

# **A Predictive Model of Residential Land Use Change in Tijuana: 1980 to 1994**

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## **Introduction**

Residential areas in Latin American cities are in a constant state of flux. Squatter settlements gradually change from dusty wastelands of cardboard shacks to solidly built neighborhoods, fully integrated into the fabric of the city. At the same time, mansions of the elite near the city center get subdivided into apartments for the middle class as wealthy residents move outward in search of more space and modern household amenities. As in most Latin American cities, residential areas in the city of Tijuana have undergone rapid transformation in the recent past. Tijuana has played a central role in the expanding economic interaction between Mexico and the United States. Since the early part of the twentieth century, Tijuana has grown from a small town focussed on recreation for U.S. military personnel to a modern industrial city. This has allowed rapid upward mobility for local residents and attracted large numbers of migrants in search of economic opportunity. As a result, the residential landscape is constantly changing. As the middle class expands in Tijuana housing quality improves. People upgrade their homes and demand better urban infrastructure from the government. Likewise, new squatter settlements develop on the edge of the city as new migrants arrive.

While residential land use change is ubiquitous in Tijuana, it is not a random process. The presence of commercial or industrial land uses, for example, can make certain areas more or less desirable places to live. This can affect the socioeconomic character of a neighborhood and influence the amount of investment people are willing to put into homes in that location. The purpose of this study is to examine features of the built and physical landscape which affect change in residential land use. With an understanding of these features, a predictive model of residential land use change is developed. The predictive capacity of the model is then tested against observed residential land use change in Tijuana between 1980 and 1994.

Predictive urban models will facilitate our understanding of how cities grow and how they are likely to look in the future. This project attempts to model residential land use change between 1980 and 1994.

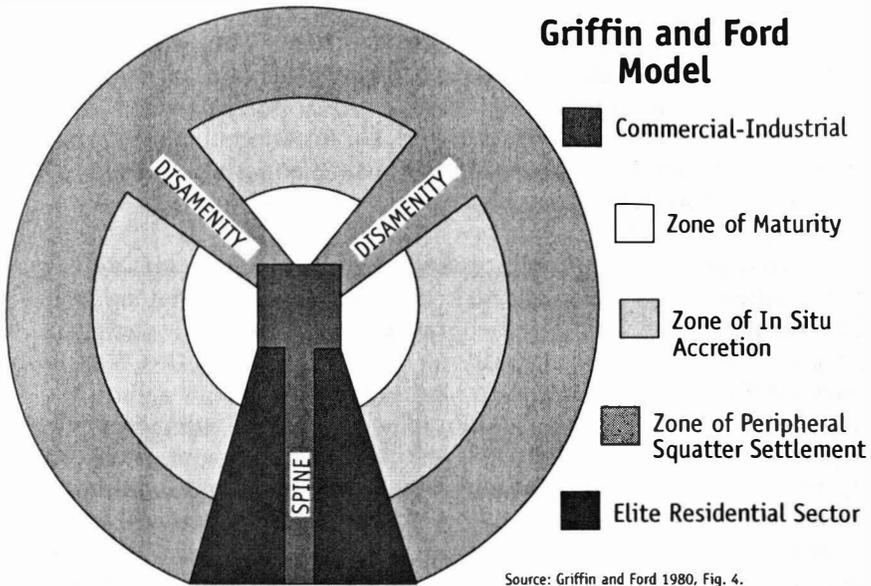
By comparing the model's predicted 1994 land use with actual 1994 land use it is possible to uncover and assess explanatory variables. Once the predictive capacity of the model is perfected, it will be possible to project change into the future. This will provide insight into future urban form and assist with the planning and management of urban growth.

## **Background Literature**

The predictive model developed in this research is based on insights gained from the literature on Latin American urbanization. Of particular significance is the literature on urban morphology and residential land use change. This section will first present a summary of models on Latin American city structure. These models are useful in explaining the spatial patterns of land uses and the processes behind their development. Second, case studies of residential land use change will be presented. These two sections provide the theoretical building blocks for the predictive model. Finally, a brief history of growth in Tijuana will provide a backdrop for the study.

## **Land Use Structure and Change**

The most commonly cited paper on Latin American city structure is written by Griffin and Ford (Griffin and Ford 1980). They present a simple, yet effective model which illustrates general patterns and processes behind Latin American urban morphology (fig. 1). They describe an elite residential sector radiating from the city center along a commercial spine. Along the outer edges of this spine are upper-middle and middle-class residences which act as a buffer between the elite and lower classes. In addition to an elite spine is a "zone of maturity" surrounding the central business district. This area is dominated by stable middle-class residences, some of which are professionally built and some which are significantly upgraded former squatter settlements. Subdivided mansions which have filtered down to the middle class are also located in this part of the city. In a ring around the zone of maturity is the "zone of in-situ accretion." This area shows signs of transition to a zone of maturity but is quite variable in housing quality. Many houses are poorly built while others are solidly constructed with concrete block. On the undeveloped outer edges of the city is the "zone of peripheral squatter settlements." While these communities are poverty stricken and often have the appearance of refugee camps, residents find hope in the fact that those before them have upgraded their neighborhoods over time. The relative size of each ring depends on the rate of in-migration compared with the pace of individual improvements of housing, and the ability of a city to provide urban services. Finally, there are wedges of disamenity areas emanating from the center city. These areas include



Source: Griffin and Ford 1980, Fig. 4.

FIGURE 1. The Griffin and Ford Model of Urban Land Use in Latin American

flood zones and steep slopes where it is difficult to build and upgrade housing.

