changes to the input data. Users can apply necessary caps or other adjustments to each time period's forecasts to filter out the effects of unsuitable allocations or short-term changes.

**Table G.1: Numerical Results in Base and Forecast Years for San Antonio**

| | Total Jobs | Job Density* (count-weighted) | Total HHs | HH Density* (count-weighted) | Job AI (from CBD) | HH AI (from CBD) |
|---|---|---|---|---|---|---|
| Lag (2008) | 759,560 | 13.84 | 627,825 | 2.49 | 225,053 | 199,095 |
| Base (2008) | 818,360 | 13.86 | 679,930 | 2.56 | 244,034 | 213,320 |
| Trend[1] | 874,087 | 10.05 | 863,584 | 2.96 | 265,185 | 267,656 |
| Emp150[1] | 1,311,130 | 16.67 | 863,586 | 2.94 | 395,718 | 268,091 |
| HH150[1] | 874,086 | 9 | 1,295,378 | 4.48 | 264,340 | 405,615 |
| TT150[1] | 874,086 | 10 | 863,586 | 2.96 | 269,326 | 268,365 |

*All densities are shown in counts per acre. [1]Results are for final forecast year (2023).

**Table G.2: Peak Densities (count-weighted) in Base and Forecast Years for San Antonio**

| | Base | Trend | EMP150 | HH150 | TT150 |
|---|---|---|---|---|---|
| Peak Job Density (jobs/acre) | 196 | 159 | 258 | 147 | 157 |
| Peak HH Density (HHs/acre) | 12.4 | 15.6 | 15.4 | 23.3 | 15.5 |

