PROFESSIONAL PAPER

A Look Newly Developed Urban Spaces

Trends among the conversion of natural and urban landscapes to newly developed urban spaces that may contribute to urban sprawl

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Final Paper

Purpose

This paper examines the conversion of land cover to newly developed urban spaces from 1996 to 2005 within the Houston – Conroe corridor and its surrounding areas. The consumption of natural spaces to urban spaces can be attributed to urban sprawl, which, by definition, can be characterized as a condition wherein improper growth and management practice result in the unnecessary consumption of the natural landscapes*. Based on this interpretation of urban sprawl, previously designated urban and natural landscape classifications (as identified in 1996) are evaluated to determine if improper conversions of pre-existing landscapes occurred to develop new urban spaces (as identified in 2005). Using remotely sensed data acquired from the National Oceanic and Atmospheric Administration's (NOAA) C-CAPP, I examined changes of land cover to newly developed urban spaces. Findings suggest two separate but related phenomena. The first indicates general urban sprawl where residents of a certain community commute long distances for work, live in low density single family settlements, and are typically of middle income and white socio-economic status. The second is more conducive to small cities associated with the metropolitan area which experienced their own kind of sprawl, I term, "rural sprawl." This type of sprawl demonstrates many of the same characteristics as provided by general sprawl with two major exceptions: (1) higher density developments are more common in these areas and (2) residence do not commute daily to another community for work, and instead work where they live. As such, these communities do not sprawl towards a larger metropolitan area (i.e. Houston), but rather radiate around smaller, satellite communities. Both forms of sprawl are most common in areas that were previously forested landscapes. Policy recommendations are offered for how to combat these two types of inefficient sprawl.*

Introduction and Background

Texas has enjoyed an unprecedented era of population growth over the past century. In fact, Texas is one of the fastest growing regions in the United States (Sherman, 2008). Its rapid expansion, before this decade, was most notable in the 1990s, when the state increased its population by 4 million people. In addition to the growth that Texas has enjoyed in general, Texas has seen its major metropolitan areas – Houston, Dallas, San Antonio and Austin – expand dramatically (Perry, 2001). The metro populations of these cities have grown substantially, and, as of 2005, 63.8% of all Texas residents lived in one of its four major metropolitan areas (Gains, 2008). Together, as connected by their respective highways, comprise the "Central Texas Triangle." This area incLIDes the Dallas-Fort Worth Metroplex at its northernmost tip, traces southwest along Interstate 45 to Houston, courses due west along Interstate 10 to San Antonio, and then runs along Interstate 35 through Austin, Waco and back to the DFW Metroplex. These four cities currently rank as the 4th (Houston), 7th (San Antonio), 8th (Dallas), and 15th (Austin) most populous cities in the United States (Gaines, 2008).

Figure 1: Central Texas Triangle

Source: Gains, James P. (2008). "Looking Boom, Texas Though 2030." Texas Economy. Reprint: Tierra Grande. Publication 1841.

However, the growth in Texas cities has not been limited to population statistics alone. The borders of the metropolitan areas are growing as well. Whether this expansion has been official (in Houston's case via annexation) or assumed (in the Dallas's case, where bordering cities are simply assumed to be part of the larger Metroplex), the sheer expansion of these cities underscores an alarming trend in modern urban planning and development. Populations are expanding, but they do not seem to be congregating near these cities' respective business hubs; the populations are moving to the suburbs. This phenomenon, where urban and natural territories are being converted into low density urban developments, is typically referred to as urban sprawl.

The urban sprawl phenomenon can be characterized a condition wherein improper growth and management practice result in the unnecessary consumption of the natural landscape (Juergensmeyer, 2001). Based on this definition, it is assumed that urban sprawl can occur in both urban and non urbanized areas where natural landscapes (as in non urban landscapes), or existing high density urban forms, are converted into inefficient low density developments. It is the opinion of this author that both trends are responsible for the sprawl-like development patterns we see today; low density developments in the natural landscape promote the inefficient consumption of the environment while the conversion of dense urban landscapes to a less dense urban form displaces population, and encourages the movement of individuals to the urban fringe where sprawl is typically most prevalent.

As such, this paper will closely analyze land class conversion patterns occurring both within the natural landscape and urban landscape. Natural to Urban or N – U conversions refer to the conversion of natural landscapes to a newly developed urban space be it high density developments (HID), medium density developments (MID), low density developments (LID) development or open space density developments (OSI) to be defined later. Conversely, Urban to Urban or U – U conversions refer to newly developed urban spaces that were created from a differing urban density as listed above. Of course, there are many sub-classes of natural areas (e.g., forest, agriculture, wetlands and scrub/shrub lands) as defined later, and will be incLIDed in this observational study. Further, this study takes a look at the socio and economic patterns that might be attributing to sprawl-like development patterns in terms of population and housing distributions.

Literature Review

Urban sprawl has been widely researched over the last several decades. Although a formal definition for what constitutes urban sprawl does not exist, there is a common "I-know-it-when-I-see-it quality" to sprawl (Dowling, 2000). The most common definition of urban sprawl is one that defines areas comprised of low density developments that span the country side, encroaching on traditionally rural communities, and, inadvertently, resulting in negative externalities to the cities and citizens that find themselves assimilated into the sprawl. As such, urban sprawl can typically be observed in areas where the amount of impermeable surface is greater than the amount of permeable surface (Yang et al., 2003). Some of the negative consequences caused or exacerbated by urban sprawl are societal, such as the natural increase in obesity and auto-dependency in urban sprawl residents; other harmful effects of urban sprawl damage the environment by way of increasing impervious surfaces, straining natural resources and increasing pollutants into the atmosphere due to increased traffic (Lathrop, 2003).

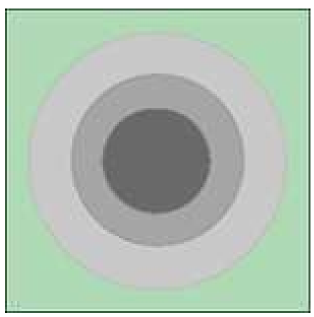
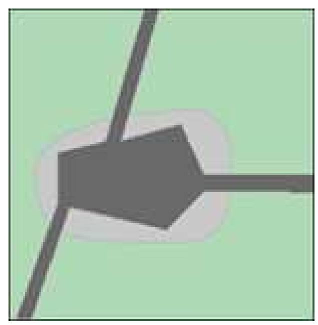
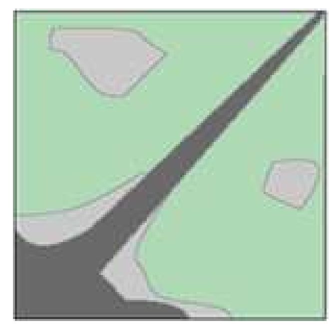
Urban sprawl is not a new problem; nonetheless, scholars and planners alike have not only failed to reach a consensus on the definition of urban sprawl, but there isn't even agreement on the type of metric required to craft such a definition. This debate has raged since the 1950s and 1960s, if not before (Rome, 1998). As such, this paper does not attempt to discern the optimal definition for urban sprawl. Instead, this paper examines the types of natural land-cover changes and associated urban form variables that might be attributing to the consumption of natural spaces that are incident to urban sprawl. As stated by American Farmland Trust, Sierra Club and other organizations and scholars, the concerns posed by the spread of urban sprawl is not the amount of growth itself, but rather "the land-consumptive and ineffective nature" of urban sprawl which ultimately results in the conversion of the "critical land resources" into some alternative form of urban development (Anon, 1994, American Farmland Trust, 1997, Burchell et al., 1998; NRCS, 1999; Sierra Club, 1999).

Types of sprawl and how they impact the built and urban environment:

As discussed above, sprawl can be defined in multiple ways. Its growth, however, is commonly described as occurring in one of two places: within the urban fringe or beyond it (Heimlich et al., 2001). The first represents the growth development pattern that is most commonly associated with sprawl. Sprawl within the urban fringe is typically continuous and located close to major roadways, as seen in suburbia-type settings (Harvey and Clark, 1965; Barnes et al., 2000; Heimlich et al., 2001). Sprawl that takes place beyond the urban fringe is known best as "exurban development." This term is descriptive of unsustainable development practices that promote the growth of rachette style developments where one single family home is built on a parcel of land between 10 or more acres (Heimlich et al., 2001). Both growth trends are highly auto dependent and are associated with the irresponsible consumption of land (Heimlich et al., 2001).

There are three basic forms of sprawl: low-density continuous sprawl, ribbon sprawl, and leapfrog development sprawl (Barnes et al., 2002; Heimlich et al., 2001) . The forms are depicted and defined in Table 1.

Table 1: Three Forms of Sprawl Defined.

Low Density Sprawl	Ribbon Sprawl	Leap Frog
		
Representative of low density continuous development just outside metropolitan areas. These types of developments are supported by extended city infrastructure by way of roads, sewers, and other services (CBMA, 2010).	Indicative of that follows major transportation corridors typically to and from major urban areas (CBMA, 2010). Commercial developments are popular along these corridors. Residential development may eventually follow to the peripheral, less heavily traveled roadways.	Represents a discontinuous form of development. Provides for patches of developed land within the natural landscape. Area resource intensive, and may incLIDe high or low density developments. (CBMA, 2010)

Source of Images: Chesapeake Bay & Mid-Atlantic - Geospatial Data.
URL: http://chesapeake.towson.edu/landscape/urbansprawl/forms.asp

Sprawl's Affect on the Natural Environment:

The Texas population is expected to reach 33 million by 2030 (Gains, James P., 2008). Given this fact, it is inevitable that the natural landscape be converted to an urban form in order to accommodate an ever-growing population. However, the growth and form patterns described above represent an insufficient and wasteful growth that results in an expedited and unnecessary loss of natural amenities (Heimlich et al., 2001). This is a problem because the growing population depends on its environments for food, water, shelter and other resource (i.e. hinterland). Agricultural, for example, provides much of the food we eat (Going, Going, Gone, 2001). In Texas, agriculture is the second largest industry, generating approximately 80 billion dollars annually and making its insufficient conversion to urban lands alarming. Ranchettes, as alLIDed to above, represent sprawl-like patterns that are threatening agricultural lands (Heimlich et al., 2001). According to a study released by the American Farmland Trust, 1,000 new farms and ranches have been established within the state since 1970. The problem is that these smaller parcels are not producing farms; they are too small to produce a viable cash crop and, instead, lead to the unwarranted effect of fragmentation (Going, Going, Gone, 2001). These types of agricultural developments are attributed to "gobbling up open space," degrading natural resources, reducing species habitats, and endangering water quality (Going, Going, Gone, 2001).

Forests are also threatened by sprawl-like development practices in Texas. Aside from providing a home for numerous plants and animals, forests act as an incubator of old and new growth trees that, if large enough, act as carbon sinks and oxygen emitters increasing water quality and reducing the effects of global warming (Goodale et al, 2002). Additionally, urban forests increase the amount of permeable surface which assist to alleviate flooding (Nowak, 2001). In regards to sprawl-like development, the Texas Forest Service reports a similar phenomenon seen within the agricultural landscape where approximately 87, 000 private forested lands are only 1 to 9 acres in size, and as a result, they produce no viable cash crop and instead increase fragmentation (Barron, 2006). Moreover, the Texas Forest Service reports that 13% of forested lands are now owned by Investment Management Organizations (TIMOs), Real Estate Investment Trust (REITs) and similar development interests; this trend is expected to increase over the coming years (Barron, 2006).

Texas leads the United States in maintaining the largest number of grassland and grassland species with 470 out of over 570 species being of native origin (Diamond, Assessed 2010). Although grasslands are part of the natural landscape of Texas, they receive relatively less attention in terms of federal and state protections (Conner et al., Assessed 2010). Grasslands are harvested for hay, and used as forage lands for certain livestock directly producing the nation's supply of "beef, milk, and milk products, and lamb and wool." (Diamond, Assessed 2010). Grasses also increase permeability of water, reduce runoff and alleviate flooding (Sprague, 1954). Aside from its relation to ranching and agricultural practices, grasslands also provide many of the same environmental benefits provided by forest, incLIDing the production of water, soil enrichment, and carbon sequestering. Grasslands are also the largest breeding sites for a number of insects incLIDing the butterfly, and provide the unique habitat for a number of wild animals incLIDing black footed ferrets, burrowing owls and the beloved prairie dog (Ross ET. AL., 1995). Improper management and the invasion of the urban landscape have allowed for an overabundance of trees and shrubs. This decreases the amount of moisture in the soil, causing an increase in soil erosion and decrease in native grasses (Grasslands AZ, 2001). Due to impending climate changes, grasslands are slowly modifying to more forested areas, and the dried landscape in combination with an increase in trees raises the chances of fires, which are a direct threat to both the natural and built landscapes.