A more complex model is presented by Bahr and Mertins (Bahr and Mertins 1982). Their model emphasizes wedges and isolated islands of residential growth, as well as industrial land use. As in the Griffin and Ford model, the upper classes move away from the center city in an outwardly expanding wedge. Also, the middle and upper-middle classes act as a buffer surrounding the elite residential wedge. As the elite leave the city center low and middle class residents move into subdivided homes. At the same time low and lower-middle class communities form alongside wedges of industrial land use. Squatter settlements develop as "islands" on the edge of the city, but also on undeveloped land within the city. Inner city squatter settlements are usually temporary due to a greater risk of forcible eviction.

Other models focus specifically on Mexican border cities with the U.S. (Gildersleeve, 1978; Hoffman, 1983; Arreola and Curtis, 1993). Arreola and Curtis (Arreola and Curtis 1993) offer the most recent model and incorporate the latest changes in urban morphology. Upper, middle, and lower class housing is organized similar to previously discussed models with one significant exception. As foreign owned assembly plants, or maquiladoras, develop near the outer edges of border cities, public housing—primarily middle-class—develops nearby.

Models of Latin American city structure show that there are discernable patterns in residential land use. While land uses are not as exclusive as in the United States, there are clear patterns which help us understand how cities grow and change. For instance, upper-class housing is rarely located near low-income housing, and industry tends to be located near low or lower-middle class housing.

While models of urban morphology illustrate how cities are organized, other studies demonstrate how particular residential areas form and transform over time. Pozas-Garza (1989), for example, studied land invasions by squatters in the city of Monterrey during the 1970's and early 1980's. Numerous organized land invasions occurred during this time which resulted in the creation of several large settlements. While these invasions were initially resisted by the government, it was soon realized that rapid industrialization was shifting the population from rural to urban areas. Soon the government began to facilitate squatter settlements by providing land, construction materials, and urban services at an affordable cost. Bennett's (1989) research on urban public services and social conflict further illustrates how communities manage to improve with time. Her research documents the popular protests which led to "Agua Para Todos" in Monterrey. This program made Monterrey the first city in Mexico to have individual house connections extend into all of its poorest neighborhoods at once. These studies show how communities evolve and improve through self-help methods and, with enough pressure, eventual government provision of public services.

Other research has examined change in upper-class housing. For example, in addition to low income neighborhoods, Ward (1990) discusses changes involving elite residents in Mexico City. His research indicates that upper-class housing not only extends outward in a wedge separated from lower-class neighborhoods by natural barriers, but has also moved into existing neighborhoods through gentrification.

## **Growth and Change in Tijuana**

Tijuana has undergone rapid growth and change during the second half of the twentieth century. During the 1940's and 1950's the city experienced rapid population growth. This was largely due to pull factors of the Bracero Program in the United States, which attracted workers from central Mexico to the border region with opportunities for agricultural work (Saghafi 1994). During this time the population of Tijuana grew from 21,977 in 1940 to 165,690 in 1960 (Zenteno Quintero and Cruz Pinero 1992). With the end of the Bracero Program population growth rates declined, however the city continued to grow significantly

in real numbers. By 1970 the population of Tijuana was 340,583. It was during this time that the city's "spine" to the southeast of the CBD grew dramatically, yet the city continued to focus on the traditional core (Griffin and Ford 1980).

During the 1970's industrial development in Tijuana accelerated and population growth continued. By 1980 there were 123 maquiladora plants in Tijuana (Comision Economica para America Latina y el Caribe 1994). This represented nearly 20% of all maquiladora plants along the U.S./ Mexico border. Initially these plants were located in commercial areas within the existing built up area of the city but soon large industrial parks on the outer edges of the city were developed (Herzog 1990). This began to pull the city outward, away from the traditional core. As Tijuana's economy expanded through the 1980's its population continued to grow. Between 1980 and 1990 the population grew 61%, from 461,257 people to 747,381 (San Diego Association of Governments 1992). Industrial expansion and population growth have continued in the 1990's. As of 1994 the population of Tijuana was 793,401 (Obec, 1997).

As can be seen, Tijuana has grown rapidly in recent decades. Compared to many Mexican cities Tijuana is young, with the majority of development occurring during the past fifty years. Even as of 1980 residential areas were concentrated around the central city and to the southwest along the spine, but this is changing. As the city grows, residential neighborhoods change. Relatively young developments have transformed from zones of in-situ accretion to zones of maturity, while new settlements have appeared on the outer edges of the city. As economic interaction continues to grow with the United States, the population of Tijuana is likely to increase. New communities will develop and old communities will change as the city and its residents adapt to changing economic and demographic conditions.

The remainder of this paper will discuss an attempt to understand and predictively model how residential areas have changed between 1980 and 1994. Insight gained from models of Latin American city structure and empirical research on housing and neighborhood transformation is used to develop a predictive model of residential land use change. With an understanding of how neighborhoods transform with time it will eventually be possible to predict where and to what degree housing quality is likely to change. This will assist urban planners and others in locating services and public facilities, hopefully resulting in a more smoothly functioning and equitable city.

## Methodology

The data sources for this project are Arc/Info land use coverages for 1980 and 1994 (San Diego State University et al. 1997). Each coverage contains approximately fifteen land use designations and six residential land use classifications. The residential land use classifications are discrete categories ranked from 1 to 6. Class R1 is elite residential and includes expansive luxury homes with full infrastructure and services. Class R2 is upper middle income residential and is similar to Class R1 but more modest in scale. Class R3 is middle income residential and includes fully serviced land with some paved roads. These homes are almost fully accreted and include government housing. Class R4 is lower middle income residential. These homes are rapidly accreting and are built with a wide range of materials. The presence of paved streets, electricity, water, and sewerage is evident but irregular. Class R5 is low income residential. In this class homes are being transformed into more stable structures. Dirt roads, pirated electricity, trucked water, and privies are common. Class R6 is squatter settlements. These dwellings are typically built with scrap materials such as metal, wood, cardboard, and plastic. Formal services and infrastructure are lacking in these areas. These coverages were created from air photo interpretation. The 1994 coverages were ground checked for accuracy.