**San Antonio: Job and Household Density Comparison**

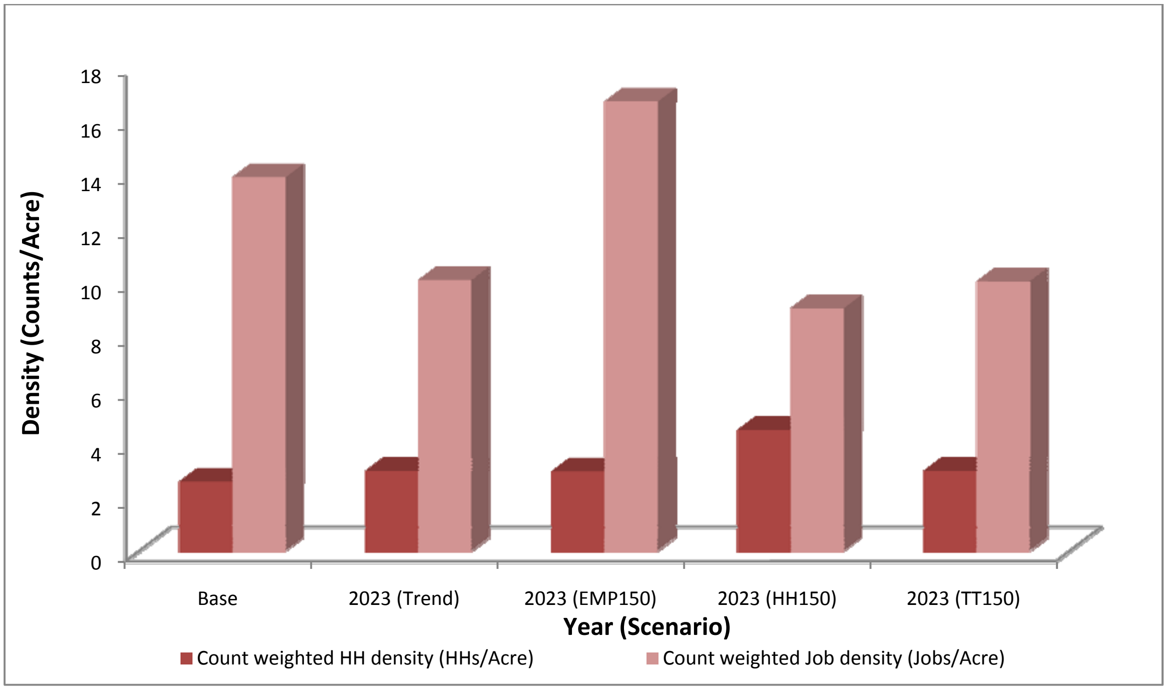



*Figure G.5: Count-Weighted HH & Job Density (Counts/Acre)*

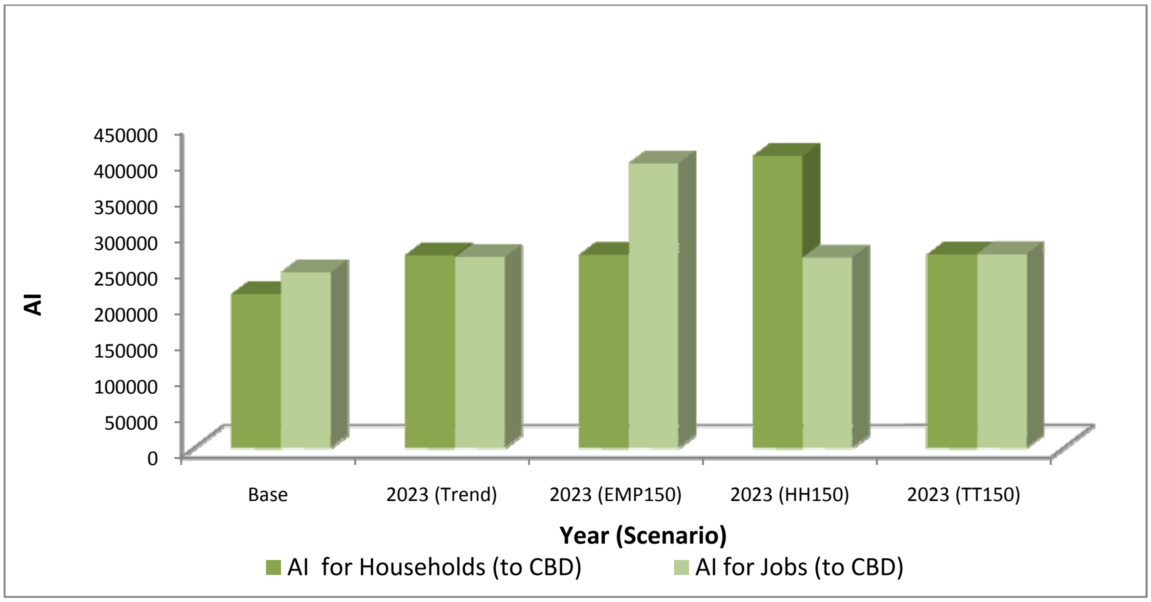



*Figure G.6: CBD AI to Households & Jobs*

## San Antonio Scenario Results

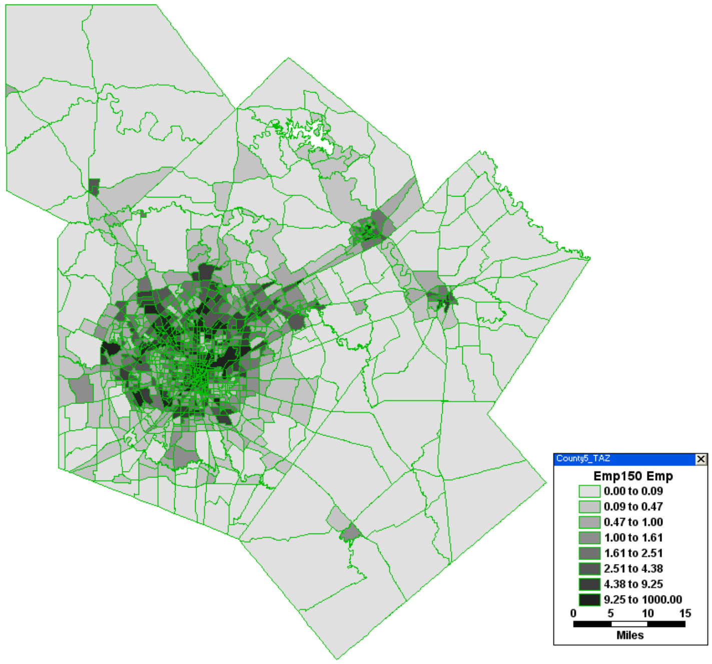



*Figure G.7: Job Density (Emp150) in 2023 for San Antonio*

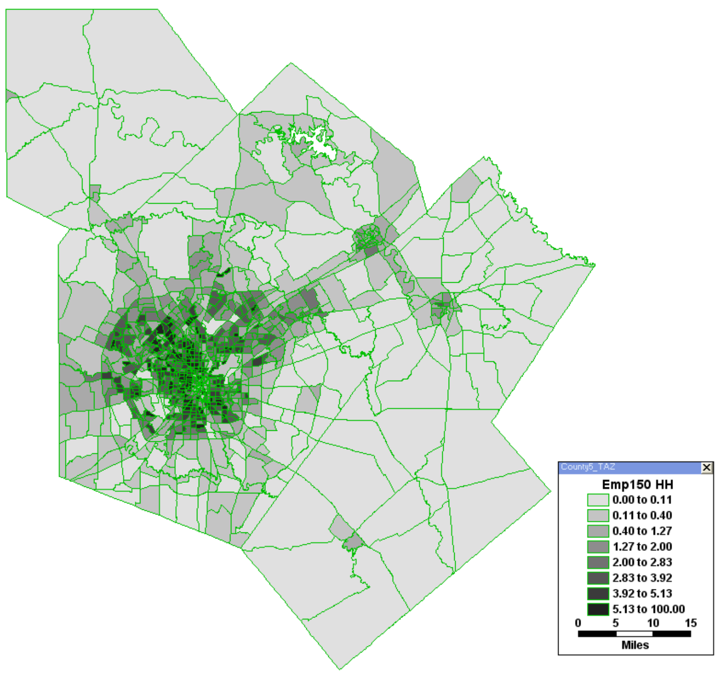



*Figure G.8: Household Density (Emp150) in 2023 for San Antonio*

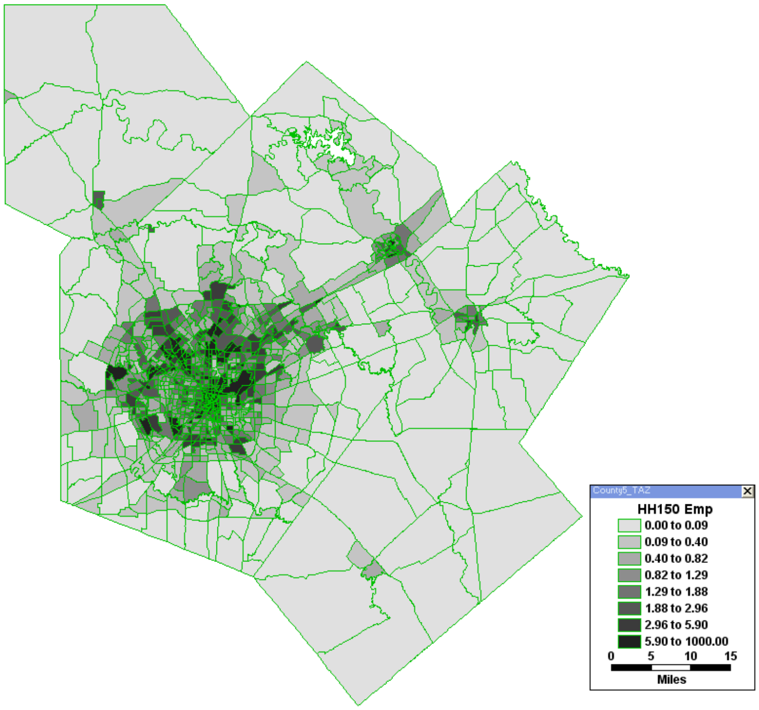



*Figure G.9: Job Density (HH150) in 2023 for San Antonio*