Wetlands are of equal importance to Texas. According Brody et al., an estimated 53% of wetlands have been lost within the United States due to human activities (2008). These unique ecosystems have been described as “the kidneys of the landscapes” due to their ability to filter and remove hazardous chemical and natural waste from water resources (Poudel, 2009). Like the natural areas described previously, wetlands also serve as large carbon sinks, and due to their relatively large surface area and high permeability, they reduce erosion, mitigate floods, and reduce the overall strength and impacts of hurricanes (Mitsch and Gosselink, 2000). Wetlands provide a unique case in terms of urban development, because, for the most part, the locations of most wetlands are unknown. However, certain wetlands are documented. In a study conducted by Brody et al., development within these areas was indicated via spatial analysis of federal wetlands alteration permits, where 22% of permits issued were within designated urban landscapes and 39% were located within the 100 year floodplain (2008).

Sprawl and Existing Urban Development:

An urban area is basically the opposite of a natural area, where the amount of impermeable surface is greater than the amount of permeable surface (Yang et al., 2003). Urban development, as a general concept, tends to exist where natural areas do not (Klein, 2000). However, many urban areas are not comprised of dense High Intensity Development. In a report analyzing the development patterns of the Phoenix metropolitan area, it was discovered that there were approximately 121 square miles of vacant undeveloped residential land in 1990. Within these vacant areas it was approximated that if the same density requirements as the urban core were implemented, the region could house up to 750,000 more individuals (Ellman, 1997). Additionally, the current land cover within urban spaces is also not being designed efficiently. Finding Lost Space: Theories of Urban Design, by Roger Tranick, further demonstrates how current city infrastructure development practices could be contributing to sprawl. For example, Tranick provides that an unnecessary amount of space is lost between a traditionally downtown (historically, on a grid street pattern) and the rest of the city (expansive network of highways). He argues that within this transition from the urban core to the greater city, the second design pattern is inefficient and thus contributes to lost space (1997).

Data Limitations – GIS Shortfalls:

To evaluate land cover change, several studies recommend the congruent use of remotely sensed data and Geographical Information Systems (GIS) (Sudhira, et al., 2003; Nagendra, 2003; Wildgen, 2000). GIS conducts spatial and math algebra functions incLIDing calculating fragmentation and patchiness. More importantly, GIS can be used to, "provide dominance in order to characterize landscape properties in terms of structure, function and change" (Sudhira, et al., 2003).

Using remotely sensed data to observe changes within land cover dates back to the 1970s (Singh, 1989). Although common consensus does not exist on how best to reflect land cover change within a study area, typical methods incLIDe comparing two images – which are spectrally based – or two maps – which are classification based (Yang, 2003). Urban land class studies are most commonly conducted with a "Landsat Multispectral Scanner (MSS) or a Landsat Thematic Mapper (TM) (Yang et al., 2003).

Remotely-sensed data is not without fault. As provided by Yang et al. map-to-map comparisons are affective, but rely heavily on the analytical skills and training of the interpreter (2003). When working with rasterized data representative of two different time periods, the author notes the following potential problems:

1) Spectral Differences: Land cover classifications' meanings may change between two associated time periods. To account for this problem, data is usually aggregated up to a level that ensures consistency between the two images.
2) Cell Homogeneity: Cells provide a single uniformed value for the entirety of its area. For example, if a certain cell is comprised of 51 percent forest and 49 percent agriculture, due to cell homogeneity, the cell will ultimately be defined as forest. The sub-pixel variation within a cell is unknown.
3) Lack of flexibility: Type and intensity of land cover change cannot be altered or specified.

Additionally, Lathrop discusses scale and resolution limitations. He notes that, from a planning and policy perspective, refined resolutions allow for better insight into large scale areas (i.e. Cities, urban and exurban territories). If data proves coarse, data must be aggregated up to the largest cell size. However, resolution and overall detail of data is improving yearly, and, for that reason, future scholars should be optimistic about the quality of available data going forward (Sudhira, et al., 2003).

Finally, when conducting a land cover change study, a land cover classification dataset should always be incLIDed within the study (Kline, 2000). In 1999, a series of indicators were selected to analyze sprawl and its effects on farmlands for the states of Georgia and Florida. Land cover indicators were not incLIDed within the study and instead only incorporated population data and area of farmland data acquired from the U.S. Census Bureau and US Census of Agriculture, respectively. Critics immediately highlighted the flaws in the 1999 study, stating that, since the data did not take land cover changes into account, the resulting study would present misleading conclusions (Kline, 2000).

Research Methods

The following section provides detailed information regarding the methods and tools used to analyze natural land conversions taking place within the study area. To provide clear indication as to the types of land-class conversions taking place between the time periods at issue for this study, both urban and natural land-classes were required. As stated above, urban sprawl is the condition wherein improper growth and management practice result in the unnecessary consumption of the natural landscape. As such, this study elects to observe the conversions of natural areas into urban development's of the sprawl (N – U), in addition to the types of land-class changes taking place among the existing urban landscape, which are described here as urban to urban developments (U – U).

Additionally, demographic data, in terms of population and housing variables were analyzed against these classifications at the block-group level. Because these population and housing figures were taken from the 1990 and 2000 censuses, there is a five year time lapse between the land-class data sets and the demographic variables. Although it would be ideal to have all data provided for the exact same year, census data is only provided at 10 year increments. However, this lapse in time is not seen as a limitation to the study, and instead enhances the study by acting as a qualifier where all data observed within the land-class data set is associated with demographic trends that started five years prior.

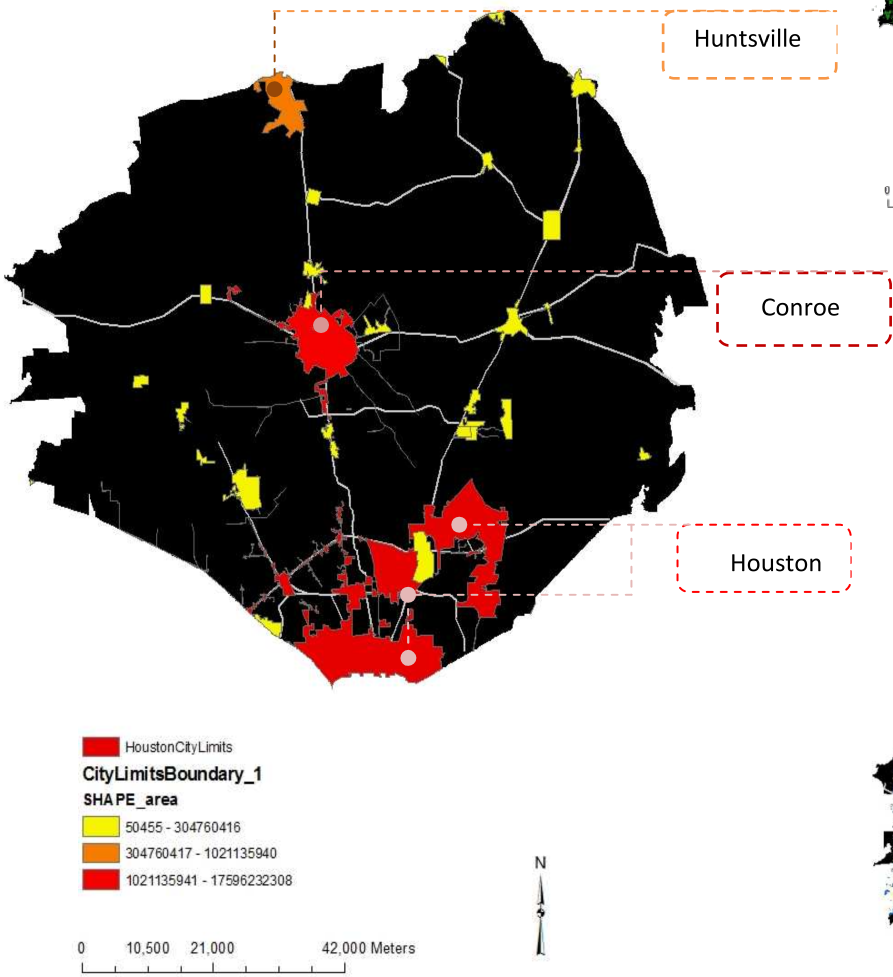
Study Area Identified:

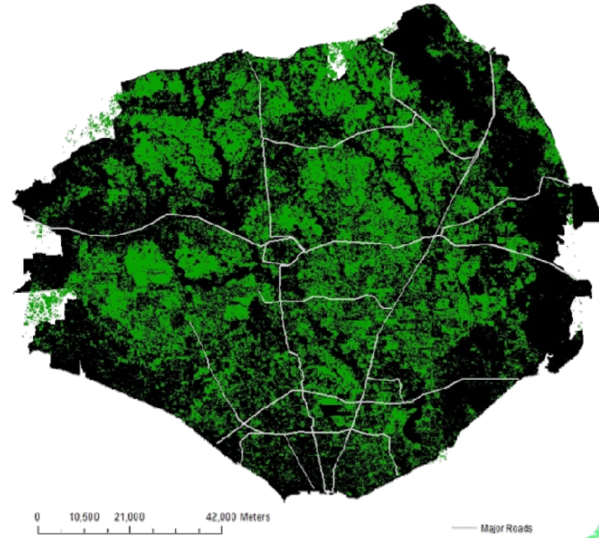
The study area comprised is representative of the Houston to Conroe corridor which follows Interstate 45 (Figure 2). As discussed briefly in the introduction to this study, urban sprawl has had a unique and profound effect on the "Central Texas Triangle" and the cities that comprise it. Houston, which is notorious for its annexation policies, is surrounded by both natural areas and sparsely to moderately populated urban areas. These areas are extremely susceptible to urban sprawl, especially for a city that is as expansion-minded as Houston. Conroe similarly provides for an interesting study area and slight contrast to Houston. One of the most important factors in Conroe's growth is its proximity to the Houston metro area. Conroe's demographics reflect this fact in that it remains a commuter city that is made up of young, professional people that work in or near downtown Houston but cannot afford the high rent that exists in those areas. Conroe's city government has made efforts to combat this daily ebb and flow of its citizens to and from Houston. Namely, Conroe recently constructed a large business and industrial park in order to retain some of these commuter-citizens. Also, an influx of retail and service businesses have arrived in order to sustain and develop this younger population. With a high density of 25-29 year old citizens (City of Conroe, 2010) Conroe is rightfully focused on earning the loyalty and allegiance of these people, however, it is still an open question as to whether or not these efforts will succeed. Whether today's youth will stay in Conroe will have major implications for the city because today's growth plans are modeled on the current population figures. With the majority of the population under the age of 35, the demand for schools, parks, and the particular residential communities that cater to young families will be difficult to gauge if families relocate to Houston once they can afford to do so. The surrounding areas will also provide an interesting analysis and should either (1) identify with Houston or (2) identify with smaller communities, such as Conroe, or there like of.

Finally, this area was selected due to its representation of the four major natural or non urban land classifications that will be discussed for the purposes of this study, which incLIDe agricultural, forest, shrub/scrub and wetlands (Figure 2a, 2b, 2c).

Figure 2: Study Area

Houston/Conroe Corridor and Surrounding Natural Areas





2A: Forest

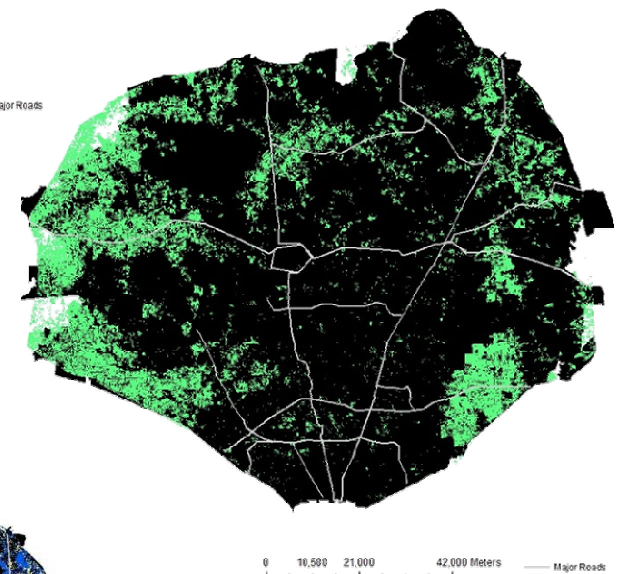
Forest	Acres
1996	904,433
2005	762,637
Change	-141,797

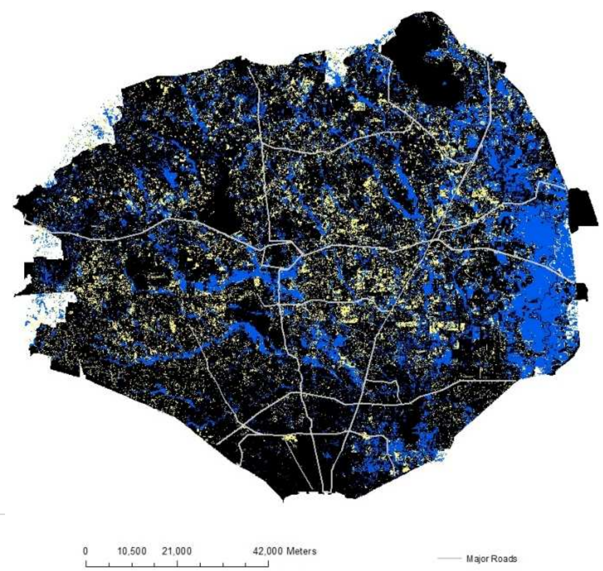
Decrease in total acreage by 2005.

