RURAL RESIDENTIAL DEVELOPMENT IN THE GREATER YELLOWSTONE:
RATES, DRIVERS, AND ALTERNATIVE FUTURE SCENARIOS

by

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April 5, 2004
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ABSTRACT

Rates of immigration and rural land use change in the American West have far exceeded the national average, and have been exceptionally rapid in the Greater Yellowstone Ecosystem. Because the Greater Yellowstone is ecologically unique, is still largely undeveloped, and is characterized by unrestrictive land use policies, it is a particularly relevant place to study past and potential future growth in rural residential development. The scientific approach used to investigate trends in rural residential development involved both the testing of specific hypotheses regarding historical development patterns, as well as exploratory statistical analyses. Growth in rural residential development was quantified according to data collected from County Tax Assessors offices. Generalized linear models were used to examine recent drivers of growth. The results of these analyses were used to parameterize a spatially explicit simulation of future rural residential development. Our study reveals that immigration and rural development within the Greater Yellowstone has been strongly influenced by a number of socio-economic and bio-physical factors including agricultural suitability, transportation and services, natural amenities, and encroaching development. We also quantified the extent to which towns of various typologies influenced residential development in adjacent rural areas. The Rural Development Simulator was based on historical rates and patterns of growth, and was used to forecast alternative scenarios of rural housing for the year 2020. The forecasted increase in rural housing ranged from 27% in a low growth scenario, to 82% in a status quo scenario, and 234% in a boom scenario. Existing land use policies were shown to have a limited impact on the forecasted distribution of homes. An alternative growth management scenario was designed in which strategic configurations of zoning districts and conservation easements were shown to protect ecologically valuable areas without limiting future regional growth. Although the possibility exists for substantial social and ecological change in rural landscapes of the Greater Yellowstone, our findings highlight the potential for local policy decisions to effectively manage growth in rural residential development.
INTRODUCTION TO THESIS

The two papers presented in this thesis focus on historical patterns in rural residential development and future rural growth scenarios within the Greater Yellowstone Ecosystem (GYE). Previous research that led to this study concluded that rates of rural land use change in the American West have far exceeded the national average (Theobald et al. 1996; Riebsame et al., 1997; Johnson, 1998; Rasker and Hansen, 2000). The rates of immigration and rural development have been exceptionally rapid in the private lands surrounding Yellowstone and Grand Teton National Parks, where the construction of rural homes has been the primary form of land use change (Rasker and Hansen, 2000). Because the region has unique ecological value, is still largely undeveloped, and is characterized by unrestrictive land use policies, it is a place where the incorporation of scientific understanding into local land use planning decisions has become increasingly important.

The first paper discusses a historical analysis of trends in rural residential development. The analysis is set in the context of a paradigm regarding the technological drivers of human settlement. The paradigm describes how the primary drivers of human settlement have shifted during three stages characterized by: (1) natural resource constraints, (2) transportation expansion and (3) pursuit of natural amenities (Huston, in review; Riebsame et al., 1996; Wyckoff and Dilsaver, 1995; James, 1995). In the paper, we evaluate the relevance of this paradigm for explaining historical trends rural residential development within the GYE. We first quantify rates of growth in rural home construction across the GYE. We then consider the extent to which agricultural
suitability, factors related to transportation, and natural amenities explain variation in the
spatial pattern of rural home development. The relevance of our findings to current
scientific theory and the implications for growth management are discussed.

The second paper discusses the design, validation, and implementation of a
decision support tool for generating scenarios of future rural development patterns for the
GYE. The Rural Development Simulator (RDS) is a regression-based, spatially explicit
model designed to facilitate the manipulation of growth inducing and limiting factors in
order to generate maps of alternative future scenarios. Four alternative scenarios were
generated for the year 2020. A “slow growth” scenario was designed to emulate the
lower range of growth potential for the region. A “status quo” scenario was modeled, in
which future rates and locations of growth were based upon past growth patterns and
current land use policies. A “boom” scenario was designed, in which some of the factors
found to be correlated with growth were manipulated. For example, the RDS was used to
forecast alternative development patterns when hypothetical road improvements were
used as model inputs. In the “growth management” scenario, additional rules
representing growth management policies were imposed. For example, hypothetical
zoning districts were used as model inputs. The forecasted rates and locations of future
growth in rural residential development, as well as the effect of zoning districts on
forecasted housing, were explored.
RATES AND DRIVERS OF RURAL RESIDENTIAL DEVELOPMENT

Introduction

In much of the world, rural landscapes are undergoing an intensification of human land use. The goods and services provided by these lands, including agricultural products, wildlife habitat, and the preservation of soil and water quality, are vital for humans as well as for the conservation of biodiversity. Globally, growth in the number of households has out-paced population growth (Liu et al., 2003). Such is the case in the United States, where rural lands are being rapidly converted to home sites. For American retirees, entrepreneurs, and others seeking small-town lifestyles and the natural amenities of rural landscapes, the countryside has become the preferred alternative to city life and suburbia (Rudzitis, 1999; Daniels, 1999).

This renewed preference for rural living can be observed in recent U.S. population trends and is especially prominent in the America West. Starting in the 1970s, U.S. rural population gains exceeded metropolitan population gains for the first time since the early 1800s (Johnson, 1998; Daniels, 1999). From that time forward, the overall trend has been one of dispersed settlement (Brown et al., in review), resulting in the conversion of extensive areas of pasture, cropland, range and forest. The growth in rural residential development has been so widespread that a full 25 percent of U.S. lands are currently occupied at exurban densities of 1 unit per 0.4 hectares to 1 unit per 16.2 hectares (Brown et al., in review). Compared to national population growth, a rapid increase occurred in the Mountain West during this time. Most of this growth has been attributed to
immigration (Johnson, 1998), and along with the newcomers, sweeping economic, political and land use change have created the “New” West (Riebsame et al., 1997; Power and Barrett, 2001). The landscape of the New West is characterized by the preferences of long time residents as well as newcomers, who are often wealthy young adults, professionals in service industries and retirees (Nelson 1999) desiring ranchette-style homes on large lots. Within some areas of the New West, such as the counties surrounding Yellowstone National Park, construction of rural homes has been the primary type of land use change (Hansen et al., 2002).

The factors driving rural development across the U.S. are thought to have evolved with human technology. One proposed paradigm of the drivers of human settlement describes three stages characterized by: (1) natural resource constraints, (2) transportation expansion and (3) pursuit of natural amenities (Huston, in review; Riebsame et al., 1996; Wyckoff and Dilsaver, 1995; James, 1995). According to this model, constraints on transportation required humans to settle close to the points of production of essential natural resources, most notably food crops. The advent of railroads and automobiles allowed resources to be transported from points of production, hence, settlement focused on transportation corridors. More recently, information technology has allowed goods and services to be shipped at very low costs and many people are choosing to live in rural mountain or lake locations distant from markets, but with high natural amenities.

In this study we evaluate the relevance of this model for explaining rural residential development in the Greater Yellowstone Ecosystem (GYE). We first quantify rates of growth in rural homes across the GYE. We then consider the extent to which
agricultural suitability, factors related to transportation, and natural amenities explain variation in the spatial pattern of rural home development. We elaborate on the model by suggesting an additional driver, that being nearby existing rural development. As rural housing density increases, more public services (e.g., roads, water lines, and schools) are provided, in turn attracting more development. In addition, the encroachment of development tends to raise property values, encouraging conversion of undeveloped land. We additionally suggest that each of the three phases of development in the model leave a “legacy” on the landscape. Patterns of settlement during the agricultural period influenced settlement during the transportation period, and both of these have affected rural development during the natural amenities period. Hence, current patterns of rural home construction integrate the effects of all three periods. For example, Bozeman, MT, was developed within the rich agricultural lands of the Gallatin Valley. The resulting population growth led to the construction of an airport, increasing the accessibility for rural home construction. Growth in tourism led to airport expansion, allowing for the relocation of high-tech businesses to the natural amenity rich valley.

Specific hypotheses are as follows for patterns of development across the GYE:

H1: Growth in rural residential development during the early 20th century was a function of the quality and distribution of natural resources, particularly agricultural suitability. This relationship weakened over time as transportation improvements and information technology allowed people to live greater distances from agricultural lands.

H2: Development in recent decades was driven by transportation infrastructure and associated services such as schools and hospitals. Similar to suburban development, patterns of rural residential development bordering towns appear to result from a particularly strong socio-economic link between the rural residents and access to the services of the nearby town.
H3: The locations of rural homes also reflect proximity to natural amenities. We suggest that while natural amenities attract growth across the landscape, they are especially important in driving the conversion of previously undeveloped parcels. Thus, when a home site is developed in an area that was previously isolated from services and infrastructure, it is often due to the presence of natural amenities, such as access to open space and scenic rivers.

H4: We also hypothesize that encroaching development acts both directly and indirectly to promote further growth in rural residential development. As rural housing density increases, more public services are provided, in turn attracting more development. The encroachment of development also tends to raise property values encouraging conversion of undeveloped land.

H5: Lastly, we hypothesize that the grouping of factors that will most accurately describe recent trends in growth will account for the combined effects of (H1) natural resources, (H2) transportation infrastructure and services, (H3) natural amenities, and (H4) previous rural development.

The study is unique in that a database of rural homes has been compiled at a spatial scale resolve enough to analyze the relative importance of various drivers of human settlement and for a large and complex region within the Rocky Mountains. We focus on the natural amenity rich Greater Yellowstone Ecosystem (GYE) in examining patterns of rural residential development within the New West. Containing Yellowstone and Grand Teton National Parks and the public and private lands adjacent to them, the GYE is a region of distinctive ecological significance within the rapidly growing Rocky Mountain region. Our hope is that an improved understanding of how and why development patterns occur will allow for society to manage rural residential development more effectively.
Study Area

Centered on the Yellowstone Plateau, the Greater Yellowstone Ecosystem (GYE) was originally defined as the range of *Ursus arctos*, the Yellowstone grizzly bear (Craighead, 1991). Subsequently, Rasker (1991) expanded the study area boundary to include the 20 counties within Montana, Wyoming and Idaho that overlap the GYE (Figure 1) in recognition of the strong ecological and socioeconomic linkages across the public and private lands of this region. The expanded boundary is appropriate for this study because development regulations and growth management plans are implemented at the county level.

Of the 145,635 square kilometers that make up the 20 counties of the GYE, only 32% of the area (47,249 km) is privately owned (Figure 1). Another 32% is managed by the USDA Forest Service, and the remaining lands are USDI Bureau of Land Management (19%), Yellowstone and Grand Teton National Parks (7%), Tribal Lands (5%), and State Lands, wildlife refuges and other federal lands (5%). Because of extensive public ownership, it is often assumed that the influence of rural residential development on the ecosystem will be limited. However, many species of wildlife in the GYE depend on resources found almost exclusively on private lands. The public lands in the GYE are relatively high in elevation and contain largely nutrient-poor soils (Rodman et al., 1996), whereas the private lands are primarily in valley bottoms and floodplains containing alluvial soils that are higher in nutrients and water-holding capacity (Hansen et al., 2002). Hence, several species of birds, butterflies, amphibians, and mammals are
found seasonally or year round in the favorable climate, soil and vegetation types of valley bottoms in the GYE (Hansen and Rotella, 2002; Hansen et al., 2002). Although only one-third of the GYE is privately owned, the private lands are a necessary component of the ecosystem.

Figure 1. The study area encompasses those twenty counties of Montana, Wyoming and Idaho that surround Yellowstone National Park. The public and tribal lands shown comprise 68% of the region.
The area is unique in the continental U.S. in that it supports several large carnivores and free-roaming populations of ungulates. Herds of elk (*Cervus elaphus*) and bison (*Bison bison*) inhabit the area, as do bighorn sheep (*Ovis canadensis*), antelope (*Antilocapra americana*), moose (*Alces alces*), wolves (*Canis lupus*), and grizzly bears. The headwaters of seven major rivers, the Yellowstone, Madison, Gallatin, Snake, Bighorn, Ruby, and Green River, originate in and around Yellowstone National Park. These rivers form biologically diverse lowland riparian habitats surrounded by the semi-arid uplands. The majority of the region is mountainous with expansive areas of forest, shrubland and grassland. These environmental qualities have been suggested as major drivers of the demographic, economic and land use changes occurring in the New West.

With just over 370,000 permanent residents in 2000, the GYE has a small but rapidly expanding population. Since 1970, the human population of the GYE has grown by more than 60%. Currently, much of the private lands in the area are undeveloped. However, developed land in the GYE is increasing faster than the rate of population growth, as large-lot rural subdivision continues to be the preferred mode of development. From 1970 to 1999, the GYE experienced an increase in population of 58% and an increase in the area of rural lands supporting residential development (at densities greater than one home per 16.2 hectares) of 350%.

**Rural Homes Database**

In order to examine trends in rural residential development in the GYE, a spatially explicit database of rural homes was compiled. This database describes the locations of
all known rural homes and the years in which they were built within the 20 counties of the Greater Yellowstone Ecosystem. Rural homes are defined as all homes that are outside of incorporated city and town site boundaries, including subdivisions and excluding mobile homes, for which location descriptions were not available. The data were collected from County Tax Assessors offices and State Departments of Revenue, and are summarized per section, within township range blocks, according to the U.S. Public Land Survey System (PLSS). The resolution of the database is therefore the area of a section, approximately 2.59 square kilometers. For any given section within the study area, the database describes the number of rural homes present during each year, from 1857 through 1999.

During the process of data entry and linking of spreadsheets to the geographic information system (GIS), error may have been introduced. Thus, an accuracy assessment of the rural homes dataset was conducted using aerial photography. Within 76 sections, the number of rural homes as reported by the tax assessor database was compared to the number of rural homes counted from aerial photographs. The sections were selected to cover a wide geographic extent within the study area and based on the availability of recent (post 1994) aerial photographs at the scale of 1:16,000 or greater. Six counties within the Greater Yellowstone Ecosystem were sampled including Madison County, MT; Gallatin County, MT; Park County, MT; Sweet Grass County, MT; Sublette County, WY; and Fremont County, WY. A paired t-test was used to test the null hypothesis that the mean of the differences in counts of homes per section between the tax assessor database and the aerial photographs was zero.
Natural Resource Constraints (1900-1999)

To examine the historical relationship between natural resources and the location of rural residential development, indices of natural resource quality and constraints were needed. Due to the mountainous terrain and semi-arid climate of the GYE, we believe that agricultural suitability and access to water were the primary natural resource constraints affecting early settlement patterns. Consequently, spatially explicit datasets describing the quality of land for agricultural purposes and the distance to surface water were used to denote natural resource constraints. Although mineral resources also influenced settlement of the West, no rating of mineral potential was available for the study area. The agricultural dataset rates suitability as a function of soil, topographic, and climatic characteristics, and is a part of the U.S. Department of Agriculture’s State Soil Geographic (STATSGO) database. Agricultural suitability was calculated as the mean non-irrigated capability class per STATSGO map unit. The hydrology dataset describes Euclidian distance to surface water features as delineated in the National Hydrography Dataset (NHD) 1999 database. The NHD is based on the U.S. Geological Survey 1:100,000-scale Digital Line Graph (DLG) hydrography data, integrated with reach-related information from the U.S. Environmental Protection Agency Reach File Version 3.0 (RF3).

To examine H1, the 20th century was divided into four even time periods (1900-1925, 1925-1950, 1950-1975 and 1975-1999). We then employed use versus availability analyses to examine the distribution of homes built within each period with respect to agricultural suitability and access to water. Soils were categorized one to five for least to
most suitable for agriculture. Distance to surface water, measured in sections, was converted to five categories (0-1, 1-3, 3-5, 5-10, and 10-30). The observed numbers of homes built per agricultural and distance category during each time period was compared to the “expected” number if homes were distributed randomly with respect to that resource. Expected numbers of homes per category were calculated as the proportion of area occupied by the category multiplied by the total number of rural homes built during the time period. If, for example, agricultural suitability was not related to development patterns, one would expect homes to be distributed according to the geographic extent of each agricultural rating category. Thus, because the highest quality soils for agriculture make up only six percent of the study area, only six percent of homes built during each time period were expected to be within these areas. For each time period a chi-square goodness of fit test was used to test the hypothesis that the observed and expected values were drawn from the same distribution.

Correlates of Recent Growth (1970-1999)

An exploratory statistical approach was used in order to examine the extent to which current patterns in rural residential development in the GYE are the result of shifting drivers of human settlement. Using an all subsets regression, all possible combinations of four alternative models (H1-H4) describing growth in rural home construction were compared. For this analysis, the response variable was the change in rural homes per section over the time period 1970-1999. This time period was selected due to the notable acceleration in rural residential development since 1970 (Figure 2). Although the annual growth rate waned during the economic recession of the 1980s (to
an average of 893 rural homes being built each year), it remained higher than the average
pre-1970 annual growth rates (during which, on average, 565 rural homes were built
annually). Growth in rural residential development then rebounded in the 1990s. This
post 1970 “boom” period of rural home construction in the Greater Yellowstone
coincides with national trends in rural development.

Figure 2. Growth rates and increase in the number of rural homes in the GYE. Given \( n \)
is equal to the number of homes during year \( t \), the annual growth rate was
calculated as \( n_t - n_{t-1} \). The average annual growth rate was calculated as \( (n_t - n_{t-10})/10 \). Decadal spikes in the annual growth rate are a result of tax assessor’s
estimation of the year in which homes were built in the cases where the exact year is unknown.

Explanatory Variables. Several datasets were compiled for use in the model
comparisons of rural residential development. These datasets describe the study area
with respect to natural resources, transportation, services (including regional services,
town-level economic services and town-level recreational services), natural amenities, and encroaching development (Table 1).

Table 1. Potential covariates of growth in rural residential development from 1970 to 1999 were compiled from the listed sources. Federal agencies from which data were acquired are abbreviated (DA = Department of Agriculture, CB = Census Bureau, GS = Geological Survey, DOT = Department of Transportation, EPA = Environmental Protection Agency).