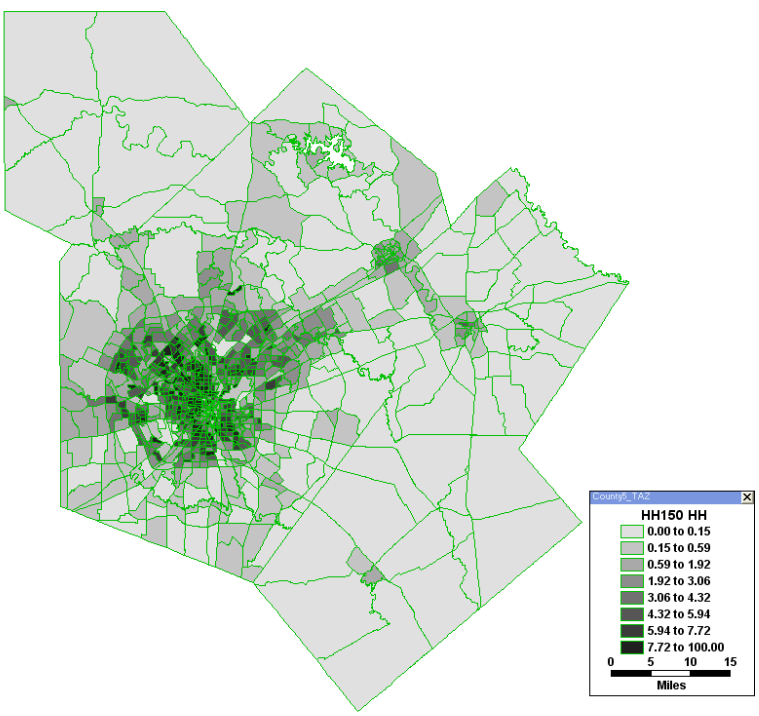



*Figure G.10: Household Density (HH150) in 2023 for San Antonio*

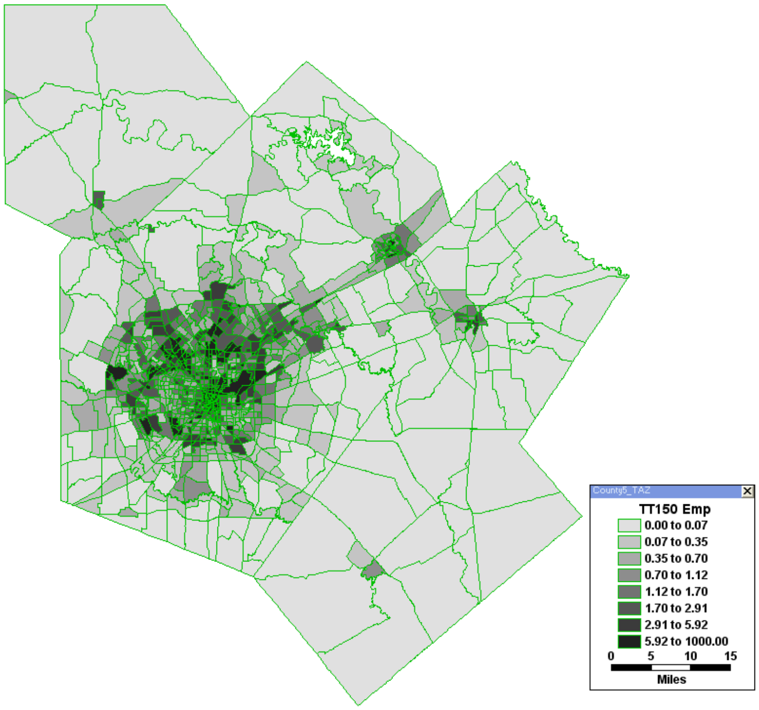



*Figure G.11: Job Density (TT150) in 2023 for San Antonio*

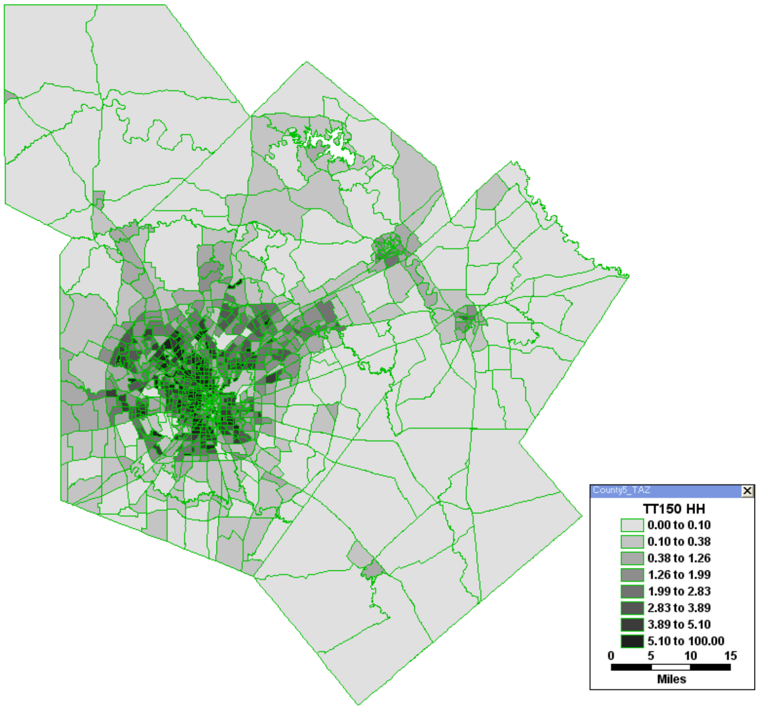



*Figure G.12: HH Density (TT150) in 2023 for San Antonio*

# APPENDIX H: WACO RESULTS

G-LUM was also implemented for the Waco region's 283 TAZs, with lag and base years of 2000 and 2005, respectively. Figure H.1 and H.2 shows the job densities in the base and forecast year (2030).

