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of Future Urban Residential Development
Near Nellis Air Force Base, Nevada

James D. Westervelt

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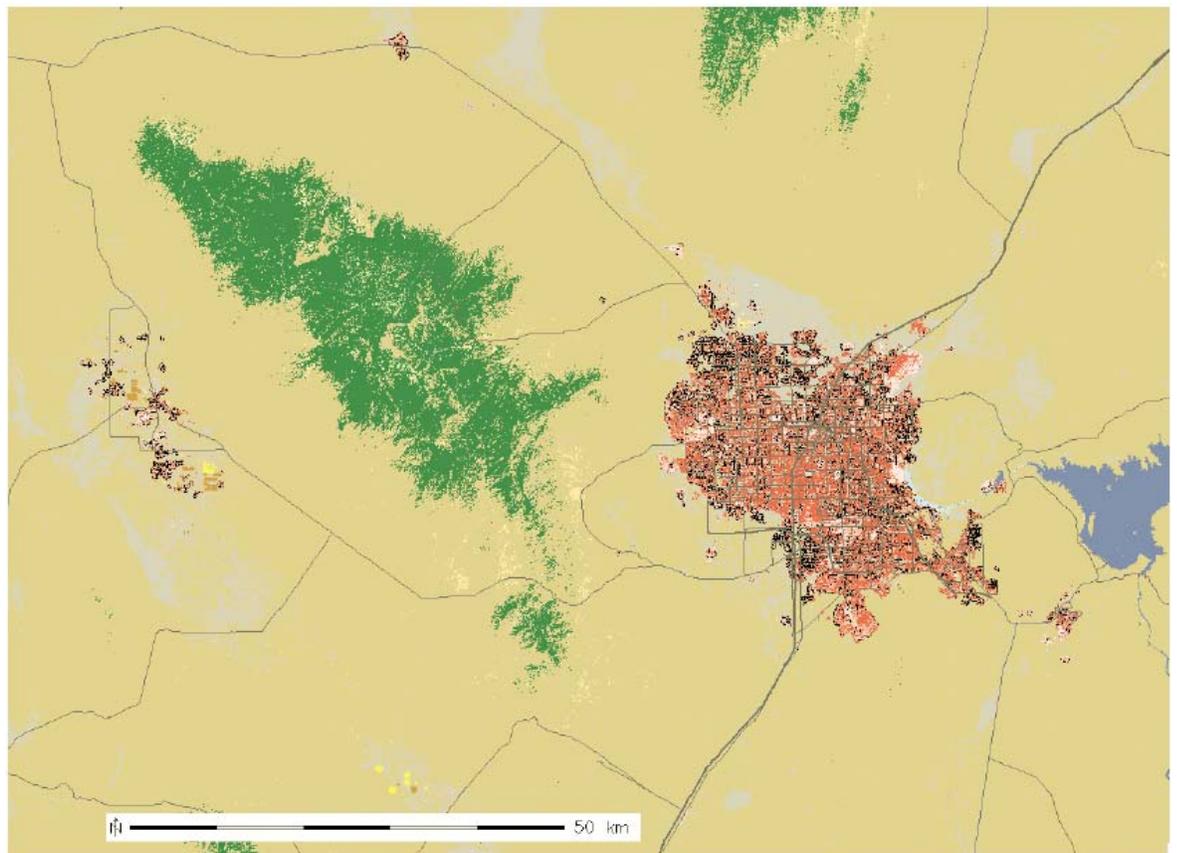
Location Forecast of Future Urban Residential Development Near Nellis Air Force Base, Nevada

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Final report

Abstract: Urban growth near military facilities could erode the ability of the military to conduct current and potential future missions in southern Nevada, especially near Nellis Air Force Base (AFB). While it is well understood that the Las Vegas urban area (and the I-15 corridor connecting it to the Los Angeles basin) have experienced significant growth, it is the anticipated patterns of future development that are most important to military planning. Proper regional planning could alter the patterns of future development near installations. This document reports the results of applying the Regional Urban Growth (RUG) model to the region surrounding Las Vegas to forecast where future growth is likely to happen. This exercise did not project any significant nearby urban development near Nellis AFB. The base appears to be blocking extension of urban development to the northeast and development pressure is not currently substantial enough to leapfrog the base. This first-cut analysis can be followed by more detailed urban growth modeling to fine-tune these results. Subsequent modeling can also test the implications of alternative regional plans involving significant highway/road construction, transfer of property rights associated with large tracts, and regional zoning.

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Preface

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1 Introduction

1.1 Background

Nellis Air Force Base (AFB), known as the "Home of the Fighter Pilot," sits at the northeast edge of the Las Vegas metropolitan area, bordering the City of North Las Vegas. Weapons training and high-speed aerial maneuvers are part of the Nellis air combat training experience. This training utilizes the Nellis airfield and an associated vast airspace above Department of Defense (DoD), Bureau of Land Management (BLM), and other government-owned, sparsely populated lands throughout much of Nevada.

Urban population currently abuts the base's physical location, since urban areas are now just outside the northwest, west, southwest, and southern boundaries of Nellis. In fact, its main southwest-northeast axis runways are directly in line with dense urban areas to the southwest. Additionally, continued urban development could encroach upon the base's potential training areas and airspace. The Las Vegas metropolitan area continues to grow rapidly, posting a growth rates of 61% during the 1980s and 83% through the 1990s, according to the U.S. Census Bureau. (Note growth from 1972–2000 by comparing Figure 1 and Figure 2 below).

1.2 Objectives

To assist with future planning for military missions in the area, the primary objective of this study was to identify where future urban residential growth would likely occur in the region surrounding Las Vegas and in particular, the region surrounding Nellis AFB.

1.3 Approach

A population modeling program known as the Regional Urban Growth (RUG) model[1] was used to perform the analysis. Applying this model, which was developed at ERDC-CERL, involved acquiring nationally available GIS maps, preparing and analyzing those maps to spatially explore the relationship between existing urban growth and various attractors to

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[1] The RUG package was built upon the GRASS geographical information system that statistically calculates the collective attraction of areas across an urbanizing area with respect to the attraction of future residential growth and then generates future urban residential development patterns based on that attractiveness.

growth such as driving time to urban centers, proximity to existing neighborhoods, and access to state and federal highways. (Details of the application and operation of this model are described in Chapter 2.)

1.4   Mode of technology transfer

More information about regional planning models utilizing the technology in this exercise, the RUG model, and a free download of the software itself are available at the following URL: http://earth.cecer.army.mil/LandSimModel.