<table>
<thead>
<tr>
<th>Potential Covariates</th>
<th>Source</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Resources</td>
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<tr>
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<tr>
<td>Road Density</td>
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<tr>
<td>Euclidian Distance from Major Roads</td>
<td>CB 2000 TIGER/Line Files</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Travel Capacity Index</td>
<td>CB 2000 TIGER/Line Files</td>
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</tr>
<tr>
<td>Airport Travel Time (All Commercial Airports)</td>
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<tr>
<td>Airport Travel Time (Enplanement &gt; 25,000)</td>
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<tr>
<td>Airport Travel Time (Enplanement &gt; 50,000)</td>
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<tr>
<td>Services</td>
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</tr>
<tr>
<td>School Travel Time</td>
<td>CB 2000 TIGER/Line Files</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Hospital Travel Time</td>
<td>CB 2000 TIGER/Line Files</td>
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<tr>
<td>Town Travel Time (Population &gt; 1,000)</td>
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<td>Services per Town - Economic</td>
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<td>Per Capita Income</td>
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<td>Services Employment</td>
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<td>Health Services Employment</td>
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<td>Construction Employment</td>
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<tr>
<td>Educational Attainment</td>
<td>CB 2000 Demographic Profiles</td>
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<td>Poverty Index</td>
<td>CB 2000 Demographic Profiles</td>
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<td>Unemployment Index</td>
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<td>Services per Town - Recreational</td>
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<td>GS 2000 Political Boundaries</td>
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<tr>
<td>Euclidian Distance to Public Land</td>
<td>Various Sourcesb 1996-2002</td>
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</tr>
<tr>
<td>Proportion Public Land within 5mi. Radius</td>
<td>Various Sourcesb 1996-2002</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Proportion Public Land within 10mi. Radius</td>
<td>Various Sourcesb 1996-2002</td>
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Table 1. Continued

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<th>Scale</th>
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<tr>
<td>Mean Annual Temperature</td>
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<td>Euclidian Distance to All Surface Water</td>
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<td>Travel Time to Major Surface Water</td>
<td>GS/EPA 1999 Hydrography</td>
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<tr>
<td>Euclidian Distance to Major Surface Water</td>
<td>GS/EPA 1999 Hydrography</td>
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<td>Euclidian Distance to Forested Areas</td>
<td>GS 1992 National Land Cover</td>
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<td>Euclidian Distance to Public Land</td>
<td>Various Sources(^b) 1996-2002</td>
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<tr>
<td>Proportion Public Land within 5mi. Radius</td>
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<td>Proportion Public Land within 10mi. Radius</td>
<td>Various Sources(^b) 1996-2002</td>
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<td>Proportion Public Land within 15mi. Radius</td>
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<td>1:100,000</td>
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<tr>
<td>Homes within 1 Section Radius</td>
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<td>Homes within 2 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000(^a)</td>
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<td>Homes within 5 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000(^a)</td>
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<td>Homes within 10 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
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<td>Homes within 20 Section Radius</td>
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<td>1:100,000(^a)</td>
</tr>
</tbody>
</table>

\(^a\) Tabular source data, such as US Census figures, were joined to spatial datasets with the listed scale.

\(^b\) Sources included the Montana Natural Heritage Program, the University of Wyoming Spatial Data and Visualization Center, and the Idaho Cooperative Fish and Wildlife Research Unit.

Following is a summary of the potential covariates compiled for use in the model comparisons of rural residential development. The agricultural suitability dataset was described in the previous section. Datasets representing the location and accessibility of roads and airports fall within the transportation class. The road density variable describes kilometers of road per square kilometer. Another variable represents the Euclidian distance to the nearest major road for all locations within the study area. The travel capacity index takes into account both road density and road class. The highest travel capacity values occur in areas containing both major highways and high road densities.
The explanatory variables representing travel time to the nearest airport were calculated using cost-distance grid functions incorporating distance and automobile speed limits, following the methods of Nelson (2001).

Another group of potential covariates was used to describe the availability of regional services, town-level economic services and town-level recreational services within the GYE. Regional service-related covariates included the travel time from schools, hospitals, and towns containing populations greater than 1000. This population threshold was used to identify towns with shopping and commercial resources. Town-level variables were used to explain variation in growth within rural areas bordering towns. The town-level economic services describe local employment opportunities and educational attainment, compiled from the 2000 U.S. Census Bureau DP-2 Demographic Profile Tables. The town-level recreational services describe the per capita number of recreation-related businesses as well as the accessibility and extent of surrounding lands that are protected from development, including public lands and conservation easements.

Variables describing climate, topography, hydrology, vegetation, and land ownership were used to represent natural amenities within the GYE. Mean annual precipitation and temperature were used to represent local climatic variation. Topographic variation was calculated as the standard deviation in elevation per square mile neighborhood. If development occurred predominantly in traditional locations, namely valley bottoms, one would expect a negative relationship. However, if development occurred primarily at the wildland interface, a positive relationship would result. Three measures of distance to surface water were used to evaluate the degree to
which riparian areas have experienced development pressure. Distance variables were also used to capture proximity to forest, proximity to the national parks, and proximity to lands protected from development, including public lands and conservation easements. The proportion of public lands and conservation easements was calculated within neighborhoods of five, ten, and fifteen mile radii.

The encroaching development variables represent the number of rural homes present prior to 1970. Like the response variable, these data were based on tax assessor records. Encroaching development was calculated within five neighborhoods, including the existing development within a circle with a one, two, five, ten, and twenty section radius. See Appendix A for further documentation of the rural homes data and all datasets collected as potential covariates of growth in rural residential development.

Statistical Analysis. Since the change in rural homes was represented as count data and the variance was greater than the mean, we used generalized linear models with the assumption of a negative binomial distribution (Proc GENMOD, SAS Institute Inc., 2001). After visually examining univariate plots of the response to the individual covariates, we specified a log link in order to transform to linear relationships. To assess the goodness of fit between the predicted models and the observed data, Pearson’s chi-square statistics were used. For a true model, the Pearson's chi-square statistic divided by the degrees of freedom should asymptotically approach one. When this value is much larger than one, the data are said to exhibit overdispersion (SAS Institute Inc., 1989). Area was incorporated in the models as an offset variable because the area of all sections was not exactly 2.59 square kilometers. For example, sections along lake shores and
county boundaries deviated substantially. An offset variable serves as a component of the linear predictor that has a fixed coefficient. Whereas regression coefficients are normally unknown parameters to be estimated by the procedure, area was assumed to have the constant coefficient of one per observation. This assumption was made because the relationship between change in home number and area of a section was expected to be multiplicative; all else being equal, twice the area should experience twice the increase in homes.

Exploratory analyses were used to identify those datasets within each of the six classes that explained the most variation in growth in rural home development (Table 1). Within each class, all variables were fit to the rural homes data using univariate generalized linear models. Those variables that explained the most variation in growth in rural home development were selected for use in the model comparisons. In cases where a second non-redundant variable within the same class improved the fit by more than 50 AIC units, the second variable was selected as well. Although the conventionally accepted cutoff for identifying the “best” model is a difference of two units, the cutoff was raised to 50 units to account for inflated delta AIC values resulting from the large sample size (n = 24,999).

The variables selected in exploratory analyses were used to build four statistical models of growth in rural residential development. The natural resources model represents our hypothesis (H1) that recent growth in rural residential development is related to a legacy of dependence upon agriculturally productive lands. The infrastructure model represents our hypothesis (H2) that transportation infrastructure and
access to services explains growth in rural residential development. This model fits most observations according to the accessibility of regional services, such as schools; however, the observations near towns are treated uniquely. An indicator variable identifies areas considered to be within the zone of influence of towns, defined as those areas that are within a ten minute drive of towns. Travel time from towns was calculated following the methods of Nelson (2001). Of all GYE towns, a sample of thirty was selected for use in this model. This sample was small enough to enable data collection, and large enough to detect whether the incorporation of town characteristics significantly improved the explanatory power of the model. The sampled towns were selected to represent the range of populations and economies characteristic of GYE towns. The indicator town variable and two interaction terms, which incorporate the effects of local economic and recreational opportunities, cause an adjustment of the y-intercept and the slope for those observations near sampled towns. Although only one equation is used to describe the system, areas near sampled towns are in effect fit to a separate model.

The natural amenities model represents our hypothesis (H3) that natural amenities drive the expansion of rural residential development, particularly in areas that were previously isolated, defined as sections (approximately 2.59 square kilometers blocks) that prior to 1970 supported no homes. Thus, in the natural amenities model, an indicator variable identifies previously isolated areas, and interaction terms incorporate the influence of natural amenities in these areas. The fourth model used for comparison represents the effects of encroaching development, or the presence of rural homes that were built prior to 1970 (H4).
The final hypothesis (H5) states that the combined effects of natural resources, transportation infrastructure and services, natural amenities, and encroaching development will most accurately describe growth in rural residential development. In order to test this hypothesis, the four statistical models representing H1, H2, H3, and H4 were grouped in all possible combinations and ranked according to Akaike’s Information Criteria (Burnham and Anderson, 2000). The model that most accurately described growth in rural residential development from 1970-1999 was identified.

**Model Validation.** Roughly one quarter of private lands in the study area, a randomly selected 6217 sections, were excluded from model building for use in assessing model accuracy. Each section was assigned a random number (between 0.0 and 1.0) generated from the uniform distribution, and those sections with numbers greater than 0.75 were excluded from the model building. For the remaining 75% of the sections, generalized linear models were fit, and the model that best described growth in rural residential development during 1970-1999 for the included sections was identified. In order to test for spatial autocorrelation, Pearson residuals from the “best” model, calculated as the raw residuals divided by the predicted standard deviation, were mapped in the geographic information system (GIS) and plotted in variograms. The “best” model was then run for the excluded sections, and errors of overestimation and underestimation were summarized.
Results

Rural Homes Data
Validation and Home Distribution

In a comparison of the tax assessor rural homes database with homes identified on aerial photographs, the mean difference in counts of rural homes was 0.17 rural homes per section with a standard deviation of 1.65. Using a paired t-test, we failed to reject the hypothesis that the mean of the differences in counts between the tax assessor database and the aerial photographs was zero (P = 0.37). Thus, we maintain a high degree of confidence in the database developed using the tax assessor information.

The tax assessor rural homes database describes the distribution of homes in the GYE at the section scale (approximately 2.59 square kilometer blocks) for each year between 1857 and 1999. Within the 145,635 square kilometer study area, there are approximately 56,000 sections, of which 45% (24,999 sections) contain some private land. As of 1999, homes were distributed on 27% (6,883 sections) of the sections containing private land. Of the rural sections containing homes, 11% (738 sections) exceeded the exurban density threshold of greater than one home per 16.2 hectares (Brown et. al, in review). This threshold is meaningful because at this home density, areas are generally considered to be more populated than working agricultural lands. Within the GYE, 66% of areas containing exurban densities were within a ten-minute drive of the nearest town. However, canyons and valleys that provide access to Yellowstone National Park, including Gallatin Canyon, Paradise Valley, Jackson Hole,
and the mouth of Shoshone Canyon, supported exurban densities beyond the ten-minute zones.

**Rates of Rural Home Growth**

The rate of rural home construction within the GYE rose in stages between 1900 and 1999, slowing only during two brief periods (Figure 2). The average annual growth in rural home development spiked during the economic boom of the 1920s, slowed briefly during the Great Depression of the 1930s, but resumed and increased gradually throughout the following three decades. A dramatic spike in the 1970s increased the annual rate of rural home construction from 356 homes in 1969 to a high of 1793 homes during 1978. Although the annual growth rate waned in the 1980s, it remained higher than the average pre-1970 annual growth rates, and recovered in the 1990s, reaching a peak rate in 1998, during which 1633 rural homes were built. During these three decades, the growth rate of the Greater Yellowstone’s population, fueled largely by immigration, exceeded that of three-quarters (78.2%) of all counties in the U.S. (Hansen et al., 2002).

However, among GYE counties, there has been wide variation in growth of rural home development. Between 1970 and 1990, the five counties with the largest increase in rural homes gained twelve times more rural homes than the five counties with the smallest increase (Figure 3). The average annual growth rate of rural homes in the 5 fastest growing counties was 127.43 rural homes per year as compared to the growth rate of the five slowest growing counties, 10.17 homes per year. Contained within the five fastest-growing counties are eight of the ten largest towns in the GYE (Idaho Falls,
Bozeman, Riverton, Cody, Lander, Ammon, Jackson, and Powell), indicating a strong link between rural home development and the location of socioeconomic centers. Also during the 1970s, 1980s, and 1990s, there was wide variation in the increase in rural home density on private lands per county. The five counties that experienced the largest increases in rural home density grew by 2.03 homes per square kilometer. In comparison, the five counties that experienced the smallest increases in rural home density grew by only 0.15 homes per square kilometer.

Figure 3. Increase in rural homes and rural home density during 1970-99 are represented per GYE County.
Sub-county analyses of growth patterns are particularly useful in the Rocky Mountain West, where counties tend to be extremely large, 6845 square kilometers on average. Due to their size, GYE counties tend to include a wide range of socio-political components, including more populated as well as extremely remote areas. Examining growth at the section level within the GYE was therefore necessary for detecting and explaining smaller scale development patterns. For example, although many of the fast growing counties during 1970 through 1999 contained larger towns, not all of the growth in rural home construction occurred adjacent to those towns. Much of the recent growth within these counties occurred in the more isolated regions. Local regions that experienced rapid growth in rural residential development were more prevalent in the northwest, west and southwest portions of the study area (Figure 4). This subset of the study area is characterized by greater average annual precipitation and more productive soils. As well, due to topographic relief and existing road corridors, the national parks are more easily accessed from these regions.

**Natural Resource Constraints (1900-1999)**

As expected, during the early 1900s, home sites were disproportionately located in highly productive soils (classes 4 and 5) and lands proximate to water (0-3 sections) (Table 2). Although we expected this relationship to weaken over time, it remained consistent throughout the four time periods considered (1900-1925, 1925-1950, 1950-1975 and 1975-1999). For each time period we rejected the hypotheses that rural homes were distributed randomly with respect to soil productivity and proximity to surface water (P<0.001).
Figure 4. Areas of rapid growth in rural residential development during 1970-99 are represented as kernel density polygons. Within these polygons are high densities of sections in which growth was greater than one standard deviation above the mean (light gray) to greater than three standard deviations above the mean (black). Some of the factors correlated with these growth patterns include: travel time from the national parks, mean annual precipitation, and land suitability for agricultural purposes.
Table 2. Differences between observed numbers of rural homes and expected numbers of rural homes per agricultural suitability class and distance to surface water class are presented over four time periods. The expected numbers signify a random distribution with respect to agriculture and distance classes, and were calculated as the proportion of area occupied by the class multiplied by the total number of observed rural homes.

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<thead>
<tr>
<th>Landscape Attribute</th>
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<tr>
<td>Agricultural Rating(^a)</td>
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<td>1</td>
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<tr>
<td>2</td>
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</tr>
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<td>5</td>
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<td>Distance to Surface Water(^b)</td>
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<tr>
<td>10 - 30</td>
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</table>

\(^a\) Soils are ranked 1 for least suitable for agriculture to 5 for most suitable for agriculture.

\(^b\) Distance to surface water is measured in sections.

Correlates of Recent Growth (1970-1999)

Exploratory Analyses. As a result of the exploratory analyses, variables within each of seven classes (natural resources, transportation, regional services, town-level economic services, town-level recreational services, natural amenities, and encroaching development) were selected for use in model comparisons (Table 3). Because coefficients of determination cannot be generated for generalized linear models, the Pearson’s statistic divided by the degrees of freedom (\(\chi^2 / \text{D.F.}\)) was used as an approximate guide to the measure of fit. For a true model, \(\chi^2 / \text{D.F.}\) should asymptotically approach one. Within the natural resources class, the suitability for agriculture variable was positively related to growth in rural residential development (p-
value < 0.0001). All transportation-related variables were significantly related to growth patterns (p-value < 0.0001). Growth was positively related to travel capacity and negatively related to distance from major roads and travel time from airports. Among the transportation variables, road density performed the best according to the Akaike weights ($\beta = 0.0169$, S.E. = 0.0003, $\chi^2 / \text{D.F.} = 1.64$), and was positively correlated with growth in rural residential development during 1970 through 1999. Within the services class, growth was negatively related to travel time from towns and schools (p-value < 0.0001). Travel time to the nearest hospital ranked the highest ($\beta = -0.0058$, S.E. = 0.0004, $\chi^2 / \text{D.F.} = 5.09$). Thus, sections proximate to hospitals tended to experience more growth in rural residential development.

Within the town-level economic services class, several of the potential covariates were insignificant at a significance level of 0.05, including the proportion of the population below poverty, and the proportion of construction, service, and health-related employment. The proportion of employment considered to be professional, including scientific, management, administrative, and waste management services, was positively related to growth in rural residential development (p-value < 0.0001). Both per capita income and unemployment were also positively related to growth (p-value < 0.01). Within the town-level economic services class, the education attainment index performed the best ($\beta = 0.0581$, S.E. = 0.0080, $\chi^2 / \text{D.F.} = 3.76$). Thus, towns in which a large proportion of the population over 25 years of age had attained a bachelor’s degree or higher tended to experience faster growth in adjacent rural areas.
Within the town-level recreational services class, many of the potential covariates were insignificant at a significance level of 0.05, including all measures of per capita recreation-related business, all measures of the extent of surrounded lands in public ownership and conservation easement, and the proportion of seasonally occupied homes. The proportion of employment in entertainment services was positively correlated with growth (p-value = 0.03). Travel time to the national parks was ranked highest ($\beta = -0.0116, \text{S.E.} = 0.0020, \chi^2 / \text{D.F.} = 3.75$). Thus, sections near towns that were more proximate to Yellowstone and Grand Teton National Parks tended to experience more growth in rural residential development. Interestingly, proximity to public lands and conservation easements, was positively related to growth. Thus, sections near towns that were further from public lands and easements tended to experience more growth.

Within the natural amenities class, all of the covariates were significantly related to growth in rural residential development, at a significance level of 0.05. Travel time to the national parks was ranked highest ($\beta = -0.0041, \text{S.E.} = 0.0004, \chi^2 / \text{D.F.} = 3.75$). Thus, undeveloped sections distant from the national parks were less likely to be developed. Although there was strong evidence favoring the travel time from national parks variable in describing growth around towns and in previously isolated areas ($\chi^2 / \text{D.F.} = 3.75$ and $9.45$ respectively), it inadequately described the variation in growth within the study area as a whole ($\chi^2 / \text{D.F.} = 499.06$). Euclidian distance to major steams, rivers and water bodies was non-redundant (V.I.F. = 1.03) and negatively correlated with growth during this time period ($\beta = -0.0001, \text{S.E.} < 0.0001$). Precipitation and temperature were positively related to growth (p-value < 0.0001). Euclidian distance
from forested areas was negatively correlated with growth (p-value < 0.0001). Similar to the town level analyses, all measures of proximity to public lands and conservation easements were positively related to growth (p-value < 0.0001).

Within the encroachment class, the variable that performed the best based on the Akaike weights was encroaching development per section ($\beta = 0.1052$, S.E. = 0.0032, $\chi^2 / \text{D.F.} = 5.28$). The quadratic form of encroachment within a 20-section radius was non-redundant (V.I.F. = 1.13) and positively related to growth during 1970 through 1999 ($\beta = 0.0019$, S.E. = 0.0001, $\chi^2 / \text{D.F.} = 3.71$). The estimated coefficient for the squared term in the quadratic was negative ($\beta = -0.0001$, S.E. < 0.0001), reflecting that the change in the rate of growth slowed with increasing encroachment. In other words, the relationship tapered as rural housing density approached some upper limit.

