# Alternative future growth scenarios for Utah's Wasatch Front: assessing the impacts of development on the loss of prime agricultural lands

G. Busch[1], R. J. Lilieholm[2], R. E. Toth[2] & T. C. Edwards, Jr.[3]
[1]*Bear River Association of Governments, USA*
[2]*Department of Environment and Society, College of Natural Resources, Utah State University, USA*
[3]*USGS Utah Cooperative Fish and Wildlife Research Unit, College of Natural Resources, Utah State University, USA*

## Abstract

Utah's Wasatch Front spans a narrow corridor from Ogden and Salt Lake City south to Provo. Current forecasts predict that the region's population of 1.9 million will increase by 75% by 2030. This project developed a series of alternative future growth scenarios to predict the spread of future development within the 2.3 million ha study area. Satellite imagery from 1990 and 2000 was used to develop a logistic regression model to predict the probability of future development based on 30x30 m pixels. Independent variables included distance from roads and development, slope, location within city boundaries, and surrounding development density. Population forecasts were then allocated across the region at various assumed future settlement densities, and the resulting development footprint for the year 2030 was determined. We found that if future development increased from the current density of 15 people/ha to 25 people/ha, 36,900 fewer ha of open space would be lost to development. In addition, if future development occurs at the rate of 15 people/ha, the region will lose over 40,400 ha of prime agricultural lands over the next 30 years.
*Keywords: demographics, economics, land use planning, logistic regression, sustainable development, urban growth models.*

 
www.witpress.com, ISSN 1743-3541 (on-line)

## 1 Introduction

The Wasatch Front is a rapidly urbanizing region of north-central Utah lying between the Wasatch Mountains to the east, and the Great Salt Lake to the west. The Greater Wasatch Area (GWA) closely follows the Interstate Highway 15 corridor from Provo north to Ogden. At roughly 2.3 million ha, the GWA encompasses all of the land area between the cities of Nephi in the south to Brigham City in the north, and from Tooele in the west to Kamas and Coalville in the east (Fig. 1).

The U.S. Census [1] found that the GWA was home to 1.9 million people in 2000. However, with an annual growth rate of 1.8%, the population is predicted to increase to 3.3 million by 2030, and as many as 5 million people could live in the region by 2050 (Envision Utah [2], GOPB [3], GOPB [5]). Due to this large population growth and an increasingly built-out land base, urban development is rapidly spreading to outlying cities and towns. If traditional sprawl-like development continues through 2050, the GWA will undergo substantial change. Indeed, while urban growth often provides opportunities for employment, income, entertainment, etc., it also typically results in increased air and water pollution, and the irreversible loss of wildlife habitat, open space, and agriculture lands.

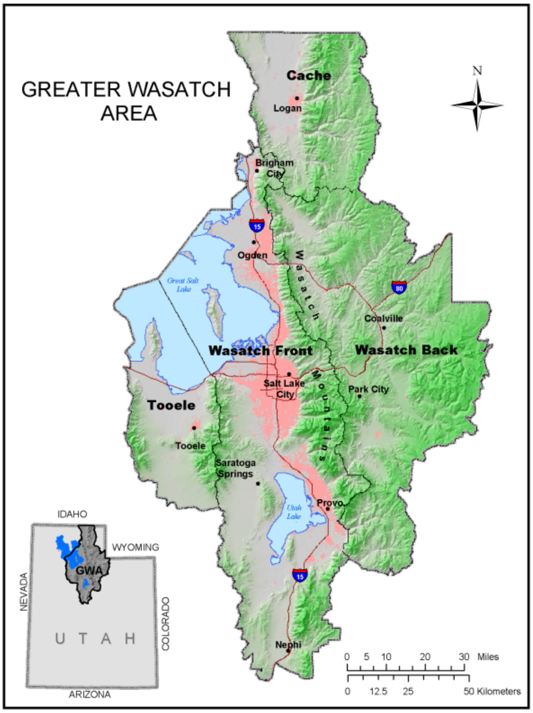


Figure 1: Utah's Greater Wasatch Area (GWA) is 2.3 million ha in size.

The goal of this research was to assess current development trends by examining how the GWA might develop over the next 30 years with the addition of 1.4 million new residents by creating hypothetical "alternative futures" (Toth [4]). We first assessed the location and scale of urbanization within the region from 1990 to 2000. Next, utilizing GIS and logistic regression, we developed a grid-based urban growth model to estimate the probability of future development for all undeveloped 30x30 m pixels in the study area. Finally, we calculated the potential loss of prime agricultural soils resulting from the conversion of open space to development under two estimates of future settlement density.