In addition, a journal article about RUG has been written and is under review at the time of this publication. ERDC-CERL personnel also have briefed various offices of the U.S. military as well as members of the Federal Planning Division of the American Planning Association during a meeting held 22 April 2009.
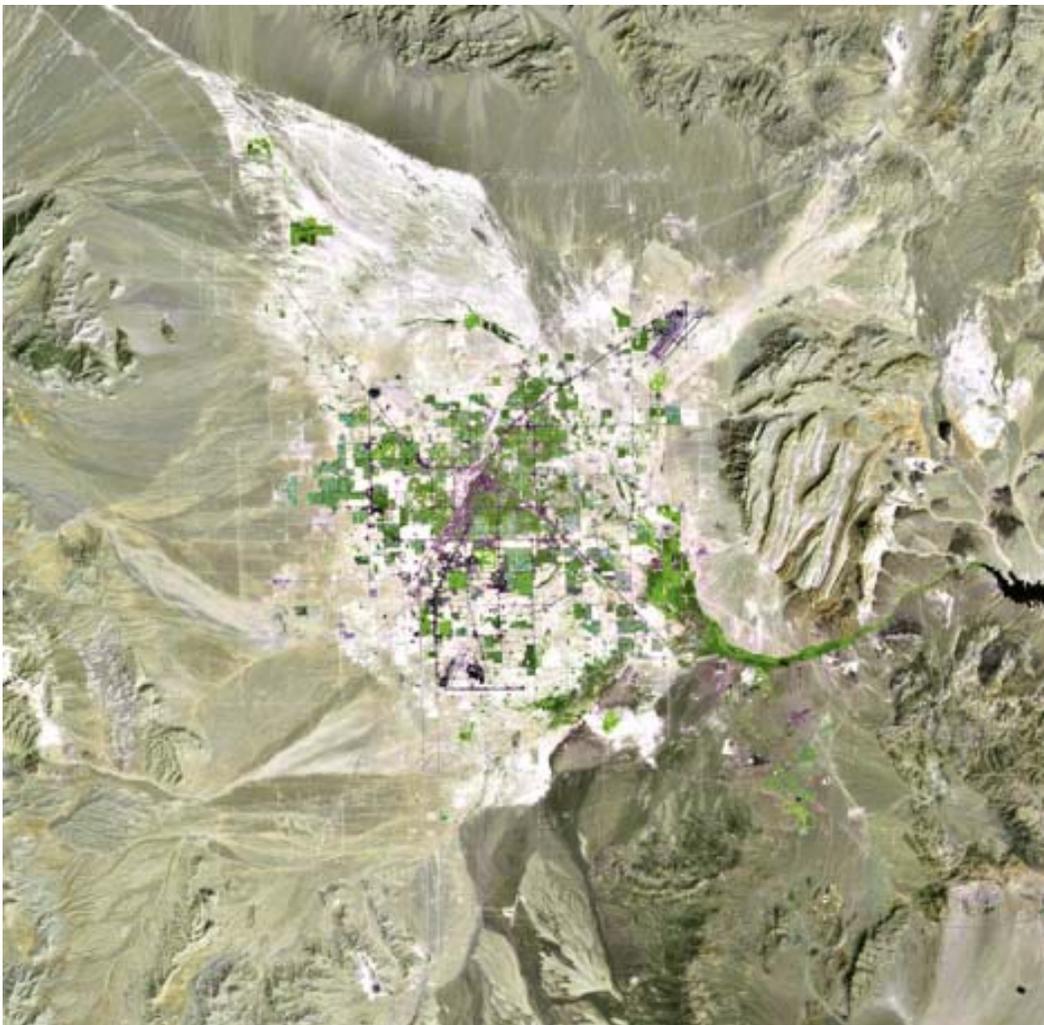
Figure 1. Las Vegas area 1972 (From United Nations Environmental Program at na.unep.net).
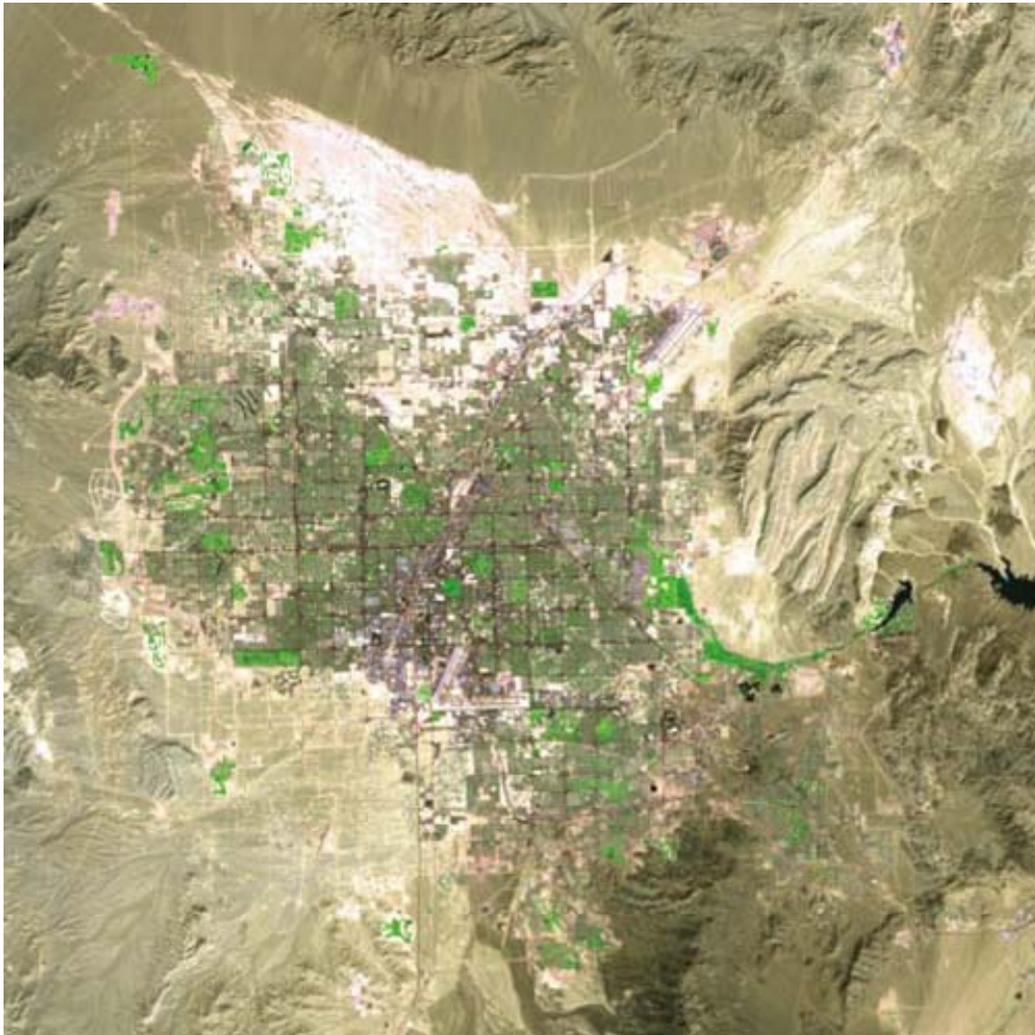
Figure 2. Las Vegas area 2000 (From United Nations Environmental Program at na.unep.net).