Table 3. Exploratory selection results are provided for the univariate models of growth in rural residential development from 1970-1999. Covariates within each category (natural resources, transportation, services, etc.) were ranked according to Delta AIC values.

<table>
<thead>
<tr>
<th>Model Factors</th>
<th>Sign</th>
<th>Delta AIC</th>
<th>$\chi^2 / \text{D.F.}$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suitability for Agriculture$^a$</td>
<td>+</td>
<td>na</td>
<td>3.09</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road Density$^a$</td>
<td>+</td>
<td>0</td>
<td>1.64</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Travel Capacity Index</td>
<td>+</td>
<td>892</td>
<td>1.62</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (Enplanement &gt; 50,000)</td>
<td>-</td>
<td>2524</td>
<td>43.33</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Euclidian Distance from Major Roads</td>
<td>-</td>
<td>2568</td>
<td>2.85</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (Enplanement &gt; 25,000)</td>
<td>-</td>
<td>2760</td>
<td>13.02</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (All Commercial Airports)</td>
<td>-</td>
<td>3066</td>
<td>9.03</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital Travel Time$^a$</td>
<td>-</td>
<td>0</td>
<td>5.09</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 1,000)</td>
<td>-</td>
<td>82</td>
<td>5.19</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>School Travel Time</td>
<td>-</td>
<td>106</td>
<td>3.64</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Services per Town - Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational Attainment$^a$</td>
<td>+</td>
<td>0</td>
<td>3.76</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>
Table 3. Continued

<table>
<thead>
<tr>
<th>Model Factors</th>
<th>Sign</th>
<th>Delta AIC</th>
<th>$\chi^2$ / D.F.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Employment</td>
<td>+</td>
<td>28</td>
<td>3.73</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Unemployment Index</td>
<td>+</td>
<td>52</td>
<td>3.73</td>
<td>0.0016</td>
</tr>
<tr>
<td>Per Capita Income</td>
<td>+</td>
<td>54</td>
<td>3.73</td>
<td>0.0044</td>
</tr>
<tr>
<td>Poverty Index</td>
<td>+</td>
<td>60</td>
<td>3.73</td>
<td>0.1785</td>
</tr>
<tr>
<td>Services Employment</td>
<td>+</td>
<td>62</td>
<td>3.73</td>
<td>0.6731</td>
</tr>
<tr>
<td>Construction Employment</td>
<td>+</td>
<td>62</td>
<td>3.73</td>
<td>0.533</td>
</tr>
<tr>
<td>Health Services Employment</td>
<td>+</td>
<td>62</td>
<td>3.73</td>
<td>0.7697</td>
</tr>
<tr>
<td>Services per Town - Recreational</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Park Travel Time$^a$</td>
<td>-</td>
<td>0</td>
<td>3.75</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Entertainment Services Employment</td>
<td>+</td>
<td>28</td>
<td>3.73</td>
<td>0.0332</td>
</tr>
<tr>
<td>Euclidian Distance to Public Land</td>
<td>+</td>
<td>30</td>
<td>3.73</td>
<td>0.0465</td>
</tr>
<tr>
<td>Guides / Resorts Index</td>
<td>+</td>
<td>32</td>
<td>3.73</td>
<td>0.3101</td>
</tr>
<tr>
<td>Sports Equipment Index</td>
<td>+</td>
<td>32</td>
<td>3.73</td>
<td>0.2766</td>
</tr>
<tr>
<td>Proportion Public Land within 5mi. Radius</td>
<td>-</td>
<td>32</td>
<td>3.73</td>
<td>0.2282</td>
</tr>
<tr>
<td>Proportion Public Land within 10mi. Radius</td>
<td>-</td>
<td>32</td>
<td>3.73</td>
<td>0.3083</td>
</tr>
<tr>
<td>Proportion Public Land within 15mi. Radius</td>
<td>-</td>
<td>32</td>
<td>3.73</td>
<td>0.2138</td>
</tr>
<tr>
<td>Seasonal Housing Proportion</td>
<td>+</td>
<td>34</td>
<td>3.73</td>
<td>0.5608</td>
</tr>
<tr>
<td>Lodging Index</td>
<td>-</td>
<td>34</td>
<td>3.73</td>
<td>0.3198</td>
</tr>
<tr>
<td>Natural Amenities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Park Travel Time$^a$</td>
<td>-</td>
<td>0</td>
<td>9.45</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Euclidian Distance to Major Surface Water$^b$</td>
<td>-</td>
<td>26</td>
<td>9.41</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Travel Time to Major Surface Water</td>
<td>-</td>
<td>34</td>
<td>9.53</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Mean Annual Precipitation</td>
<td>+</td>
<td>62</td>
<td>9.36</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Euclidian Distance to Forested Areas</td>
<td>-</td>
<td>64</td>
<td>9.34</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Euclidian Distance to All Surface Water</td>
<td>-</td>
<td>68</td>
<td>9.33</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Euclidian Distance to Public Land</td>
<td>+</td>
<td>72</td>
<td>9.32</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Proportion Public Land within 15mi. Radius</td>
<td>-</td>
<td>74</td>
<td>9.49</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Mean Annual Temperature</td>
<td>+</td>
<td>74</td>
<td>9.33</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Variation in Elevation</td>
<td>-</td>
<td>74</td>
<td>9.32</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Proportion Public Land within 10mi. Radius</td>
<td>-</td>
<td>76</td>
<td>9.33</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Proportion Public Land within 5mi. Radius</td>
<td>-</td>
<td>76</td>
<td>9.32</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Encroachment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homes within 1 Section Radius$^a$</td>
<td>+</td>
<td>0</td>
<td>5.28</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Homes within 2 Section Radius</td>
<td>+</td>
<td>206</td>
<td>5.24</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Homes within 5 Section Radius</td>
<td>+</td>
<td>620</td>
<td>5.34</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Homes within 10 Section Radius</td>
<td>+</td>
<td>1168</td>
<td>4.74</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Homes within 20 Section Radius$^b$</td>
<td>+</td>
<td>1670</td>
<td>3.71</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

$^a$ AIC weights equal 1 for these factors and 0 for the remaining factors within the same class.

$^b$ Factors not redundant with the highest ranked factor within the same class which were selected for use in model comparisons.
**Statistical Models.** The variables selected in exploratory analyses were used to build four statistical models of growth in rural homes (Table 4). These models represent the hypotheses stated in the introduction. Interaction terms were included to represent the relationships between town characteristics and adjacent rural residential development, and previously isolated areas and natural amenities. Among the four individual models (H1-H4) of growth in rural residential development during 1970 to 1999 (Table 5), the data most strongly supported the transportation and services model (H2, AIC weight = 1). The natural amenities model (H3) was ranked second after the transportation and services model (Delta AIC = 124). The encroaching development model (H4) ranked third (Delta AIC = 1273), followed by the natural resources model (H1, Delta AIC = 3710).

Table 4. The structure of the hypothesized models of growth in rural residential development from 1970 to 1999 was determined via exploratory analysis.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Description</th>
<th>Model Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Natural Resources</td>
<td>Ag</td>
</tr>
<tr>
<td>H2</td>
<td>Transportation and Services</td>
<td>RdDens + Hosp + Twn + (Twn<em>Np) + (Twn</em>Edu)</td>
</tr>
<tr>
<td>H3</td>
<td>Natural Amenities</td>
<td>Wat + Isol + (Isol*Np)</td>
</tr>
<tr>
<td>H4</td>
<td>Encroaching Development</td>
<td>Enc1 + Enc20 + Enc20*Enc20</td>
</tr>
<tr>
<td>H5</td>
<td>Combined Models</td>
<td>All possible combinations of H1, H2, H3, and H4</td>
</tr>
</tbody>
</table>

Ag = rating for agricultural suitability; RdDens = road density; Hosp = travel time from nearest hospital; Twn = within town zone of influence (indicator); Np = travel time from national parks; Edu = education attainment; Wat = euclidian distance from major rivers and water bodies; Isol = previously isolated area (indicator); Enc1 = encroaching development per section; Enc20 = encroaching development within 20 section neighborhood.

Among the fifteen individual and combined models of growth in rural residential development during 1970 to 1999 (Table 5), there was clear support for one model according to the Akaike weights. This model (H5) incorporated agricultural suitability, encroaching development, transportation infrastructure and accessibility to services, as well as the effects of towns and natural amenities. Goodness of fit was evaluated using
the Pearson chi-square statistic divided by the degrees of freedom (3.11). All variables in the combined model were significant except for the interaction between the town indicator and the education attainment index (p-value = 0.53). The signs of the coefficient estimates remained the same as in the exploratory analyses, except for the coefficient estimate for agricultural suitability. That the estimate changed to a negative value in the combined model indicated that the variable was redundant, despite having a low V.I.F. (1.15). Growth was positively related to road density, encroaching development and the education attainment index, and negatively related to the distance from surface water, travel time to hospitals and travel time to national parks.

Table 5. Model selection results for all possible combinations of the hypothesized models of growth in rural residential development from 1970 to 1999. "k" is the number of estimated parameters per model.

<table>
<thead>
<tr>
<th>Model Structure</th>
<th>k</th>
<th>Delta AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inf + Nat + Enc + Ag*</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Inf + Nat + Enc</td>
<td>13</td>
<td>88</td>
</tr>
<tr>
<td>Inf + Nat + Ag</td>
<td>11</td>
<td>425</td>
</tr>
<tr>
<td>Inf + Nat</td>
<td>10</td>
<td>459</td>
</tr>
<tr>
<td>Inf + Enc + Ag</td>
<td>11</td>
<td>1805</td>
</tr>
<tr>
<td>Inf + Enc</td>
<td>10</td>
<td>1825</td>
</tr>
<tr>
<td>Nat + Enc + Ag</td>
<td>9</td>
<td>2444</td>
</tr>
<tr>
<td>Nat + Enc</td>
<td>8</td>
<td>2459</td>
</tr>
<tr>
<td>Inf + Ag</td>
<td>8</td>
<td>3136</td>
</tr>
<tr>
<td>Inf</td>
<td>7</td>
<td>3156</td>
</tr>
<tr>
<td>Nat + Ag</td>
<td>6</td>
<td>3254</td>
</tr>
<tr>
<td>Nat</td>
<td>5</td>
<td>3275</td>
</tr>
<tr>
<td>Ag + Enc</td>
<td>6</td>
<td>4424</td>
</tr>
<tr>
<td>Enc</td>
<td>5</td>
<td>4425</td>
</tr>
<tr>
<td>Ag</td>
<td>3</td>
<td>6858</td>
</tr>
</tbody>
</table>

Ag = (H1) natural resource constraints; Inf = (H2) transportation infrastructure and services; Nat = (H3) natural amenities; Enc = (H4) encroaching development.

* AIC weight equals 1 for the most inclusive model and 0 for the remaining models; AIC value = -83765.
Model Validation. Leaving out the redundant agricultural suitability explanatory variable, Pearson residuals were calculated for the combined model, mapped in GIS, and plotted in a variogram (Figure 5). No spatial pattern was evident in the GIS map of Pearson residuals, and the variogram showed only weak spatial autocorrelation in the residual variation. It is therefore likely that the combined model captured the relevant covariates to explain existing spatial patterns in rural residential development.

Figure 5. Weak spatial autocorrelation is evident in the variation in Pearson residuals of the “best” model. Spatial independence increases slightly with increasing distance and plateaus at roughly 30km.

The combined model was run for the excluded sections, and errors of overestimation and underestimation were calculated. The mean difference between predicted growth in the number of rural homes and observed growth per section was -1.18 homes with a standard deviation of 9.59. Of the 6217 sections evaluated, the increase in the number of rural homes was correctly predicted for 80% (4953 sections).
In 104 sections growth was overestimated, and in 1160 sections growth was underestimated (Figure 6). Of those sections in which growth was underestimated, the mean difference was 7 homes. Of the sections in which growth was overestimated, the mean difference was 4 homes. Using a paired t-test, we failed to reject the hypothesis that the mean of the differences between observed and predicted change in rural homes was zero (P = 0.11).

![Graph showing the distribution of predicted minus observed growth in rural homes per section.](image)

Figure 6. A linear equation representing the “best” model was used to calculate the predicted values of growth in rural homes per section. The observed growth in rural homes was subtracted from the predicted growth, and the differences were plotted according to frequency. Errors of over and underestimation are represented.

**Discussion**

The prerequisite for effective landscape planning is an understanding of the natural and social processes that shape our environment (Van Langevelde, 1994). The focus of this paper has been to analyze the rates and drivers of rural residential
development, a process that has resulted in the conversion of vast amounts of farmland and undisturbed habitat. Our hypotheses were drawn from the context of a paradigm of the drivers of human settlement. The paradigm proposes natural resource constraints, gains in transportation, and the attraction to natural amenities as large scale spatial and temporal drivers of human settlement patterns. The paradigm allows us to evaluate trends in land use change in a geographic and historical context.

Rates of Rural Residential Development

During the past century, the rate of rural home construction within the GYE rose in stages, responding to cultural shifts and periods of national economic growth and recession (Figure 2). Growth in rural home development spiked during the economic boom of the 1920s, when the automobile began to enable more dispersed settlement. Rural home construction then slowed for a brief period during the Great Depression of the 1930s, but resumed and increased slowly throughout the following three decades. The 1970s were known nationally as the time of “rural renaissance”, during which the populations of non-metropolitan counties grew at a faster pace than metropolitan counties, and rural development trends in the GYE mirror this national trend. The large-scale immigration to rural areas during the 1970s has been linked to the crime and racial conflicts associated with metropolitan areas, as well as the social movement to reconnect with nature (Daniels, 1999). Our data support that natural amenities have been a key driver of rural residential development within the GYE throughout the 1970s, 80s and 90s. Several researchers believe that immigration to areas rich in natural amenities will continue, and the population of the GYE will grow faster than the nation as a whole
(Cromartie and Wardell, 1999). It has also been suggested that, in many regions of the world, the primary pressure on local biodiversity will come from sprawl and impacts associated with increased household numbers (Liu et al., 2003). Indeed, this may be the case for the Greater Yellowstone Ecosystem.

Drivers of Rural Residential Development

Our results indicate that the proportion of homes built on highly productive soils and lands proximate to water has remained consistently high throughout the 1900s. We expected access to natural resources to be the primary determinant of the location of home sites during earlier time periods, when the lack of existing transportation infrastructure necessitated self sufficiency. This expectation was supported by the data. Due to technological advances allowing for the efficient transport of goods, we expected the tie between natural resources and rural residential development to have weakened during the later half of the century. However, this hypothesis (H1) was not supported. One possible explanation is that the natural resources measured, soil quality and proximity to water, continue to constrain growth. However, farming and other natural resource industries have become increasingly marginal to rural economies (Galston and Baehler, 1995; Power and Barrett, 2001). Thus, this scenario is improbable and not supported by the literature. We suspect that newer homes continue to be built near water and productive soils because of the influence of early settlement patterns and transportation routes established during the period of natural resource constraints. That growth begets growth has been well documented in both transportation and planning literature (Daniels, 1999; Hills, 1996). It is also probable that the role of natural
resources in attracting growth has changed over time. Historically home sites may have been situated proximate to water out of necessity, whereas current development trends may reflect the aesthetic and recreational value of river and lakeshores. Lastly, although the proportion of rural housing on less suitable agricultural lands has remained roughly constant, the number has dramatically increased. For example, between 1950 and 1999 the number of rural homes in sections bordering federal land increased by 302% (from 9,942 to 39,944 homes). Because the federal lands in the GYE are relatively high in elevation and are comprised of largely nutrient-poor soils (Rodman et al., 1996), these homes deviate from traditional agricultural housing locations. Fire and wildlife management policies will surely be affected by the increase in rural housing at the wildland interface.

Our analysis of recent drivers of rural residential development confirmed the influence of transportation infrastructure and associated services in driving rural residential development in the GYE (H2). Infrastructure and service related factors, including road density and travel time from hospitals, were the most influential category of covariates of rural residential development. Several natural amenities were found to be significantly, positively correlated with increasing rural residential development (H3), including climatic variables, as well as all variables related to proximity of national parks, forested areas, and surface water. However, the extent and proximity to public lands was inversely related to growth. We suspect that this occurred for two reasons: (1) the majority of rural residential development occurred in valley bottoms as opposed to the foothills and mountains flanking the public lands; and (2) this covariate did not
distinguish between public land types and management objectives. For example, Bureau of Land Management areas are often intensively managed for extractive purposes, occur in drier shrubland environments, and may be considered less scenic than other types of public land.

Our results confirm that development of new home sites encourages further conversion of undeveloped land (H4), as shown by the strong correlation between past development and new development. This phenomenon has been explained by the associated construction of roads, schools, and utility lines as well as rises in property value (Daniels, 1999). We also found that rural residential development continues to occur disproportionately on highly productive lands near water. When coupled, these relationships may be particularly undesirable in terms of their implications for both agricultural and biological conservation in the Greater Yellowstone Ecosystem. The more productive farmlands will likely continue to experience a disproportionate level of residential development, as will the biologically diverse lowland riparian habitats. In order for communities to maintain a balance between future growth and environmental quality, planning practices such as zoning and the purchase of development rights will become increasingly important.

Our data showed strongest support for the model combining agricultural suitability, transportation and services, natural amenities, and encroaching development as the primary determinants of rural residential development across the Greater Yellowstone Ecosystem (H5). That agricultural suitability was redundant with other covariates underscores the relevance of the paradigm of shifting drivers of human
settlement. The GYE’s current landscape is explained by (1) the legacy of early settlement constrained by natural resources, and (2) the continuing role of infrastructure, natural amenities, and encroaching development in driving growth.

The most explanatory model also incorporated the concept of zones of influence around each town. Within these zones, rural residential growth could not be adequately explained without socio-economic and recreation-related qualities of the respective towns. This finding emphasizes that not all towns are equally likely to attract rural residential development. Towns near Yellowstone and Grand Teton National Parks were more likely to experience home construction in adjacent rural lands, as were towns characterized by a highly educated population and a large proportion of employment in the professional sector. Such towns included Rexburg, Driggs, and Victor in Idaho, Bozeman, Ennis, and West Yellowstone in Montana, and Pinedale and Jackson in Wyoming. This trend is likely a result of the large-scale immigration of workers, new businesses and affluent retirees leaving urban areas for more scenic rural environments (Power and Barrett, 2001; McDaniel, 2000; Johnson and Rasker, 1995). These new residents require physicians, accountants, lawyers, and other services, resulting in an increase in professional jobs. Responding to this demand, service and high technology businesses take advantage of their footloose nature to move to areas rich in natural amenities (McDaniel, 2000), thereby increasing the number of professional jobs and the number of educated workers in and around natural amenity rich towns. Outside of the zone of towns’ influence, natural amenities continue to play a driving role in the expansion of rural residential development into previously undeveloped areas. These
areas were more likely to become home sites if they were near the national parks. This trend likely reflects the increase in vacation homes, as well as the number of retirees and professionals that work from home in the GYE (U.S. Census Bureau 1990; U.S. Census Bureau, 2000).