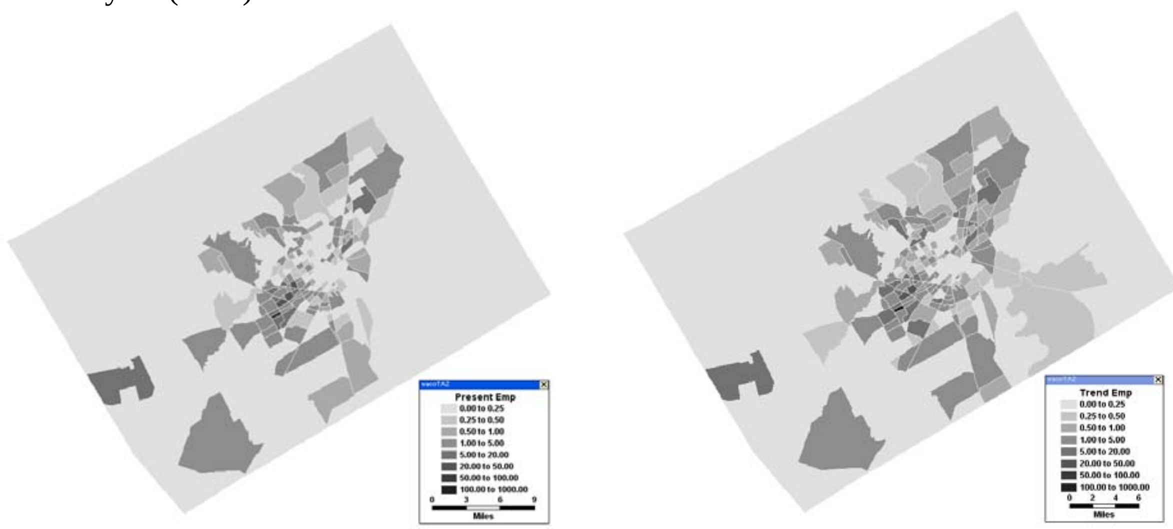



*Figure H.1: 2D Employment Density (Jobs per Acre) in Base and Forecasted Years (2005 & 2030)*

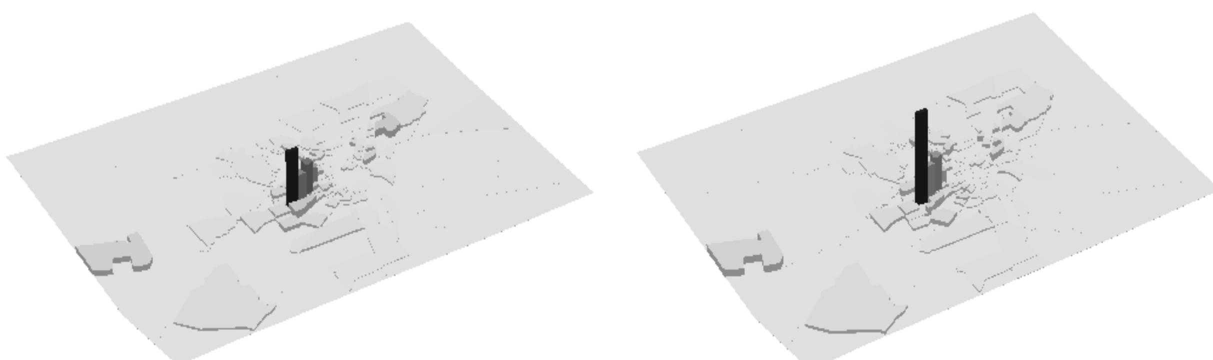


*Figure H.2: 3D Employment Density (Jobs per Acre) in Base and Forecasted Years (2005 & 2030)*

Waco's job counts were assumed to increase from 90,965 in 2005 to 113,315 in 2030 (provided by the Waco MPO), while count-weighted job density was predicted to rise from 5.67 to 7.54 jobs per acre. This indicates an increasing clustering among jobs, which can also be seen in the maps. A peak density of 109 jobs per acre was forecasted in Waco's downtown area (TAZ# 218). Job accessibility from the CBD increased from 18,612 in 2005 to 23,607 in 2030.

Figure H.3 and H.4 illustrate the household density in base and forecast years. The total number of households was assumed to increase from 82,153 in 2005 to 102,995 in 2030, an increase of 25% (provided by the Waco MPO). The count-weighted household density was predicted to increase from 2.28 to 2.64 HHs per acre over that 25-year period, indicating centralization of jobs. Peak count-weighted household density was found to be 26.5 households per acre in TAZ# 190, near Baylor University. The accessibility of households from the CBD increased from 16,655 in 2005 to 20,478 in 2030.


*Figure H.3: 2D Household Density (HHs per Acre) in Base and Forecasted Years (2005 & 2030)*

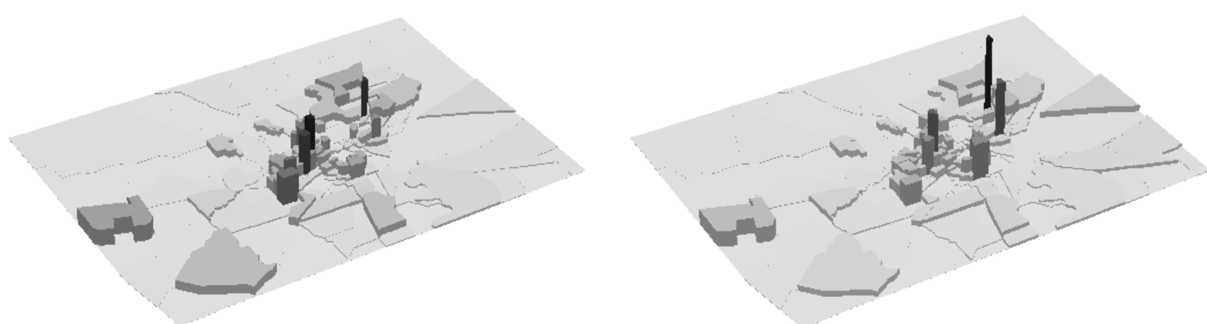


*Figure H.4: 3D Household Density (HHs per Acre) in Base and Forecasted Years (2005 & 2030)*