2B: Agriculture

Forest	Acres
1996	460,411
2005	450,471
Change	-9940

Decrease in total acreage by 2005.





2C: Wetlands

Forest	Acres
1996	481,147
2005	463,399
Change	- 7,749

Decrease in total acreage by 2005.

2C: Scrub/Shrub

Forest	Acres
1996	282,541
2005	387,972
Change	105,431

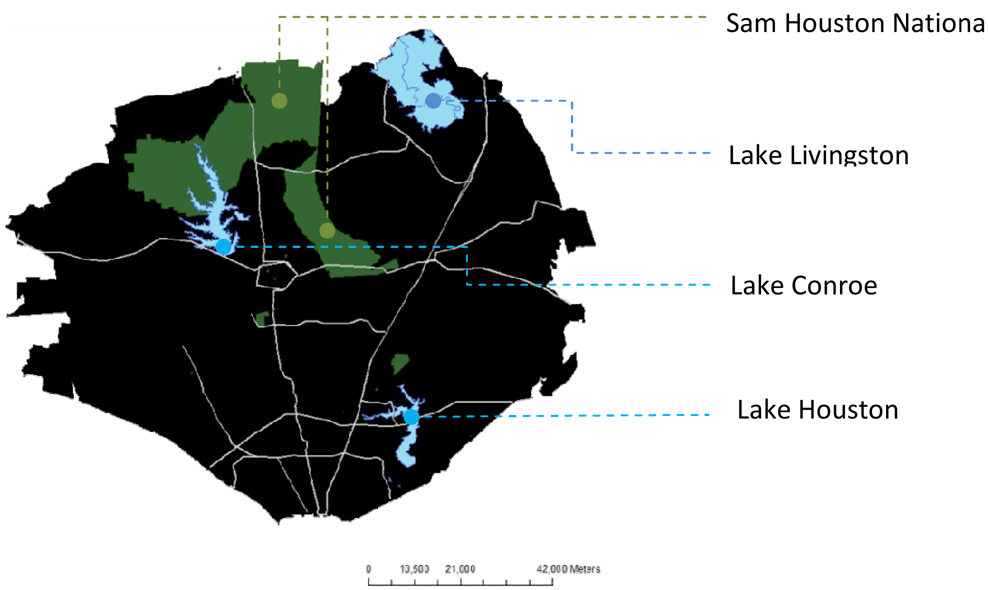
Decrease in total acreage by 2005.

With that particular area in mind, the specific geographical area that is the subject of this study was further defined by using existing major highways in and around the study area as natural borders. For this study, these borders consisted of:

Boundary	**Texas Roadway**
Northern Boundary	Texas 105
Eastern Boundary	US 90
Southern Boundary	610 Interstate Highway/ North Loop Freeway
Western Boundary	US 290

Dominant lake features and state parks are also within the study area (Figure 3). Although these areas are not being evaluated for N – U and U – U conversion, these entities are noted as possible attractions for development – not development within these areas, but around. Given the desire of individuals to live closer to nature, parks and water bodies may prove influential in attracting new settlements for individuals interested in living closer to the natural landscape as opposed to dense city developments.

Figure 3: Study Area – Parks and Major Lakes



Land Classifications Method and Associated Steps Identified:

In order to properly execute this study, data that addresses both natural and urban land classifications are required. Although many types of land classification data exist, this study was conducted using the land class data acquired from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) data sets for the years 1996 and 2005. These data are provided in a minimum mapping unit of 30 meters (1/4 acres) and resolution standard of 1:100,000 or 30 meters per pixel. Unlike other land classification datasets, these data have been nationally standardized for direct comparison where a data point in 1996 is indicative of the same spatial location the related data point in 2005. The dataset maintains an 85% target accuracy rate. So, at a minimum, the problematic aspects pertaining to typical land classification data is mitigated to the greatest extent possible.

The data in its raw form was subdivided into 24 land classifications for the 1996 dataset and 22 for the 2005 dataset. Despite these changes in natural land subclasses that occurred between 1996 and 2005, the data was manipulated and reclassified using the reclassify tool in ArcGIS and segregated into 8 general categories for the purposes of this analysis. Four of these new categories represent urban development types, and four categories represent natural land classes. All groupings follow recommendations by the C-CAP Land Cover Classification Scheme (NOAA, C-CAPP) classification. Based on these groupings (groups based off of their associated definitions), the 1996 and 2005 datasets used in the study are more easily compared. Land classification variables are defined in Table 2 and 3.

Table 2: Identified Land Class Variables		
Land Classes Identified	Old Value Names (C-CAPP 1996 & 2005)	Assigned Definition (As Provided by NOAA)
Urban		
High Intensity Development (HID)	- High Intensity/High Developed	IncLIDes highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80 to 100 percent of the total cover.
Medium Intensity Development (MID)	- Medium Intensity/Medium Developed	IncLIDes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. IncLIDes grassland areas dominated by gramminoid or herbaceous vegetation and shrub/scrub areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation, incLIDing true shrubs, young trees in an early successional stage, or trees stunted due to harsh environmental conditions. Management techniques that associate soil, water, and forage-vegetation resources are more suitable for rangeland management than are practices generally used in managing pastureland. Some rangelands have been or may be seeded to introduced or domesticated plant species.
Low Urban Intensity (LID)	- Low Intensity/Low Developed	Low Urban Intensity: IncLIDes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 21 to 49 percent of total cover.
Open Space Intensity (OSI)	- Developed Open Space/Non Low Space Development	IncLIDes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover.

Table 3: Identified Land Class Variables		
Land Classes Identified	Old Value Names (C-CAPP 1996 & 2005)	Assigned Definition (As Provided by NOAA)
Natural		
Agriculture:	- Cultivated Crop - Pasture/Hay	Crop/Pasture Hay vegetation accounts for greater than 20 percent of total vegetation. Cultivated crops are described as areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. This class also incLIDes all actively tilled land. Pasture/Hay is described as grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle.
Forest	- Deciduous Forest - Evergreen Forest - Mixed Forest	Areas dominated by trees generally taller than 5 meters, and greater than 20% of total vegetation cover. IncLIDes deciduous forest, evergreen forest, and mixed forest.
Wetlands	- Palustrine Forested Wetland - Palustrine Scrub/Shrub wetland - Palustrine Emergent Wetland - Estuarine Forested Wetland - Estuarine Scrub/shrub Wetland - Estuarine Emergent Wetland	Total vegetation coverage is greater than 20 percent. Areas dominated by saturated soils and often standing water. Wetlands vegetation is adapted to withstand long-term immersion and saturated, oxygen-depleted soils. These are divided into two salinity regimes: Palustrine for freshwater wetlands and Estuarine for saltwater wetlands. These are further divided into Forested, Shrub/Scrub, and Emergent wetlands.
Scrub/Shrub	- Scrub/Shrub and Bareland	IncLIDes grassland areas dominated by gramminoid or herbaceous vegetation and shrub/scrub areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation, incLIDing true shrubs, young trees in an early successional stage, or trees stunted due to harsh environmental conditions. Management techniques that associate soil, water, and forage-vegetation resources are more suitable for rangeland management than are practices generally used in managing pastureland. Some rangelands have been or may be seeded to introduced or domesticated plant species
Source: http://www.csc.noaa.gov		

Logical Tool: Combinatorial And

Combinatorial And is a logical math tool that allows for two rasters to be combined without losing the unique attributes associated with each. The tool understands inputs as either a zero or non-zero value which is interpreted as true and false, respectively. Based on this interpretation, a new "value" is provided for each unique combination made between the two input rasters along with an associated count value that indicates the number of times a unique pairing occurred (ESRI: Combinatorial And, 2008).

Due to the reclassification process described above, an integer was assigned to each pairing of the 8 sub-classes described in (Table 4). That process resulted in 121 unique combinations of urban and natural sub-class conversion patterns. However, not all unique combinations were required for the purposes of this paper. Only pairings that resulted in a "to urban" form combination, whether a natural to urban combination (N - U) or an urban to urban combination (U - U), were considered pertinent to this study. Also, urban forms that did not change (i.e. HID to HID) were not incLIDed in this study as they are not considered "newly developed to" urban land classifications. "To urban" pairing, consist of four subclasses: HID, MID, LID, OSI. These subclasses were used to evaluate both N – U and U – U conversions. Using HID as an example, the following types of unique combinations were analyzed for the purpose of this study:

Table 4: Combinatorial And Example - "To HID"	
Natural	**Urban**
Agriculture converted to HID	MID converted to HID
Forest converted to HID	LID converted to HID
Wetlands converted to HID	OSI converted to HID
Scrub/Shrub converted to HID	

Zonal Analysis by Attribute

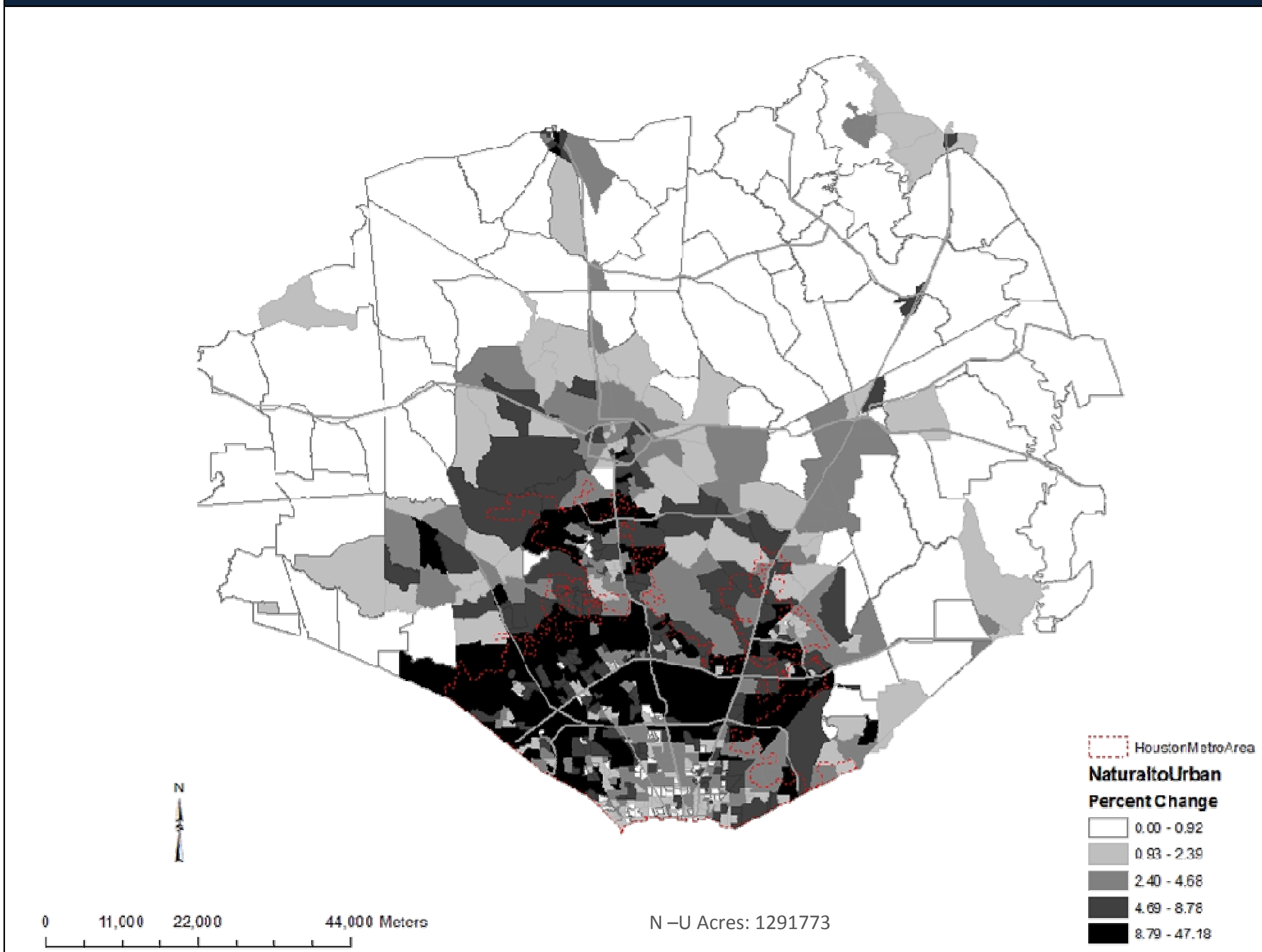
The spatial majority of each N – U and U – U was evaluated using the Zonal Statistics tool provided in the Spatial Analysis toolbox. "Zonal majority" determines the unique value (or combination of values as described above) that occurs the most often within a zone. Using the 1996-2005 Combinatorial And output rasters, zonal majorities were conducted for the entire study area. To gain a better understanding of the types of land class conversions that occurred throughout the entire study area, the 2009 Census block group boundaries were applied to this geographic area being analyzed in this study; this resulted in 755 observation zones which adhered to the U. S. Census Block Group (BG).