Based on our results, several profiles exist for communities with high potential for rapid growth in rural residential development. Although many booming rural areas in the GYE are located in highly productive agricultural valleys, the legacy of agriculture dependant early settlement has not always resulted in rapid rural growth. Communities such as Thermopolis, WY and Soda Springs, ID with highly productive agricultural soils have experienced relatively little rural growth, likely due to a lack of natural amenities. In addition, some boom areas did not descend from the agricultural history. Communities such as Jackson, WY, Big Sky, MT, and park gateway communities such as West Yellowstone, MT and Driggs, ID developed well after the agricultural period. These communities may have fostered rural growth by drawing on the viewsheds and recreation opportunities provided by their natural setting. For communities utilizing their natural amenities to promote growth, we expect that preservation of environmental quality will be instrumental for assuring a high quality of life, rising property values and continued growth.

**Consequences**

Knowledge of the factors that increase growth potential is needed because several characteristics of land development tend to be ecologically problematic. A multitude of mechanisms by which land use change impacts ecological processes have been identified.
These include introductions of new species, alteration of biotic interactions, changes in habitat extent and juxtaposition, changes to disturbance regimes, biomass changes, and effects on air and water quality, light quality, and noise pollution (Dale et al., in review, Hansen et al., in review). In comparison with urban land use change, the effects of rural residential development are likely to be disproportionately large (Theobald et al., 2000), because low-density development consumes more land, resulting in more extensive habitat conversion and fragmentation (Daniels, 1999; Noss et al., 1994). Also, rural residential development tends to be distributed in areas with high levels of biodiversity due to biophysical factors and natural amenities (Hansen et al., in review). The attraction of adaptive species, often termed synanthropes, and the avoidance by species sensitive to human presence can result in highly modified community assemblages near rural homes (McKinney, 2002; Hansen and Rotella, 2000; Garrott et al., 1993; Hansen et al., in review). In addition to the local effects, exurban development may alter ecological processes and biodiversity on adjacent and even distant public lands (Hansen et al., in review).

Within the GYE, the patterns of rural residential development we have described potentially threaten biodiversity within the Yellowstone and Grand Teton National Parks. Because the parks lack significant amounts of lowland habitat, several wildlife species, such as grizzly bears and certain migratory songbirds, commonly seen in the national parks, may not be able to persist there without access to habitats outside the parks (Hansen and Rotella, 2002). Our results suggest that rural residential development during recent decades has occurred disproportionately on lands bordering the parks, potentially
eroding the quality of the lowland habitats most used by park species. As well, this configuration of rural residential development may result in a barrier between wildlife species and the undeveloped lowland habitats upon which they depend. Ungulates, such as pronghorn antelope, moose, elk and mule deer, with annual migrations that winter on private lands may be especially vulnerable (Boccadori, 2002; Yellowstone National Park, 1997).

In addition to the ecological costs, rural residential development has been linked to health and social problems. Rural on-site septic systems for sewage disposal often overflow and leak, leading to water quality problems and health hazards (Daniels, 1999). Rural residents commuting long distances to work and shopping burn more gasoline and generate more air pollution (Daniels, 1999; Liu et al., 2003). As well, employment opportunities and traditional ways of life are rapidly changing as farms and ranches are subdivided and converted to home sites (Hansen et al., 2002).

The economic consequences of rural residential development are related largely to the costs of community services. Rural development increases demands for new schools, fire stations, roads, sewer, water and utility lines. These components of services and infrastructure are heavily subsidized by urban taxpayers and utility customers (Daniels, 1999). Costing more in services than is generated in property taxes, rural residential development is often a net drain on local government budgets (Urban Land Institute, 1992). In the GYE, most new growth is low density, dispersed development that is more costly to provide services to than compact development (Haggerty, 1997). In response to growth in rural home construction, local governments tend to encourage commercial and
industrial development that require fewer services and produce a surplus in revenue. However, new businesses attract new residential developments, once again driving up the cost of services. That public services are funded by development is a major challenge to growth management in the U.S. (Daniels, 1999).

Limitations

Our current understanding of the drivers of rural residential development is limited by our inability to directly infer causation. We have identified bio-physical and socio-economic variables that are highly correlated with growth in rural residential development; however, in some cases, these variables have been shown to both cause growth and result from growth. Expansion of transportation infrastructure, either through new miles of roadway or through expanded capacity along existing roadways, is one such variable (Charlier, 2003; Hills, 1996; Goodwin, 1996). For example, growth and increased demand often lead to roadway additions, which induce additional traffic via encouragement of increases in vehicle trips and encouragement of commercial and residential development along the improved route (Charlier, 2003).

The bio-physical and socio-economic factors we have identified add to a growing body of literature investigating the drivers of human settlement patterns (Walsh et al., 2003; Hansen et al., 2002; Schnaiberg et al., 2002; Schneider and Pontius, 2001; Kok and Veldkamp, 2001; Serneels and Lambin, 2001; Verburg et al., 1999). In general, these studies have been hampered by the lack of available spatially explicit socio-economic data (Veldkamp and Lambin, 2001). Our application of town scale socio-economic data to describe nearby rural development patterns was a novel approach that significantly
improved the explanatory power of our modeling. We conservatively assumed that rural areas within a ten minute drive of town limits were within the town’s zone of influence. However, more research is needed to further understand the scales at which rural lands are connected to neighboring urban centers.

Although the paradigm of drivers of human settlement is not a place-specific concept, our results are consistent with the paradigm. Still, the extrapolation of these results to rural areas outside the GYE should be undertaken with caution. One major difference between the GYE and many other regions of the U.S. lies in the strength of the land use regulations. Despite high rates of development and population growth, fifteen of the twenty GYE counties have no county-wide zoning, and four GYE counties have no full-time planners on staff. The variation in topography and extensive public lands also make the region unique. The specific drivers of rural residential development within the GYE are likely representative of other Rocky Mountain regions rich in natural amenities.

Implications

Three stages have been used to describe changes in the drivers of human settlement over time. These stages have evolved with human technology, and are characterized by: (1) natural resource constraints, (2) transportation expansion and (3) pursuit of natural amenities (Huston, in review; Riebsame et al., 1996; Wyckoff and Dilsaver, 1995; James, 1995). Several aspects of our analyses support that these stages have shaped patterns of rural residential development within the GYE. Additionally, our research suggests that each phase of development has left a legacy on the landscape, and that current patterns of rural home construction integrate the effects of all three periods.
Our data demonstrate that the factors that drove early settlement patterns remain strongly correlated with patterns of land use today.

The ecological and socio-economic implications of past, present and future rural land use changes are generally under-studied. Within the GYE, the patterns of rural residential development we have observed potentially threaten biodiversity within the Yellowstone and Grand Teton National Parks. The consequence of land use change on nature reserves when adjacent lands are developed deserves more attention. Also, the extent to which rural residential development has contributed to the introduction of non-indigenous species and the alteration of natural fire and flooding cycles remains largely unknown. Future patterns of rural development have the potential to effect water and air quality, as well as the stability of local economies and communities.

Our findings highlight the importance of local policy decisions in effecting rural residential development. Rural development regulations are almost always applied at the local level (Theobald et al., 2000). Thus, the additive effect of land use change results from the accumulation of many smaller decisions by individual landowners and local governments (Theobald et al., 2000). Because new home sites tend to encourage further residential development, subdivisions proposed in undeveloped areas should be conscientiously reviewed. Also, because growth is strongly related to the characteristics of nearby towns, municipal and county planners should cooperate to develop a comprehensive regional vision (Daniels, 1999). This is especially the case for those municipalities characterized by factors highly correlated with rural residential development, such as close proximity to the national parks, a highly educated workforce
and a large proportion of employment in professional industries. Finding solutions to the economic and environmental problems caused by rural residential development, such as meeting demands for new schools, roads, water consumption and land protection, will require foresight and cooperation among local governments (Daniels, 1999).

As rural residential development continues to expand into rural landscapes, the incorporation of scientific understanding of natural systems into local government decision-making will become increasingly important. In particular, there is an increasing need to support local decisions about the impacts of development on the environment. Analytical tools for simulating future growth can be used by local governments to visualize growth scenarios and make decisions with a more complete understanding of the consequences. However, development of realistic simulations requires knowledge of the relevant parameters and the extent to which they influence growth. The knowledge gained from this study will enable the parameterization of simulations of growth in rural residential development within the Greater Yellowstone Ecosystem.
Introduction

The development of rural lands is the result of many decisions made by individual landowners and local governments (Theobald, 2000). These decisions are often made without scientific input. However, as rural residential development continues to expand into rural landscapes, the incorporation of scientific understanding of natural systems into local government decision-making will become increasingly important. In particular, there is a growing need to support local decisions about the impacts of development on the environment. Analytical tools for simulating future growth are needed so that local governments can visualize growth scenarios and make decisions with a more complete understanding of the consequences for natural systems.

For several reasons, the Greater Yellowstone Ecosystem (GYE) is in much need of tools that could facilitate the process of growth management. Situated within the mountain west in the area encompassing Yellowstone and Grand Teton National Parks, the GYE is one of the fastest growing regions in the US. During the 1970s, 1980s, and 1990s, the growth rate of the GYE’s population, fueled largely by immigration, exceeded that of three-quarters (78.2%) of all counties in the U.S. (Hansen et al., 2002). The region is characterized by the values of the development preferences of the newcomers, who are often wealthy young adults, professionals in service industries and retirees (Nelson 1999) desiring ranchette-style homes on large lots. The construction of rural homes has been the GYE’s primary form of land use change (Rasker and Hansen, 2000).
Still, it is a region characterized by vast amounts of undeveloped land, unrestrictive land use policies, and generally under-funded and understaffed county planning departments. Thus, there exists high potential for undirected and unmanaged growth on the private lands surrounding one of the nation’s most well known nature reserves.

The primary objective of this study was to simulate alternative future scenarios of rural development in the GYE. Thus, we designed the Rural Development Simulator (RDS), a computer decision support tool. The RDS is a regression-based, spatially explicit model that forecasts growth in rural residential development as a function of transportation infrastructure, natural amenities, and existing residential development. A statistical approach was selected over other modeling approaches, such as cellular automata and agent-based models, due to limitations in the current understanding of drivers of land use change. Cellular automata and agent-based models require knowledge of the factors that influence the individual’s decisions and interactions within the modeled system (Grimm, 1999). Conversely, the statistical approach allowed us to make predictions, with a measured degree of confidence, of spatial and temporal patterns of rural residential development based upon regional covariates.

The RDS was designed to facilitate the manipulation of growth inducing and limiting factors in order to generate maps of alternative future scenarios. The objective of this study was to use the RDS to generate four alternative scenarios for the year 2020. A status quo scenario was generated, which projected current rate of growth into the future. In this scenario, the construction of future rural homes proceeded according to the statistical relationships between past (1990-1999) rural development patterns and the
correlates of growth. A slow growth scenario was designed to emulate the lower range of
growth potential for the region, and a boom scenario was designed to emulate the upper
range. This range of future development potential was determined statistically, using
back-transformed confidence intervals, and through the incorporation of expert opinion
regarding possible transportation infrastructure changes such as road and airport
expansion. The status quo, slow growth, and boom scenarios are contrasted with a
growth management scenario, in which land conservation policies were simulated to
directed development away from places of high conservation value. These four scenarios
will allow policy makers to visualize the region in the future under current, slow, and
rapid growth trends, and under policies aimed at sustaining ecological value.

Development of the RDS required knowledge of the relevant parameters and the
extent to which they influence growth. Most case studies point to the important role of
social, political, and economic factors in driving land use change (Veldkamp and
Lambin, 2001). However, most statistical models of land use change fail to incorporate
such factors due to the lack of available spatially explicit socio-economic and political
data (Veldkamp and Lambin, 2001). The majority of analyses of historical patterns of
development have concentrated on variables considered to be proximate rather than
actual causes of growth (Irwin and Geoghegan, 2001). For example, distance to towns is
often used to represent the direct influence of markets and the availability of services.
Measures of distance to towns and roads, and measures of land productivity, such as land
cover, climate and soils, are among the factors most frequently cited as being strongly
correlated with land use change (Verburg et al., 1999; Pontius et al., 2001; Schneider and Pontius, 2001; Serneels and Lambin, 2001; Kok and Veldkamp, 2001).

In the previous paper, drivers of rural residential development within the GYE during the boom period of 1970 to 1999 were identified using exploratory statistical analyses. Similar to past statistical models of land use change, the analysis relied to some extent on variables that were likely proxies for underlying driving forces. However, unlike previous models, town scale socio-economic data were used to describe local rural development patterns within the regional scale model. This was a novel approach that significantly improved the explanatory power of our analyses.

The factors found to be strongly correlated with rural residential development patterns included measures of transportation infrastructure and associated services, natural amenities, past development patterns, and town scale socio-economic indices. Infrastructure and service related factors, including road density and travel time from hospitals, were the most influential category of covariates of rural residential development. Past development and new development were also strongly correlated. This relationship has been explained by the associated construction of roads, schools, and utility lines as well as rises in property value that are the causal mechanisms (Daniels, 1999). Several natural amenities were found to be significantly, positively correlated with increasing rural residential development, including climatic variables, as well as all variables related to proximity of national parks, forested areas, and surface water. Lastly, socio-economic and recreation-related qualities of towns were found to influence home construction in adjacent rural lands. Towns near Yellowstone and Grand Teton National
Parks were more likely to experience home construction in adjacent rural lands, as were towns characterized by a highly educated population and a large proportion of employment in the professional sector.

In the current paper, we use a similar modeling approach to identify the correlates of growth from 1990 to 1999. This statistical analysis is used to parameterize simulations of future rural residential development in the GYE to the year 2020. Our hope is to provide land use planners and land conservation organizations a tool to incorporate non-biased data into the planning process and assess the possible consequences of alternative growth scenarios for the GYE.

**Methods**

Several steps were involved in generating alternative future scenarios of rural residential development for the GYE. The extent of the study area and the time period of analysis were decided upon. A suite of potential explanatory variables for rural residential development was compiled, and differences in the relationships between these variables and rural residential development patterns among portions of the GYE were assessed. This was necessary in order to determine whether regions of the GYE should be modeled separately. Next, the assumptions and specifications of multivariate statistical models were decided upon, as well the methodology for model selection and testing for spatial autocorrelation. An accuracy assessment of the best model of past development patterns was performed before parameterizing the simulation of future development patterns. Finally, the structure of the simulation model was specified, and
modifications to this basic structure were made in order to generate the three alternative future scenarios.

**Study Area**

Centered on the Yellowstone Plateau, the Greater Yellowstone Ecosystem (GYE) was originally defined as the range of *Ursus arctos*, the Yellowstone grizzly bear (Craighead, 1991). Subsequently, Rasker (1991) expanded the study area boundary to include the 20 counties within Montana, Wyoming and Idaho that overlap the GYE in recognition of the strong ecological and socio-economic linkages across the public and private lands of this region. The expanded boundary is appropriate for this study because development regulations and growth management are implemented at the county level.

Of the 145,635 square kilometers that make up the 20 counties of the GYE, public and tribal lands comprise 68% (98,386 km$^2$) of the region. Land ownership is divided between private land owners (32%), the USDA Forest Service (32%), the USDI Bureau of Land Management (19%), Yellowstone and Grand Teton National Parks (7%), Tribal Lands (5%), and State Lands, wildlife refuges and other federal lands (5%). Because of extensive public ownership, it is often assumed that the influence of rural residential development on the ecosystem will be limited. However, many species of wildlife in the GYE depend on resources found almost exclusively on the privately owned lowland valleys, where land use is intensifying.

The region is unique in the continental U.S. in that it supports several large carnivores and free-roaming populations of ungulates. Herds of elk (*Cervus elaphus*) and bison (*Bison bison*) inhabit the area, as do bighorn sheep (*Ovis canadensis*), antelope
(*Antilocapra americana*), moose (*Alces alces*), wolves (*Canis lupus*), and grizzly bears. The headwaters of seven major rivers originate in and around Yellowstone National Park. These rivers flow mainly through private lands where they form biologically diverse lowland riparian habitats surrounded by the semi-arid uplands. The vegetation of the GYE consists of a combination of forest, shrub and grassland. Coniferous forests occupy much of the Yellowstone Plateau and mountainous terrain, while shrub and grassland vegetation is more common in valley bottom and alpine habitats.

With just over 370,000 permanent residents in 2000, the GYE has a small but rapidly expanding population. Since 1970, the human population of the GYE has grown by more than 60%. Currently, much of the private lands in the area are undeveloped. However, developed land in the GYE is increasing faster than the rate of population growth, as large-lot rural subdivision continues to be the preferred mode of development. From 1970 to 1999, the GYE experienced an increase in population of 58% and an increase in the area of rural lands supporting residential development (at densities greater than one home per 16.2 hectares) of 350%.

**Correlates of Past Growth**

The correlates of recent growth were analyzed in order to better understand what parameters could be used in forecasting changes in rural home density within the near future. The interval of one decade was chosen for the analyses in order to capture general temporal trends in rural development. Thus, the response variable was the change in rural homes per section over the time period 1990-1999. The rapid rate of rural home construction in the GYE during the 1990s (Figure 2) is expected to persist according to
demographic trends, such as the retirement of baby boomers and patterns of migration into the rural west (Cromartie and Wardell, 1999). Therefore, the time period serves as a reasonable model of growth rates within the near future.

**Explanatory Variables.** Several datasets were compiled for the analysis of correlates of growth in rural residential development during the 1990s. Similar to the analysis of growth patterns during 1970-1999 discussed in the previous paper, these datasets describe the study area with respect to natural resources, transportation, services (including regional services, town-level economic services and town-level recreational services), natural amenities, and past home development (Table 6). Full documentation for all potential explanatory variables is provided in Appendix A.

Table 6. Potential covariates of growth in rural residential development from 1990 to 1999 were compiled from the listed sources. Federal agencies from which data were acquired are abbreviated (CB = Census Bureau, GS = Geological Survey, DOT = Department of Transportation, EPA = Environmental Protection Agency).