2 Analysis Methodology

2.1 Hedonic logic

The goal of the RUG model is to generate residential attractiveness and growth projection maps, based on nationally available data sets. The application of RUG requires little human intervention to produce the results. Such maps can help to inform policy decisions and elicit stakeholder input about growth and its effects on a range of processes. The approach involves hedonic modeling of the relative attractiveness values for new residential development in all locations within a study area.

Hedonic modeling (regression) is a statistical approach for identifying the relative importance of factors that set the price or value of a property, including those that contribute to the interior of the property and those that define its location (Haas 1922; Wallace 1926; Court 1939; Sirmans, Macpherson and Zietz 2005). The linear form of the Hedonic regression function is:

$$A = \sum_{i=1}^{k} \beta_i V_i \qquad (1)$$

where:

A = overall attractiveness of a parcel to development
β_i = Regression coefficient
V_i = Value of attractor (k values)

To forecast residential urban growth, RUG modeling uses a logistic regression model to combine the hedonic attractors:

$$A = \beta_0 + \sum_{i=1}^{k} \beta_i V_i \quad , \quad P = \frac{e^A}{1 + e^A} \qquad (2)$$

where:

β_0 = Y axis intercept of the regression
β_i = regression coefficient

$\qquad$ V$_i$ = value of attractor (k values)

$\qquad$ *P* = probability of urban growth occurring on cell

Any number of land parcel characteristics can be considered by the model. In the interest of evaluation efficiency and cost effectiveness (in terms of both time and data collection requirements), we focused on a relatively small number of site characteristics, most of which involved travel time to attractors. Those included the density of the surrounding urban neighborhood; distance to neighborhood forest resources; and driving time to urban centers, interstate highways, intersections, state roads, and county roads. These potential attractors were used because they are typically viewed by urban modelers as amenities associated with new development; other attractors could easily be integrated into this framework if desired.

2.2 Modeling process overview

The basic RUG modeling process is accomplished through six main steps:

1. Acquire data and resample into a common coordinate system
2. Identify a set of locations for each attractor believed to influence development
3. Calculate travel times to each attractor (forms a map)
4. Convert the travel-time maps to attractiveness maps
5. Combine resulting attractiveness maps to generate a single, comprehensive urban development attractiveness map
6. Forecast future urban development patterns by specifying growth rates and other parameters of new growth

Each of these six steps is discussed in detail below.

2.3 Step 1: Data acquisition

The first step uses basic GIS and data management skills to locate and download maps from nationally available databases. The required maps are a digital elevation map (DEM), a transportation map (roads and highways), a land cover map, and a map of areas where growth is unlikely or prohibited (i.e., a no-growth map that includes preserved areas, publicly owned recreation areas, military lands, etc.). These are all available from the U.S. Geological Survey (USGS) Seamless data download site[2] for the

$\rule{2in}{0.5pt}$

[2] http://seamless.usgs.gov

region of interest, but they may be augmented with more precise state or local data. Nationally available land use/land cover maps include the 1992 or 2001 versions of the USGS National Land Class Dataset (NLCD) (USGS 2003, 2008). National road maps such as the U.S. Census Bureau's TIGER[3]/Line® road network maps (U.S. Census Bureau 2008) are also available.

2.4   Step 2: Identify attractor locations

To develop travel-time maps we first identified the locations for attractors of new development; the locations are derived from original maps of digital elevation, no-growth areas, road network, and land cover. The locations of roads, intersections, highways, and interstate ramps (all major attractors of development) are straightforward to identify because they can be readily extracted from the base transportation map. Identifying the exact locations of urban centers (another major attractor), however, poses a greater challenge. We used our team's previously developed procedure to rapidly identify urban centers of attractiveness within the regional urban patterns defined in a land use map. Our goal was to identify and select sites at the center of locally dense urban area.

To do this, we implemented algorithms to locate peaks in an urban density map derived from land use data. We began by assigning low-density urban areas a value of 1 and high-density areas a value of 2. The resulting map was passed through an inverse-distance weighted neighborhood filter in which final cell values increase in proportion to the number of close, positively valued neighbors. We used the Geographic Resources Analysis Support System (GRASS) [4] *r.mfilter program*[5] (Shapiro 2008b) with a 15-cell radius to generate a new map showing how well each cell correlates with nearby urban cells. Closer neighborhood cells are afforded a higher influence, and the resulting patterns resemble a topographic map, in which elevation values represent the neighborhood density of urban cells.

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[3] Topologically Integrated Geographic Encoding Referencing (TIGER) system files contain features such as roads, railroads, rivers, as well as legal and statistical geographic areas.

[4] Geographic Resources Analysis Support System (GRASS) is a Graphical Information System (GIS) used for geospatial data management and analysis in academic, commercial, governmental and environmental settings.

[5] *r.mfilter* program is a raster map matrix filter.

A second program, The GRASS *r.slope.aspect program*[6], was then used to generate a profile curvature analysis. This analysis identifies peaks in the urban density map by calculating the change in slope (derivative) and rate of change in slope (second derivative) of "topography" map (Shapiro and Waupotitsch 2008). We identified peaks in the map by selecting locations whose value exceed a threshold, as indicated by the black areas highlighted by white dots. These areas were then clumped together into patches of contiguous cells. Each patch was given a distinct value using the GRASS *r.clump program*[7], (Shapiro 2008a) and its centroid (geographical center) was identified and captured as a new map. This process provided an indicator of the actual centers and sub-centers of urban areas throughout a region being studied.

To further reduce computational time, the inverse distance-weighted values at each sub-center centroid were divided into four levels; those with the highest values were considered to be the most attractive, and the lowest values the least attractive.

2.5   Step 3: Calculate travel times to attractors

We then calculated the minimum travel time for every grid cell (location) to each of the nearest individual attractors of growth (highways, on-ramps, lakes, etc.). This process used a GRASS *r.cost program*[8] (Awaida and Westervelt 2006) that used our sub-center point map (derived in Step 2 above) and a travel cost map as inputs to produce the travel time needed to cross every 30-meter grid cell. The original *r.cost program* assumes that all cells are connected to their immediate neighbors, which is not true in the case of roads/highways that cross but do not intersect. We modified the program to restrict limited-access highway connections to those streets with on-ramps. RUG scripts prepared two additional inputs for the modified *r.cost program*: a map of travel times across the limited access highway network and a map showing the points linking the original transportation map and the limited-access highway map. At the completion of this step, we had produced a set of minimum travel-time maps to the various sets of attractors.