The results of the Zonal Majority were analyzed using Microsoft Excel's pivot table summation function. The total area change was calculated for each block group. Based on the result provided, the top 50 block groups, or "hotspots", that showed the greatest area change were selected for further analysis. As discussed in the results section, little variability in the types of land classes most commonly converted existed. To provide a better understanding as to the types of conversions occurring among each conversion to urban classification, the hotspots (top 50 N – U conversions) were also separately evaluated in terms of HID, MID, LID and OSI.

RESULTS: Summary of Analytical Process

The results of this study emphasize the common phenomenon taking place on the fringes of major cities and small towns today known as urban sprawl. As discussed previously, urban sprawl is typically defined “as low-density residential and nonresidential intrusions into rural and undeveloped areas [where] there is almost total reliance upon the automobile as a means of accessing the individual land use.” (Juergensmeyer, 2001). Urban sprawl consists of land conversions to a form of urban development. In other words, it could also be conceptualized as the sum of natural conversions to urban developments (N - U) and urban conversions into different inefficient urban developments (U - U). With that in mind, those two types of land conversion patterns (N - U and U – U) were compared and addressed in order to see what trends, if any, could be discerned about this growing phenomenon.

Figure 4: Conversion from Natural to Urban (N – U) land use from 1996 – 2005.

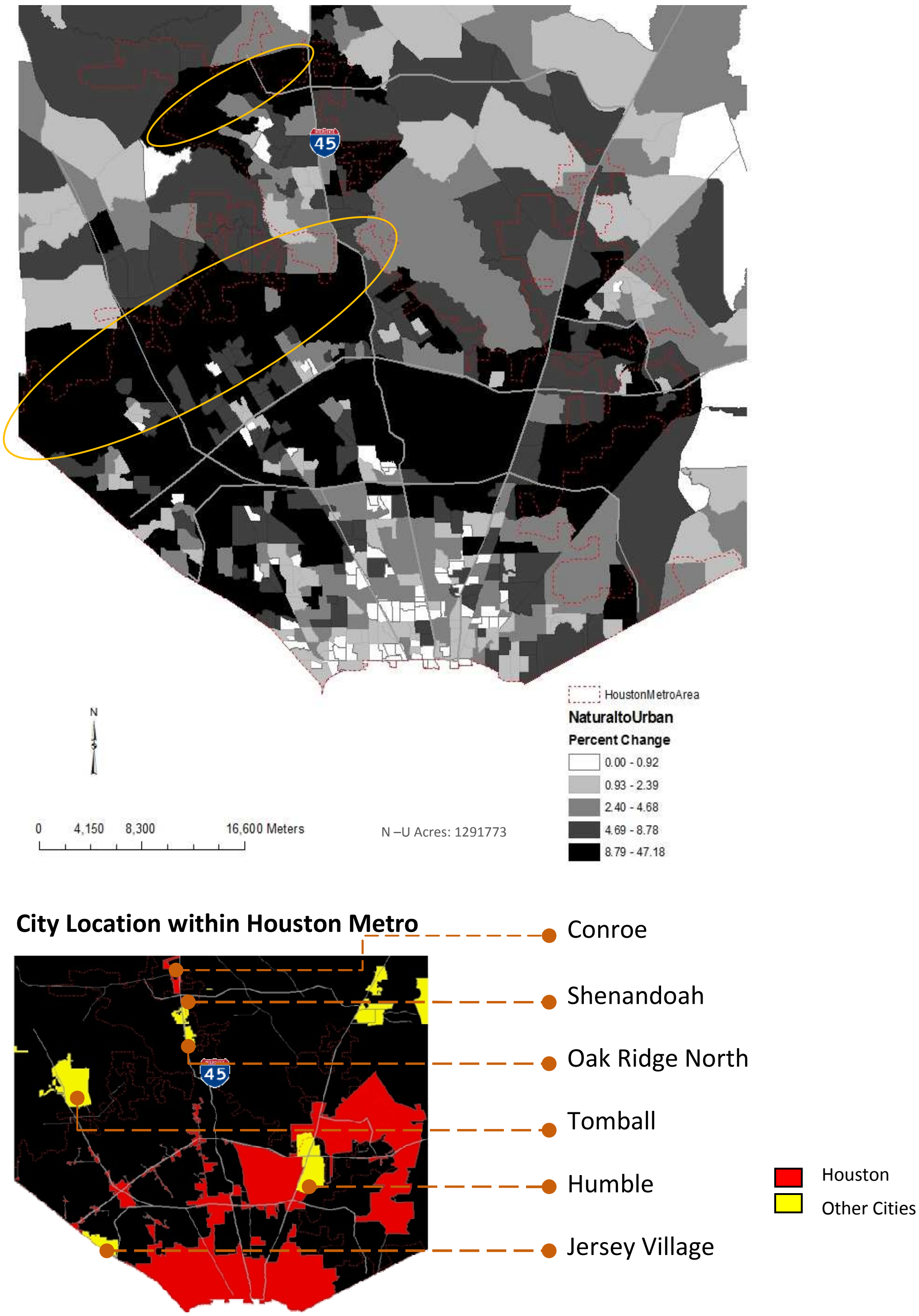


General Overview of Study Area:

As expected, there was a percent rise in the number of newly developed urban spaces that were previously natural areas (N – U) from 1996 to 2005. N – U conversions are divided into subclasses based on the spatial reclassification tool as discussed under the methodology portion of this report. These sub-classes of urban development include – High Intensity Development (HID), Medium Intensity Development (MID), Low Urban Intensity (LID) and Open Space Development (OSI) – and will be used to observe both N – U and U – U conversions of newly developed open space.

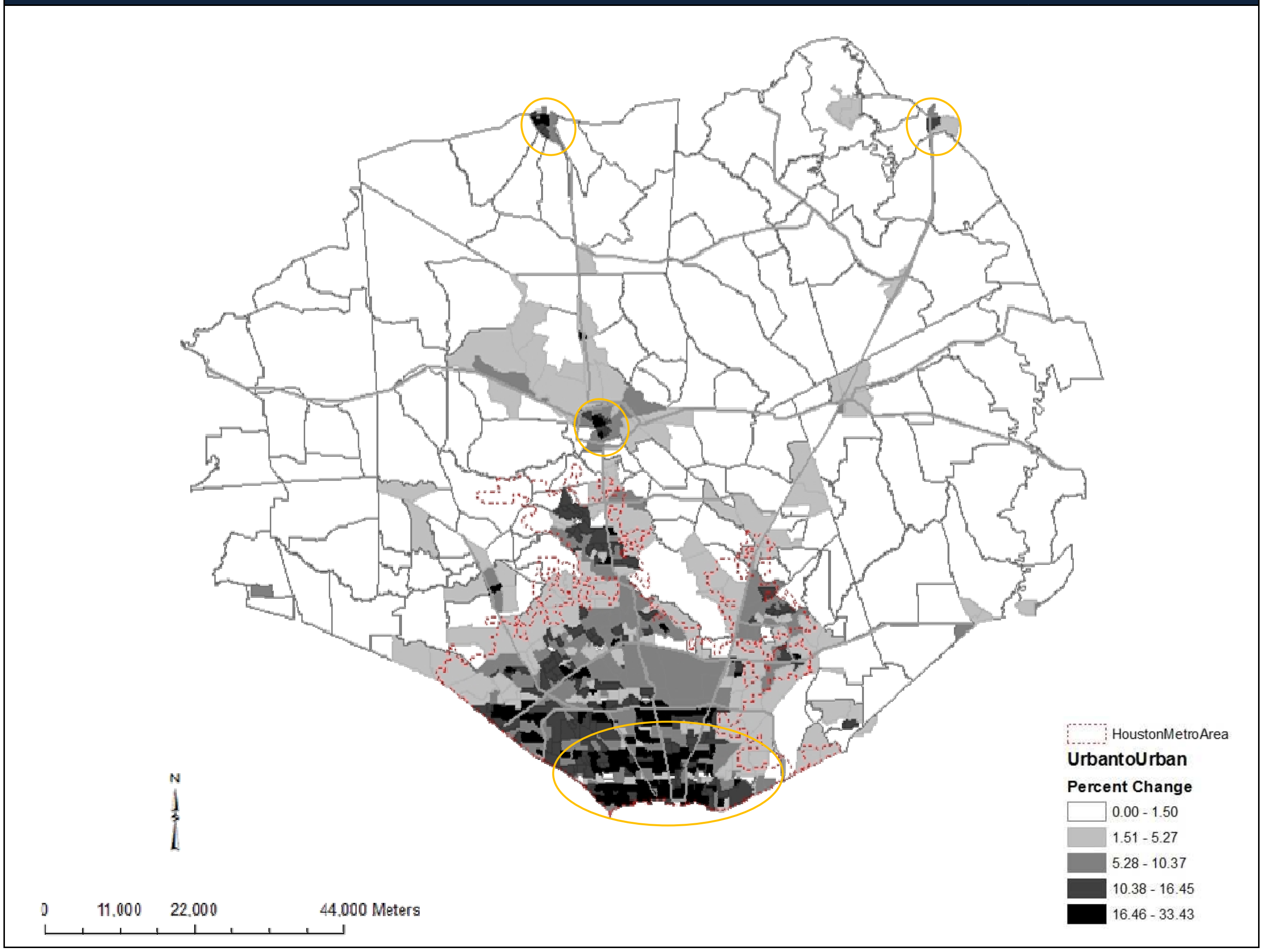
As depicted in Figures 4 conversions occur predominately within block groups located in and around city limits. However, the greatest percent change of N – U takes place just outside of the Houston city limits, which is still considered part of the greater Houston metropolitan area (Figure 4a). This Houston extension is comprised of several existing cities including Shenadoah, Oak Ridge North, Tomball, Humble, Jersey Village, and the southern outskirts of Conroe.

Figure 4a: N – U Conversions within Houston Metropolitan Area



After observing this trend with respect to N - U conversions, the study area was also evaluated in terms of urban to urban conversions (U – U), which will show the percent change from one urban land classification to newly developed urban spaces. This data is shown in Figure 5.

Figure 5: Conversion to U - U (U – U) land cover from 1996 – 2005

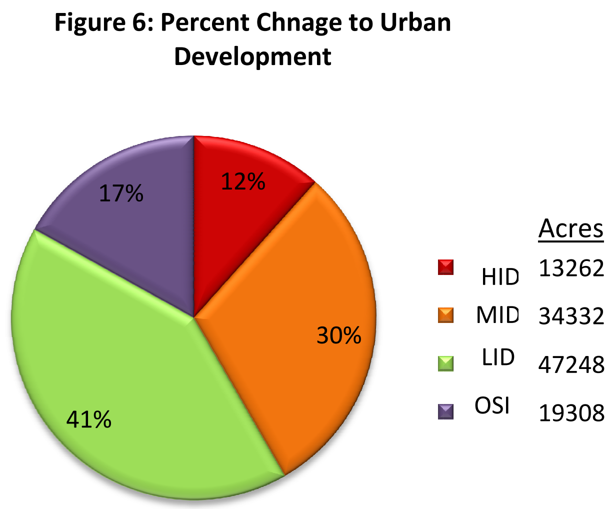


As observed, the distribution of U – U development is concentrated around and within the Houston city limits. Although the amount of infill is much greater within the Houston city limits, the U – U influence can be seen throughout the entire study area (i.e Conroe, Livingston, and Huntsville) as highlighted in Figure 5.

In the same manner, population and housing demographics are observed using the 1990 and 2000 census data. With a lapse of approximately five year's time between the census and land classification data, possible associations may be observed within the dataset in terms of the types of people and homes associated with N - U conversions.

Breakdown of General Study Area

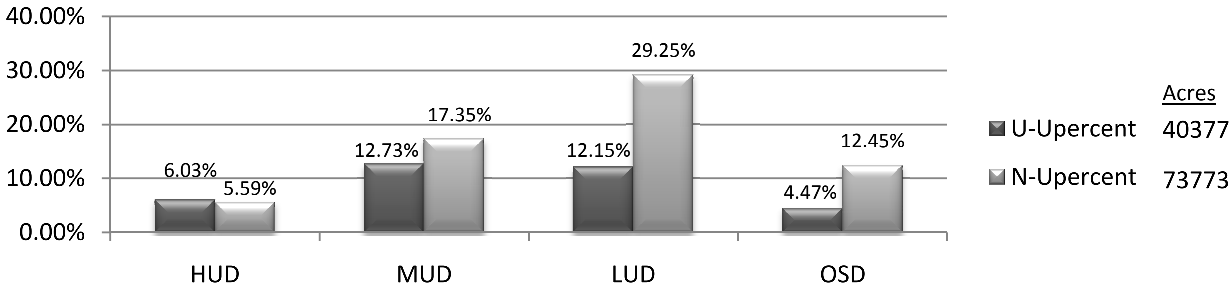
To evaluate all newly developed urban spaces, both N – U and U – U conversions were evaluated jointly. From 1996 to 2005 approximately 228,963 acres or 33% of the study area was converted into a new urban development. Of that percentage, 64% (73773 Acres) originated from previously natural spaces while 35% (40,377 Acres) were created from previously developed urban spaces (Figure 7). As seen in Figure 6, when considering the sum of both types of conversion patterns, LID was shown to be the most common conversion type with 41% of all conversions being of this variety. MID was the next most popular change at 30%, followed by HID at 17%. Finally, only 12% of urban development consisted of OSI.