<table>
<thead>
<tr>
<th>Model Factors</th>
<th>Source</th>
<th>Scale</th>
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<tbody>
<tr>
<td>Natural Resources</td>
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<tr>
<td>Suitability for Agriculture</td>
<td>DA State Soil Geographic Database</td>
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<tr>
<td>Transportation</td>
<td></td>
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<tr>
<td>Airport Travel Time (All Airports)</td>
<td>GS/DOT 1998 National Atlas</td>
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<tr>
<td>Airport Travel Time (Enplanement &gt; 25,000)</td>
<td>GS/DOT 1998 National Atlas</td>
<td>1:2,000,000</td>
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<tr>
<td>Airport Travel Time (Enplanement &gt; 50,000)</td>
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<td>Road Density</td>
<td>CB 1990, 2000 TIGER/Line Files</td>
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<tr>
<td>Euclidian Distance from Major Roads</td>
<td>CB 2000 TIGER/Line Files</td>
<td>1:100,000</td>
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<td>Travel Capacity Index</td>
<td>CB 2000 TIGER/Line Files</td>
<td>1:100,000</td>
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<tr>
<td>Regional Services</td>
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<td>Town Travel Time (Population &gt; 1,000)</td>
<td>CB 2000 TIGER/Line Files</td>
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<td>Town Travel Time (Population &gt; 5,000)</td>
<td>CB 2000 TIGER/Line Files</td>
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<td>Town Travel Time (Population &gt; 7,500)</td>
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<td>Town Travel Time (Population &gt; 10,000)</td>
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<td>Town Travel Time (Population &gt; 20,000)</td>
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<td>School Travel Time</td>
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<td>GS 2000 Political Boundaries</td>
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<td>Proportion Protected Land in 5mi. Radius</td>
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</tr>
<tr>
<td>Proportion Protected Land in 15mi. Radius</td>
<td>Various Sources&lt;sup&gt;b&lt;/sup&gt; 1996-2002</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Mean Annual Precipitation</td>
<td>Univ. of MT 1997 DayMet</td>
<td>1:24,000</td>
</tr>
<tr>
<td>Mean Annual Temperature</td>
<td>Univ. of MT 1997 DayMet</td>
<td>1:24,000</td>
</tr>
<tr>
<td>Proximity to Forested Areas</td>
<td>GS 1992 National Land Cover</td>
<td>1:24,000</td>
</tr>
<tr>
<td>Travel Time from Forested Areas</td>
<td>GS 1992 National Land Cover</td>
<td>1:24,000</td>
</tr>
<tr>
<td>Proximity to Forest Service Lands</td>
<td>Various Sources&lt;sup&gt;b&lt;/sup&gt; 1996-2002</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Travel Time from Forest Service Lands</td>
<td>Various Sources&lt;sup&gt;b&lt;/sup&gt; 1996-2002</td>
<td>1:100,000</td>
</tr>
<tr>
<td><strong>Past Home Development</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homes within 1 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homes within 2 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homes within 5 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homes within 10 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homes within 20 Section Radius</td>
<td>County Tax Assessors 1999-2001</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homes Built in Previous Decade</td>
<td>County Tax Assessors 1999-2002</td>
<td>1:100,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Tabular source data, such as US Census figures, were joined to spatial datasets with the listed scale.

<sup>b</sup> Sources for public land boundaries include Montana Natural Heritage Program, University of Wyoming Spatial Data and Visualization Center, and Idaho Cooperative Fish and Wildlife Research Unit.
Assessment of Regional Differences. In order to determine whether change in rural home density should be modeled separately for regions of the GYE, we visually examined univariate plots to assess whether the correlates of rural residential development tended to differ among portions of the GYE. The twenty counties within the study area were ranked according to three criteria and subdivided into groups. The first criterion by which counties were ranked was the proportion of each county's population that was born in-state (US Census, 2000). This criterion was selected because we suspected that the development preferences of newcomers would be different from those of locals. For example, job opportunities are more likely a driving force of development patterns by long time residents. However, proximity to natural amenities and recreation opportunities may be more important to new arrivals from other regions of the US. Hence, different factors would be needed to explain the resulting development patterns. The ten counties with the highest proportions of newcomers were grouped, as were the ten counties with the lowest proportions. For both groups, univariate plots were created to explore the relationships potential explanatory variables (Table 6) and the change in homes per section from 1990-1999. The plots were visually compared in order to assess whether the relationships differed between groups. Per plot, any substantial differences in sign and slope were recorded.

This same process was repeated for groups of counties divided according to two other criteria. One of these criteria was the proportion of professional jobs per county (Census, 2000). This criterion was selected because we suspected that the factors driving development patterns might differ around wealthier communities. The last criterion by
which the twenty counties were ranked was the mean driving time to the nearest airport from any location within the county. Again, we suspected that the factors driving development patterns might differ in areas that were less isolated. None of the three grouping criteria showed that correlates of growth differed between regions, therefore our next step was to identify those variables (Table 6) that explained the most variation in growth in rural home development within the GYE as a whole.

**Statistical Analysis.** All potential explanatory variables were centered and scaled to fall between -1 and 1 according to the formula

\[ X_{1\text{Scaled}} = \frac{(X_1 - \text{midpoint})}{\text{midrange}} \]

in which the midpoint was found by adding the minimum and maximum values and dividing by 2 and the midrange was found by subtracting the minimum value from the maximum value and dividing by 2 (SAS Institute Inc., 1989). The variables were centered and scaled in order to make the magnitude of differences in coefficient estimates indicative of the relative influence of each covariate (Neter et al., 1996).

Roughly one quarter of private lands in the study area, a randomly selected 6217 sections, were excluded from the analysis as a “hold-back” dataset for use in assessing model accuracy. For the remaining 75% of the sections, the potential explanatory variables were fit to the response variable using univariate generalized linear models. Since the change in rural homes was represented as count data and the variance was greater than the mean, we used generalized linear models with the assumption of a negative binomial distribution (Proc GENMOD, SAS Institute Inc., 2001). After visually examining univariate plots of the response to the individual covariates, we specified a log
link in order to transform to linear relationships. To assess the goodness of fit between the predicted models and the observed data, Pearson’s chi-square statistics were used. Area was incorporated in the models as an offset variable because the area of all sections was not exactly 2.59 square kilometers. The SAS code is presented in Appendix B.

Within each of six categories (Table 6), those variables that explained the most variation in growth in rural home development during the 1990s were identified. In cases where a second, non-redundant variable within the same class improved the fit by more than 50 Akaike’s Information Criteria (AIC) units (Burnham and Anderson, 2000), the second variable was selected as well. Although the conventionally accepted cutoff for identifying the “best” model is a difference of 2 units, the cutoff was raised to 50 units to account for inflated delta AIC values resulting from the large sample size (n = 24,999) (Taper, personal communication). All possible combinations of the selected variables were ranked according to differences in AIC scores, and the best model was identified.

A potential problem with using regression models to analyze spatial land use change data is that the statistical test assumes the residuals are independent (Overmars et al., 2003). Often model errors tend to be spatially dependent, a phenomena known as spatial autocorrelation. In order to test for spatial autocorrelation, Pearson residuals from the “best” model, calculated as the raw residuals divided by the predicted standard deviation, were mapped in the geographic information system (GIS) and plotted in variograms. The SAS code used to generate the variograms is presented in Appendix B. The “best” model was then run for the previously excluded sections, and errors of overestimation and underestimation were summarized. In order to address the concern
that the accuracy of the best model may be inflated by the use of explanatory variables from the year 2000 to predict growth during the 1990s, the subset of explanatory variables represented in the best model were collected for the year 1990. This approach was taken because spatially explicit historical data are often unavailable or difficult to find. The best model was rerun using explanatory variables from 1990 to allow the point estimates for the coefficients to shift. This model was then run for the previously excluded sections, and the resulting accuracy was assessed.

Simulation of Future Development

Using the “best” generalized linear model of growth during the 1990s, the RDS was run for two iterations of one decade each, in order to forecast development patterns for 2010 and 2020 (Figure 7). The RDS was used to produce four alternative scenarios of rural residential development: the slow growth, status quo, boom, and growth management scenarios. A slow growth scenario was created using the lower limit of the back-transformed confidence interval. The status quo scenario shows potential future rural land use change given a growth rate consistent with that observed during 1990-1999 and existing growth management policies. The boom scenario was created using the upper limit of the back-transformed confidence interval, and incorporated information about future gains in transportation infrastructure and future subdivisions from workshops with land use planners. The growth management scenario imposed rules representative of hypothetical growth management policies in order to achieve a conservation planning goal.
The Rural Development Simulator (RDS) consists of interacting Java and ARC/INFO programs that helped to execute the process diagrammed in Figure 7. Specifically, the RDS was used to implement zoning and other growth management regulations that affected allowable housing densities, and to calculate the “past development” variables that were used as model inputs. For example, the forecasted development for 2010 became an input for the 2020 regression model in the form the past development variables, including: (1) the number of homes per section, (2) the number of homes within a one section radius, (3) the number of homes within a 20 section radius, and (4) the extent of development during the previous decade. These four variables were recalculated by the RDS between each modeled time step.

**RDS Structure and Flow.** Each run of the RDS began with the Java program initializing the starting point of the simulation to 1999, and generating forecasts for 2010 (Figure 8). Next, the ARC/INFO program imported the forecasted 2010 housing and recalculated model inputs for the following iteration. Next, the Java program imported these newly created inputs, initialized the starting point to 2010, and generated forecasts for 2020. Last, the ARC/INFO program imported the forecasted 2020 housing dataset into the GIS.
Figure 7. The best regression model was used iteratively to forecast rural residential development for the years 2010 and 2020.
The portions of the RDS that were programmed in Java executed five main events (Figure 8): (1) importing the predictor datasets and growth management regulations, (2) initializing the simulation starting point, (3) running the regression equation to generate the forecasted home density per section for the following decade, (4) implementing the growth management regulations, and (5) exporting the forecasted rural housing densities and locations to the geographic information system (GIS). For each section within the study area, the Java portion of the RDS maintained attributes representing the number of homes, the area, and the change in number of homes during the previous time step, and the growth management regulations. Several options could be specified, including whether or not to implement growth management regulations and whether to generate minimum, mean, or maximum forecasts. The mean predicted growth in rural housing per section was calculated using the point estimate for each coefficient within the regression equation. The minimum and maximum forecasts were calculated by using the lower and upper estimates for the 95% confidence limits for each estimated parameter within the regression equation. The ARC/INFO portions of the RDS were programmed in Arc Macro Language and were used to (Figure 8): (1) import forecasted rural housing densities and locations (2) recalculate the predictor datasets pertaining to “past development”, and (3) export the newly calculated predictor datasets for use in the next model iteration.
RDS Java Program

1. Import the predictor variables.
2. Set starting point:
   - If 1st iteration: 1999
   - If 2nd iteration: 2010
3. Generate the predicted change in rural homes for \( \chi \) section according to the regression equation.
4. Displace predicted homes to similar sections within the commutershed.
5. Export the data:
   - If 1st iteration: 2010 Predictions
   - If 2nd iteration: 2020 Predictions
6. Import predicted development into GIS
7. Incorporate newly predicted homes into "past development" variables for the 2nd iteration.
8. Export the "past development" variables for use in the next iteration.

RDS ARC/INFO Program

Simulation is complete

(1) Import the predictor variables.
(2) Set starting point:
   - If 1st iteration: 1999
   - If 2nd iteration: 2010
(3) Generate the predicted change in rural homes for \( \chi \) section according to the regression equation.
(4) Displace predicted homes to similar sections within the commutershed.
(5) Export the data:
   - If 1st iteration: 2010 Predictions
   - If 2nd iteration: 2020 Predictions
(6) Import predicted development into GIS
(7) Incorporate newly predicted homes into "past development" variables for the 2nd iteration.
(8) Export the "past development" variables for use in the next iteration.

Figure 8. The program flow of the Rural Development Simulator (RDS) consists of interacting Java and ARC/INFO programs that create rural housing forecasts for the years 2010 and 2020.

RDS Handling of Growth Management Regulations. The RDS was used to quantify the extent to which zoning districts and other growth management regulations, such as conservation easements, affected forecasted rural development patterns. During 2001, we produced a map of conservation easements within the GYE compiled from
various government agencies and land trusts. The degree to which this dataset is complete is difficult to assess because records of easements are maintained by the individual organizations that manage the easements, and no collective list of easements exists that we know of. We were able to assemble data regarding the locations and specific regulations of zoning districts within the GYE, with the exception of Bonneville County, ID. “Rule based” zoning where no minimum parcel size was specified, for example, unlimited allowable subdivision by family, was not incorporated into the model.

We assumed that the forecasts generated using the best regression model captured regional demand for rural housing, thus local zoning districts were assumed to redirect rather than cap regional growth. When forecasted development exceeded the allowable home density as specified by a zoning district, the RDS displaced the forecasted homes into similar sections within the same county. Because GYE counties tend to be very large (6845 square kilometers on average), several GYE counties were further subdivided into commutersheds containing less than 2500 square kilometers of private land. Commutershed boundaries were subjectively drawn to include larger towns and surrounding rural areas. On average, 2.3 commutersheds were delineated per GYE County. The average commutershed area was approximately 1000 square kilometers of private land. Only one commutershed was delineated to cross county boundaries; the Jackson Hole commutershed included the northern portion of Star Valley, WY, and the southern portion of Teton Valley, ID.

In order to ensure that homes displaced from growth regulated sections were displaced to reasonably similar sections, each section was assigned a similarity rating
based on the predictor variables from the best regression model. A similarity rating was assigned to each unique combination of the predictor variables. However, the use of all predictor variables resulted in cases in which the RDS was unable to find similar developable sections within the same commutershed. Thus, only three of the predictor variables from the best model could be used to generate the similarity index: (1) housing density within a one section radius, (2) travel time to the nearest town, and (3) travel time to large forested areas. For example, all sections with high rural housing densities, near a town, and far from forested areas would be assigned the same similarity rating. The RDS allowed displacement between sections with the same rating.

When forecasted development exceeded the allowable home density as specified by the modeled growth management regulation, the RDS’ displacement algorithm selected a random section within the current commutershed. If the similarity index of the randomly selected section matched that of the current section, a home was assigned to the randomly selected section. Otherwise, another section was randomly selected from within the commutershed and the similarity index tested. This process was repeated until all forecasted homes were assigned to reasonably similar sections within the same commutershed. All RDS source code is provided in Appendix C.

**RDS Alternative Future Growth Scenarios.** The RDS was designed to facilitate the manipulation of growth inducing and limiting factors in order to generate maps of alternative future scenarios. Four alternative scenarios were generated for the purpose of visualizing the potential for growth in the GYE and assessing existing and hypothetical growth management policies (Table 7).
Table 7. The future growth scenarios generated by the RDS use different assumptions of growth rates, limiting, and driving factors.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Years Simulated</th>
<th>Rate of Rural Home Construction</th>
<th>Limiting Factors</th>
<th>Driving Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>2010, 2020</td>
<td>Point estimates of coefficients from best regression model</td>
<td>Existing zoning districts and conservation easements</td>
<td>Covariates from best regression model</td>
</tr>
<tr>
<td>Low Growth</td>
<td>2010, 2020</td>
<td>Lower coefficient estimates from back-transformed 95% confidence limit</td>
<td>Existing zoning districts and conservation easements</td>
<td>Covariates from best regression model</td>
</tr>
<tr>
<td>Boom</td>
<td>2010, 2020</td>
<td>Using upper coefficient estimates from back-transformed 95% confidence limit</td>
<td>Existing zoning districts and conservation easements</td>
<td>Covariates from best regression model are altered to reflect hypothetical gains in transportation infrastructure and rural housing</td>
</tr>
<tr>
<td>Growth Management</td>
<td>2010, 2020</td>
<td>Point estimates of coefficients from best regression model</td>
<td>Existing and hypothetical zoning districts and conservation easements</td>
<td>Covariates from best regression model</td>
</tr>
</tbody>
</table>

“Status Quo” and “Low Growth” Future Scenarios. For both the status quo and low growth scenarios, the RDS was run for two decades (2000-2020) with the assumption that no changes are made to existing growth management policies during that time period. In the status quo scenario, future rural land use change was assumed to occur at a rate consistent with that observed during 1990-1999. For the low growth scenario,
parameters of the RDS were altered to approximate a statistically probable lower estimate of growth. This was done by rerunning the best regression model using the lower coefficient estimates from the 95% confidence limits for each parameter.

“Boom” Future Growth Scenario. For the boom scenario the parameters of the RDS were altered to approximate a statistically probable upper estimate of growth for the GYE. To accomplish this, the best regression model was rerun using the upper coefficient estimates from the 95% confidence limits for each parameter. In addition, expert opinion regarding future locations of road improvements and subdivisions were incorporated into the model. Finally, we assumed airport expansion would occur in several existing GYE airports. The assumed transportation and subdivision gains were distributed within several GYE counties (Figure 9).

Workshops were held in which five planners and zoning administrators from Idaho and ten planners from Montana identified on hard copy maps areas where they anticipate new subdivisions, new roads, and major road improvements are most likely to occur within a ten year time horizon. The locations of future roads and road improvements were then digitized. Sections identified by the planners as "subdivision areas" were coded in the attribute table of the tax assessor homes database. The subdivision areas that planners had identified during the workshops were incorporated into the boom scenario by augmenting the forecasted 2010 development with additional rural homes. The planner specified future road improvements were incorporated by recalculating transportation related model inputs. Airport related model inputs were recalculated as well to reflect hypothetical airport growth. Because the hypothetical
changes to transportation infrastructure were assumed to take place in the future (and had not taken place by 1999), they did not affect the first iteration of the simulation (1999-2010). Rather, the changes to transportation infrastructure were assumed to be in effect by 2010, and affected the second iteration of the simulation (2010-2020).

Figure 9. The locations of future subdivisions, new roads and major road improvements were identified by planners from around the Greater Yellowstone, and were incorporated into the boom scenario. Travel time to airports was recalculated to include all commercial airports within the Greater Yellowstone.
In order to incorporate the hypothetical subdivision areas identified by planners, the upper estimate of forecasted homes built between 1999 and 2010 was compared to the number of homes assigned to the planner specified subdivision areas according to a “subdivision rule”. This rule was based upon the observed rates of subdivision within the 1990s, and generated estimates of the number of homes built within the planner identified subdivision areas by the year 2010. For areas in which growth occurred in the 1990s, those sections with 0 homes in 1990 experienced an average increase of 2 homes within the following decade. Sections with 1 to 10 homes in 1990 experienced an average increase of 3 homes within the following decade. Sections with greater than 10 homes in 1990 experienced an average increase of 10 homes within the following decade. Based on these trends, subdivision areas were assigned homes depending upon the number of homes observed in the beginning of the decade. The year 1999 was used instead of 2000, since the tax assessor homes database is only uniformly current through the year 1999. For sections within subdivision areas in which 0 homes were present in 1999, a uniform random number of homes between 1 and 3 was assigned for 2010. For sections within subdivision areas in which 1 to 10 homes were present in 1999, a uniform random number of homes between 2 and 4 was assigned for 2010. Finally, for sections within subdivision areas in which greater than 10 homes were present in 1999, a uniform random number of homes between 5 and 10 was assigned for 2010. In 52 of the 268 sections within subdivision areas, the number of homes assigned by the subdivision rule was greater than the statistical upper estimate. The larger number of homes, as generated by either the “subdivision rule” or the statistical upper estimate, was assigned to each
section. The “past development” model inputs were recalculated to reflect the hypothetical increases in rural housing.