**Table H.1: Numerical Results in Base and Forecast Years for Waco**

| | Total Jobs | Job Density* (count-weighted) | Total HHs | HH Density* (count-weighted) | Job AI (to CBD) | HH AI (to CBD) |
|---|---|---|---|---|---|---|
| Lag | 92,045 | 3.75 | 84,980 | 2.3 | 17,944 | 17,058 |
| Base | 90,965 | 5.67 | 82,153 | 2.28 | 18,612 | 16,655 |
| Trend | 113,315 | 7.54 | 102,995 | 2.64 | 23,607 | 20,478 |
| Emp150 | 169,973 | 11.62 | 102,995 | 2.61 | 35,557 | 20,423 |
| HH150 | 113,316 | 6.32 | 154,494 | 3.75 | 23,489 | 30,512 |
| TT150 | 113,316 | 7.59 | 102,995 | 2.67 | 23,758 | 20,760 |

*All densities are shown in counts per acre.

**Table H.2: Peak Densities (count-weighted) in Base and Forecast Years for Waco**

| | Base | Trend | EMP150 | HH150 | TT150 |
|---|---|---|---|---|---|
| Peak Job Density (jobs/acre) | 65 | 109 | 160 | 98 | 110 |
| Peak HH Density (HHs/acre) | 15.8 | 26.5 | 26.6 | 35.8 | 25.4 |