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[6] *r.slope.aspect* generates raster map layers of sloped, aspect, curvatures and partial derivatives from a raster map layer of true elevation values.

[7] *r.clump* recategorizes data in a raster map layer by grouping cells that form physically discrete areas into unique categories.

[8] *r.cost* outputs a raster map layer showing the cumulative cost of moving between different geographic locations on an input raster map layer whose cell category values represent cost.

2.6   Step 4: Convert travel time maps to attractiveness maps

In the fourth step, we captured the functional relationship between cumulative-travel times and the probability of finding urban residential areas. Research on human responses to the environment has found that this relationship is often logarithmic rather than linear, and is called the Weber-Fechner Law[9] (Dehaene 2003). Therefore, we log-transformed cumulative-travel times (computed in Step 3 above) and then divided the results into 20 equal intervals known as sub-ranges. Using the GRASS *r.stats program*[10] (Shapiro 2007), we then calculated the percentage of our study area in each sub-range that has developed into urban areas (while subtracting the no-growth areas). These values, when matched with the mid-point of each sub-range, gave a series of *x-y* coordinates that defined our conversion function, translating driving time into development probability.

Note that this step in the RUG analysis required a map of developed areas, which were extracted from the land use map. We assumed that the urban patterns in that map reflected the land's current attractiveness for the de-velopment of urban areas, and that future development patterns would mimic the historical development patterns. This may be misleading if the costs and opportunities of transportation and communication have changed since the first urban areas were developed. Optionally, if consecu-tive land use maps are available (or if recent building or construction per-mits are easily available and time allowed), this analysis could be focused only on recent development patterns, which would yield a functional rela-tionship that mirrors modern development preferences and patterns.

2.7   Step 5: Combine maps to generate urban development attractiveness map

In the fifth step, the *GRASS r.mapcalc program*[11] (Shapiro and Clements 2007) was used to convert the cumulative travel-time map to a probabil-ity-of-occurrence map for each attractor under consideration. At this point in the procedure, a full set of hedonic-attractor maps was generated and a

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[9] The Weber–Fechner law attempts to describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli.

[10] *r. stats* generates area statistics for raster map layers.

[11] *r.mapcalc* performs arithmetic on raster map layers. New raster map layers can be created which are arithmetic expressions involving existing raster map layers, integer or floating point constants, and functions.

final development probability was calculated using Equation 2 (which required coefficients for each attractor).

One approach to developing these required coefficients was to interview knowledgeable local stakeholders, as a means of identifying decisions about land use tradeoffs and collectively rating a set of attractors. Other approaches include analytical methods such as multi-attribute utility theory (Schkade and Payne 1993), the analytic hierarchy process (Saaty 1996), or contingent valuation (Mahan, Polasky, and Adams 2000). However, the intensive interviewing necessary to collect this data requires significant investments of time and money and a primary objective of this study was to rapidly generate an urban growth projection.

Our approach involved performing a logistic regression analysis (Equation 2) to estimate coefficients that reflect the weight or importance of each attractor (Hosmer and Lemeshow 1989). To do this, RUG interfaced with the *R statistical package*[12] (Pebesma and Bivand 2005; Hornik 2008) to predict whether a cell will develop or remain undeveloped (binary dependent variable from land-use map), based on the attractiveness values of every attractor at each cell location (independent variables) using *R's lrm* (logistic regression model) *module*. Finally, RUG generated the final urban growth attractiveness for each cell, using the resulting equation to calculate the logit probability (P; between 0 and 1). This equation was applied using the GRASS raster calculator engine, *r.mapcalc*, to generate the urban growth attractiveness raster map.

2.8   Step 6: Forecast future urban patterns

Future urban growth patterns were then forecasted using information on the relative attractiveness of each grid cell to new development (the results of Step 5). We developed a new GRASS-based program called *r.rug* (Raster analysis for Regional Urban Growth) to generate the future urban patterns. This program takes, as inputs:

- The urban growth attractiveness map (from Step 5)
- The number of 30 x 30-m urban cells needed per year
- The number of simulation years (*r.rug* can run in 1-yr increments)

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[12] *R statistical package* is a free, open source, multi-platform statistical analysis program and can be used for statistical analysis, simulation modeling, and advanced data analysis. More information available at http://www.r-project.org/.

- A coefficient denoting the weight of the attractiveness index (as calcu-lated in Steps 1-5).
- A coefficient denoting the weight of random or spontaneous growth (see below)

This last point above reflects the uncertainty in the calculated attractive-ness and the coefficients can be experimentally balanced to generate the best possible forecasts. The uncertainty is caused by lack of consideration of influences such as property owner goals, parcel sizes, and specific de-velop needs based on which industries will actually develop. Random growth is represented by artificially adjusting the attractiveness of cells downward by a random value, thereby representing non-optimal decisions by landowners or developers.

Using this information, each location was assigned a probability of devel-opment (see Carroll and Ruppert 1988 for more information on functional form) based on:

$$O = A^{\lambda} R^{\varphi} \qquad\qquad (3)$$

where:

O = the overall attractiveness
A = the attractiveness calculated in Step 5 (between 0 and 1)
R = a unique random number between 0 and 1
λ and φ = input coefficients between the value of 0 and 1. (Note: The 'random growth coefficient' φ does not represent random growth, per se, but rather represents a random adjustment downward on attractiveness.)
$\beta 0$ = Y axis intercept of the regression