Based on the literature discussed above it is evident that land uses are dynamic yet arranged in particular patterns. Independent variables were chosen which reflect the relationships between different land uses. Distances between residential classes, commercial, industrial, non-developed, and agricultural land were chosen to reflect these relationships. An additional independent variable of slope was used to determine if steep, less desirable land changed at a slower rate. The dependent variable was the degree of change in each polygon between 1980 and 1994.

Calculation of the necessary variables was done in Arc/Info. The entire residential area of Tijuana was converted to 30 meter polygons. In order to study change in residential quality, only areas that existed in 1980 were used. Residential areas developed after 1980 were blacked out of the 1994 coverage. The degree of change between 1980 and 1994 was then calculated for each 30 meter polygon (fig. 2 and 3). For example, no change gave a value of 0 while a change from R5 to R3 gave a value of 2. A decrease in quality gave a negative number. For the independent variables, the distance from each 30 meter polygon to the nearest polygon of each land use and housing class was calculated. For example, an R3 polygon would have the distance to the nearest R1, R2, R4, R5, and R6 polygon, as well as the distance to the nearest commer-

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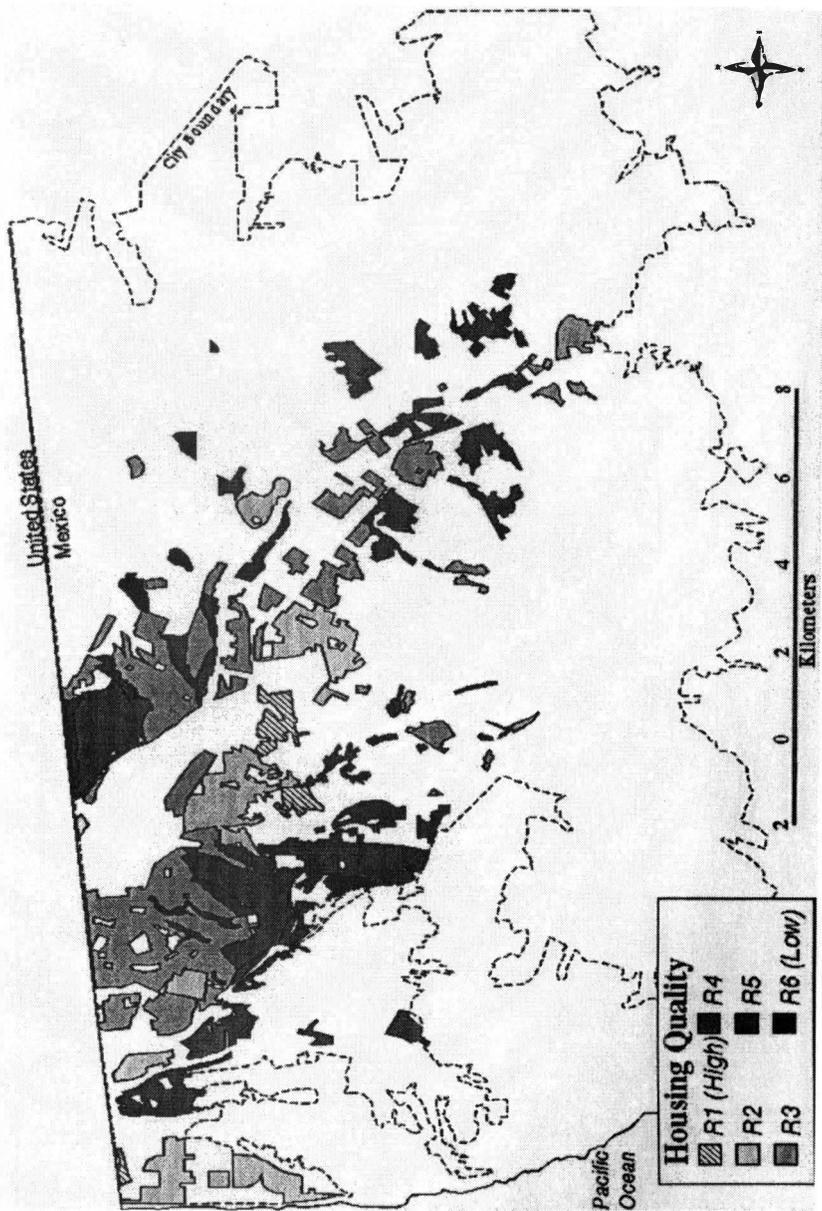