## Waco: Job and Household Density Comparison

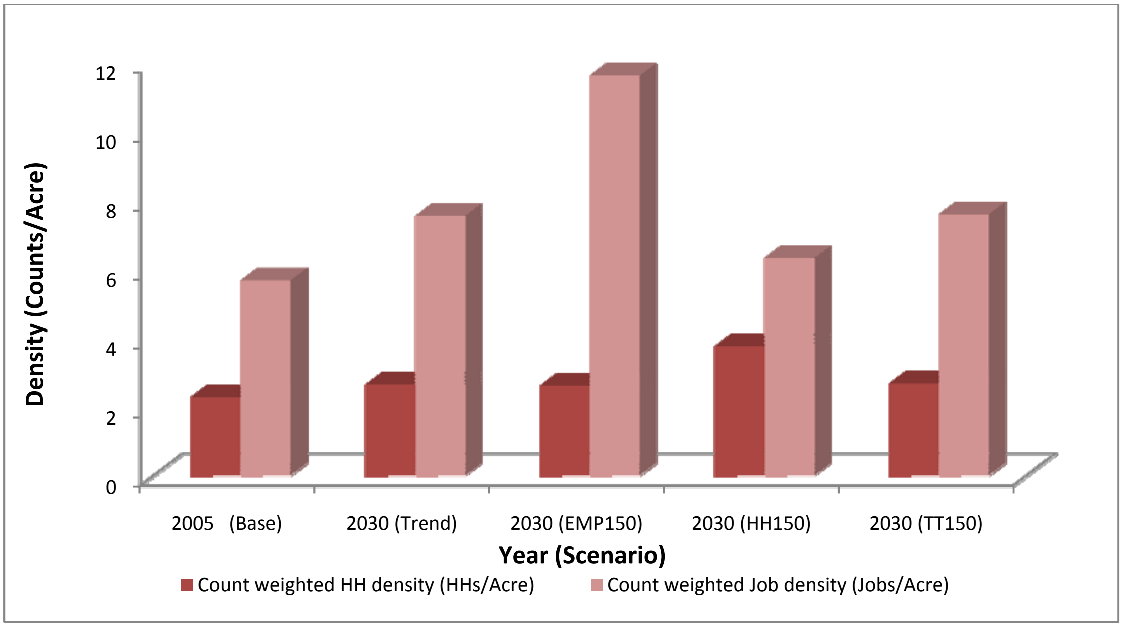



*Figure H.5: Count-Weighted HH & Job Density (Counts/Acre)*

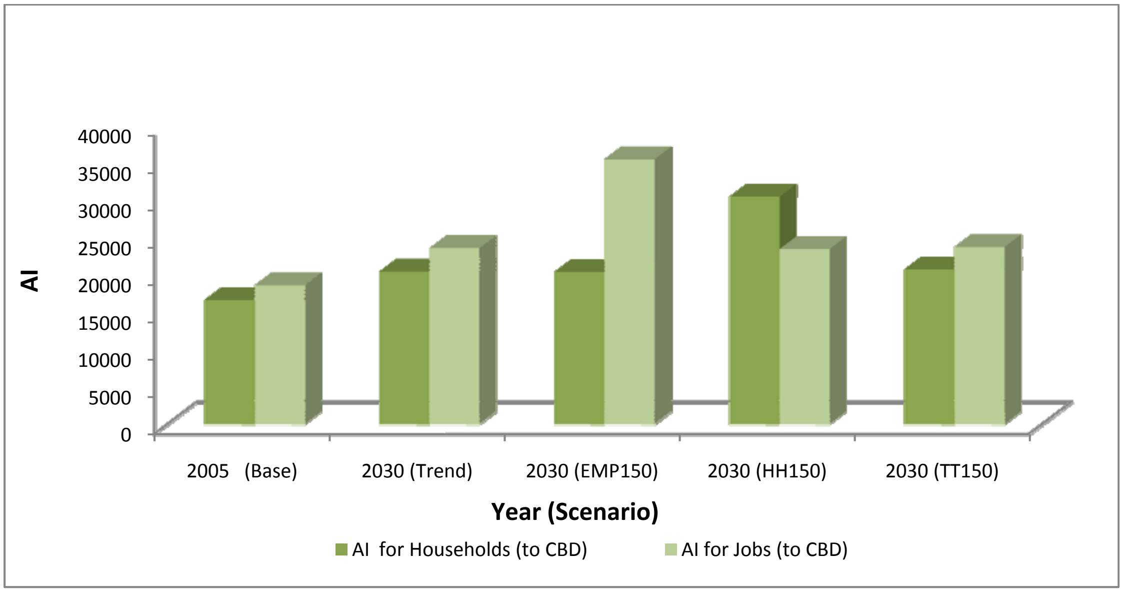



*Figure H.6: CBD AI to Households & Jobs*

**Waco Scenario Results**

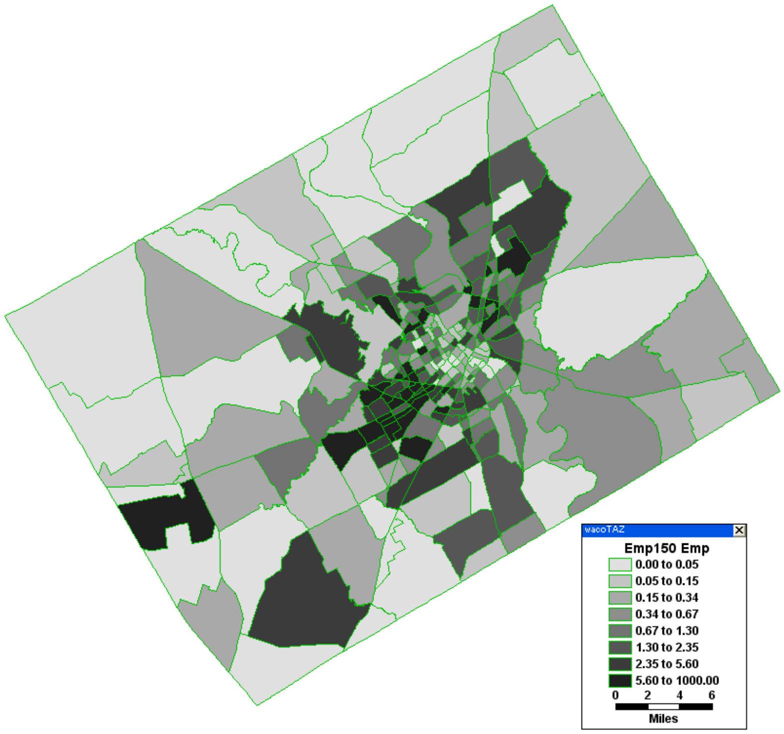



*Figure H.7: Job Density (Emp150) in 2030 for Waco*

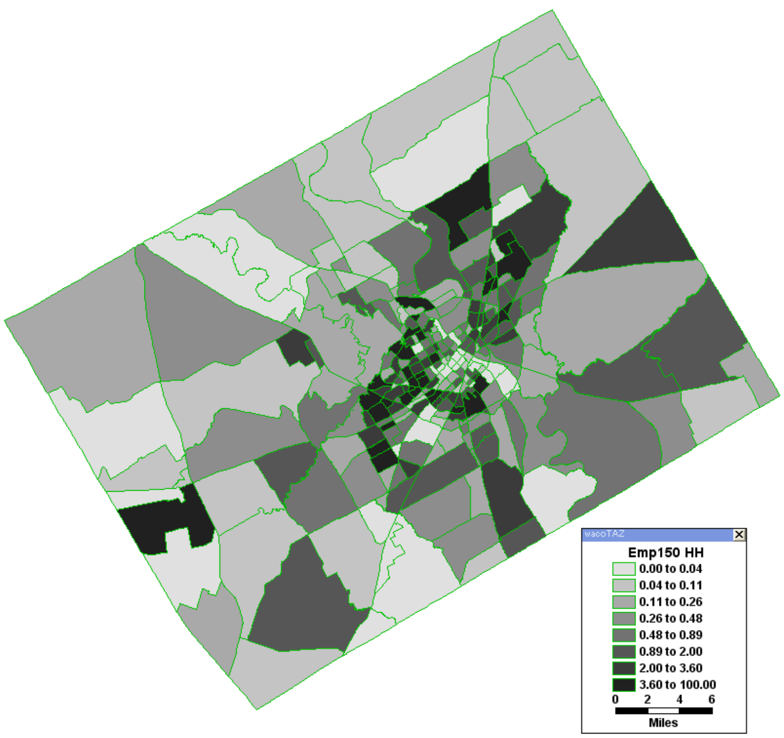



*Figure H.8: Household Density (Emp150) in 2030 for Waco*


*Figure H.9: Job Density (HH150) in 2030 for Waco*

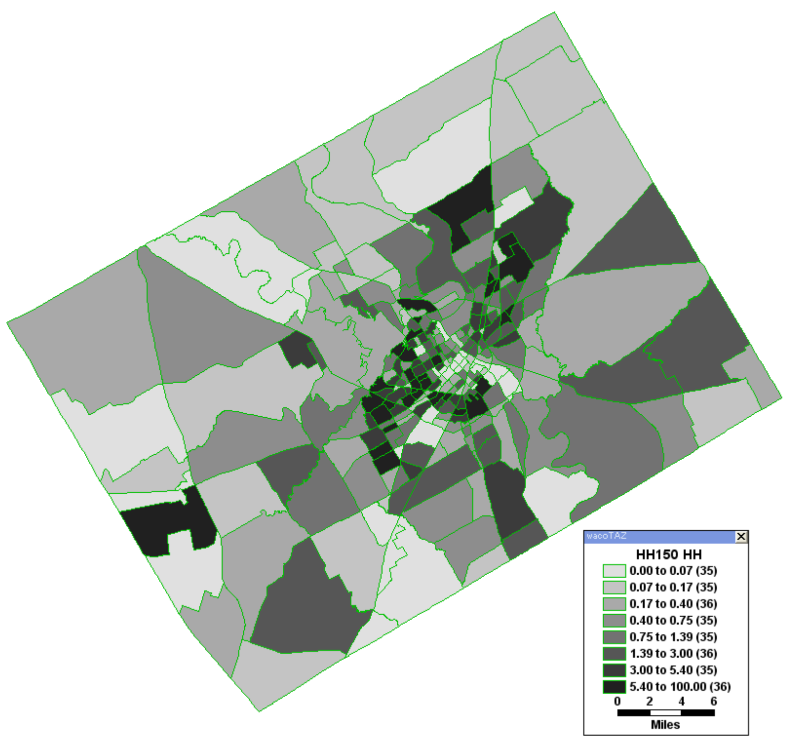



*Figure H.10: Household Density (HH150) in 2030 for Waco*

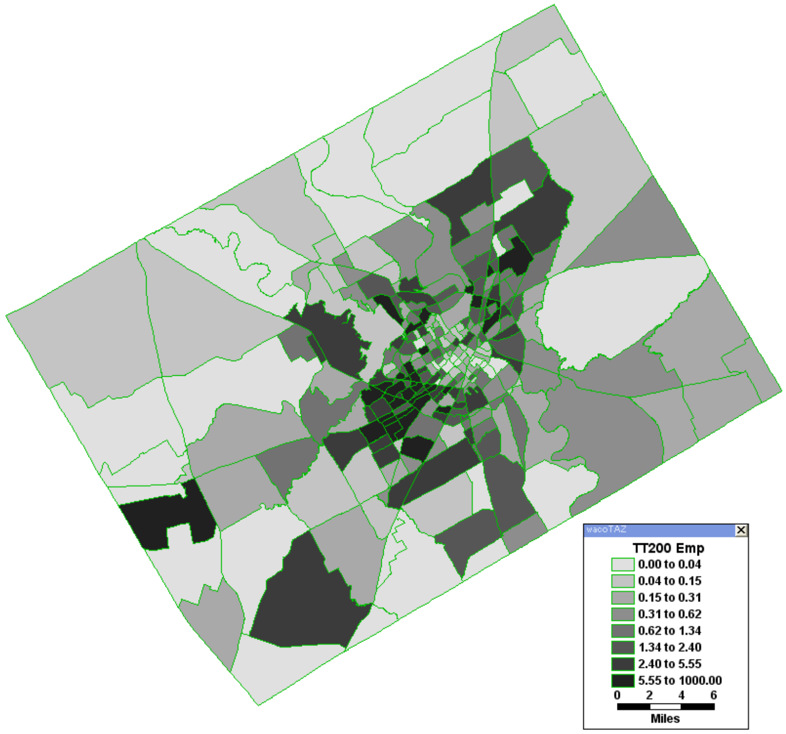



*Figure H.11: Job Density (TT150) in 2030 for Waco*