3   Study Area

The study area for this analysis includes surrounds Las Vegas in southern Nevada, extending west past the town of Pahrump near the California border (Figure 3).
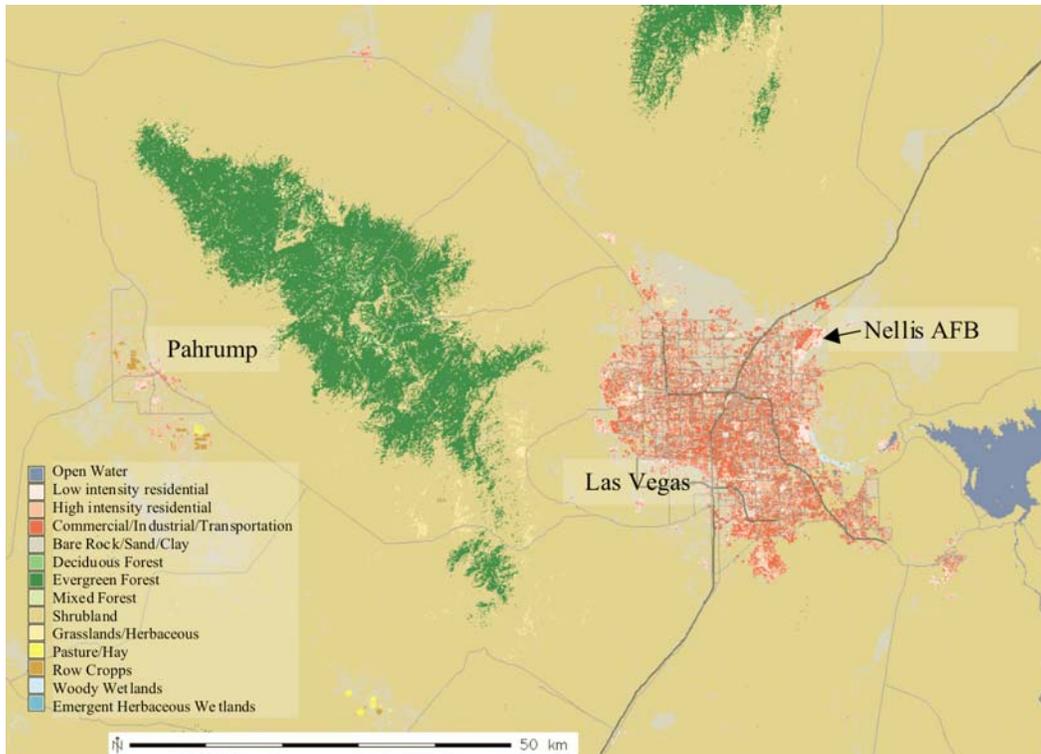

Figure 3: Study area surrounding Las Vegas, NV.

4   Results

4.1   Model outputs

The steps described above (Chapter 2, Analysis Methodology) were fol-
lowed to conduct the analysis. National Elevation Data DEM,
roads/highways, National Atlas land use, and NLCD (2001) maps were
downloaded. [13] The land use forecast category chosen was NLCD Category
22, high-density urban residential. All processing was based on 30 x 30-m
grid cells, with a raster GIS and a Universal Transverse Mercator (UTM)
projection. The NLCD map was processed to yield four categories of urban
centers. Travel-time maps were then generated to provide calculations of
time from every cell to the closest attractor, using the following sets of at-
tractors:

- Low density urban centers
- Medium density urban centers
- High density urban centers
- Very high density urban centers
- Highways/state roads
- Highway Intersections
- Interstate highways
- Forest
- Water

In addition, slope and local neighborhood density maps were generated.

Next, the correlation between the values in these maps and the probability
of a grid cell containing high-density urban (Category 22) in the NLCD
map was established; for each attractor map, a probability of each cell con-
taining Category 22 was calculated. The results are displayed in the follow-
ing figures. Each images shows the entire study area and, for reference,
displays interstates as black lines, state highways as grey lines, and water
bodies as blue. (Note that the westernmost piece of Lake Mead is the water
body on the east edge of the study area.) Each image uses the same color
scale for probability of residential development: 0% - white and 50+% -
black.

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[13] http://seamless.usgs.gov

Figure 4 shows the spatial correlation of a residential area to driving time from ramps that connect to limited-access highways (generally interstate highways). Similarly, Figure 5 shows the probability of finding residential areas with respect to driving times from state highway intersections. The notion for both of these is that the ability to drive on highways in four different directions (rather than two) may hold an attraction. Indeed a correlation is found, but it is maintained for shorter distances from highway intersections rather than from limited highway access on/off ramps. Continuing in that theme, the correlation between intersections of highways and secondary roads also exists, but is clearly weaker (Figure 6).

Figure 4. Development probability with respect to interstate access.

Figure 5. Development probability with respect to highway intersections.

Figure 6. Development probability with respect to highway access.

The next set of images shows the spatial correlation of residential development with respect to urban density attractors: "Low" density attractors in Figure 7, "medium" density attractors in Figure 8, "high" density attractors" in Figure 9, and "very high-density" attractors in Figure 10. Each shows a strong attraction indicated by the relative darkness of the grey near each attractor. The reach of that attraction diminishes quickest for the low-density attractors and much more gradually for the very high-density attractors. This is as one might expect, based on the reach of influence that is seen by small towns vs. large cities. The final correlation image (Figure 11) shows the influence of residential neighborhoods developing near existing neighborhoods. That relationship is also very high, but trails off quickly. Finally, Figure 12 shows the correlation for slope. Note that the grey-scale for this image is very different, with the highest probability of finding urban at about 0.4% due to the great amount of low slope areas in the surrounding broad desert valleys.
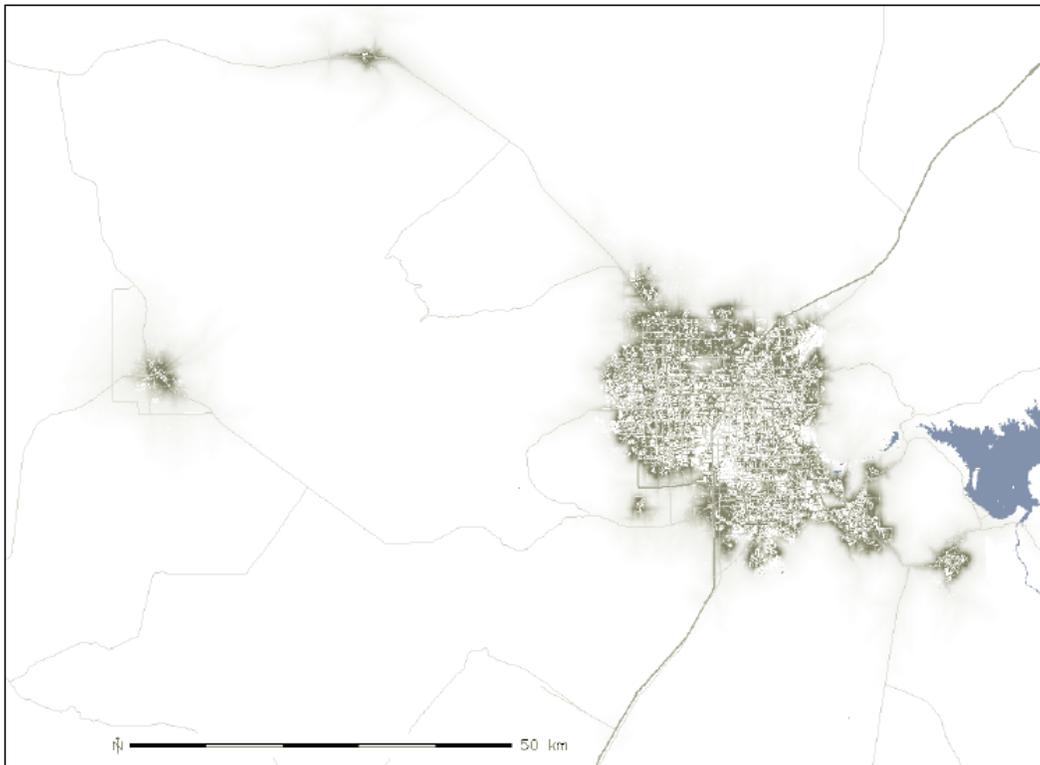

Figure 7: Development probability with respect to driving times to "low" density urban centers.