FIGURE 2. Observed Residential Landuse for Tijuana in 1980

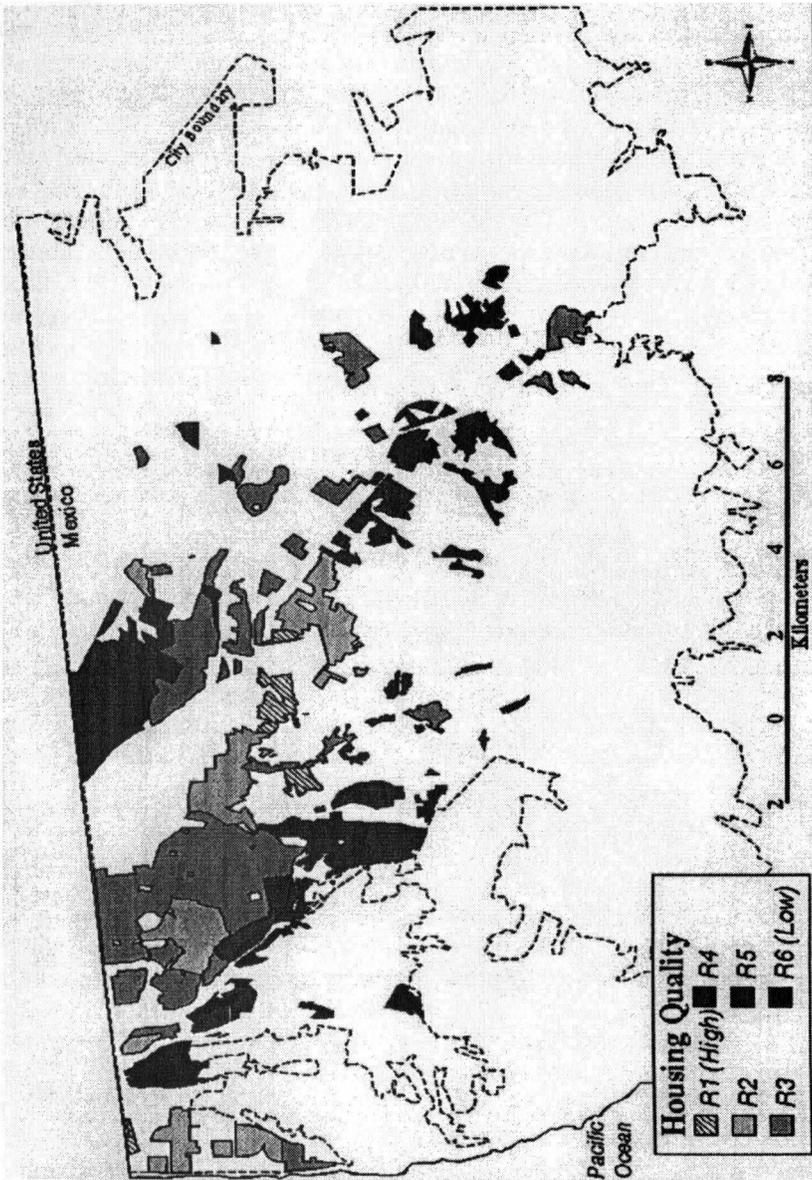


FIGURE 3. Observed Residential Landuse for Tijuana in 1994

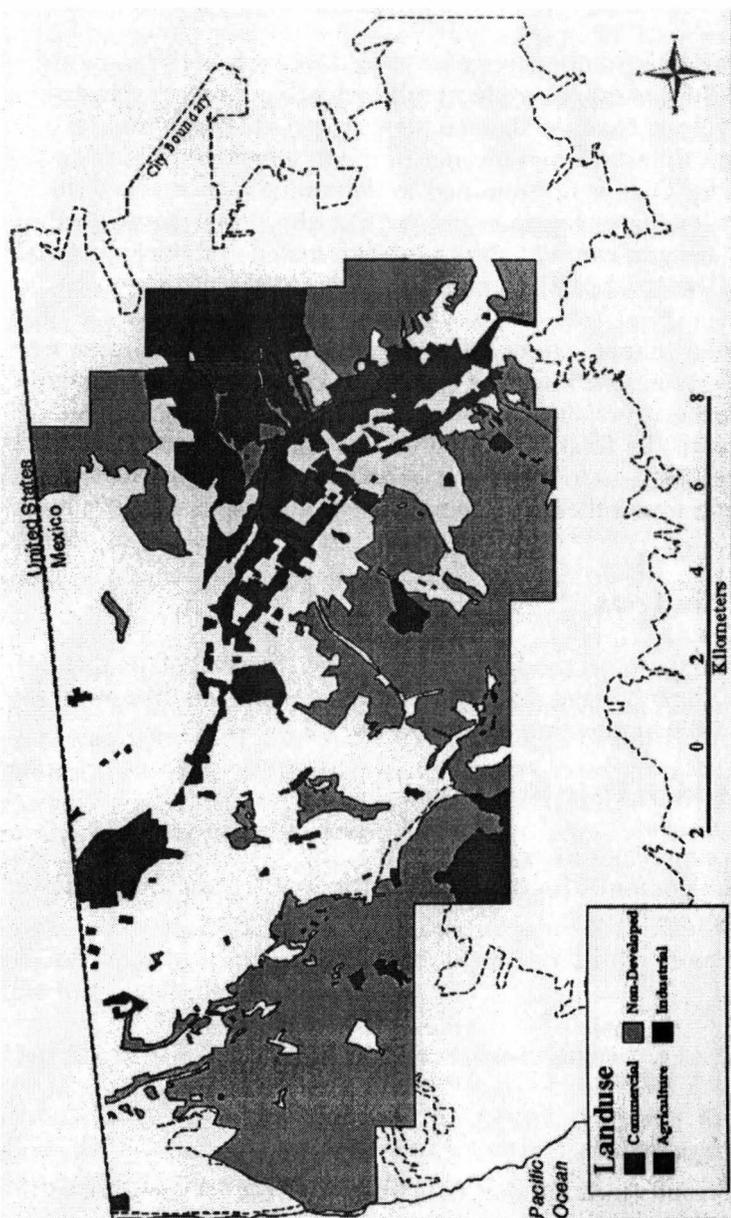


FIGURE 4. Landuse for Tijuana in 1980

cial, industrial, agricultural, and non-developed polygon (fig. 2 and 4). The 1980 land use coverages were used for these calculations. In addition, the degree of slope was added to each 30 meter polygon.