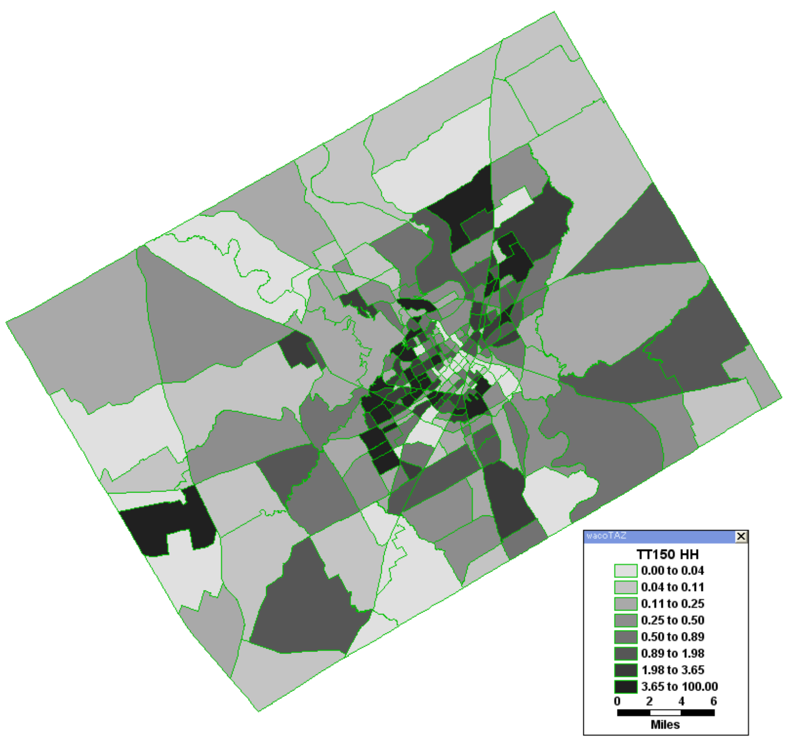



*Figure H.12: Household Density (TT150) in 2030 for Waco*

# APPENDIX I: EL PASO RESULTS

The data required to run G-LUM for El Paso was not fully available for the desired base and lag years. As a result, data manipulation and other adjustments had to be made using some of the acquired data. This situation is not uncommon for many small to medium MPOs and the solution is not too complicated for those familiar with GIS and other tools. First, a base and lag year (2007 and 2002) were chosen, in which most of the data was found. Then, the rest of the data was adjusted/extrapolated to match the chosen base and lag years.