Based on the definition of what constitutes sprawl, this breakdown was to be expected where an over abundance of low density developments or LIDs persist. Interestingly, the relative closeness between LID and MID was not expected based on the specified low density definition. However, the likeness could be due to the absence of OSI within the LID total percentage. Although OSIs are different then LIDs, they may represent the ranchett phenomenon as opposed to suburbia developments, respectively. If evaluated as a single sub-category, the combined change rate of LID and OSI (lower density developments) provides for 58% of all newly developed urban spaces or more than half all new developments.

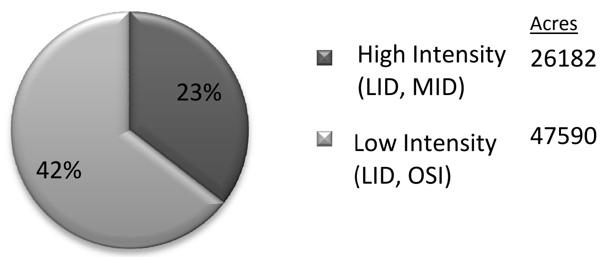
To evaluate these trends further, the percent of newly developed spaces were observed separately for N –U and U – U conversions. Whereas Figure 6 represented the sum of all U - U and N - U conversions, Figures 7 shows the two types of land conversions on an individual basis by series.

Figure 7: N-U and U-U New Developments



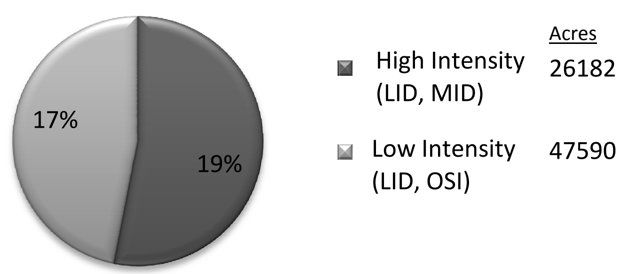
As stated above, the percent to which natural and urban landscapes individually contributed to newly develop urban spaces were analyzed and are depicted in Figure 7. Mirroring the trend seen in Figure 6, MID and LID were the two most frequently utilized development classes for both N – U and U – U developments. As expected, LID were most commonly converted from previously non developed landscapes or N – U conversions (29%). However, MID was not expected to be the second most common N – U conversion (17%). Given the general definition of sprawl, OSI was expected to the second highest N – U classification (12%). However, when comparing higher density developments (HID & MID) with lower density developments (LID & OSI) in terms of N – U conversions, lower density developments prove to be more prevalent as depicted in Figure 7a; a trend descriptive of urban sprawl.

Figure 7a: N - U Conversions



U – U conversions, on the other hand, are representative of the percent of previously developed landscapes to newly developed landscapes between 1996 and 2005. As shown in Figure 7, MID developments are the most common U – U conversion (12.75%), but are only marginally greater than the amount of LID U – U conversions occurring within the study area (12.15%). However, as provided in Figure 7b, newly developed higher density developments are more common within the

Figure 7b: U - U Conversions



study area then lower density developments, although marginal (2%). Regardless, this marginal difference could be indicative of responsible U – U conversions where newly developed urban spaces are becoming denser.

Given these general observations, it is important to understand what, in terms of existing land classifications, are being converted into inefficient newly developed urban spaces. To answer this question, the following sections look at HID, MID, LID and OSI developments individually and identify the land classifications most commonly converted for each. 8 land classifications were evaluated and incLIDe natural landscapes – *previously* identified forest, agriculture, wetlands, and shrub landscapes – and urban landscapes – *previously* identified HID, MID, LID and OSI. In particular, the following questions will be asked:

- *What landscapes are most frequently being converted to high density developments? And, similarly, low density developments?*
- *What natural or non urban landscapes are most popular in terms of newly developed high density developments? And, similarly, low density developments?*
- *What trends, if any, might be contributing to the phenomenon known as urban sprawl?*

1) High Intensity Development (HID):

With respect to all of the N – U and U – U developments, only 1.39% of the study area is occupied by HID and is seen mainly within city limit boundaries. As shown in Figure 6, conversions to High Intensity Development consisted of 12% of all conversions that occurred from 1996 to 2005 (Figure 6). Of that 12%, 52% was converted from previously urbanized areas, while 48% was converted from the natural landscape. The breakdown, by sub-class of those conversions is shown below in Table 6 and graphically represented in Figure 8.

Figure 8: General Subland Classes Contributing to HID

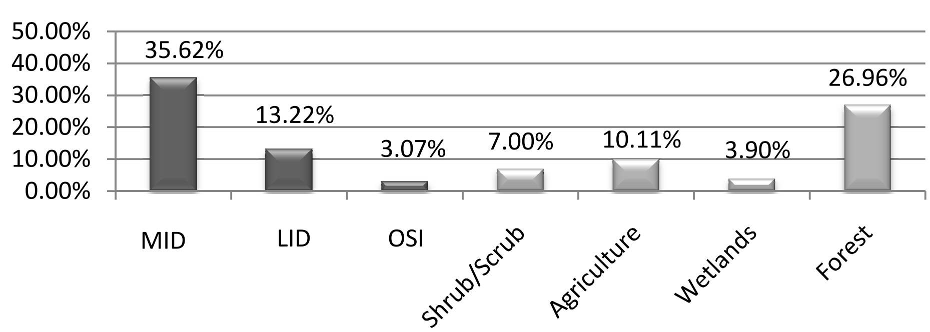


Table 6: Change to High Intensity Development (1996-2005)[1]			
	Land Class	**Acres**	**Percent**
Urban – Urban	Medium Density	4724	35.62
	Low Density	1754	13.22
	Open Density	407	3.07
	Total of Urban to HID Development	6885	51.91
	Land Class	**Acres**	**Percent**
Natural – Urban	Scrub/Shrub	944	7.00
	Agriculture	1341	10.11
	Wetlands	517	3.90
	Forest	3576	26.96
	Total of Natural to HID Development	6377	48.09
	To New HID Development	13262	100

Among the natural and urban development types, HID most often occurred from lands that were previously categorized as MID. This is hardly surprising, as it confirms the gradual trend in urban development that was discussed earlier – namely that land gradually becomes denser as populations grow (LID to MID to HID). The natural area that appeared most conducive to HID conversions was forests (27%). However, scrub/shrub lands and agricultural lands also contribute to this type of urban development with a combined change to rate of 17%. It is interesting to note, that the amount of N – U and U – U conversions occurring to HID are almost equivalent. This could indicate responsible high density development practices with both N – U and U – U newly developed urban spaces. Although the change to urban landscapes from a previous urban landscape may seem more prevalent at first, it is important to reiterate that nearly 50% of all conversions within this category were converted from a natural area. This means that nearly all new HID developments are occurring on lands that were not

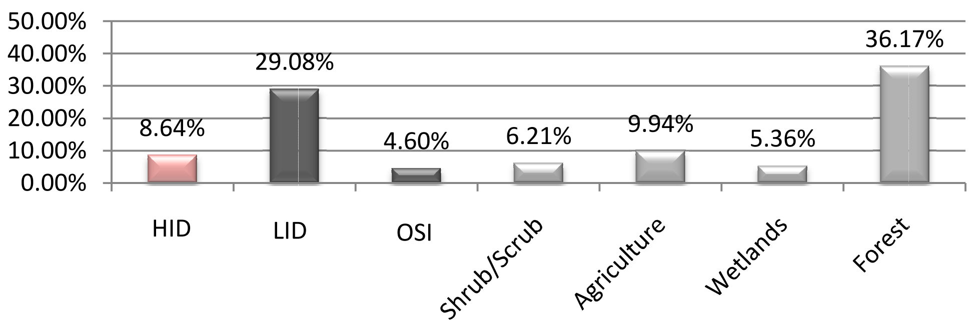
[1] The general study area was evaluated after conducting the Combinatorial And. As such, all areas were calculated based a 30 by 30 cell size area.

previously developed. However, this trend may show a representation of responsible growth practices where new developments are high density developments and not low density development which is indicative of sprawl.

2) Medium Intensity Development:

MID comprises 3.93% of the study area and can be seen both within city limits and outer exurban areas. Of this number 30% changed to MID development from a differing land class (Figure 6). Urban Development accounts for 42% of the change to MID, and the other 58% of medium density developments were created from natural areas as seen in Table 7 and shown in Table 9.

Figure 9: General Subland Classes Contributing to MUI



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

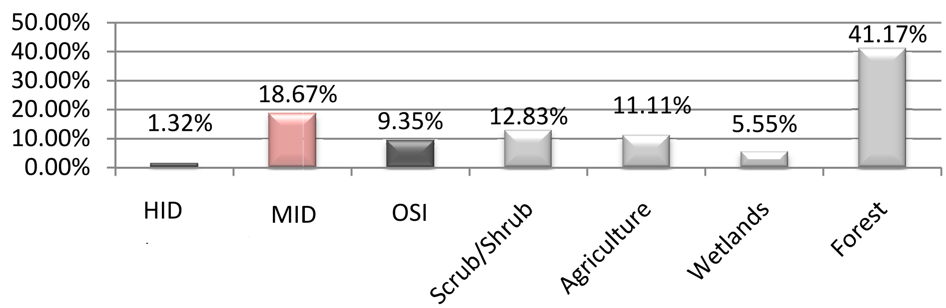
By a vast margin, LID was the most significant land conversion to MID from 1996 to 2005. Again, as seen with HID developments, this is expected given the general understanding that communities tend to become denser as populations grow. Going against this logic, however, the data shows a decrease in density as well where previously developed HIDs contributed to 9% of newly developed MIDs; a possible indication of sprawl-like practices. Of the natural landscape, forests were most heavily converted at 36%. Agricultural lands were the second most common natural area to be converted into medium density developments at 10%. The data shows an alarming amount of natural lands that are converted from a natural landscape to MID. Although preferable to LID and OSI developments (with respect to the general need to reduce sprawl), this could be an indication of an increase in strip mall/exurban type development.

Table 7: Change to Medium Intensity Development (1996-2005)			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	High Density	2965	8.64
	Low Density	9983	29.08
	Open Density	1578	4.60
	Total of Urban to MID Development	14527	42.31
Natural – Urban	**Land Class**		**Percent**
	Scrub/Shrub	2133	6.21
	Agriculture	3413	9.94
	Wetlands	1841	5.36
	Forest	12417	36.17
	Total of Natural to MID Development	19805	57.69
	Total New MID Development	34332	100

3) Low Intensity Development:

The entire study area is occupied by 5.9% of LID, which represents the largest class of to urban developments within the study area. New LID areas constituted 41% of all newly developed urban spaces (Figure 6). Of the conversions to LID, 29% was previously an urban sub-type, while 71% of newly developed LID was preceded by natural areas as show in Table 8 and Figure 10.

Figure 10: General Subland Classes Contributing to LUI



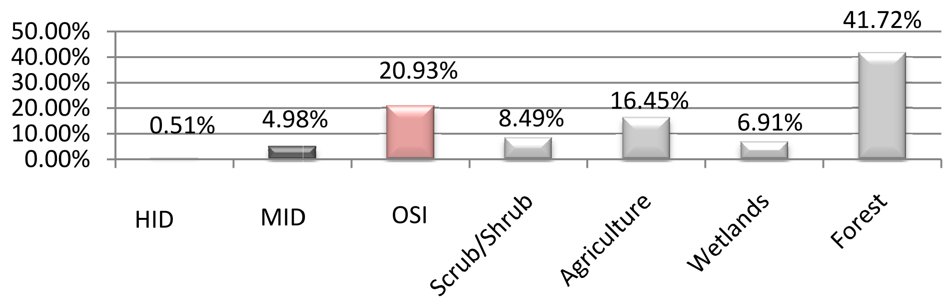
As displayed in Table 8 and Figure 10, forest represents the natural area most heavily converted natural area (41%). Interestingly medium development is the next highest land class showing a conversion of 18.4% from High Intensity Development to Low Urban Intensity. This is interesting because alLIDes to similar trends observed in the MID section of analysis where a higher urban class is converting to a lower urban class which may provide some insight into the conversion of N – U.

Table 8: Change to Low Intensity Development (1996-2005)			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	High Density	625	1.32
	Medium Density	8823	18.67
	Open Density	4418	9.35
	Total of Urban to LID Development	13865	29.34
Natural – Urban	**Land Class**	**Acres**	**Percent**
	Scrub/Shrub	6060	12.83
	Agriculture	5249	11.11
	Wetlands	2621	5.55
	Forest	19454	41.17
	Total of Natural to LID Development	33383	70.66
	Total of New LID Development	47248	100

4) Open Space Intensity Development:

OSI accounts for 2.35% of the study area of which there was a 17% increase in change to area from 1996 to 2005 (Figure 6). Out of that percent, 26% was converted from low and medium density developments (with an additional, unexpected .5% of OSI resulting from conversions from HID), while 74% was converted from the natural landscape as seen in Table 9 and Figure 11.