Fifty random numbers were generated for each of the six housing classes and the correspondingly numbered polygons were selected for statistical analysis. Ordinary Least Squares regressions were run for each housing class to test the significance of the independent variables. The diagnostics for OLS were examined to determine if heteroskedasticity, spatial error, or spatial lag were present (Anselin, 1992). Based on these diagnostics, insignificant variables were eliminated and the appropriate model (OLS, heteroskedastic, error, or lag) was run.

Predicted change values for each polygon in the study area were then calculated in Arc/Info. The regression coefficients for the significant independent variables were multiplied by the values in each 30 meter polygon. The final change value was usually a fraction so numbers were rounded off to the nearest whole number. The predicted 1994 housing classes were then mapped along with the observed 1994 housing classes.

**Results/ Analysis**

Separate statistical models were developed for each of the six housing classes. The following discussion explains what variables were significant (at 0.05) in affecting residential land use change.

**The R1 Model: Elite Housing**

Regression diagnostics indicated that the Spatial Error Model was the best estimator for R1 housing change. The Spatial Error Model showed the following coefficients:

VARIABLE	COEFF	S.D.	PROB.
Constant	-.271196	0.0785604	0.000556
R2dist	0.000486896	0.000136135	0.000348
Lambda	7.75488	1.00748	0.000000

AIC<sup>1</sup>: -37.50

These results indicate that the closer R1 areas are to R2 areas the more likely they are to decrease in quality. The positive coefficient for R2 distance shows that as the distance between R1 and R2 increases (ie. they are located further from each other), the R1 change value increases. Conversely, as distance decreases the change value decreases. Since R1

is the highest category of housing quality it is not possible for them to increase in quality. These results fit with theoretical models in that high quality housing is rarely found near low quality housing. Thus housing classes below R2 have no influence on change in R1. Also, even though R2 housing is only slightly lower in quality, if a R1 area is going to decrease in quality it is more likely to be closer to a lower quality area. Thus lower housing quality has a negative impact on higher quality housing.

### **The R2 Model: Upper Middle-Income Housing**

The Ordinary Least Squares model proved to be the best estimator for R2 housing change. OLS showed the following coefficients:

VARIABLE	COEFF	S.D.	PROB
Constant	0.0224747	0.105634	0.832475
R4dist	0.000600642	8.30967E-05	0.000000
R5dist	-0.00018197	3.23162E-05	0.000001
R6dist	-0.000212732	3.4002E-05	0.000000
CommDIST	0.000274447	0.000114428	0.020673

AIC: -14.67

These results fit less clearly with theoretical models than the R1 results. While R4 areas tend to pull R2 areas down in quality the closer they are, R5 and R6 areas have the opposite affect. No theoretical models explain why the lowest quality housing types would have a positive influence on areas of higher housing quality. Commercial distance has a negative influence on R2 change as well—the closer an R2 area is to commercial land uses the less likely it is to improve. Models of Latin American city structure indicate that higher income housing is located close to elite commercial areas. The negative relationship found with this data may indicate a threshold distance where commercial land uses are too close to upper middle class housing (R2) for them to become elite housing (R1).

### **The R3 Model: Middle Income Housing**

In the case of R3 housing, the Heteroskedastic Error Model (Groupwise) was the best estimator of housing quality change. This model showed the following coefficients:

VARIABLE	COEFF	S.D.	PROB
Constant	-0.753497	0.144957	0.000000
R2dist	-0.000348484	6.29847E-05	0.000000
R6dist	0.000206936	4.6958E-05	0.000010
Inddist	0.00037144	8.50799E-05	0.000013

R-square(Buse)<sup>2</sup>: 0.42

These results show that higher quality housing increases the rate of change in R3 areas while lower quality housing decreases the rate of change. As can be seen, the closer R3 areas are to R2 areas the more likely they are to upgrade and the closer R3 areas are to R6 areas the less likely they are to upgrade. The distance to industry is also a significant variable and has a negative impact on change in R3 areas. Many industrial land uses in Tijuana produce noxious emissions and are not desirable places to live for those with private transportation. Therefore middle-income areas (R3) are not likely to upgrade to upper middle (R2) or elite (R1) residential areas if they are too close to industry.

### The R4 Model: Lower Middle Income

Regression diagnostics for R4 change indicate that the Spatial Lag model was the most appropriate predictor.<sup>5</sup> The Spatial Lag Model shows the following coefficients:

VARIABLE	COEFF	S.D.	PROB
W_Change	24.0699	4.12408	0.000000
Constant	1.21292	0.218993	0.000000
R2dist	0.000423042	0.000121804	0.000514
R3dist	-0.00069071	0.000145183	0.000002
R6dist	-0.000282885	7.55776E-05	0.000182
CommDIST	-0.000985117	0.000276067	0.000359
Slope	-0.0275261	0.011568	0.017336

AIC: 44.646

The results of this regression present inconsistent theoretical patterns. Higher quality housing has both a positive and negative influence on change in R4 areas. R4 areas tend to upgrade more if they are closer to R3 areas, however they tend to upgrade less if they are closer to R2 areas. Furthermore, R6 areas nearby cause housing to upgrade more quickly. These inconsistent patterns can not be explained with traditional theoretical models. Other significant variables fit better with Latin American city structure theory. Commercial areas have a positive influence on change in R4 areas. Lower middle income (R4) residents are less likely to own private transportation so proximity to commercial land uses is desirable. This makes shopping and travel to work cheaper

and less time consuming. In addition, change occurs more rapidly on gradual slopes than on steep slopes. Steep slopes are more prone to instability and are less desirable places to live so there is less upgrading in these areas.