In order to incorporate the hypothetical transportation improvements as identified by planners, the model inputs incorporating road locations were recalculated. These parameters included road density, travel time to forested areas, and variables representing encroaching development. Travel time to nearest major airport was recalculated as well. By the year 2010, all commercial airports within the GYE were assumed to have surpassed the minimum number of annual enplanements (125,000) used previously to identify major airports. Given that Gallatin Field Airport's annual enplanements increased by approximately 125,000 passengers between 1990-2000, this assumption was considered reasonable for the “boom” scenario. Thus, all commercial airports were included in the calculation of travel time to the nearest major airport.

“Growth Management” Future Scenario. The overall objective of this scenario was to model protection of a subset of lands within the GYE considered to be high priorities for conservation. Like the status quo scenario, the rate of rural home construction for the growth management scenario was assumed to be the same as the rate observed during 1990-1999. Forecasted rural residential development was directed away from ecologically sensitive areas by imposing hypothetical growth management policies including the purchase of conservation easements and the delineation of zoning districts. When forecasted development exceeded the allowable home density as specified by the hypothetical growth management policies, the RDS displaced the forecasted homes into similar sections within the same commutershed. Although the total forecasted increase in
rural residential development was the same as that forecasted for in status quo scenario, the location of forecasted development in the growth management scenario differed. This scenario provides an example of applying the RDS for growth management and conservation oriented planning.

Specifically, the goal was to develop growth management policies that would protect one quarter of the GYE’s most ecologically valuable private lands. In order to accomplish this goal, 4047 square kilometers of private land were designated as conservation easements, in which no forecasted development would be allowed. An additional 12,141 square kilometers of private land were zoned for agricultural housing densities. The goal of 4047 square kilometers of land in conservation easements was chosen as an optimistic, but not unreachable, target according to members of several land trusts within the GYE (personal communication, Lange).

Four spatial indices were used to rank the priority of lands for conservation. The first was an assessment of the irreplaceability of sites within the GYE based upon nine biological criteria (Noss et al., 2002). The concept of irreplaceability in land conservation planning is defined as the likelihood that an area is needed to reach an explicit conservation goal (Pressey, 2001). The biological criteria in Noss et al.’s (2002) assessment of irreplaceability included:

1. Contribution to the goal of protecting at least 10 viable occurrences of all imperiled, local-scale species in the ecoregion,

2. Contribution to the goal of protecting at least 10 viable occurrences of vulnerable and declining bird species in the ecoregion,
3. Contribution to the goal of protecting habitat capable of supporting 50-70% of the populations of elk and large carnivores, as identified by habitat suitability models,

4. Contribution to the goal of maintaining viable populations of grizzly bear, wolf, and wolverine, as determined by PATCH dynamic model.

5. Contribution to the goal of protecting at least 10 viable occurrences of coarse-scale and regional-scale aquatic species in the ecoregion,

6. Contribution to the goal of protecting 100% of all viable occurrences of imperiled plant communities and at least 10 occurrences of plant communities of high conservation interest in the ecoregion,

7. Contribution to the goal of representing at least 35% of the area of each wetland vegetation type and at least 25% of the area of all other vegetation types in the ecoregion,

8. Contribution to the goal of representing at least 10% of the area of each combined vegetation and abiotic (geoclimatic) habitat type in the ecoregion, and

9. Contribution to the goal of representing at least 35% of the length of each aquatic habitat type in the ecoregion.

The second index of conservation priority was based upon an analysis of wildlife movement corridors (Walker and Craighead, 1997). The placement of corridors was based upon habitat suitability models for grizzly bears, elk and cougars, which were combined with measures of road density to create a spatially explicit “cost of movement” surface (Walker and Craighead, 1997). For each focal species, a least cost path analysis was performed using ARC/GRID software in order to identify broad potential corridors. Walker and Craighead (1997) further refined the corridors map by identifying probable movement routes, barriers, bottlenecks, and areas where corridor routes intersected high risk habitat.
The third index of conservation priority was based upon modeled bird species richness and abundance for the GYE (Hansen, unpublished data). Bird species richness and abundance were generated from USGS Breeding Bird Survey (BBS) data. Predictor data on topography, climate, and vegetation composition and productivity were collected, and model selection procedures were used to evaluate relationships between the predictor data and the biodiversity response variables. The resulting best models were used to extrapolate bird richness and abundance across the GYE. Areas of high bird biodiversity potential were defined as areas with predicted total abundance greater than 70% of maximum and predicted species richness greater than 70% of maximum (Hansen, personal communication).

The forth index identified lowland riparian areas and uplands containing a deciduous forest component. These data were generated using the US Geological Survey’s National Land Cover Characterization Project, digital elevation models, and Parmenter et al.’s GYE Landsat classification (Parmenter et al., 2003). Although minor components of western landscapes, riparian and upland deciduous habitats have been characterized as centers of avian diversity and sustain rare plants and butterfly species (Hansen and Rotella, 2002, Barnett and Stohlgren, 2001). These habitats are also known for high levels of primary productivity, and as a consequence forage production, which benefits native ungulates (Bartos and Cambell, 1998). The four indices were scaled from zero to one and weighted equally. The mean value was calculated and used to represent a gradient of conservation priorities across the GYE (Figure 10).
Figure 10. Four indices of biological irreplaceability, connectivity, biodiversity and riparian habitat were used to prioritize lands in the GYE according to their conservation value.

The highest ranked quarter of private lands were identified according to the final conservation prioritization scheme (10). The subset of these lands with current agricultural housing densities, lot sizes greater than 16.2 hectares in 1999, and high forecasted development pressure, forecasted development exceeding the exurban density threshold, were designated as high priority conservation easement areas (Figure 11). In order to reach a goal of approximately 4047 square kilometers of conservation easement
designated areas, the remaining unprotected highest ranked conservation areas with current agricultural housing densities were also added as second priority conservation easement areas (Figure 11).

Figure 11. Hypothetical conservation easements were designated for use in the growth management scenario. The easements were identified as either having high or low likelihood of conversion from agricultural to exurban land use according to the RDS. In both cases, further rural home construction was prohibited in these areas in the growth management scenario.

Designation of second priority conservation easement areas was made regardless of development pressure. This was done because development pressure is dependant upon land availability. The highest ranked quarter of private lands, with current
agricultural housing densities, that were not designated as conservation easement areas were specified as agriculturally zoned districts, in which housing densities were to be maintained below the exurban threshold (Figure 12). In total, 4047 square kilometers of land were specified as conservation easement areas in which no forecasted development was allowable, and an additional 12,141 square kilometers of land were zoned for agricultural land use. The RDS was run with these growth management regulations in place.

Results

Assessment of Regional Differences

Plots of the univariate relationships between potential explanatory variables and the change in rural homes during the 1990s were generated per region. Among the regions, defined as groups of GYE counties with similar socio-economic characteristics, the relationships between potential explanatory variables and growth in rural residential development were visually determined to be similar in intercept, slope, and shape. Since the form of the relationships driving growth was not found to differ regionally, the response variable used for the analysis of past correlates of rural residential development was the change in rural homes per section within the entire GYE. Therefore, we proceeded with model selection for the entire study area, excluding those areas used for model validation.
Figure 12. Hypothetical zoning districts were used to direct the location of development in the growth management scenario. Rural housing was limited to agricultural densities within the modeled zoning districts.
Statistical Analysis

Eleven variables were selected for use in all subsets model selection based upon differences in their AIC values (Table 8). As indicated by the magnitude of the coefficient estimates, the encroaching development and transportation variables were most strongly related to rural residential development during the 1990s, followed by natural amenities, services, suitability for agriculture, and town scale economic and recreation variables. Model selection, ranking all possible combinations of the eleven explanatory variables by differences in AIC values, yielded a “best” model (Table 9).

Table 8. The coefficient estimates, confidence intervals, and significance levels are described for the univariate exploratory models of growth in rural residential development from 1990 to 1999.

<table>
<thead>
<tr>
<th>Model Factors</th>
<th>Beta</th>
<th>DeltaAIC</th>
<th>CHI/d.f.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suitability for Agriculture</td>
<td>1.16</td>
<td>na</td>
<td>2.84</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road Density</td>
<td>11.73</td>
<td>0.00</td>
<td>1.85</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Travel Capacity Index</td>
<td>17.30</td>
<td>679.54</td>
<td>1.91</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (Enplanement &gt; 25,000)</td>
<td>-6.73</td>
<td>1097.36</td>
<td>2682.95</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (Enplanement &gt; 50,000)</td>
<td>-5.97</td>
<td>1288.78</td>
<td>542.89</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Euclidian Distance from Major Roads</td>
<td>-2.03</td>
<td>1681.12</td>
<td>2.58</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Airport Travel Time (All Commercial Airports)</td>
<td>-6.32</td>
<td>1766.42</td>
<td>1691.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 5,000)</td>
<td>-6.50</td>
<td>0.00</td>
<td>3.24</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 12,500)</td>
<td>-4.60</td>
<td>166.44</td>
<td>2.12</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 15,000)</td>
<td>-4.70</td>
<td>171.06</td>
<td>2.08</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 20,000)</td>
<td>-3.43</td>
<td>178.34</td>
<td>2.07</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 10,000)</td>
<td>-4.73</td>
<td>588.70</td>
<td>2.48</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 7,500)</td>
<td>-3.94</td>
<td>594.84</td>
<td>2.59</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Town Travel Time (Population &gt; 1,000)</td>
<td>-8.11</td>
<td>639.99</td>
<td>96728.18</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hospital Travel Time</td>
<td>-6.33</td>
<td>661.97</td>
<td>2273.25</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>School Travel Time</td>
<td>-6.68</td>
<td>763.92</td>
<td>5986.83</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Services per Town - Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational Attainment&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.51</td>
<td>0.00</td>
<td>2.73</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Professional Employment</td>
<td>0.94</td>
<td>34.28</td>
<td>2.71</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Per Capita Income</td>
<td>1.45</td>
<td>39.31</td>
<td>2.72</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Unemployment Index</td>
<td>0.69</td>
<td>49.28</td>
<td>2.71</td>
<td>0.0042</td>
</tr>
<tr>
<td>Construction Employment</td>
<td>0.52</td>
<td>52.90</td>
<td>2.72</td>
<td>0.0273</td>
</tr>
<tr>
<td>Model Factors</td>
<td>Beta</td>
<td>DeltaAIC</td>
<td>CHI/d.f.</td>
<td>p-value</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------</td>
<td>----------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>Services Employment</td>
<td>0.41</td>
<td>57.06</td>
<td>2.72</td>
<td>0.3396</td>
</tr>
<tr>
<td>Health Services Employment</td>
<td>-0.20</td>
<td>57.24</td>
<td>2.71</td>
<td>0.3752</td>
</tr>
<tr>
<td>Poverty Index</td>
<td>0.25</td>
<td>57.25</td>
<td>2.71</td>
<td>0.3900</td>
</tr>
<tr>
<td>Services per Town - Recreational</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Park Travel Time*</td>
<td>-1.79</td>
<td>0.00</td>
<td>2.74</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Entertainment Services Employment</td>
<td>1.14</td>
<td>41.19</td>
<td>2.73</td>
<td>0.0042</td>
</tr>
<tr>
<td>Guides / Resorts Index</td>
<td>0.24</td>
<td>49.33</td>
<td>2.72</td>
<td>0.2034</td>
</tr>
<tr>
<td>Sports Equipment Index</td>
<td>0.23</td>
<td>49.60</td>
<td>2.72</td>
<td>0.2440</td>
</tr>
<tr>
<td>Seasonal Housing Proportion</td>
<td>0.13</td>
<td>50.59</td>
<td>2.71</td>
<td>0.4752</td>
</tr>
<tr>
<td>Proportion Protected Land within 5mi. Radius</td>
<td>-0.13</td>
<td>50.60</td>
<td>2.71</td>
<td>0.4607</td>
</tr>
<tr>
<td>Lodging Index</td>
<td>-0.20</td>
<td>50.77</td>
<td>2.71</td>
<td>0.5400</td>
</tr>
<tr>
<td>Proximity to Protected Land</td>
<td>0.10</td>
<td>50.86</td>
<td>2.71</td>
<td>0.6074</td>
</tr>
<tr>
<td>Proportion Protected Land within 10mi. Radius</td>
<td>-0.04</td>
<td>51.08</td>
<td>2.71</td>
<td>0.8147</td>
</tr>
<tr>
<td>Proportion Protected Land within 15mi. Radius</td>
<td>-0.03</td>
<td>51.10</td>
<td>2.71</td>
<td>0.8657</td>
</tr>
<tr>
<td>Natural Amenities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time from Forested Areas*</td>
<td>-4.86</td>
<td>0.00</td>
<td>3.33</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Travel Time to Major Water Bodies</td>
<td>-8.63</td>
<td>581.83</td>
<td>11.59</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>National Park Travel Time</td>
<td>-8.63</td>
<td>588.33</td>
<td>64978.85</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Travel Time from Forest Service Lands</td>
<td>-4.93</td>
<td>596.35</td>
<td>3.57</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximity to Major Water Bodies*</td>
<td>-3.15</td>
<td>1043.89</td>
<td>2.92</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximity to Forested Areas</td>
<td>-2.34</td>
<td>1453.76</td>
<td>3.15</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximity to Forest Service Lands</td>
<td>-2.21</td>
<td>1467.74</td>
<td>3.10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean Annual Precipitation</td>
<td>2.67</td>
<td>1710.96</td>
<td>2.97</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proportion Protected Land within 5mi. Radius</td>
<td>-0.68</td>
<td>1759.73</td>
<td>2.14</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximity to Surface Water</td>
<td>-4.11</td>
<td>1827.98</td>
<td>2.35</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximity to Protected Land</td>
<td>2.49</td>
<td>1833.77</td>
<td>2.01</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proportion Protected Land within 10mi. Radius</td>
<td>-0.44</td>
<td>1864.74</td>
<td>2.29</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Variation in Elevation</td>
<td>-0.45</td>
<td>1919.91</td>
<td>2.46</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean Annual Temperature</td>
<td>0.20</td>
<td>1928.08</td>
<td>2.52</td>
<td>0.0476</td>
</tr>
<tr>
<td>Proportion Protected Land within 15mi. Radius</td>
<td>-0.25</td>
<td>1945.43</td>
<td>2.35</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Encroachment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homes within 1 Section Radius*</td>
<td>27.5162</td>
<td>0.00</td>
<td>1.5823</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Homes built in previous decade*</td>
<td>53.1773</td>
<td>879.10</td>
<td>9.2979</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Homes within 2 Section Radius</td>
<td>10.0614</td>
<td>1872.39</td>
<td>4.7866</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Homes within 5 Section Radius</td>
<td>6.4496</td>
<td>2062.06</td>
<td>4.3747</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Homes within 20 Section Radius*</td>
<td>2.644</td>
<td>2155.50</td>
<td>2.4692</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Homes within 10 Section Radius</td>
<td>16.1063</td>
<td>2362.52</td>
<td>3.3392</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*a* AIC weights equal 1 for these factors and 0 for the remaining factors within the same class.

* Factors not redundant with the highest ranked factor within the same class which were selected for use in model comparisons.
Table 9. The coefficient estimates, confidence intervals, and significance levels are described for the parameters of the best model (delta AIC = 0) and second best model (delta AIC = 205).

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>β</th>
<th>95% Confidence Limits</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta AIC = 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>9.02</td>
<td>7.39, 10.73</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Road Density</td>
<td>3.01</td>
<td>2.53, 3.49</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Airport Travel Time</td>
<td>-0.65</td>
<td>-0.98, -0.34</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Development Indicator</td>
<td>1.75</td>
<td>1.65, 1.86</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Homes in 1 Section Radius</td>
<td>3.80</td>
<td>3.12, 4.52</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Homes in 20 Section Radius</td>
<td>0.16</td>
<td>0.03, 0.30</td>
<td>0.0203</td>
</tr>
<tr>
<td>Homes in 20 Section Radius - Quadratic Term</td>
<td>-0.89</td>
<td>-1.12, -0.66</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Construction During Previous Decade</td>
<td>9.76</td>
<td>8.14, 11.47</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Streams/ Rivers Proximity</td>
<td>-1.12</td>
<td>-1.33, -0.92</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Forest Areas Travel Time</td>
<td>-3.31</td>
<td>-3.58, -3.03</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Dispersion</td>
<td>3.67</td>
<td>3.46, 3.89</td>
<td></td>
</tr>
<tr>
<td>Delta AIC = 205</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>1.38</td>
<td>0.48, 2.29</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Road Density</td>
<td>3.65</td>
<td>3.16, 4.15</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Airport Travel Time</td>
<td>-0.59</td>
<td>-0.95, -0.25</td>
<td>0.0009</td>
</tr>
<tr>
<td>Development Indicator</td>
<td>2.24</td>
<td>1.80, 2.69</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Homes in 1 Section Radius</td>
<td>5.60</td>
<td>4.84, 6.40</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Homes in 20 Section Radius</td>
<td>0.11</td>
<td>-0.03, 0.25</td>
<td>0.1122</td>
</tr>
<tr>
<td>Homes in 20 Section Radius - Quadratic Term</td>
<td>-0.96</td>
<td>-1.19, -0.72</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Streams/ Rivers Proximity</td>
<td>-1.08</td>
<td>-1.29, -0.88</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Forested Areas Travel Time</td>
<td>-3.63</td>
<td>-3.94, -3.32</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Town Indicator</td>
<td>1.01</td>
<td>0.23, 1.79</td>
<td>0.0108</td>
</tr>
<tr>
<td>Town Indicator * National Park Travel Time</td>
<td>-0.44</td>
<td>-0.81, -0.07</td>
<td>0.0197</td>
</tr>
<tr>
<td>Dispersion</td>
<td>3.95</td>
<td>3.73, 4.19</td>
<td></td>
</tr>
</tbody>
</table>

Pearson residuals were calculated for the “best” model, mapped in GIS, and plotted in a variogram (Figure 13). No spatial pattern was evident in the GIS map of Pearson residuals, and the variogram showed no evidence of spatial autocorrelation in the residual variation. It is therefore likely that the “best” model captured the relevant covariates to explain existing spatial patterns in rural residential development.
The combined model was run for the validation dataset that consisted of 6217 previously excluded sections. Errors of overestimation and underestimation were calculated. The mean difference between predicted and observed growth in number of rural homes per section was 0.14 homes with a standard deviation of 3.92. Of the 6217 sections evaluated, the increase in number of rural homes was correctly predicted for 83% (5161) of sections. The increase in the number of rural homes was correctly predicted to plus or minus one home in 94% (5835) of sections. In 630 sections growth was overestimated, and in 427 sections growth was underestimated (Figure 14). Of those sections in which growth was underestimated, the mean difference was 3 homes. Of the sections in which growth was overestimated, the mean difference was 4 homes. In sections where growth occurred during the 1990s, the mean percent deviation was 7.31%.
Thus, in sections where 100 homes where developed, the model was off by 7.3 homes on average. In sections where fewer than 14 homes were built, the model was off by less than one home on average.