# 2 Methods

## 2.1 Modeling approach

Three main steps were followed to develop future growth scenarios for the GWA: (1) develop a logistic growth model for the region; (2) allocate future population growth across the study area; and (3) assess the impacts of future growth on environmental parameters – namely the loss of prime agricultural lands.

The first step was to develop a logistic regression growth model that predicted the probability of future development for undeveloped lands based on past growth patterns and each pixel's spatial characteristics. The result is a map showing the probability of any given location changing from undeveloped to developed status, based on the spatial attributes of that location. Logistic regression has been used to develop future growth scenarios for San Francisco (Landis [6]), the Mojave Desert (Hunter et al. [7]), and Camden County, New Jersey (Agung [8]).

The second step was population allocation. Allocation refers to placing a predicted future population across a landscape based on the most probable locations as determined by the logistic regression model. The result is a development "footprint" for the region at some point in the future.

The final step is an assessment of the effects that predicted future development will have on various parameters of concern. This is generally accomplished by overlaying the predicted development footprint onto a map of environmental factors to locate areas of overlap (Landis [6]). This process can be applied to any factor that has spatial overlap with the future development footprint. Here we calculated the expected loss of prime agricultural lands across the GWA.

The logistic growth model is a spatially oriented growth model. As such, the growth model's processes were, for the most part, modeled within a Geographic Information System (GIS), though some of the data were pre-processed using other software. Within the GIS, all spatial data were represented in a raster format using a 30x30 m pixel size.

## 2.2 Development of the logistic regression growth model

Logistic regression was used to calculate the probability of an undeveloped pixel becoming developed (the binary dependent variable) based on the pixel's

location. The characteristics of each pixel (the independent variables) include site-specific and surrounding spatial factors that describe each pixel in context to neighboring pixels. Site-specific attributes include whether or not a pixel is developed, if the pixel is located within a municipal boundary, and the slope of the pixel. Spatial variables include the distance of a pixel to the nearest road, or the development density of surrounding pixels. Each variable has a different relationship with the dependent variable, but they typically follow a similar form:
$Pr\ (development) = f(-x_1 - x_2 - x_3 - x_4 + x_5 + x_6)$
where:
$x_1$ = distance from the nearest major road;
$x_2$ = distance from the nearest secondary road;
$x_3$ = slope;
$x_4$ = distance from existing development;
$x_5$ = location within a city boundary; and
$x_6$ = development density of surrounding cells within a 19x19 pixel window.

Logistic regression then determines the degree to which each variable contributes to the probability of a pixel being developed based on the relationship between these independent variables and development over some past time interval. When the logistic model is applied to each undeveloped pixel in the study area, it results in a future development probability gradient map.

#### 2.2.1 Development, the dependent variable

Developed areas for both 1990 and 2000 were determined using remotely sensed data. Images from NASA's Landsat-5 platform were selected for its high temporal and spatial resolution. Full coverage of the GWA was acquired from two Landsat images, row38 path32 and row38 path31. Late season images were selected to highlight the variation between irrigated lands and drier natural landscapes within the GWA. Each image was corrected for sun angle, atmospheric attenuation, and instrument calibration as described in Chavez [9].

To assess the accuracy of the image classifications, the two 1990 images were joined into a complete development map for 1990. The two 2000 images were joined in a similar process. Accuracies of both development maps were assessed using 1996 aerial digital Ortho-photo quads (DOQ) (USGS [10]). An examination process was set up prior to the accuracy assessment. The overall classification accuracy of 94% and 95%, respectively, for the 1990 and 2000 images is quite good. The final step in processing the satellite imagery was to compare the 1990 development map to the 2000 development map to determine where new development had occurred during the 10-year interval. This new development dataset became the dependent variable used to calibrate the growth model.

#### 2.2.2 The independent variables

**2.2.2.1 Roads** A 1986 dataset of roads was used for the 1990 time period due to a lack of temporal data. The 2000 road layer that came from TIGER was considered accurate for this analysis. Once editing was completed, the road layers were reclassified into two layers consisting of major and secondary roads.

The vector datasets were then rasterized to a 30-m pixel size. Finally, the Euclidian distance command was run in ARCINFO Grid to determine the distance from each pixel to the nearest road.