**The R5 Model: Low Income**

The Spatial Error Model was the most appropriate for R5 areas and resulted in numerous significant variables—R1, R2, R3, R4 distance; commercial, agriculture, and industry distance; and slope. The coefficients for these variables are listed below:

VARIABLE	COEFF	S.D.	PROB
Constant	1.36577	0.417095	0.001059
R1dist	-0.000347936	7.54484E-05	0.000004
R2dis	0.00123563	0.000141364	0.000000
R3dit	-0.00210654	0.000184004	0.000000
R4dist	0.00100278	0.000225516	0.000009
CommDIST	-0.00151772	0.000252103	0.000000
Slope	0.0228838	0.00671277	0.000652
Agdist	0.000645821	9.73855E-05	0.000000
Inddist	-0.000755259	0.00015525	0.000001
Lambda	16.3565	2.17433	0.000000

AIC: 44.65

The results of this model are inconsistent with Latin American city structure theory as well. The coefficients show that two higher quality housing classes, R1 and R3, increase change in R5 the closer they are, while two other higher quality housing classes, R2 and R4, decrease change. Once again, this can not be explained by traditional theory. Another counter-intuitive result relates to the slope coefficient. Unlike with the R4 areas, R5 areas upgraded more on steeper slopes, despite the fact that these areas are more difficult to develop. Both commercial and industrial land uses had a positive affect on change in R5 areas. This is because low income residents are less concerned with the negative externalities of commercial and industrial land uses than they are about reducing the travel costs of work and shopping. Finally, R5 areas changed less the closer they were to agricultural land.

**The R6 Model: Squatter Settlements**

The Heteroskedastic Error Model (Goupwise) was the most appropriate model for R6 housing change. Listed on the following page are the coefficients for this model:

VARIABLE	COEFF	S.D.	PROB
Constant	9.09491	1.32577	0.000000
R2dist	0.00167012	0.000282022	0.000000
R3dist	-0.00133751	0.000183994	0.000000
R4dist	-0.00387374	0.000455885	0.000000
R5dist	0.000751955	0.000255526	0.003253
CommDIST	0.000531753	0.000193213	0.005920
Nddist	0.0039045	0.000431427	0.000000
Agdist	0.00224627	0.000280899	0.000000
Inddist	0.002877	0.000608305	0.000002

R-square(Buse): 0.98

Again two higher quality residential classes, R3 and R4, increased change with proximity while two others, R2 and R5, decreased change. A more consistent pattern emerges with respect to the other significant variables. R6 areas are the lowest quality housing in Tijuana. Many settlements of this type form illegally on vacant land, were occupants do not have legal title to their plot. More remote settlements, in this case those further away from commercial, industrial, and agricultural land, face less threat of forced removal. This is due to the fact that remote areas have less economic value for property owners. A reduced threat of removal means that people are more willing to invest in improvements of their homes. Thus change occurs more rapidly. A problem with this explanation, however, is that R6 areas further from non-developed land also upgraded more rapidly. This leaves R6 polygons surrounded by other R6 polygons, as well as R5 and R2 polygons as the most likely to improve.

### **Mapping and Accuracy of 1994 Predicted Residential Land Use**

Based on the regression coefficients discussed above, residential land use change was "projected" from 1980 to 1994. This resulted in a predicted 1994 residential land use map (fig. 5). Since this project only examined change in housing quality since 1980, all post-1980 development was blacked out of the map. A visual comparison of the predicted 1994 land use map with the observed 1994 land use map indicates that the models were not 100 percent accurate in predicting change in housing quality. Areas of correctly and incorrectly predicted land use can be seen in figure 6.

A quantitative summary of figure 5 was calculated through a classification error matrix (fig. 7). This matrix compares the area of observed and predicted residential land use classes. The matrix indicates that 65 percent of the residential areas were correctly predicted. These results