Figure 8: Development probability with respect to "medium" density urban centers.
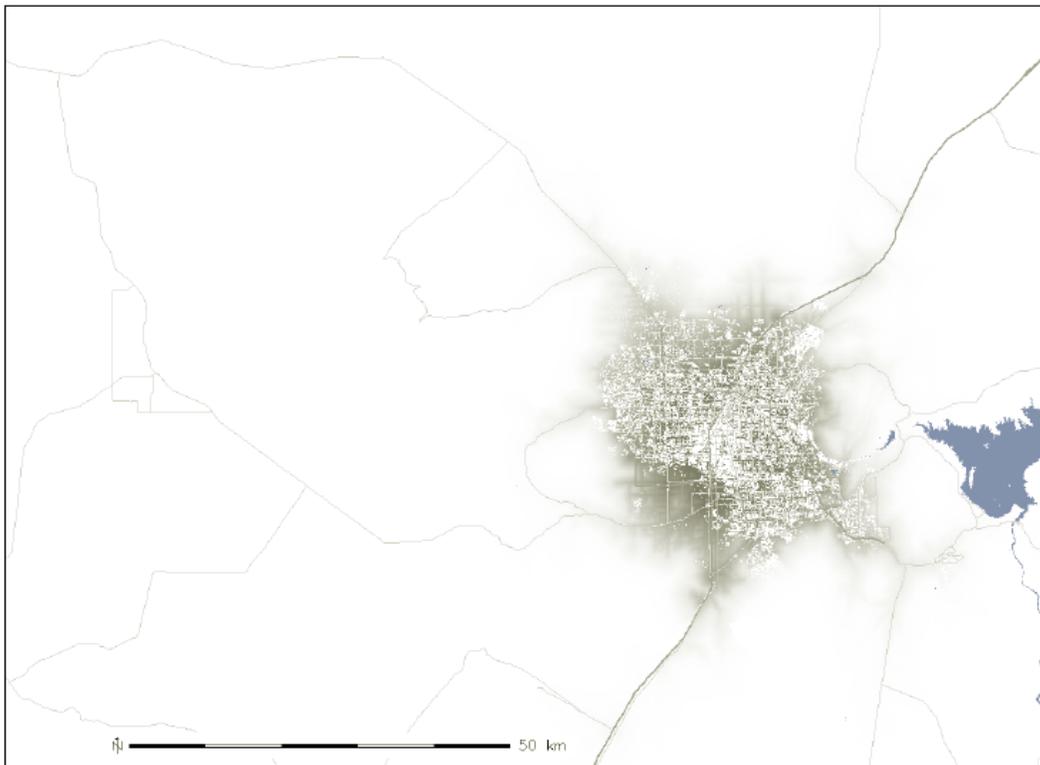
Figure 9: Development probability with respect to "high" density urban centers.
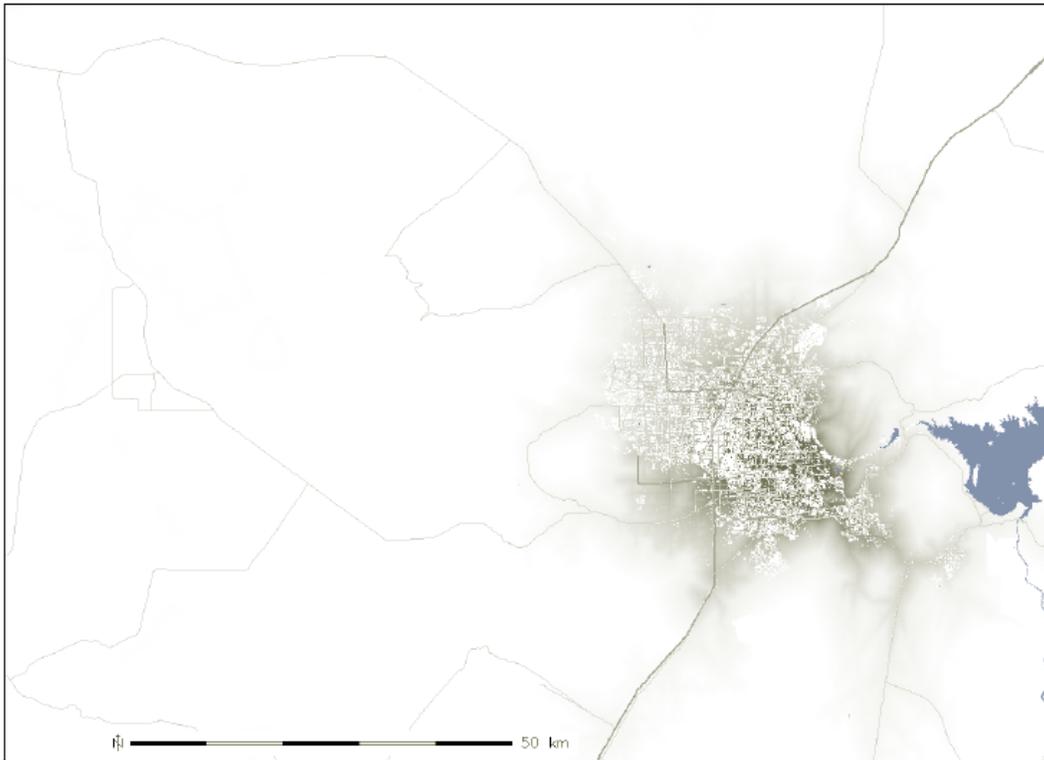
Figure 10: Development probability with respect to. "highest" density urban centers.
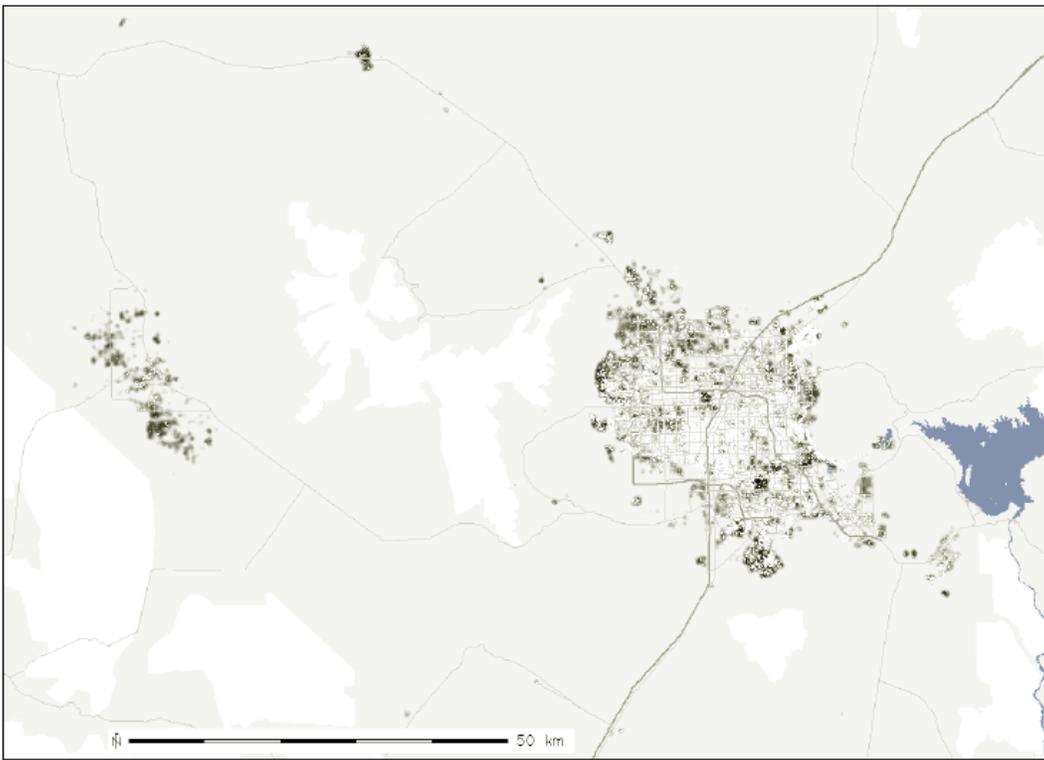