Figure 11: General Subland Classes Contributing to OSI



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

Table 9: Change to Open Space Intensity (1996-2005)			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	High Density	98	.51
	Medium Density	961	4.98
	Low Density	4042	20.93
	Total of Urban to Open Space Development	5101	26.42
Natural – Urban	**Land Class**	**Acres**	**Percent**
	Scrub/Shrub	1693	8.49
	Agriculture	3177	16.45
	Wetlands	1335	6.91
	Forest	8057	41.72
	Total of Natural to Open Space Development	14207	73.54
	Total of New OSI Development	19308	100

As seen in LID, forests are the most heavily converted to OSI at 42%. Agriculture and Scrub/Shrub land were the second most commonly converted natural land classes at a summed percentage of approximately 25%. Interestingly, the same downgrade conversion to LID from a more dense development is seen in the conversion of LDU to OSI at 21%.

Socio-Economic Trends within Study Area:

In an effort to explain the land class conversions discussed within the prescribed study area, population and housing demographics were collected from the 1990 and 2000 census (See Methodology for description of variables and selection process). Variables to be analyzed incLIDe:

- Population Demographics: Population count, race, ethnicity (Hispanic Only) income, educational attainment and travel time to work.
- Housing Demographics: Household value, household type, year the structure was built, and number of household units.

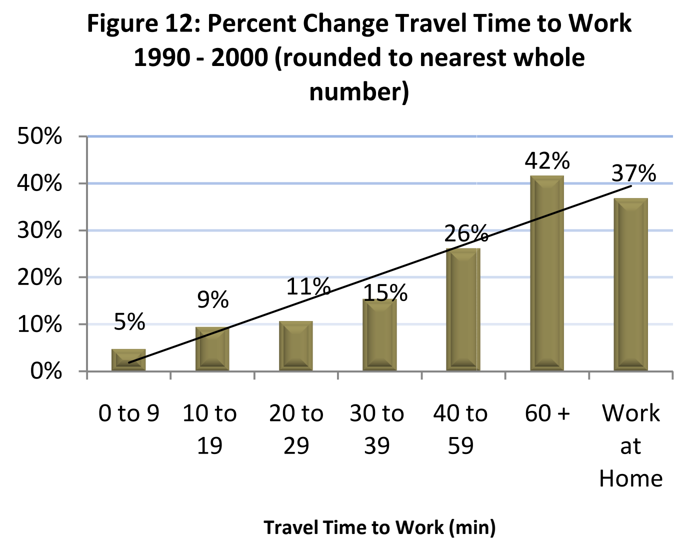
Population:

The study area increased in population by 752,532 people from 3,193,320 in 1990 to 3,945,852 in 2000. As expected the study area is predominately white (2,438,163 people). However, contrary to expected urban sprawl assumptions, the white population showed the least amount of growth between 1990 and 2000 at 14%. The black population the black population rose 16% for a total of 683,078 individuals. Interesting, the greatest percent change occurred within the "other" category at 76% resulting in a total population of 824,611 individuals. However, the greatest percent change in a defined ethnic group is observed in the Hispanic population which grew almost 80% for a total of 1,189,152 individuals within the study area. Although Hispanics can be white, it is important to note that the increase in the Hispanic population results in a population that is nearly half that of the white population.

With respect to the level of education attained by the people in the study area, the data shows only a slight increase in all educational levels with the exception of associate's degrees which jumps almost 100% and people with some college experience increased by 70%. Graduate degrees show the smallest percent increase at only 10%. Given the definition of urban sprawl, this trend is expected where higher education is commonly associated with a higher degree of wealth. However, the marginal change in population actually obtaining a graduate level degree (i.e. Bachelors and above) is surprising.

Housing:

The study area consist of mainly single family homes (65%), some multifamily homes (25%) and a few homes categorized as "other" which incLIDe mobile homes (10%). Again, this pattern is relatively uninteresting and typically seen within sprawl like development patterns.



"Travel Time to Work" shows the greatest percent change (42%) among workers traveling more than 60 minutes. As depicted in Figure 12, the amount of workers traveling 0 to 9 minutes to work increased 4.73%, which was the smallest increase among the various groups. The relationship expressed by this variable set is clear: more workers are traveling greater distances in 2000 than they did in 1990. As the number of minutes per workday commute increases, the percent difference in the amount of people making such a commute increases as well. An exception exists with respect to the group of commuters that "Work at Home"; this group increased by 37%. Again, these patterns are indicative of traditional urban sprawl patterns.

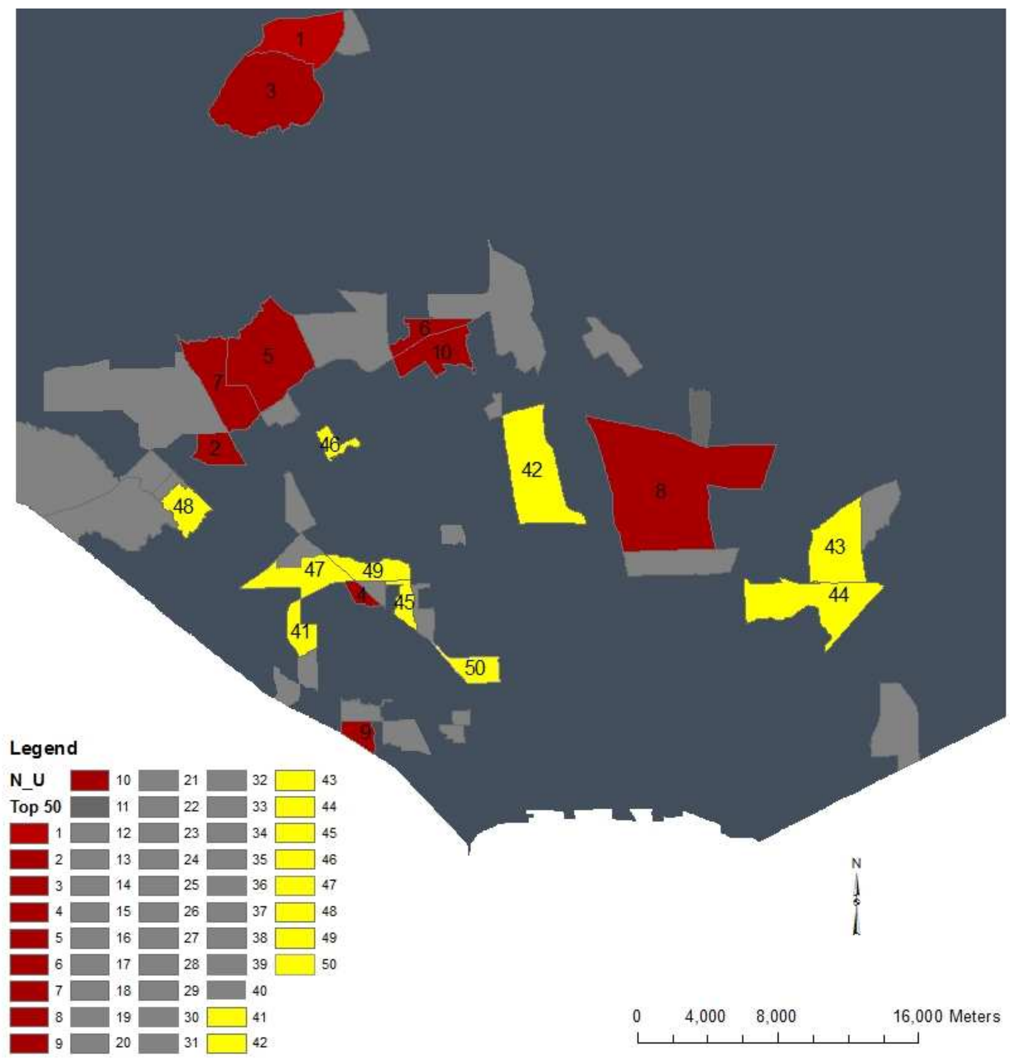
Summary of General Study Area Observations:

In summary, there appears to be conversions taking place within both U – U and N – U land cover changes that could be associated with an increase consumption of natural spaces or sprawl. As expected, LID was the most highly represented subclass among N – U conversions affecting mainly forested landscapes. However, LID conversions were also the most common among U – U conversions. What is surprising is that the majority of LID conversions were not from areas previously identified as OSI. Instead, among U –U conversions, LID developments were mostly converted from previously MID and HID developments. This indicates a general decease in density and increase in lower density developments within the general study area. Additionally, the socio and economic data further verify a sprawl-like environment where the population is predominately white and educated. The largest indication of sprawl, however, is indicated by the amount of time residents are willing to travel to work, 60+ minutes.

Top 50 Areas of Interest:

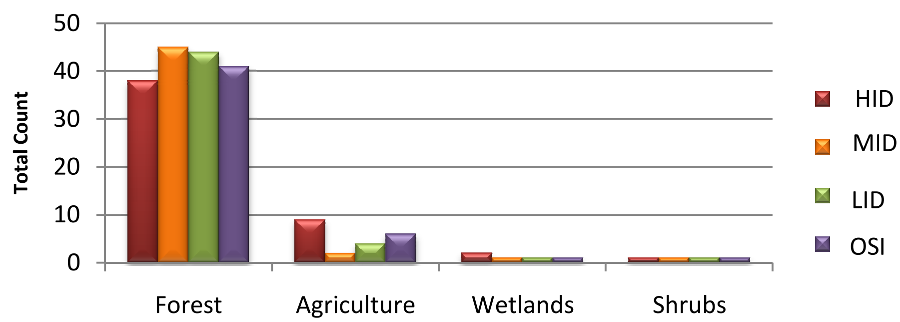
The trends provided to this point have been reported based on general observations made for the entire study area. However, in order to better understand the type of land-class conversions that occurred between 1996 and 2005, it is important to further evaluate the dataset at a more localized level for comparison. The top 50 block groups that underwent the greatest change from N – U were identified and are displayed in Figure 13. N – U conversions are the most prevalent concern of this study, and as such U – U conversions taking place within these areas will be analyzed in an effort to explain the types of conversions occurring within the top 50 N – U blockgroups.

Figure 13: Top 50 Block groups in Study Area [2]



As displayed in Figure 13, almost all N - U conversions took place around major highways and are located predominately in the Houston metropolitan area. As seen within the general study area, forested areas were the most frequently converted to urban development between 1996 and 2005. Although significantly less important, agricultural lands are the second most highly converted while the other land classes play little to no role in N – U conversions.

Figure 14: Top 50 Most Common N - U Natural Area Converion



To determine if this trend is consistent throughout the top 50 individual block groups, the data set was further divided into 5 cohorts of 10, as represented in Figure 14. Cohort 1 consisted of the 10 block groups with the highest percentage change in N - U development from 1996 to 2005, Cohort 2 represented the 10 block groups with the next-highest percentage change in N - U, and so on. Based on the results, each cohort was predominately converted by previously forested areas. However, cohort 5, which represents areas closer to Houston city limits, maintained a higher count of agriculture landscape to urban conversions (Table 10).

Table 10: N – U Most commonly converted Natural Area

	HID	MID	LID	OSI
1 to 10	Forest	Forest	Forest	Forest
11 to 20	Forest	Forest	Forest	Forest
21 to 30	Forest	Forest	Forest	Forest
31 to 40	Forest	Forest	Forest	Forest
41 to 50	Forest	**Agriculture**	**Agriculture**	**Agriculture**

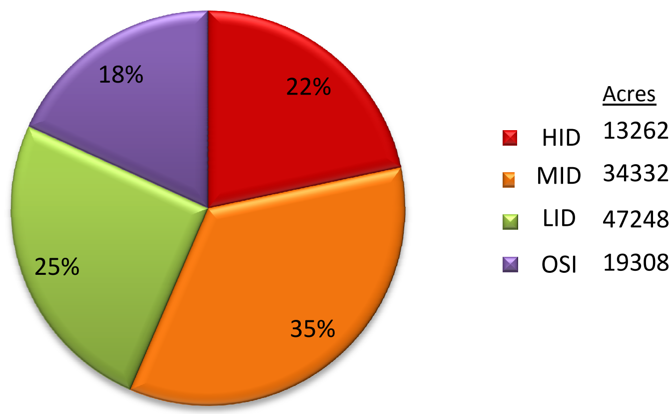
***** *Greater than 60% of the cohort attributed to natural area identified.*

Based on the findings provided from table 10, N – U conversions were still be evaluated, but emphasis in the following subjections were given to N –U conversions occurring within these top 50 block groups.