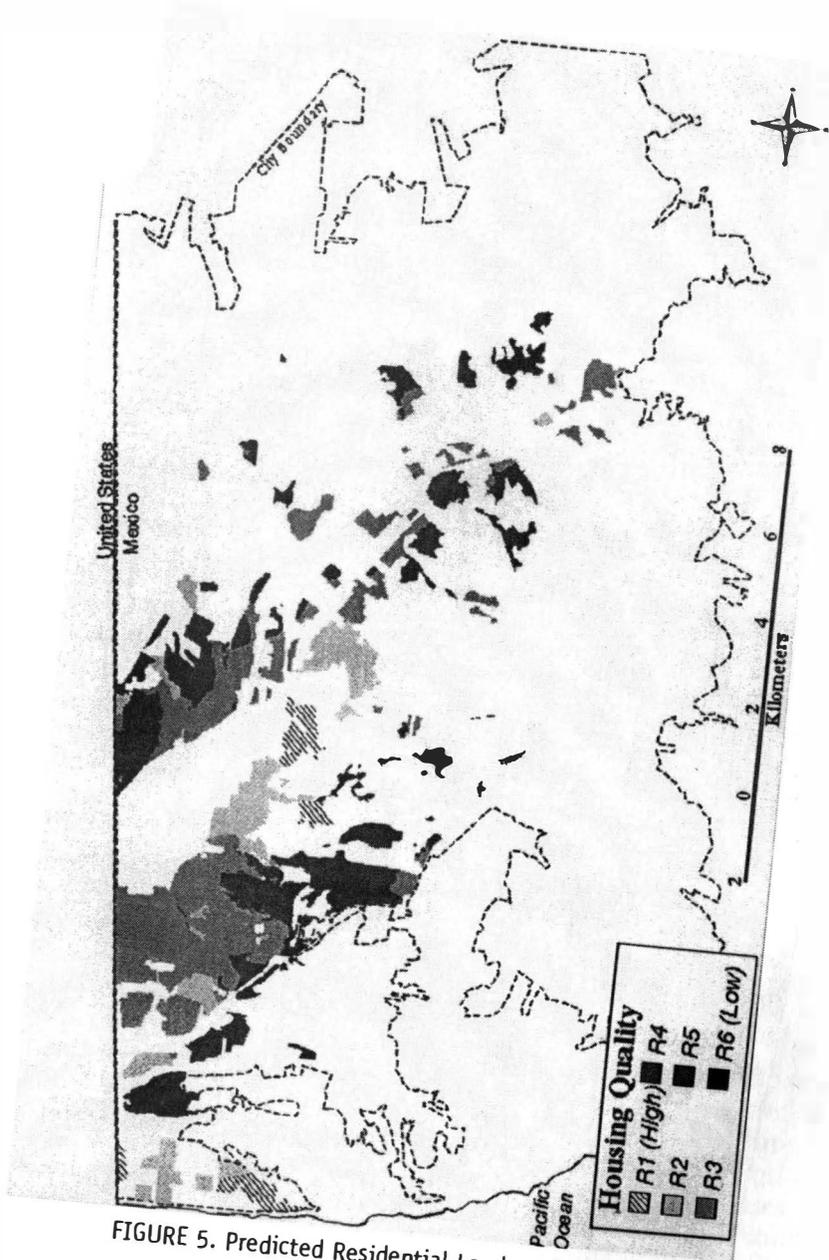


FIGURE 5. Predicted Residential Landuse for Tijuana in 1994

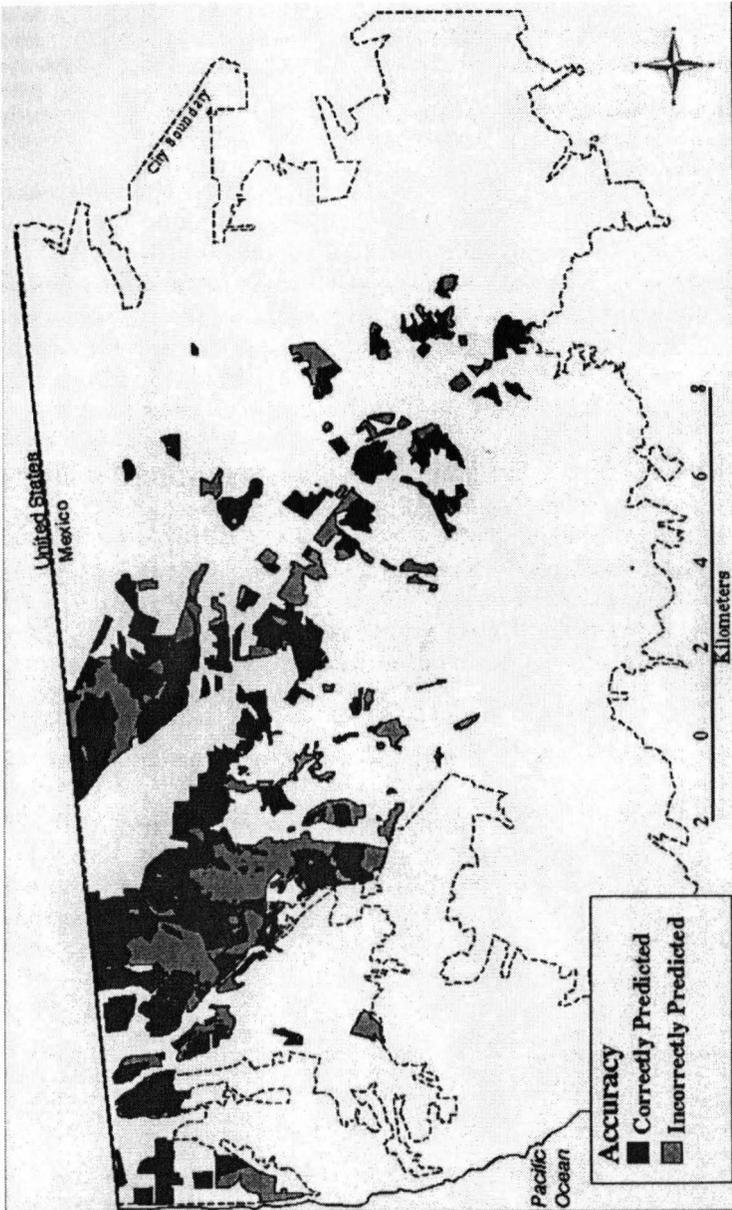


FIGURE 6. Accuracy of Predicted Residential Landuse in 1994

**Observed 1994 Area**

		Observed 1994 Area						
Class		1	2	3	4	5	6	Row total
Predicted 1994 Area	<1	539	0	53903	93369	38887	337684	524383
	1	1111979	373434	398034	10260	0	0	1893705
	2	131980	5444399	579534	445393	494	0	6601800
	3	564	1828828	11339267	3327544	35366	92441	16624010
	4	0	4991	3250515	6414313	1393997	294887	11358704
	5	0	0	242449	484382	1675288	673057	3075176
	6	0	5799	94361	226655	281866	1767875	2376556
	>6	0	0	0	0	0	121816	121816
Col. Total	1245062	7657450	15958064	11001916	3425899	3287758	42576149	

User's Accuracy		Overall Accuracy
1	0.59	0.65
2	0.82	
3	0.68	
4	0.56	
5	0.54	
6	0.74	

FIGURE 7. Classification Error Matrix and Model Accuracy

vary by class however. A user's accuracy, or the probability that a given classification actually represents what is on the ground, varies from 54 to 82 percent. Housing classes 2, 3, and 6 were higher than 65 percent, while classes 1, 4, and 5 were below the 65 percent overall accuracy. Figure 8 shows the breakdown of predicted housing classes by observed housing class. The models for classes 2, 3, 4, and 5 correctly predicted greater than 90 percent of the area within one value of the observed housing class. Only classes 1 and 6 had less than 90 percent of the predicted area within one housing class of the observed area.