**2.2.2.2 Slope** Percent slope was derived from a Digital Elevation Model using the slope command in ARCINFO.

**2.2.2.3 Development** The origins of the 1990 and 2000 development datasets were explained above. These binary raster maps were processed further into two new data layers: development density and distance from development. Development density was calculated using a 19x19-pixel roving window, which calculated the percentage of developed pixels within the 361-pixel window. Development distance was calculated using the Euclidian distance command in ARCINFO Grid. Another development data set called the Water Related Land Use (WRLU) was obtained from the Utah Department of Water Resources. This vector-based data set delineates several land use categories using aerial photography from 1995 to 1997 (Utah Department of Natural Resources [11]). The WRLU was used to determine current population density, as well as areas to be excluded from new development (see "Exclusion Layer" below). These data also provided the 2000 development baseline from which future growth was allocated under the predictive scenarios.

**2.2.2.4 City boundaries** U.S. Census data provided both the 1990 and 2000 city boundary datasets. For this analysis, only incorporated cities were used, leaving out the Census Designated Places (U.S. Census Bureau [1]). Municipalities were then converted to a binary map such that pixels were either located within a city (1) or not (0).

**2.2.2.5 Exclusion layer** The exclusion layer is a combination of several datasets that represent areas unable to accommodate future development. Included are areas already developed, public lands, and water bodies, as well as local parks and designated open spaces.

#### 2.2.3 Model calibration: establishing variable relationships

Logistic regression was used to calculate if and to what degree a statistical relationship exists between the dependent variable (areas developed between 1990 and 2000) and each of the six independent variables. The variables were run through the regression process in a stepwise, non-interacting manner. The result is a logistic regression growth model that, based on past growth patterns, calculates the probability of future development for each undeveloped pixel in the GWA that is available for development.

### 2.3 Population allocation

Population allocation is the process of populating the probability map with new residents in order to estimate the spatial extent of future development. This process includes three basic steps. First, future population within the region is

 
www.witpress.com, ISSN 1743-3541 (on-line)

estimated. Next, the average future settlement density for new residents is estimated to determine the amount of land that will likely be developed to accommodate these new residents. It should be noted that land is developed not just for residential homes, but also for streets, parks, commercial, and industrial uses, and can thus be thought of as a development footprint. Also note that the new development is allocated across currently undeveloped lands in the GWA based on the probability map derived above.

Population forecasts based on various economic indicators and the current demographic profile of the state project that the GWA's population will increase from 1.9 million in 2000 to 3.3 million by 2030 (Spendlove [12]). Next, an estimate of the density that future residents will settle across the landscape was needed. Two future settlement densities were modeled – the current density of 15 people/ha (6.8 people/ac), and a higher density of 25 people/ha (10 people/ac). Note that 25 people/ha is nearly the density of Los Angeles (Soule [13]) and would result in the conversion of far less land than the other alternative. While this density may be unrealistic to expect in more rural regions of the GWA, it is possible to consider for future development along the urbanized Wasatch Front, where the majority of Utah's population live. For comparison, U.S. metropolitan areas range from a high of 27.1 people/ha in Los Angeles, to a low of 6.9 people/ha in Atlanta (Soule [13]).

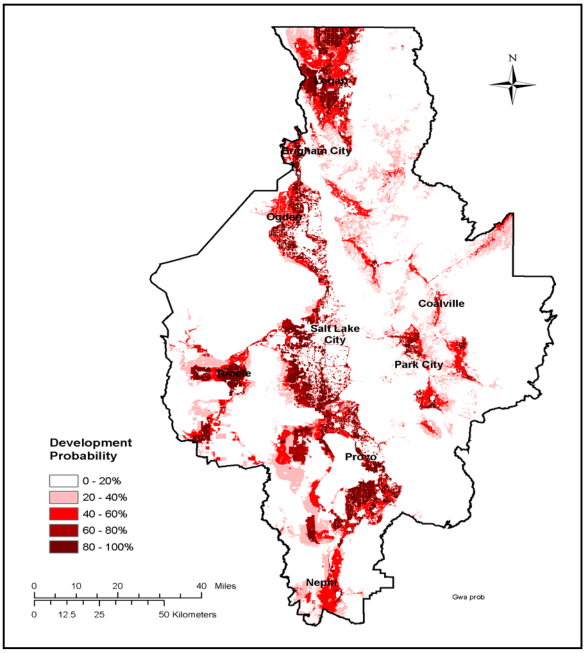


Figure 2: Probability of future development.