Figure 14. The best model of rural residential development during the 1990s was used to calculate the predicted values of growth in rural homes per section. The observed growth was subtracted from the predicted growth, and differences were plotted according to frequency. Errors of over and underestimation are represented.

Differences in the accuracy of the best model were found to be minimal when explanatory variables from 1990 were substituted. Within the best model, the variables that required recalculation included road density, travel time from airports, and travel time from forested areas. All three variables were recalculated using the 1990 U.S. Census Bureau TIGER/Line roads dataset. Of the 6217 sections used to evaluate model accuracy, the increase in number of rural homes was correctly predicted for 82% of sections, or 5126 sections compared to the 5161 sections correctly classified using
explanatory variables from the year 2000. The increase in the number of rural homes was correctly predicted to plus or minus one home in 94% of sections, or 5839 sections compared to the 5835 sections correctly classified using explanatory variables from the year 2000.

Simulation of Future Development

The mathematical models for all four scenarios were in the form of linear equations; however, forecasted growth was non-linear (Figure 15) due to the influence of the “past development” variables. In both the status quo and growth management scenario, the number of rural homes within the GYE was forecasted to increase by 82.38% (44,011 homes) from 1999 to 2020. The forecasted increase was from 53,425 homes in 1999 to 73,052 in 2010, and 97,436 in 2020 (Figure 15). In the low growth scenario, an increase of 27.51% (14,697 homes) was forecasted to occur by 2020. In the 2010 low growth scenario, 62,371 homes were forecasted, and, in 2020, 68,122 homes were forecasted. An increase of 233.63% (124,817) was forecasted to occur by 2020 according to the boom scenario. In the 2010 boom scenario, 96,515 homes were forecasted, and, in 2020, 178,242 homes were forecasted.

The difference between the total number of homes between the boom estimate and the status quo estimate was greater than the difference between the low growth estimate and the status quo estimate. This deviation occurred for two reasons. First, the response variable for the best regression model, change in homes per section, was log transformed. Thus, the inverse function of the natural logarithm was applied to RDS forecasted growth, causing larger values to expand. Second, the boom scenario
incorporated expert opinion with regards to future gains in transportation infrastructure and subdivision, causing forecasted growth to increase in certain areas. Approximately 90% of the difference between the forecasted growth in the status quo and boom scenarios was attributable to using the upper coefficient estimates from the 95% confidence intervals, and 10% was attributable to modifications associated with expert opinion, including the assumptions of future airport expansion, road construction, and subdivision.

Figure 15. The RDS was used to forecast rural residential development for the years 2010 and 2020. Forecasts for the status quo and growth management scenarios were substantially lower than forecasts for the boom scenario, created by using the upper limit of the back-transformed confidence interval and incorporating expert opinion from local land use planners.
Trends Common to all Scenarios. In all scenarios, the distribution of forecasted homes for the year 2020 was skewed towards the northern and western portions of the study area (Figure 16). Development was forecasted to occur most densely in the Gallatin Valley, the area surrounding Idaho Falls, the Island Park area, the Jackson Hole, the southern Teton Valley, the Rexburg area, the northern Star Valley, the northern Paradise Valley, and the area surrounding Cody, WY. By and large, the forecasted homes were disproportionately distributed near towns and protected areas (Table 10).

Figure 16. Dark red polygons represent areas in which the density of forecasted homes in the status quo scenario are greater than 50% of the maximum forecasted kernel density. These general areas were forecasted to experience growth in all future scenarios.
Table 10. The ratio of forecasted homes from the status quo scenario to expected homes reveals that forecasted homes occurred disproportionately on lands proximate to towns and protected areas.

<table>
<thead>
<tr>
<th>Private Land Classes</th>
<th>Percent of Total Private Lands</th>
<th>Status Quo 2020 Forecasted Homes</th>
<th>2020 Expected Homes*</th>
<th>Ratio of Forecasted / Expected Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 15 min. Travel of a Town</td>
<td>8.86%</td>
<td>34307</td>
<td>7999</td>
<td>4.29</td>
</tr>
<tr>
<td>Within 15 min. Travel of Protected* Land</td>
<td>28.09%</td>
<td>40001</td>
<td>25355</td>
<td>1.58</td>
</tr>
<tr>
<td>Other Private Land</td>
<td>63.05%</td>
<td>15970</td>
<td>56924</td>
<td>0.28</td>
</tr>
</tbody>
</table>

* The expected numbers of homes reflect a random distribution with respect to the private land classes, and were calculated as the proportion of area occupied by the class multiplied by the total number of forecasted homes.
* Protected lands were defined according to an existing classification of public lands created by the Sonoran Institute, and included: national parks, wilderness, roadless areas, and adjacent multiple use areas.

Differences between Scenarios. Beyond these general trends, there were several differences in the pattern of forecasted rural housing between the low growth, status quo, boom, and growth management scenarios (Figure 17). In a comparison of the 2020 boom and status quo scenarios, the boom scenario had 514 fewer undeveloped sections, 412 fewer sections with 1 to 5 homes, and 1461 more sections with greater than 5 homes. The boom scenario had 690 more sections with greater than 50 homes. In comparing the 2020 low growth and status quo scenarios, the opposite pattern is observed. The low growth scenario resulted in 971 more sections with 0 to 5 homes, and 633 fewer sections with greater than 5 homes. In a comparison of the 2020 growth management scenario with the status quo scenario, the growth management scenario resulted in fewer sections being developed at housing densities greater than 15 homes per section. This result was expected due to the hypothetical zoning districts and conservation easements.
incorporated into the growth management scenario. However, an unintended consequence of these hypothetical policies resulted in fewer undeveloped sections.

Figure 17. Rural housing in the 2020 status quo scenario is compared to rural housing in 1999, and rural housing in the 2020 low growth, boom, and growth management scenarios. The difference in the number of sections occupied at various densities of rural housing is indicated. For example, in 1999, there were 250 more sections with 0 homes than in the 2020 status quo scenario.

The extent of differences in the spatial pattern of rural housing between the four scenarios can be observed in a close up of Gallatin County, MT (Figure 18). Differences in the spatial pattern of forecasted growth resulted from: (1) the use of upper and lower confidence limits, (2) the incorporation of hypothetical gains in transportation and subdivision, and (3) the incorporation of hypothetical growth management policies.
### Alternative Future Scenarios for Gallatin County, MT

**Existing Rural Development in 1999**

- **Low Growth Scenario 2020**
- **Status Quo Scenario 2020**
- **Boom Scenario 2020**
- **Growth Management Scenario 2020**

#### Agricultural Housing Densities (lot size > 16.2 ha)

#### Exurban Housing Densities (4.1 ha < lot size < 16.2 ha)

#### Suburban Housing Densities (lot size < 4.1 ha)

#### Major Towns

---

**Figure 18.** The distribution of existing rural housing in 1999 is contrasted with the alternative growth scenarios for 2020.
The largest differences in the spatial pattern of rural housing between the status quo and boom scenarios occurred in several core areas (Figure 19). The lands surrounding the city of Idaho Falls, ID experienced substantially higher levels of growth in the boom scenario. This difference is partly due to the hypothetical growth of the Idaho Falls airport. The next largest difference occurred in the Gallatin Valley, MT. In this area, planners provided information regarding future transportation improvements and future subdivision sites that influenced forecasted development in the boom scenario. The rural areas surrounding the city of Rexburg, ID also experienced much higher rates of development in the boom scenario, attributable in part to hypothetical airport growth and planner specified road and subdivision sites. The southern portion of Teton Valley, ID was also influenced by hypothetical airport growth and planner specified road improvements and future subdivision sites. Other areas that experienced a large increase in the forecasted development in the boom scenario included: Jackson Hole, WY, Paradise Valley, MT, Star Valley, WY, and the rural lands surrounding the cities of Cody, Lander, and Riverton, WY.

The areas in which the distribution of housing differed between the low growth and status quo scenarios, were similar to the areas in which housing differed between the boom and status quo scenarios (Figure 19). Sections identified as having a positive difference in the boom scenario tended to have fewer homes in the low growth scenario. In addition to those areas that experienced large differences between the boom and status quo scenarios, there were substantial differences between the low growth and status quo scenarios in the Big Sky and Island Park areas.
Core areas of difference between the 2020 status quo scenario and the other scenarios were identified as those areas where the difference in forecasted housing densities was greater than 25% of the maximum difference. Red polygons represent core areas of more forecasted growth than in the 2020 status quo scenario, and blue polygons represent core areas of less forecasted growth than in the 2020 status quo scenario.
Differences between the status quo and growth management scenarios were concentrated in areas ranked as high priorities for biological conservation (Figure 19). There were eight areas in which the growth management scenario has substantially fewer homes. The top location where this occurred was in the Big Sky, MT area. The next largest differences occurred in Jackson Hole, WY, southern Teton Valley, ID, and the West Yellowstone and Island Park areas of MT and ID. Other areas in which the growth management scenario forecasted fewer homes included the Shoshone Canyon, WY, the Bozeman Pass area in MT, NE of Pinedale, WY, and SW of Red Lodge, MT. The most notable areas that experienced more forecasted development in the growth management scenario were western Gallatin Valley, MT and Star Valley, WY. In the Gallatin Valley homes were displaced from the southeastern portion of the valley adjacent to the mountains. Much of Star Valley had been converted to exurban development by 1999, and was therefore not protected by the hypothetical policies implemented in the growth management scenario. Thus, in the growth management scenario, a large amount of displacement occurred from Jackson Hole, WY and southern Teton Valley, ID into the Star Valley. Many of the areas that experienced more forecasted development in the growth management scenario were sections proximate to the high conservation priority areas that had already been developed to exurban housing densities by 1999. These areas included portions of Jackson Hole, WY, Teton Valley, ID, Gallatin Valley, MT, Big Sky, MT, Island Park, ID, and West Yellowstone MT.
**Forecasted Growth Summarized by County.** The forecasted growth in rural residential development varied considerably between counties (Figure 20). For the purpose of examining county scale differences in the distribution of rural homes, the status quo and growth management scenarios are equivalent. Although the location of forecasted homes within each county differed between the status quo and growth management scenarios, the forecasted number of rural homes was the same. The only exception occurred in the Jackson Hole commutershed, in which spill-over from Teton, WY resulted in slight differences in forecasted development in Teton, ID and Lincoln, WY between the status quo and growth management scenarios.

In both the status quo and growth management scenarios, Gallatin County, MT was forecasted to experience the largest raw increase in rural residential development between 1999 and 2020 (7595 homes), followed by Bonneville County, ID (4717 homes), and Fremont County, ID (3718 homes). In the boom scenario, Gallatin and Bonneville Counties ranked highest with respect to the raw increase in rural homes, however the increase in Park County, MT exceeded that of Fremont County, ID. In the low growth scenario, Park, WY, Gallatin, MT, and Lincoln, WY were the highest ranked counties in terms of raw increases in rural housing. In the status quo and growth management scenarios, the increase in rural home density on private lands exceeded one home per square kilometer in eight counties: Teton County, WY (3.42), Teton County, ID (7.82), Fremont County, ID (2.46), Gallatin County, MT (2.31), Bonneville County, ID (2.17), Lincoln, WY (1.42), Park, MT (1.16), and Park, WY (1.07). For these counties, the forecasted increase in the boom scenario exceeded two rural homes per
square kilometer. In the boom scenario, the forecasted increase in rural home density on private lands exceeded one home per square kilometer in 15 of the 20 GYE counties. In the low growth scenario, the forecasted increase in rural home density on private lands exceeded one home per square kilometer in only Teton County, WY. The forecasted increase in rural housing densities was greater than 50% in 2 of the 20 GYE counties in the low growth scenario, 14 of the 20 counties for the status quo scenario, and in 19 of 20 counties for the boom scenario (Figure 21).

![Figure 20. Forecasted growth is represented as the increase in density of rural homes on private lands within each county of the GYE. Counties are sorted by the observed rural housing densities in 1999. Counties in which planners contributed information for the boom scenario are demarcated (*)](image)

- 1999 Existing Rural Home Density
- 2020 Low Growth Rural Home Density
- 2020 Status Quo and Growth Management Rural Home Density
- 2020 Boom Predicted Rural Home Density
Figure 21. Forecasted growth is represented as the percent increase in density of rural homes on private lands within each county of the GYE. Counties in which planners contributed information for the boom scenario are demarcated (*).

**Forecasted Agricultural to Exurban Conversion.** The conversion of land use from agricultural to exurban housing densities of greater than one home per 16.2 hectares (Brown et. al, in review) were concentrated in eight counties, including: Gallatin and Park, MT; Fremont, Madison, Teton, and Bonneville, ID; and Teton and Lincoln, WY, in the status quo and boom scenarios. In the status quo scenario, conversion from agricultural to exurban housing densities was forecasted to occur in 559 sections, or approximately 1551 square kilometers of land, by the year 2020. In the boom scenario approximately 4307 square kilometers of rural lands were converted from agricultural to exurban housing densities. Although a substantial amount of land conversion from agricultural to exurban densities occurred proximate to the larger towns within the GYE,
the intensity of land use was forecasted to increase a fragmented pattern, rather than in concentric circles approaching each town, as was suggested by early economists and agriculturalists (Brown, 1999).

In the growth management scenario, conversion from agricultural to exurban housing densities of greater than one home per 16.2 hectares (Brown et. al, in review) was forecasted to occur in 333 sections, or approximately 863 square kilometers of land, by the year 2020. Although the number of forecasted homes in the growth management scenario was equal to the number of forecasted homes in the status quo scenario, the extent of exurban development was less. Thus, forecasted rural homes were more widely distributed across the landscape in the growth management scenario. Within the highest ranked quarter of GYE lands, according to the conservation priorities map, no forecasted agriculture to exurban conversion took place 1999 and 2020 (Table 11, Figure 22). In the status quo scenario, the extent of agricultural to exurban land use change nearly doubled within this same subset of the GYE.

Table 11. The proportion of land converted from agricultural to exurban densities is shown per conservation priority class. The class representing the highest ranked quarter of GYE lands underwent the most conversion in the status quo scenario and no conversion in the growth management scenario.

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<th>Conservation Priority</th>
<th>Status Quo 2020</th>
<th>Growth Management 2020</th>
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</thead>
<tbody>
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<td>Lowest Ranked 25% of GYE</td>
<td>7.32%</td>
<td>14.11%</td>
</tr>
<tr>
<td>Low-Mid 25%</td>
<td>17.97%</td>
<td>36.94%</td>
</tr>
<tr>
<td>Mid-High 25%</td>
<td>24.63%</td>
<td>48.95%</td>
</tr>
<tr>
<td>Highest Ranked 25% of GYE</td>
<td>50.08%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Figure 22. The area of exurban development in the highest ranked quarter of GYE lands did not increase between 1999 and 2020 in the growth management scenario. In the status quo scenario the area nearly doubled.

**Forecasted Effect of Growth Management Policies.** The effect of growth management policies within the GYE was measured by the extent to which the forecasted home density was locally constrained by the regulation, for example, the specified minimum parcel size (MPS) per zoning district. Cumulative for the GYE, current rural zoning districts affected the location of a total of 4,884 forecasted homes by the year 2010, and 11,835 forecasted homes by the year 2020 according to the status quo scenario. In the boom scenario, a total of 8,727 forecasted homes were affected by the year 2010, and 21,271 homes were affected by the year 2020. The pattern of status quo forecasted
displacement of future development caused by current zoning districts is evident in close-ups of the Bozeman and Jackson areas (Figure 23). The forecasted spatial pattern of rural development resulting from existing zoning districts and conservation easements can be compared with the pattern resulting from the hypothetical zoning districts and conservation easements used in the growth management scenario (Figure 24). In the growth management scenario, the locations of a total of 7,552 forecasted homes were affected by the year 2010, and 19,731 homes were affected by the year 2020. The pattern of displacement was from higher ranked private lands to lower ranked private lands.

The forecasted impacts of existing zoning varied substantially by county. Eight of the 20 counties within the study area had not implemented rural zoning districts at the time of data collection (the summer of 2002). The counties in which zoning districts with specific MPS regulations were not implemented included: (1) Madison, MT; (2) Stillwater, MT; (3) Carbon, MT; (4) Fremont, WY; (5) Bear Lake, ID; (6) Hot Springs, WY; (6) Fremont, ID; and (8) Caribou, ID. Madison County, MT utilized floodplain setbacks, and the latter three in the list implemented rule based development standards.

Of the 12 counties that did implement MPS specific zoning districts, we were able to collect data regarding the locations and attributes of the zoning districts with the exception of Bonneville, ID. In all eleven counties but three, the location of forecasted homes was affected by zoning districts (Figure 25).
Figure 23. The effect of zoning in the 2020 status quo scenario is represented by the red and blue shaded areas. In the Bozeman area, forecasted homes were displaced from areas near town to areas further from town. In the Jackson Hole area, the “spill-over” of rural residential development is forecasted to have a large effect on the southern portion of Idaho’s Teton Valley.
Figure 24. The effect of zoning in the 2020 growth management scenario is described by the red and blue areas. In the Bozeman area, forecasted development was directed away from Bozeman Pass and the foothills of the Gallatin and Bridger ranges. In the Jackson Hole / Teton Valley area, forecasted homes were directed towards existing towns and Star Valley, WY to the south.
In both the status quo and boom scenarios, Teton, WY had the most restrictive zoning as indicated by the percent of forecasted homes displaced by zoning, followed by Sublette, WY (Figure 25). In the status quo scenario, more than 15% of rural homes were displaced by zoning within Gallatin, MT, and Park, WY. In the boom scenario, more than 15% of rural homes were displaced by zoning within Gallatin, MT, Park, WY, and Teton and Madison, ID. In both scenarios, the zoning districts within Lincoln, WY, Sweet Grass, MT, Franklin, ID, and Clark, ID had little or no effect upon the forecasted growth in rural residential development. Lincoln, WY was forecasted to experience the third highest percent increase in rural home density, however zoning districts within the
county are generally unrestricted with “rural” districts designated at a 2 acre MPS (equivalent to 320 homes per section) and “mixed use” districts designated at a 0.5 acres MPS (equivalent to 1280 homes per section). Both Sweet Grass, MT and Franklin, ID had relatively low forecasted growth, and generally unrestricted zoning. Roughly 10% of the rural lands within Sweet Grass, MT were zoned, and the forecasted development pressure within these areas was relatively low. The majority of rural areas within Franklin, ID had a “multi use” designation of 1 acre MPS. Clark, ID utilized restrictive zoning policies, where all rural areas had “agricultural” designations at either 20 or 40 acre MPS, but had extremely low forecasted growth. Thus, the forecasted growth in rural housing in Clark, ID never exceeded the zoning regulations in place.