General and Top 50 Block Group Comparison:

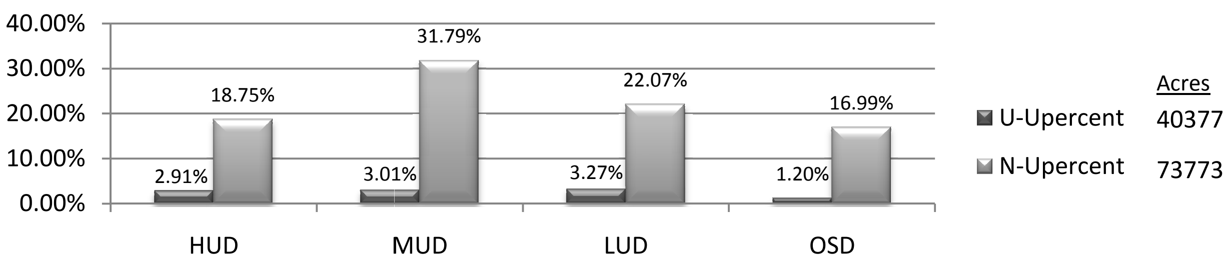
Within the Top 50 Block groups, MID represents the most common newly developed urban space (Figure 15). This trend differs from the general study area which provided for an overwhelming conversion to LID urban spaces (Figure 6) which represents the second most common newly developed urban space among the top 50 block groups. This could provide for a different trend in land conversions taking place within the Top 50 Block groups; namely one that promotes higher density development practices.

Figure 15: Top 50 Newly Developed Spaces



Additionally, the top 50 block groups differ from the general study area in terms of the types of land classes being converted into newly developed urban spaces; as shown in Figure 16, new urban spaces were overwhelming developed from previously natural or non urban landscapes which account for nearly 90% of all newly developed landscapes. Given the location of these block groups (within fringe of the Houston metropolitan area) this is largely expected given most of these areas are largely rural.

Figure 16: N - U and U - U Developments



However, it is interesting to note, that unlike the general study area, the majority of the conversions taking place are largely higher density developments within both N – U and U – U conversion classes (Figure 16a and 16 b). Within the general study area, natural areas were predominately being converted into low density developments, as opposed to the top 50 block groups which show a stronger occurance of MID developments. This could indicate that the general area is more representative of traditional sprawl elements, while the top 50 block groups represent a more dense development practices. Although MIDs are preferred over LID developments (in terms of land conservation), the increase of MID developments may not be a result of efficient development practices, but may be representative of strip commercial development commonly found along highway corridors.

Figure 16a: Top 50 N - U Conversions

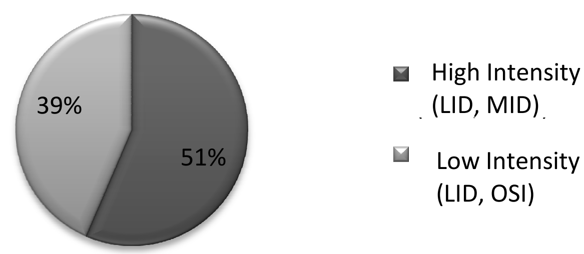
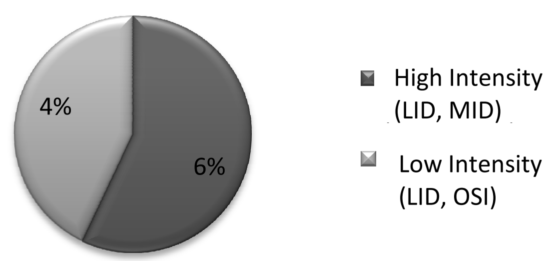


Figure 16b: Top 50 U - U Conversions

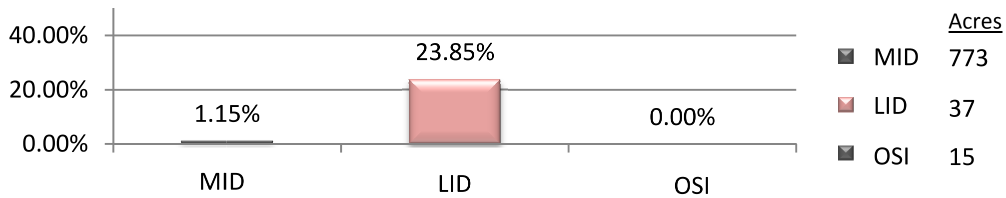


To gain a better understanding of the types of changes taking place within each of the general land classes both N – U and U – U conversions were evaluated based on the 8 subcategories as previously described and evaluated within the general study area. However, because this area is overwhelmingly dominated by forested natural landscape conversions, the following sections will not graphically represent the changes taking place within N – U conversions, and instead will focus on U – U conversions. N – U conversions, in terms of percent developed and total acreage, will still be provided for in the associated tables of HID, MID, LID and OSI developments.

1) High Intensity Developments (HID):

High density developments account for 22% of all newly developed urban spaces within the top 50 block groups (Figure 22). As summarized in Table 11 and Figure 17, the highest contributing landclass to newly developed HID were previously LID developments (23%). Although MID is also noted as a contributing landclass, it is marginal by comparision (1%). The trend provided at the block group level differs from the general study area which dipicts a common trend where cities densify in a general progression from LID to MID to HID. This jump from LID to HID developments may indicate rapid development within smaller town where the presence of schools, community centers, and strip mall development, *within* previously suburban communities may be occuring (i.e single family residential neighborhoods).

Figure 17: Land Classes Contributing to HUD



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

As previously noted, forested landscapes represents the land class most commonly converted to HID developments within this category. Again, this does not necessarily comply with the general progression in density seen in city development, and may provide for the same general inferences made for LID to HID conversions as stated earlier. Although not as common as forest, agricultural lands represent 10 % of all N – U conversions for high density developments. Based on the results provided by Table 10, it is assumed that the majority of these land class conversions are taking places within the southernmost block groups, or cohort 5.

Table 11: Top 50 Change to High Density Development (1996-2005)[3]			
	Land Class	**Acres**	**Percent**
	Medium Density	773	1.15
Urban – Urban	Low Density	37	23.85
	Open Density	15	.45
	Total of Urban to HID Development	825	25.45
Natural – Urban	**Land Class**	**Acres**	**Percent**

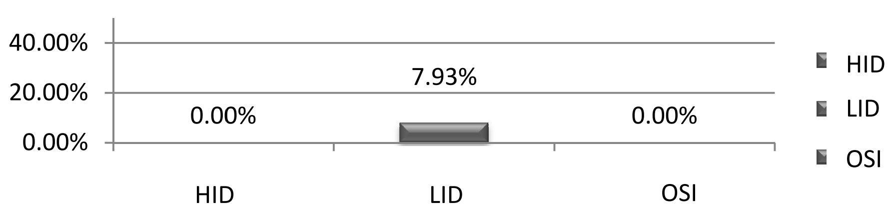
[3] The general study area was evaluated after conducting the Combinatorial And. As such, all areas were calculated based a 30 by 30 cell size area.

Table 11: Top 50 Change to High Density Development (1996-2005)[3]			
	Scrub/Shrub	71	2.18
	Agriculture	321	9.89
	Wetlands	33	1.01
	Forest	1993	61.47
	Total of Natural to HID Development	5308	74.55
	To New HID Development	6105	100

2) Medium Intensity Developments (MID)

Medium density developments account for 35% of all newly developed spaces within the prescribed top 50 block groups. As depicted in Figure 18 and Table 11, LID U –U represents the highest U – U conversion class. This means that 8% of all newly developed MIDs were previously LID urban spaces. This trend is similar to that seen in the general study area (Figure 9 and Table 7), and is an expected development trend.

Figure 18: Land Classes Contributing to MUD



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

However, it is important to note that forested areas, again represent the highest converted land class to medium density developments. This is also reflective of the general study area, but the degree to which the forested landscape is affected vs. the urban landscape is much greater within the top 50 block groups.

The most interesting observation from this section, however, is the total amount of acres being converted to MID developments. As provided by Tables 10, 11, and 12, MID is provides for the most acres developed at 6105, 8998, and 7172 respectively; this is also represented by Figure 15.

Table 11: Top 50 Change to Medium Density Development (1996-2005)[4]			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	Medium Density	50	.50
	Low Density	781	7.93
	Open Density	22	.22
	Total of Urban to HID Development	852	8.65
Natural – Urban	**Land Class**	**Acres**	**Percent**
	Scrub/Shrub	24	.24
	Agriculture	113	1.15
	Wetlands	4	.04
	Forest	8857	89.92
	Total of Natural to HID Development	8998	91.35
	Top New MID Development	9850	100

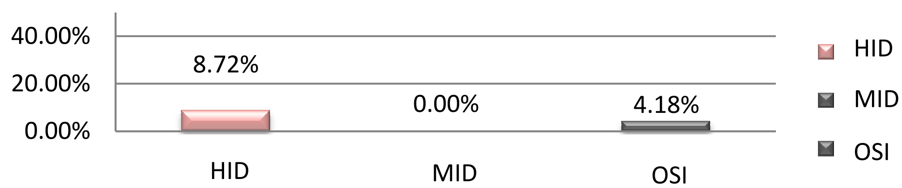
3) Low Intensity Developments:

Low density developments attribute to 25% of all newly developed urban spaces within the top 50 block groups (Figure 15). Figure 18 and Table 11 depict the land classes converted into to LID. The

[4] The general study area was evaluated after conducting the Combinatorial And. As such, all areas were calculated based a 30 by 30 cell size area.

data provided within LID developments largely mimics the general study area where OSI contributes significantly (when compared to other U - U) to LID (4%). However, unlike the general study area, HID and not MID represents the U – U landclass most commonly converted to low density urban spaces. However, the interpretation of this phenomenon is the same where this type of conversion represents an increase less dense development practices.

Figure 19: Land Classes Contributing to LUD



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

As expected forest are the highest N – U land class conversion to low density developments. Again, as seen with the previous two sections, agriculture is the next highest N – U conversion class.

Table 11: Top 50 Change to Low Density Development (1996-2005)[5]			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	Medium Density	625	8.72
	Low Density	0	0
	Open Density	300	4.18
	Total of Urban to HID Development	925	12.90
Natural – Urban	**Land Class**	**Acres**	**Percent**
	Scrub/Shrub	19	.26
	Agriculture	698	9.73
	Wetlands	130	1.81

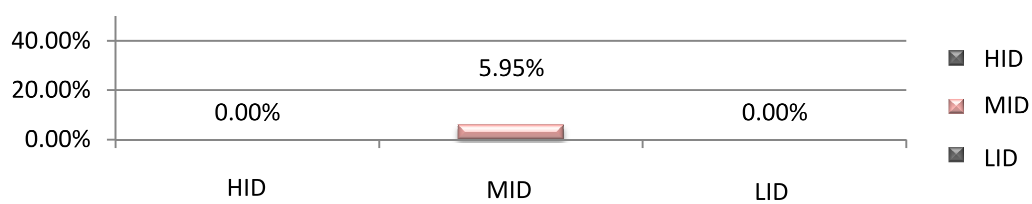
[5] The general study area was evaluated after conducting the Combinatorial And. As such, all areas were calculated based a 30 by 30 cell size area.

Table 11: Top 50 Change to Low Density Development (1996-2005)[5]			
	Forest	5400	75.30
	Total of Natural to LID Development	6247	87.10
	Top New LID Development	7172	100

4) Open Space Developments

Open space developments account for 18% of all newly developed urban spaces, and as seen in the general study area (Figure 6) represents the smallest conversion class. However, unlike the general study area, MID and not LID is the largest U – U land class conversion, meaning that more landscapes being converted to OSI developments within the top 50 block groups are occurring from lands that were previously MID whereas the same is true for LID developments within the general study area.

Land Classes Contributing to OSD



** Pink column indicates a negative development practice where previously dense developments are being converted to less dense urban spaces.*

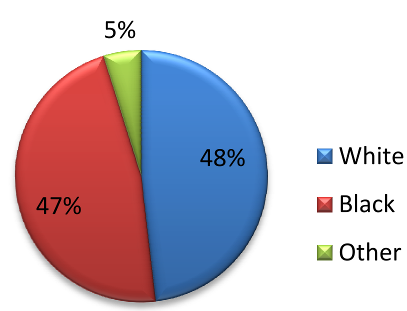
The natural landscape, again, shows the same phenomenon as reported in the three sections prior to this one.

Table 11: Top 50 Change to Open Space Development (1996-2005)[6]			
Urban – Urban	**Land Class**	**Acres**	**Percent**
	Medium Density	4	0.06
	Low Density	336	5.95
	Open Density	0	0
	Total of Urban to HID Development	340	6.02
Natural – Urban	**Land Class**	**Acres**	**Percent**
	Scrub/Shrub	8	0.15
	Agriculture	136	2.41
	Wetlands	14	0.26
	Forest	5149	91.1
	Total of Natural to HID Development	53.08	93.99
	Top New OSI Development	5648	100

Socio-Economic Trends within Top 50 Block groups:

Population was measured in these areas for good measure, and it was expected that the results would mimic that of the general study area: middle to upper class households that maintain some form of a higher degree, and who are willing to drive 60+ minutes to work daily. However, the results proved to be anything but ordinary.