Figure 11: Development probability with respect to driving times to local residential density.
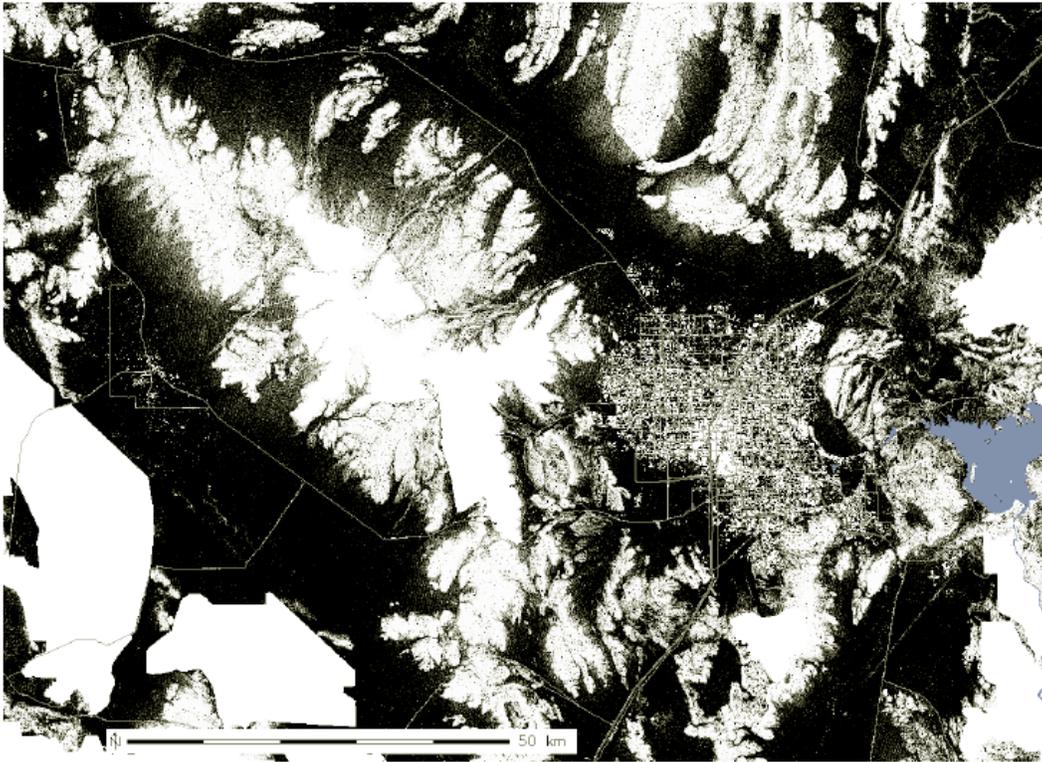
Figure 12: Development probability with respect to slope (0%, white to .42%, black).

The development probabilities (all values between 0 and 1) must be combined to provide an overall development probability for each location across the study area. Our approach involves performing a logistic regression analysis (Equation 2) to estimate coefficients for each attractor, which reflect the weight or importance of each (Hosmer and Lemeshow, 1989). To do this, RUG interfaces with the *R statistical package[14]* (Pebesma and Bivand 2005; Hornik 2009) to predict whether a cell will develop or remain undeveloped (binary dependent variable from land-use map), based on the attractiveness values of every attractor at each cell location (independent variables). The presence or absence of urban residential in the NLCD map provides the dependent variable used to generate the coefficients for the logistic regression equation (Equation 2).

The logistic regression coefficients generated by *R* are listed below in Table 1 and, when applied to each grid cell in the study area, generated the map in Figure 13.

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[14] R statistical package is a free, open source, multi-platform, statistical analysis program.

Table 1. Logistic regression coefficients.

	Coefficient (β_i)
Intercept (β_0)	-10.2519
Low Density Urban Centers	3.4565
Medium Density Urban Centers	1.3484
High Density Urban Centers	2.9319
Very High Density Urban Centers	1.9660
Highway	5.8307
Highway Intersections	-1.8634
Interstate Ramps	2.6379
Residential Neighbor Index	10.0838
Slope	429.8353
Forest	203.2941

The regional urban growth model, *r.rug*, was run using the growth probability map (Figure 13). To adjust for the human behavior not modeled in this exercise, the following equation was applied to each grid cell.

$$O = A^\lambda R^\varphi \tag{4}$$

where:

> O = final attractiveness.
> A = attractiveness calculated in Step 5 (a value between 0 and 1).
> R = a unique random number between 0 and 1.
> λ and φ are input coefficients between the value of 0 and 1. (Note: The 'random growth coefficient' φ does not represent random growth, per se, but rather represents a random adjustment downward on attractiveness.)