**Conclusions/Future Work**

As the above results and discussion indicate, general patterns are difficult to find in the data. While higher quality housing sometimes has a positive influence on change in nearby areas, this is not always the case. Frequently the data shows that lower quality housing has a positive influence on change. Likewise steep slopes have a positive influence in some cases and a negative influence in other cases. These inconsistencies can not be explained easily with traditional models of Latin American city structure. Rather, this illuminates the limits of morphological models. While models of urban structure can show general patterns of land use, the real world is much messier. Models of Latin

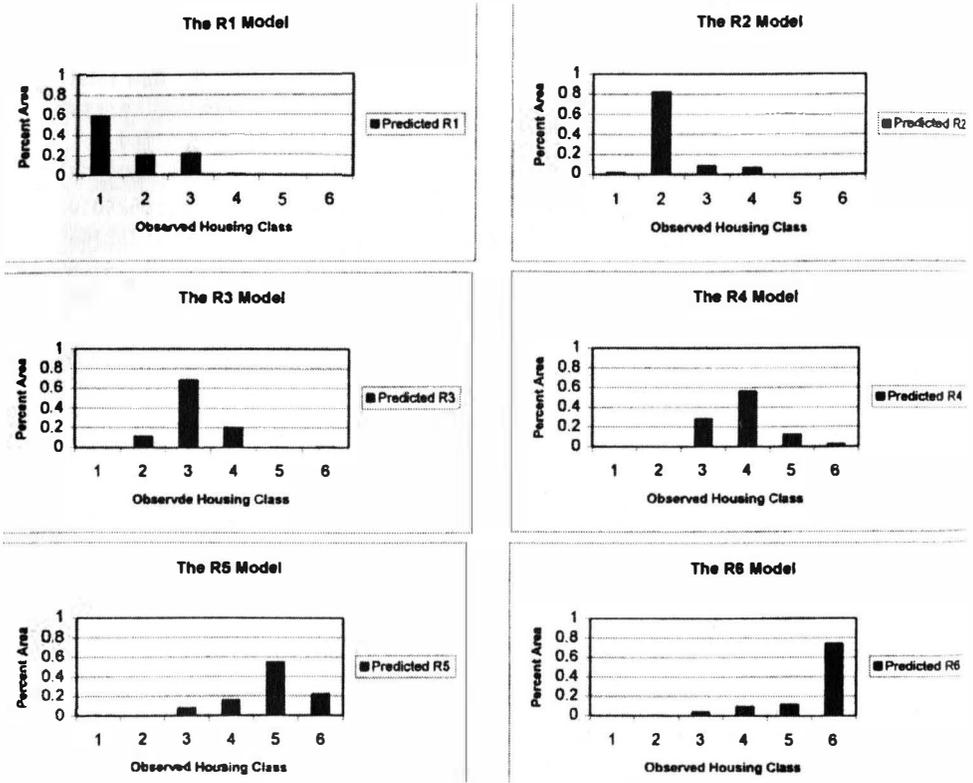


FIGURE 8. Distribution of Predicted Housing Class Area

American urban structure can assist in identifying appropriate explanatory variables, but the idiosyncratic nature of cities means that generalized forms can never be fully described or explained. Each city's unique physical setting and historical development creates a different urban form. The predictive model developed through this research correctly classified 65% of residential area change. Additional explanatory capacity may come from economic or demographic theory, which is not explicitly included in most urban morphological models. Future research will incorporate new variables and utilize spatially explicit limited dependent variable models to more accurately assess land use relationships in Tijuana. It is hoped that these models will uncover more consistent patterns and improve the model's predictive capacity.

In addition, future work will include predicting not only how existing residential areas change, but where new residential areas will develop. Both change and growth will then be projected to the year 2020 in an attempt to map how Tijuana is likely to look roughly 20

years from now. Integration with predictive demographic models will allow different scenarios to be run based on varying levels of population growth and decline.

Predictive models such as this are useful for urban planners, social service providers and others who need to efficiently allocate limited resources. Government, business, and non-profit agencies have long relied on population projections to plan for the future. Predictive land use models attempt to determine not only how *many* people there will be, but *where* they will live. With an understanding of where different people of different socioeconomic conditions are going to be, it becomes easier to plan for change. If it is known, for example, where squatter settlements are likely to develop, plans for the provision of infrastructure can be established beforehand. Likewise, placement of schools and health care facilities can be planned based on the needs of different populations. Spatial information such as this will hopefully lead to better functioning and more livable cities.

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## **Notes**

<sup>1</sup> The Akaike Information Criterion (AIC) is a goodness of fit measurement which corrects for overfitting when additional variables are added. Lower values indicate better fits (Anselin, 1992).

<sup>2</sup> FGLS estimation for the heteroskedastic error model does not include the AIC measure of fit. Therefore, the R-square(Buse) measure for models with non-spherical errors is included (Anselin, 1992).

<sup>3</sup> The Spatial Lag Model does not allow for easy calculation of predicted values in Arc/Info. Because of this, coefficients for the predictive map come from the OLS Model.