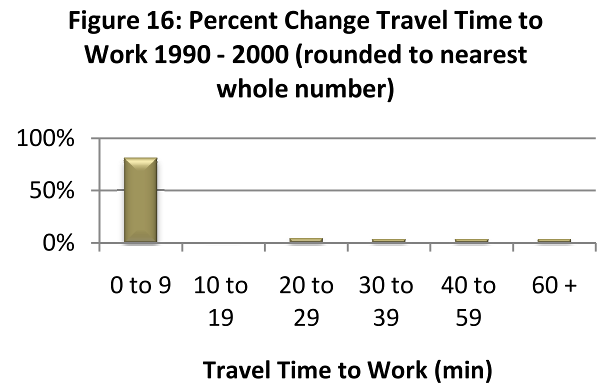
Figure 15: Race, Top 50 Block Groups



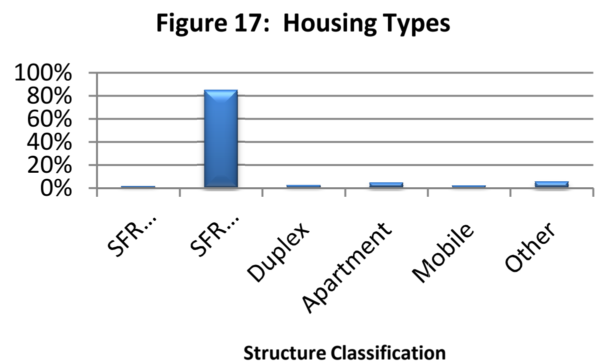
Contrary to the general study area, the most common race represented in these block groups are white. However, unlike the general study area, this percent is more common with general assumptions made about the populations that live in sprawl-like

[6] The general study area was evaluated after conducting the Combinatorial And. As such, all areas were calculated based a 30 by 30 cell size area.

developments. However, the black population showed an almost equal representation within the block groups while the "other" race group is almost non-existent within the top 50 block groups (Figure 15). Educational attainment mirrored the general study area, and as such is not discussed in detail.



The top 50 block groups also show a contradiction in the percent of individuals willing to drive 60+ minutes to work (See Figure 9). As represented in Figure 16, this population was less likely to drive long distance to work then seen in the general study area. This indicates that within the top 50 N – U conversions, individuals were working within the communities they resided in.



With all the variations between the general study area and the top 50 block groups, housing types were also evaluated. However, the results were as expected where the overwhelming majority of units consisted of single family detached homes. Interestingly, the next highest percentage shown in Figure 17 was provided by the "other" category which is typical of non-traditional housing units (i.e. campers). Although the percentage is marginal at a mere 5%, it is provides for an interesting observation.

Summary of Top 50 Block Group Observations:

As expected the top 50 block groups largely reflect the trends seen in the general study area. However, there are some significant differences between the two; namely, the percent to which MID developments are occurring within this smaller sample area. Although there is a larger percent of N – U conversions taking place, the type of urban spaces being developed are actually higher in density then that of the general study area. Again, as noted within the results section, although higher density developments are preferred, they are not always desired; this kind of development within rural communities could be an indication of strip mall type developments that are becoming more and more common along Texas highways. However, as seen in the general study area, there does seem to be a general downgrade in high density developments in terms of U – U conversions. Although significantly less influential, this may present the same types of problems noted for the general study area. Finally, the socio economic variables provide the greatest contrast to the general study area in terms of the amount of time people are willing to travel to work. As opposed to the general study area where there a sharp rise in the number of individuals willing to travel 60+ minutes to work is observed, this smaller subset of block groups provides for a work force that travels less than 10.

Discussion:

At first glance the Houston to Conroe study area proves to be a classic case of urban sprawl where natural spaces are being converted to sparsely dense, single-family developments which are occupied predominantly by white, middle class Americans that commute daily to the larger metropolitan area for work. However, selecting a smaller sample from within the study area proves that although this initial perception may be true, another form of sprawled urban development is occurring, not around large city hubs, but rather smaller towns. In this scenario the N – U conversions are still seen, but the types of individuals influencing the transformation of the natural landscape are not necessarily commuters making their way to larger metropolitan "hubs" for work, but rather individuals who live and work within the community.

These two types of scenarios represent a common problem, sprawl; however, due to the unique circumstances provided by each, related policies to retard or eliminate this type of growth can differ. That's not to say some policies should not and do not overlap from one scenario to the other, and should as needed. However, to address these issues as a "one size fits all" approach would be an irresponsible approach to planning. As such, the first type of sprawl defined – traditional sprawl – should concentrate on policies that (1) stop the trend of bedroom communities and (2) provide for more mixed use and MID and HID developments within existing urban infrastructure. The second type of sprawl – defined a rural sprawl for the purposes of this study – require policies which (1) increase density requirements of new developments, (2) prevent leap frog development and (3) protect natural landscapes.

Again, the recommendations can and should be implemented within communities across the board where appropriate. In fact, it is the opinion this researcher that the remedy for the first type of sprawl gives rise to the second type of sprawl, where communities' ability to retain their workforce during the day faces the new dilemma of increased growth, rapid infrastructure expansion and, in short, the pains of rural sprawl.

In the paragraphs that follow, possible policy recommendations which pertain to the prevention and elimination of urban sprawl will be discussed as they pertain to each sprawl type as defined above. Following this discussion, additional policies will be recommended for specific trends seen within both study areas, and this will specifically focus on policies that address the two most prevalent natural areas affected by N – U conversions: forest and agriculture.

Scenario 1 – Bedroom Communities: A Case of Classic Urban Sprawl

The first analysis – looking at the study as a whole – provided little surprise. Clearly, as discussed in depth in the results section, the results of this analysis confirmed that, with respect to the study area as a whole, typical urban sprawl had proliferated during the time period of 1996 to 2005. Urban developments were more common among N – U than U- U developments, and LID conversions were the most common type of development seen within the study area. The largest indication of urban sprawl can be seen from the interpretation of how long individuals are willing commute daily to work as more people in this area travel 60+ minutes to work. This theory is further supported by *where* the majority of N – U conversions are occurring. As noted in the result section, most of the N – U developments occurred in and around the Houston city limits and within the Houston metropolitan area.

Jobs-to-housing balance requirements: From a planning perspective, there are numerous papers and theories that suggest methods to combat these types of problems. The most common recommendation lies in the community's ability to provide enough skilled and unskilled jobs to retain its population during the day. Diversity in the types of jobs provided in a city is essential where the community is able to define its economic base with a more diversified portfolio. Although this particular policy recommendation, at first glance, may seem irrelevant to N – U conversions, they actually provide for a greater retention rate of workers during the day. This results in communities that are more self contained, where additional infrastructure, such as highways, gas station, etc. are reduced.

Mixed Use Zoning: Zoning can also be used as tool to increase mixed use development and diversify housing structure types. As provided by the data, bedroom communities typically consist of single family dwelling units. This provides for homogenous communities that must commute for certain services, goods, and entertainment. By creating mixed-use districts, communities may provide for specified areas within a landscape that may be used as community centers or central areas of interest. Likewise communities may also elect to provide for business districts and other forms of development that will provide the basic needs of its residents, ultimately resulting in a self-sustained community.

Scenario 2: Urban Sprawl

The second type of sprawl observed is best described as Urban Sprawl which is defined academically as pending rural sprawl. This type of sprawl is typically on the outskirts of smaller rural communities or located around strip-like developments. In this sense, these types of developments are located within a short driving distance of necessary amenities such as grocery stores, restaurants, and other forms of entertainment such as the cinema and shopping. Additionally, these areas also provide areas places of employment which provides for local jobs as well (MRSC, 2010).

Comprehensive Plan: The development of a comprehensive plan is essential for proper growth management in these areas. Although this recommendation seems obvious to some, many smaller communities do not have one. The result is that communities are planning with a set blueprint or guideline. For example, many communities attest to the rural life style and do not want to allow for denser developments. Although this desire is understandable, it may not be desirable in a community expected to more than double its population in a period of ten years. Creating a comprehensive plan the community, in a sense, forces it to not only look at its population, but to evaluate its current infrastructure in terms of services, jobs and housing. Can sprasely developed urban landscapes be maintained? By developing a comprehensive plan, rural communities are forced to answer this vital question.

Open Space Zoning: Open space zoning is another popular tool that is commonly used to combat rural sprawl, especially in terms of strip developments that are sometimes characterized as rural clustering. Open space zoning allows for certain types of LID and OSI developments to occur, but only within a specified area. The goal of this type of zoning is to prevent the formation of unnecessary and wasteful "Ranchette." Ranchettes, as the name may suggest, are small ranches that basically provide a homestead as opposed to a working ranch (or farm). These properties do not provide a cash crop and are not necessarily economically viable in the greater sense of the community. In fact, city infrastructure (or county, depending) is strained when the a natural area is converted to this type of development where sewer lines, roads, etc. must be newly constructed and maintained going forward. Open space zoning works to combat this problem by (1) specifying minimum lot requirements that must be farmed and/or ranched yearly and (2) specifying the total acreage of land that must be purchased as one contiguous unit to meet the definition of what constitutes open space and (3) defining the number of dwelling units allowed on the premises. These three specifications not only prevent unwanted ranchettes from developing, but also prevents "rural clustering." Rural clustering occurs when a medium to high density development occurs in an area that is mainly surrounded by natural areas which basically translates to suburban type developments in the middle of nowhere. Again, this type of development not only causes a strain of local community resources, but is also causes fragmentation of leap frog type development patterns. Moreover, this type of development may also provide for future competition with surrounding local communities, where areas of a certain size may elect to become their own community.

Capital Improvement Plans: Rural communities may also make use of capital improvements plans that specify where and when future infrastructure is expected to be provided for a certain part of a community. This tool allows the community to not only provide a blueprint for development, but it also allows for communities to deny certain types of developments that (1) require infrastructure that is not currently present and (2) specify the types of infrastructures that are expected to be provided within each designated area. As taught in any basic Planning Law course, this provides against any future "takings" claims where the smaller communities may defend denial of development by providing a blueprint that was developed well before a certain high density development (ie. Rural clustering, strip mall development) was proposed.

Protection of Natural Areas from Sprawl

The biggest challenge within any community is finding ways to influence positive growth patterns that do not cause detriment to the environment, which, in many cases, is what attracts individuals to settle in these areas in the first place (i.e. Conroe). As seen in this study, the highest conversions of N – U developments and U – U developments took place, by a large majority, in forested landscapes. As depicted in Figures 2a (Forest), 2b (Agriculture), and 2c (Wetlands, Scrub/Shrub), the fact that the greatest number of forested lands converted from N – U is no surprise. However, what is surprising is the percent of N – U conversions that are taking place when compared to U – U conversion. Although it is true that an urban area can only become so dense before it can no longer be developed, it is not the opinion of this researcher, that that is the phenomenon occurring in this instance. Based on the results provided by this study, there seems to be a lack in the development potential of already existing infrastructure. Policies which promote the use of this underutilized commodity will not only decrease the amount of N –U taking place, but will also provide some protective means for the environment. Recognizing that not all development will adhere to such policy recommendation, separate policies which provide exclusive protections to natural areas should also be developed. In this sense, if sprawl cannot be stopped, its impacts can at least be managed.

Infill Development: Infill development is the most obvious development practice that can be recommended by a community. Although legally, this type of development cannon is enforced, cities can work to provide incentives, by way of tax breaks or easements that may allow for easier construction of infill. The city may choose to develop the program as it sees fit, however, according to Texas state law, property tax abatements may only apply to new investments and can last for a maximum of 10 years.

Growth Boundaries: Growth boundaries may also be implemented. Growth boundaries prevent development from occurring outside of a city's jurisdiction. In a sense, growth boundaries are similar to capital improvement programs, but are not necessarily committed to a timeline. Instead, growth boundaries are provided within a community's ETJ where the city can simply for development to occur within these areas. Growth boundaries can be controversial and are not to be confused with " no build zones." No build zones provide that no development will occur within a designated area, while a growth boundary merely states where a city plans to extend its infrastructure and services.

Study Limitations and Future Research:

The study's original intention focused primarily on the N – U conversion where it was initially assumed that the most popular landscapes converted would be located closest to dense natural areas such as forest, agricultural and bodies of water (see Figure 3). However, this theory proved to be false. This may be due to the limitation provided by the study area. Although the scale of analysis of at the block group level proved sufficient, the scope of the study area was limited. To enhance the quality of the study, it is recommended that the area being viewed be expanded to incLIDe those areas north of Conroe where the natural landscape is more prevalent. Moreover, the city of Houston largely influenced the results of this study which was not anticipated, although proved to be an interesting factor within the results. To further assess the results of this study, it is also recommended that a similar geographic area with two or more cities of the same population size be compared. Although this method was largely criticized within the literature review, this method does avoid complications as seen with the city of Houston.

The main tool used for the purposes of this research was conducted using ArcGIS. Although the tool was sufficient for the purposes of this study, other software, such as that pertinent to remote sensing, are better equipped to analyze and manipulate raster data. As a result, operations that could easily be conducted with alternative software took an extensive amount of time to perform in ArcGIS. Additionally, certain analysis, such as correlations cannot be conducted in ArcGIS, making Microsoft Excel essential. Again, although the results proved to be the same, the process of transferring data to and from ArcGIS via .dbf files proved cumbersome and time consuming. Software more equipped for this type of analysis can be seen in software such as EDRISI.

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