Cells are sorted by their new values, O, and then the top cells (here 200,000) are selected for development. The resulting final map is displayed in Figure 14.

Figure 13: Probability for future urban growth.

Figure 14: Forecast for future growth.

4.2 Interpretation of results

The forecasted new high-density urban development (defined by NLCD Category 22 and shown in Figure 14) is overlaid on the starting NLCD map and displayed in Figure 15. To properly interpret this forecast, it is important to review some of the key modeling assumptions.

First, in this base scenario, the existing highway and road networks are (a) maintained as is, with no further development and (b) are not further congested. The primary implication is that the travel times along roads and highways are presumed to remain unchanged. Of course, it would be possible to rerun the model to test the implication of establishing new neighborhood roads, new highways, and new connections to limited-access highways.

Second, there is no zoning expressed in this base scenario to force residential development into specific areas. In reality, most developed areas have at least some zoning ordinances, even at the non-urban level.

Third, the pattern of the residential areas in the 2001 map are presumed to reflect the current and future desires of residential dwellers. Those desires can change as a result of changes in such areas as the cost-effectiveness of communication and transportation technologies. For example, an increase in highway travel speeds and a decrease in the cost of personal auto operation could help to physically spread out future residential development. Similarly, a decrease in high bandwidth communication cost could bring about an increase in telecommuting.

Fourth, this model is only forecasting the development locations of future high-density urban residential development. In reality, this development will be competing with the development of other land uses including commercial, industrial, and urban open space.

The fifth assumption is that urban residential development will occur as individually separate 30 x 30-m areas; in reality, residential development often occurs as neighborhoods that are developed as a whole.

The final assumption is that new development will not affect the probabilities of even newer development. These simplifying assumptions allow for the relatively rapid generation of future urban patterns that can be useful in forecasting the future.
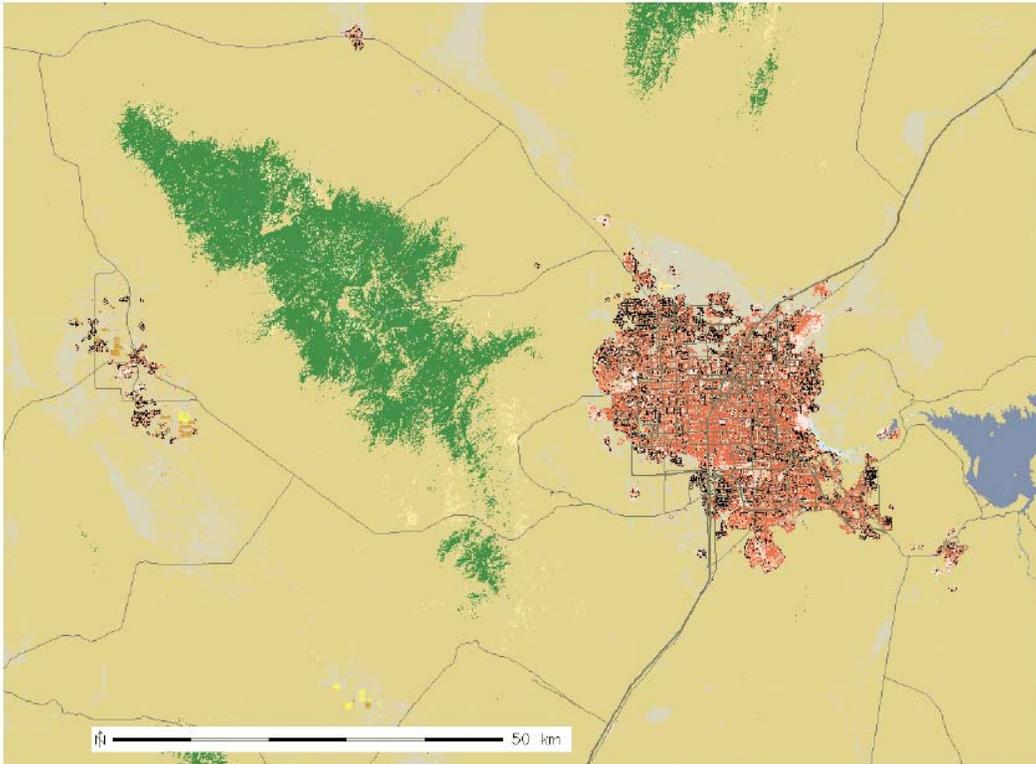
Figure 15: New residential growth overlaid on the 2001 NLCD map.

From the standpoint of Nellis AFB, this exercise is not projecting any significant nearby urban development. Residential development is primarily occurring on the northern, southern, eastern, and southeastern edges of the metropolitan area. Nellis appears to be blocking the extension of urban areas to the northeast, and any urban development pressure is not currently substantial enough to leapfrog the base.

4.3   Next steps

This is a first-cut urban growth modeling exercise that is possible through the acceptance of the simplifying assumptions discussed above. With the calibrated model, it is possible to test various regional planning scenarios. For example, how much development might be expected in proposed neighborhoods? Neighborhoods can be placed anywhere, including in areas where they would conflict with both current or future Nellis operations. How might different zoning plans shift the development patterns? How might the establishment of new business centers affect future residential development?

This effort was accomplished with nationally available data that allows for a consistent-analysis approach that can be applied anywhere across the United States. A more precise and localized analysis can be performed using local data and local expertise. The LEAMgroup Inc.[15] has worked with various DoD entities to conduct focused analyses for local municipalities to more thoroughly forecast urban growth patterns around military installations.

[15] mLEAM is a suite of software tools and application processes that help predict how current and proposed state, county, and local planning will affect future training and testing opportunities at military installations. More information is available at http://www.leamgroup.com

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14. ABSTRACT

Urban growth near military facilities could erode the ability of the military to conduct current and potential future missions in southern Nevada, especially near Nellis Air Force Base (AFB). While it is well understood that the Las Vegas urban area (and the I-15 corridor connecting it to the Los Angeles basin) have experienced significant growth, it is the anticipated patterns of future development that are most important to military planning. Proper regional planning could alter the patterns of future development near installations. This document reports the results of applying the Regional Urban Growth (RUG) model to the region surrounding Las Vegas to forecast where future growth is likely to happen. This exercise did not project any significant nearby urban development near Nellis AFB. The base appears to be blocking extension of urban development to the northeast and development pressure is not currently substantial enough to leapfrog the base. This first-cut analysis can be followed by more detailed urban growth modeling to fine-tune these results. Subsequent modeling can also test the implications of alternative regional plans involving significant highway/road construction, transfer of property rights associated with large tracts, and regional zoning.

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