# 3 Results and discussion

## 3.1 Significant independent variables

Based on the logistic regression analysis, the final model fit the data well. The rescaled $R^2$ for the model was 0.6811, with the concordant pairs at 93%. Of the six independent variables considered, four stand out as important indicators of development between 1990 and 2000. These were percent slope, development density, the distance from existing development, and location within a city boundary. The slope coefficient was negative as expected, indicating that as slope increases, the probability of development decreases. Conceptually this makes sense since the majority of development in the GWA occurs on relatively flat farmlands formed on the bottom of ancient Lake Bonneville. In contrast, less development occurs on steep lands due to limited access and higher development costs. The coefficient for development density was positive, indicating that between 1990 and 2000, new development tended to cluster in locations of higher density development. The third variable, distance from existing development, had a negative coefficient, indicating that an increase in the distance from existing development brought a decrease in the likelihood of new development. The fourth variable, city boundaries, had a positive coefficient, indicating that locations within an incorporated area had a higher probability of new development. Figure 2 shows the probability gradient map for the GWA.

## 3.2 Future development in the GWA

Over the next 30 years, the population of the GWA is expected to increase from 1.9 million in 2000, to 3.3 million in 2030 -- an increase of 1.4 million people or 75%. The approximate footprint of urban development in 2000 was 115,807 hectares (447 $mi^2$). Depending on densities of future development, the new population could increase the developed area by as little as 48% (55,308 ha) at 25 people per ha, or as much as 80% (92,281 ha) at 15 people per hectare.

The allocation process used to create the development footprints is best understood through an example. Using the high density GWA scenario, in time period 2000 – 2010, 449,619 new residents are predicted to settle the area at a density of 25 people/ha, thus requiring 18,195 new hectares of development. Next the 18,195 ha is converted to 30 m pixels (11.111 pixels/ha), requiring 202,172 pixels to be converted. In other words, the 202,172 pixels with the highest probability for development are identified and designated for development for this time step. This process is continued for the next two time steps, resulting in the predicted development footprint for 2030 at 25 people/ha.

The spatial result of each of these density alternatives is then represented in map form showing the extent of the development footprint as it grows through time. The maps suggest that the GWA's new residents will be settling throughout the region. The model predicts significant new development along the I-15 corridor between Ogden and Brigham City, in the northern portion of Cache Valley, around Tooele, and west of Spanish Fork.

### 3.3 Development and the loss of prime agricultural lands

Throughout Utah, and especially within the GWA, urban and residential development is taking place on agriculturally productive lands. This trend is similar throughout the United States, where significant amounts of farmland are converted every year from the production of food to homes (Alterman [14]). In many respects, this conversion represents an irreversible process. Reporting potential trends of farmland loss is of political, social, and economic concern, and is one of many potential applications of this logistic growth model.

While the total area of farmland converted to development is of interest, the *quality* of the land is important as well. Indeed, not all soils are equal when it comes to producing crops. The Natural Resource Conservation Service (NRCS) describes soils according to several characteristics and ranks them into categories with prime soils being the most productive. For this analysis, prime soils were determined by the NRCS in the Soil Survey Geographic database (SSURGO) (Soil Survey Staff [15]).

Note that pre-settlement prime soils are those prime soils that existed before urban development removed them from agriculture. The amount of prime soils lost to development can be estimated by superimposing maps of development over the pre-settlement prime soils map. This analysis was done in two steps. First prime soils were compared to the existing urban footprint derived from the Water Relater Land Use to obtain an estimate of historic loss. This process establishes the baseline of prime soils which have already been lost to urban development since the arrival of settlers beginning around 1847. The second step is to compare the loss of remaining prime soils between 2000 and 2030 under the density scenarios. This analysis is expected to show that as density of urban development increases, the amount of prime soils lost to urban development will decrease.

Table 1: Actual and predicted prime soil loss from 2000 to 2030 for the GWA.

| | | | | |
|---|---|---|---|---|
| Total pre-settlement prime soils (hectares) | | 212,810 | | |
| **Estimated prime soils loss using development footprint from WRLU (hectares)** | | | | |
| | Loss | % loss | | |
| 2000 | 49,486 | 23.25% | | |
| **Predicted prime soils loss using development density alternatives** | | | | |
| | **25 people per hectare** | | **15 people per hectare** | |
| | Predicted loss | % loss | Predicted loss | % loss |
| 2010 | 9,235 | 4.34% | 14,992 | 7.04% |
| 2020 | 8,986 | 4.22% | 13,881 | 6.52% |
| 2030 | 7,572 | 3.56% | 11,511 | 5.41% |
| **Predicted loss 2000-2030** | 25,794 | 12.12% | 40,385 | 18.98% |
| **Remaining prime soils** | 137,529 | 64.63% | 122,938 | 57.77% |

Of the 1,286,449 hectares of private lands within the GWA, 212,810 ha (16.5%) have the potential to be prime soil (Table 1). Of this potentially prime soil, 49,486 ha (23%) had been built upon by 2000. By 2030, 25,794 additional hectares of prime soil will be lost under the highest density alternative, and 40,385 hectares under the low-density alternative. Based on these scenarios, the GWA will retain as much as 63% or as little as 46% of its potentially prime soils by the year 2030.