The El Paso region consists of 640 Texas zones and 41 New Mexico zones. Because of inconsistencies in the New Mexico data, only Texas zones were considered for this G-LUM application. Basic, retail, and service job counts were provided for the base and lag years, so no adjustments were made to these. Land-use data came from El Paso MPO's 2009 GIS parcel shape file, which was joined to the El Paso TAZ shape file, using ArcGIS (in order to get the most acreages of land use at the TAZ level). Unusable land-use acreage and land dedicated to streets and highways was estimated by zone using Austin's average zone shares.

Table I.1 provides count-weighted densities for El Paso. Employment density estimates (count-weighted, and thus appropriately biased toward more populated zones) are unusually high, as compared to Waco, Austin, and San Antonio. But this is true in the base year as well, mainly due to the very high concentration of MPO-provided job counts in El Paso's CBD.

**Table I.1: Numerical Results for the El Paso Region in Base and Forecast Years**

| | Count-weighted HHDENS (hhs/sq. mi.) | Count-weighted EMPDENS (jobs/sq. mi.) |
|---|---|---|
| **2007** | 1,794 | 23,391 |
| **2032** | 4,784 | 24,694 |

El Paso's count-weighted household density is predicted to increase more than 160% over 25 years, whereas employment's density rises much more gently, by just 6%. This lower increase comes from a predicted decentralization of jobs in future years. El Paso currently has a dense central region, with small zones, where most jobs and households are located. The outer, rural zones are large and undeveloped and include large lots of land allotted to a state air base. Figure I.1 shows base-year household and employment densities, while Figures I.2 and I.3 show future predictions. Overall, model predictions show jobs distributed all over the region, with households mostly staying central. In reality, a wider distribution of households (relative to jobs) may be expected. G-LUM is, of course, a simplification of reality and calibrated based on two time points whose data may be imperfect in multiple ways.

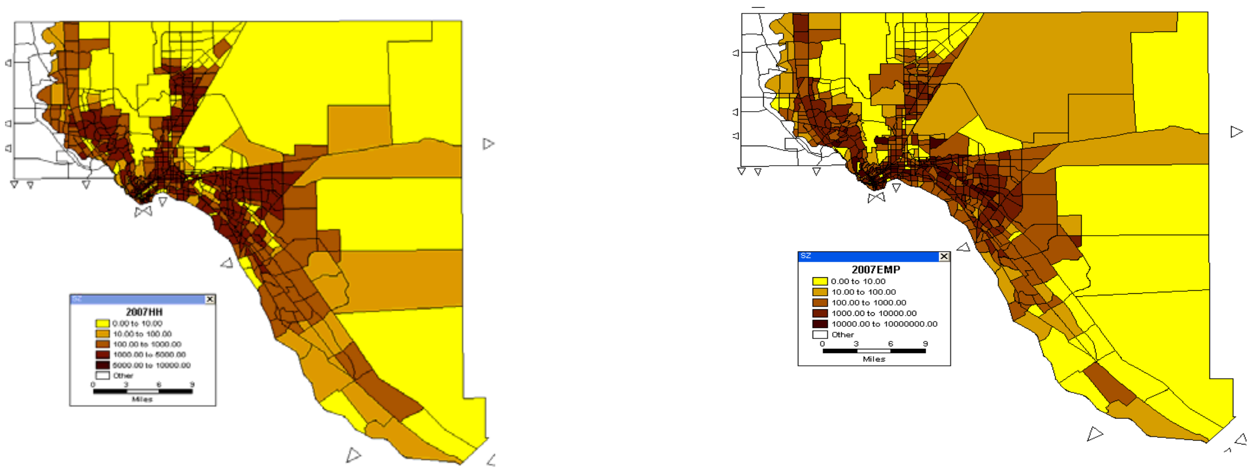



*Figure I.1: HH & Employment Density (Counts per Acre) in Base (2007)*


*Figure I.2: Projected Household Density (HHs per Acre) in 2032*

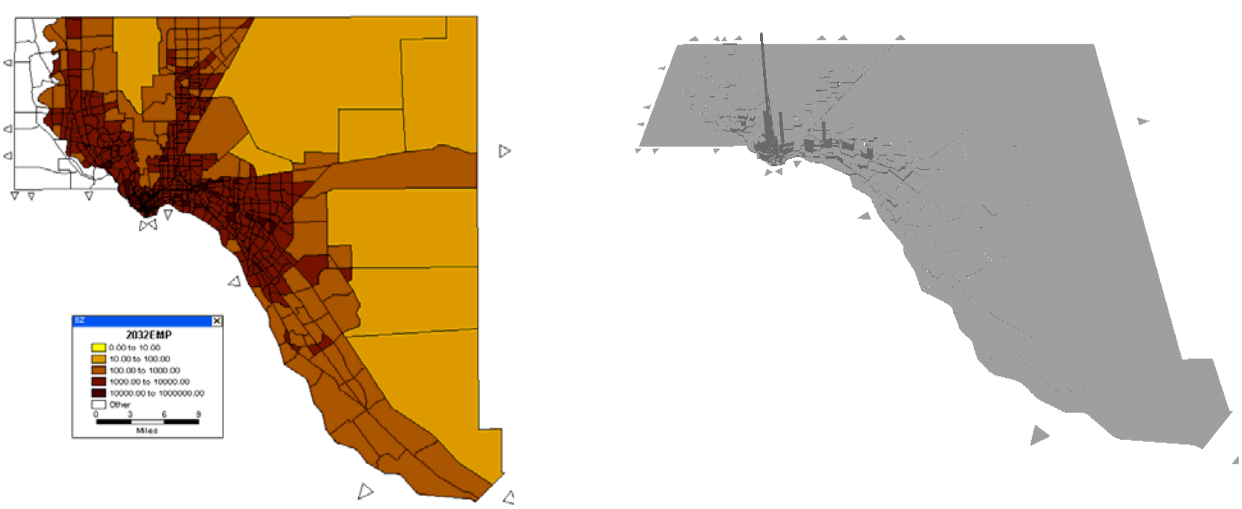



*Figure I.3: Employment Density (Counts per Acre) in 2032*

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