Under these alternatives, the majority of prime soils remaining in 2030 are likely to be west and south of Utah Lake (See Fig. 1). This is an important result because it is doubtful that sufficient irrigation water would be available in those areas to provide for agricultural needs. Therefore, by 2030, it is likely that urbanization development will displace much of the GWA's economically viable farmland.

## 4 Conclusions

The population of Utah's GWA is expected to increase from 1.9 million to 3.3 million over the next 30 years. This growth will cause the built environment to increase and will lead to significant changes to the landscape of the GWA. While the scale of change will differ depending on the region, significant human-caused land use change will be a reality nonetheless.

The purpose of this research was threefold. First, it aimed to project present land use trends into the future to illustrate the likely outcomes of current land use decisions. Second, the research sought to explore the possible outcomes of alternative land use decisions in the form of higher development densities. Finally, the research applied the model results to look at potential loss of prime agricultural soils under the various density scenarios.

Based on the analysis presented here, if future populations continue to settle under the existing densities of 15 people/ha, new urban developments will likely cover an additional 92,281 ha (356 $mi^2$) by 2030. However, if settlement densities increased to 25 people/ha, the future developed area could be reduced to 55,368 ha (213 $mi^2$). Given these two scenarios, prime soils could be reduced by as much as 40,385 hectares at 15 people/ha, or as little as 25,794 hectares at 25 people/ha.

## References

[1] U.S. Census Bureau, Appendix A, Census 2000 Geographic Terms and Concepts. www.census.gov/geo/www/tiger/glossary2.pdf.

[2] Envision Utah. Salt Lake City, UT, www.envisionutah.org.

[3] Governor's Office of Planning and Budget, Scenario Analysis, Review Draft. Salt Lake City, UT, 1999.

[4] Toth, R.E., Edwards, T.C. Jr., Lilieholm, R.J., Bell, D.L. & Buteau, E.R., Alternative futures for Utah's Wasatch Front: bioregional planning for the maintenance and conservation of open space. Final Project Report No.

2002-2, Utah Cooperative Fish and Wildlife Research Unit, Utah State University, Logan, UT 84322-5290 USA, 2002.
[5] Governor's Office of Planning and Budget, Quality growth and efficiency tools; Baseline 2003. Salt Lake City, UT, 2003.
[6] Landis, J., Imagining land use futures: applying the California urban futures model. *Journal of the American Planning Association,* **61(1)**, pp. 438-457, 1995.
[7] Hunter, L.M., Gonzales, M.J., Stevenson, M., Karish, K., Toth, R., Edwards, T.C. Jr., Lilieholm, R.J. & Cablk, M., Populations and land use change in the Mojave: natural habitat implications of alternative futures. *Population Research and Policy Review*, **22**, pp. 373 – 397, 2003.
[8] Agung, A.A.G., Grid-based urban growth model. Dissertation, New Brunswick Graduate School, Rutgers State University of New Jersey, 2000.
[9] Chavez, P.S. Jr., Image-based atmospheric corrections—revisited and revised. *Photogrammetric Engineering and Remote Sensing* **62(9)**, pp. 1025-1036, 1996.
[10] U.S. Geographical Society, Digital Orthophoto Quadrangles. geography.usgs.gov/digitalbackyard/doqbkyd.html.
[11] Utah Division of Natural Resources, A water-related land use summary of the State of Utah. Salt Lake City, Utah, 1999.
[12] Spendlove, R., Personal communication, 17 September 2004, Governor's Office of Planning and Budget, Salt Lake City, Utah.
[13] Soule, D., Confronting housing, transportation, and regional growth. *Land Lines*, Lincoln Institute of Land Policy, **16(2)**, pp. 12-14, 2004.
[14] Alterman, R., The challenge of farmland preservation: lessons from a six-nation comparison. *Journal of the American Planning Association,* **63(2)**, pp. 220-239, 1997.
[15] Soil Survey Staff, Natural Resources Conservation Service. *National Soil Survey Handbook*, Title 430-VI, Section 622.04, 2001.