Discussion

Review of Results

The drivers of rural residential development during the 1990s were consistent with those factors found to be strongly correlated with growth patterns during 1970-1999. Encroaching development, transportation and services, and natural amenities were found to be the primary determinants of rural residential development across the Greater Yellowstone Ecosystem. Model accuracy was improved over that reported in the previous paper, most likely due to the shorter time period being modeled and inclusion of two new explanatory variables: the travel time from forested areas and the timing of encroaching development. The negative relationship between travel time from forested areas and rural home construction suggests a high demand for lands at the wildland
interface. The extent of recent development, during the 1980s, was a powerful predictor of growth during the 1990s. This factor was probably informative for two reasons. First, new development may signify increased availability of previously inaccessible parcels of land. Second, recent home construction most likely reflects desirable qualities of an area that were not otherwise represented by the explanatory variables within our model.

Results from our analysis of drivers of rural residential development during the 1990s were used to parameterize the Rural Development Simulator (RDS). During the twenty year period begin modeled (2000-2020), an 27% to 234% increase in rural residential development was forecasted to occur within the GYE in the low growth and boom scenarios. An 82% increase in rural housing was forecasted in the status quo scenario. The rate of increase varied substantially by county. The five counties with highest forecasted rates of increase are commonly typified as tourism and recreation destinations, as is evidenced by extremely high proportions of seasonal housing (greater than 10% in each county) (U.S. Census Bureau, 2000). These counties included Teton, Bear Lake, and Fremont Counties in Idaho, Park County in Montana, and Lincoln County in Wyoming. The utility of zoning policies was shown by the extent to which forecasted growth was affected by different zoning districts that ranged in restrictiveness. Eight of twenty GYE counties currently do not implement zoning, and the majority of existing zoning districts are only minimally restrictive. Only nine percent of forecasted rural homes within the GYE were affected by current zoning regulations in the status quo scenario. However, in the growth management scenario, the hypothetical zoning districts
affected the distribution of 45% of forecasted homes. The forecasted homes affected by zoning districts in the growth management scenario were directed away from areas of high conservation priority.

Approximately 1551 square kilometers of rural land were forecasted to be converted from agricultural to exurban home densities between 1999 and 2020 in the status quo scenario. Although this area represents only 6.2% of rural private lands in the GYE, it encompasses more land than Grand Teton National Park. In the boom scenario, an area roughly half the size of Yellowstone National Park was forecasted to undergo conversion from agricultural to exurban home densities. In the growth management scenario, the extent of agriculture to exurban conversion was roughly half that in the status quo scenario. Within GYE lands deemed most important for conservation purposes, the area of exurban development remained static between 1999 and 2020. In comparison, in the status quo scenario, growth in exurban development occurred disproportionately in high priority conservation lands, nearly doubling in these areas. Overall there was less area forecasted to be occupied at exurban densities in the growth management scenario. However, the homes were more widely distributed and less clustered in the growth management scenario. This outcome was an unintended result of the hypothetical policies employed in the growth management scenario. Future scenarios generated by the RDS could be used to assess incentives for clustering rural development adjacent to existing towns and in lower ranked areas for conservation.
Comparison to the Literature

The RDS differed from other land use change models in that both the rate and location of growth were determined via a scientifically rigorous yet simple approach. The modeling approach employed in the RDS was based upon a mathematical equation that effectively described historical growth patterns. Thus, the propagation of compounded error that often results from more complication system models, such as the CLUE model, was avoided (Verburg et al., 1999). The importance of validation in modeling land use change has been stressed by many researchers (Pontius, 2000; Schneider and Pontius, 2001; Kok et al, 2001), and tends to be constrained by limitations in the availability of data (Pontius et al., 2001). In the case of the RDS, one quarter of the study area (more than 6000 observations) was excluded from model development and used in an accuracy assessment of the model predictions.

Another quantitative matter of increasing importance in land use modeling involves the presence of spatial autocorrelation in spatial land use analyses, in which the data are assumed to be statistically independent (Overmars et al., 2003). Because the statistical methodology employed by the RDS assumed that model residuals were independent, variograms were used to quantify spatial dependence over several distance classes. Autocorrelation of the residual variation was found to be negligible, indicating the model had captured the relevant covariates to explain existing spatial patterns in rural residential development.
Limitations and Simulation Assumptions

The scientific approach to modeling land use change, although accurate and unbiased, was restrictive. The forecasted rate of future rural home construction was based on historical rates of rural home construction in the 1990s. Substantial changes in federal policies, the economy, or stochastic events such as natural disasters could result in future rates of rural home construction outside of the range forecasted in the alternative scenarios. We included only those regional and local drivers of growth for which we could acquire sufficient data to parameterize the model. Thus, macro-economic and socio-political processes, such as economic recession, the influence of baby boomer retirement, perceived crowding in suburbia, and federal agricultural subsidies effect upon the land markets, were not incorporated into the RDS. A second limitation of our modeling application stems from our inability to directly infer causation regarding the drivers of rural residential development. The statistical procedures we used allowed us to identify the degree to which bio-physical and local socio-economic variables were correlated with growth in rural residential development; however, we were unable to establish whether the variables caused or resulted from growth.

In the boom scenario, assumptions were made regarding future locations of road construction and subdivision based on input from 15 planners and zoning administrators from 8 of the 20 GYE counties. Twelve of the 20 counties were not represented at the workshops in which these data were collected. All commercial airports were significantly related to growth in rural residential development, however three airports, those in Billings, MT, Bozeman, MT, and Jackson, WY, were identified during model
selection as being most strongly related to rural growth patterns. In the boom scenario, all commercial airports were assumed be as influential as the top three. In reality, this might only occur with the provision of federal subsidies or other stimuli to encourage airport expansion. Approximately 10% of the difference between the forecasted growth in the status quo and boom scenarios was attributable to modifications associated with expert opinion, including the assumptions of road construction, subdivision, and future airport expansion.

The growth management scenario was based on the assumption that undeveloped lands within the highest ranked quarter of GYE private lands, according to the conservation prioritization scheme, could be protected through the use of zoning districts and conservation easements. In total, 4047 square kilometers (approximately 1 million acres) of land were specified as conservation easement areas in which no forecasted development was allowable. An additional 12,141 square kilometers (approximately 3 million acres) of land were zoned for agricultural land use, which a minimum parcel size of 0.16 square kilometers (40 acres).

All future scenarios implemented existing land use regulations. Thus, the accuracy of forecasted development patterns was influenced by the accuracy and completeness of the land use regulations data collected, and the assumptions about how specific regulations would influence growth patterns. We assemble data regarding the locations and specific regulations of conservation easements and zoning districts within the GYE. “Rule based” zoning where no minimum parcel size was specified, for example, unlimited allowable subdivision by family, was not incorporated into the model.
We assumed that the forecasts generated using the best regression model captured regional demand for rural housing, thus local land use regulations were assumed to redirect rather than cap regional growth. When forecasted development exceeded the allowable home density as specified by a zoning district, the RDS displaced the forecasted homes into similar sections within the same local area, with similarity defined by variables from the best regression model.

**Implications**

The RDS was designed as a decision support tool for generating alternative scenarios of future rural development patterns. The four scenarios run, the low growth, status quo, boom, and growth management scenarios, were intended to provide a visualization of the spectrum of possible outcomes of land use change in the Greater Yellowstone Ecosystem. Rather than necessarily guiding local planning decisions along the most desirable path, the growth management scenario serves as an example of incorporating the RDS as a decision support tool in planning ahead for future growth.

Major conclusions from this modeling exercise include:

1. Rural areas of the GYE will likely experience major changes in land use by 2020. In a business as usual scenario of land use change, rural residential development is expected to increase by 82% from 2000 to 2020. At the lower statistical limit of our modeling efforts, the number of homes would increase by 27%, and at the upper statistical limit, the number of rural homes would more than triple.

2. While the number of additional rural homes will impact the ecosystem, the distribution of future rural homes may be a more important factor. Although less growth is forecasted to occur in the low growth scenario, the potential for land use conversion remains high due to the dispersed nature of the forecasted development.
3. Rural residential development within the GYE will likely continue to be concentrated in the areas most important for agriculture and wildlife, including private lands with highly productive soils, and those adjacent to nature reserves and water.

4. Current zoning regulations had a limited impact on the distribution of forecasted homes. Because land use regulations are planned and implemented on a county by county basis, these policies are not designed with an ecosystem-wide regional vision of growth in mind.

5. By employing landscape ecology and planning principles, the growth management scenario was able to protect sensitive ecological areas without limiting overall growth in rural housing.

6. Knowledge of future development pressure can aid in prioritizing land use planning and conservation targets in terms of risk. However, development pressure changes as land availability changes, potentially leading to negative unintended consequences of growth management policies. The RDS can help planners avoid such oversights by providing visualizations of the outcomes of alternative planning strategies.

Future research efforts employing the RDS will involve measuring the potential ecological change under the alternative development scenarios. The RDS will be provided to land use planners and land conservation organizations as a tool for incorporated scientific knowledge into the planning process and assessing the consequences of alternative planning policies at landscape scales.
CONCLUSIONS

The two papers presented in this thesis have explored in detail the rates, drivers, and potential future growth of rural residential development within the Greater Yellowstone Ecosystem (GYE). The scientific approach used to investigate these issues involved the both the formation and testing of specific hypotheses regarding historical development patterns, as well as exploratory statistical analyses. The results of the analyses of historical growth patterns were used to parameterize a simulation of future rural residential development. The Rural Development Simulator (RDS) was run through the year 2020 in order to assess the potential rates and locations of future rural development within GYE.

Our study reveals that large-scale immigration and rural development within the GYE has been strongly influenced by a number of socio-economic and bio-physical factors. The analysis of recent drivers of rural residential development showed strongest support for the model representing agricultural suitability, transportation and services, natural amenities, and encroaching development as the primary determinants of rural residential development. This model also incorporated the concept of zones of influence around each town. Within these zones, rural residential growth could not be adequately explained without socio-economic and recreation-related qualities of the respective towns. Our results also indicate that the proportion of homes built on highly productive soils and lands proximate to water has remained consistently high throughout the 1900s. We suspect that newer homes continue to be built near water and productive soils because of the influence of early settlement patterns and transportation routes. We
conclude from our research that the GYE’s current landscape reflects a history of shifting drivers of human settlement in (1) the legacy of early settlement constrained by natural resources, and (2) the continuing role of infrastructure and natural amenities in driving growth.

Predictions of future growth in rural residential development emphasize the potential for substantial changes in the rural landscape of the GYE within the near future. An 82% increase in rural housing was predicted to occur between 1999 and 2020 in a business-as-usual development scenario. During this time period, an area larger than Grand Teton National Park was predicted to shift from agricultural to exurban housing densities. Counties with fastest predicted rates of rural development shared a common characterization as tourism and recreation destinations. The utility of zoning policies was shown by the extent to which predicted growth was effected by different zoning districts that ranged in restrictiveness. Despite the fact that 40% of GYE counties currently do not implement zoning and the majority of existing zoning districts are only minimally restrictive, more than 27% of predicted rural homes within the GYE were affected by current zoning regulations.

The implications of this research for land conservation are critically important. Our results suggest that the more productive farmlands will likely continue to experience a disproportionate level of development pressure, as will the biologically diverse lowland riparian habitats. As well, rural residential development during recent decades has occurred disproportionately on lands bordering the parks, potentially eroding the quality of the lowland habitats most used by park species. The homes predicted to occur over the
next two decades were also distributed disproportionately near protected lands, including national parks, wilderness areas, federally designated roadless areas, and adjacent multiple use areas.

Although the possibility exists for substantial social and ecological change in rural landscapes of the GYE, our findings highlight the potential for local policy decisions to effectively manage growth in rural residential development. Because new home sites tend to encourage further residential development, subdivisions proposed in ecologically or socially sensitive undeveloped areas should be conscientiously reviewed. Also, because growth is strongly related to the characteristics of nearby towns, municipal and county planners should cooperate to develop a comprehensive regional vision. Lastly, although current zoning regulations within the GYE are generally laissez faire, growth management policies have the potential to direct growth in a manner that complements land protection and biological conservation.

The use of planning practices to manage growth will become increasingly important in order for GYE communities to maintain a balance between future growth and social and environmental quality. Our hope is that an improved understanding of how and why development patterns occur will allow for society to manage rural residential development more effectively. The future growth scenarios, generated by the RDS, can provide land use planners and land conservation organizations a tool to be able to incorporate scientific knowledge into the planning process and assess the ecological consequences of rural residential development at landscape scales.
LITERATURE CITED


APPENDIX A
DATA DOCUMENTATION
STANDARDS FOR ALL DATASETS

GEODATASET EXTENT: Greater Yellowstone Ecosystem, including:

- Madison County, Montana
- Gallatin County, Montana
- Park County, Montana
- Sweet Grass County, Montana
- Stillwater County, Montana
- Park County, Wyoming
- Hot Springs County, Wyoming
- Fremont County, Wyoming
- Sublette County, Wyoming
- Teton County, Wyoming
- Lincoln County, Wyoming
- Clark County, Idaho
- Fremont County, Idaho
- Madison County, Idaho
- Teton County, Idaho
- Bonneville County, Idaho
- Caribou County, Idaho
- Bear Lake County, Idaho
- Franklin County, Idaho

PROJECTION PARAMETERS:

- Projection: UTM
- Units: meters
- Datum: NAD27
- Zone: 12

GRID CELL SIZE:

- 64.374 meters
- (25 x 25 cells per square mile section)
TAX ASSESSOR RURAL HOMES DATABASE

Geodataset Type: COVER
Geodataset Feature: POLY

GENERAL DESCRIPTION:

This dataset describes the locations of rural homes and the years in which they were built within the 20 counties of the Greater Yellowstone Ecosystem. Rural homes are defined as all homes that are outside of incorporated city and town site boundaries, including subdivisions and excluding mobile homes. The data were collected from the county tax assessors offices and state departments of revenue, and are summarized per Township Range Section (approximately one square mile) according to the Public Land Survey System (PLSS). Montana and Wyoming tax assessor data are current through 1999 & Idaho tax assessor data are current through 2001.

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DATA SOURCE(S):

Montana Department of Revenue
Wyoming Department of Revenue
Caribou County, ID, Tax Assessor
Clark County, ID, Tax Assessor
Bear Lake County, ID, Tax Assessor
Bonneville County, ID, Tax Assessor
Franklin County, ID, Tax Assessor
Fremont County, ID, Tax Assessor
Madison County, ID, Tax Assessor
Teton County, ID, Tax Assessor

DATE OF AUTOMATION OR SOURCE:

Montana PLSS Boundaries, unknown
Wyoming PLSS Boundaries, unknown
Idaho PLSS Boundaries, 1993
Montana and Wyoming Tax Data, 2000
Idaho Tax Data, 2002

SCALE OF ORIGINAL SOURCE MAPS: 1:100,000

DATA LINEAGE SUMMARY:

In 2000, Ute Langner of the Landscape Biodiversity Lab collected the Montana and Wyoming tax assessor data in the form of spreadsheets from the state revenue departments. These data (rural home locations in the form of TRS and year built) were joined to a spatial PLSS database using Township Range Section as the key item. This portion of the dataset is considered to be accurate up and through 1999.

In 2002, Patty Hernandez, Patrick Hutchinson and Erin Hermanson of the Landscape Biodiversity Lab collected rural homes data from the individual Idaho County Tax Assessors. Teton County, Caribou County, and Bear Lake County required taking trips to collect the information because they were not available in digital spreadsheets. Laptops were taken to these counties and the data were entered manually. The other 5 Idaho counties were able to mail us hard copy print outs with the information we requested (rural home locations in the form of TRS and year built). The Idaho Public Land Survey System (Township Range Section) data were downloaded from http://www.idwr.state.id.us/gisdata/. The tax data were joined to the Idaho PLSS database, and finally mapjoined to the Montana and Wyoming database using ARC/INFO.

DATA SOURCES CONTACT(S):

Name: Idaho Department of Water Resources
Abbr. Name: IDWR
Address: 1301 N. Orchard St.
          Boise, ID 83706
Phone: (208) 327-7995
Fax: (208) 327-7866
Contact Person: Linda Davis, Senior GIS Analyst
Email: ldavis@idwr.state.id.us
Web site: http://www.idwr.state.id.us/gisdata/

Name: University of Wyoming
      Spatial Data and Visualization Center
Abbr. Name: SDVC
Address: P.O. Box 4008 University Station
          Laramie, WY 82071
Phone: (307) 766-2735
Web site: http://www.sdvc.uwyo.edu/clearinghouse/boundaries.html

Name: Montana Department of Revenue
      Tax Policy and Research
Address: P.O. Box 8505
        Helena, MT, 59604-5805
Phone: (406) 444-2668
Fax: (406) 444-3696
Contact Person: Dallas Reese, Tax Policy Analyst
Web site: http://www.state.mt.us/revenue/rev.htm
Name: Wyoming Department of Revenue
      Ad Valorem Tax Division
Address: Herschler Building
2nd Floor West
122 W. 25th Street
Cheyenne, WY 82002-0110
Phone: (307) 777-7961
Fax: (307) 777-7722
Contact Person: Jim Felton, Local Assessed Supervisor
Web Site: http://www.revenue.state.wy.us

Name: Caribou County Tax Assessor, ID
County Courthouse
P.O. Box 775
Soda Springs, ID 83276-0775
Phone: (208) 547-4749
Contact Person: Carol

Name: Clark County Tax Assessor, ID
Address: P.O. Box 7
Dubois, ID 83423
Phone: (208) 374-5404
Contact Person: Betty Kirkpatrick

Name: Bear Lake County Tax Assessor, ID
Phone: (208) 945-2155
Address: County Courthouse
P.O. Box 190
Paris, ID 83261-0190
Contact Person: Lynn Lewis

Name: Bonneville County Tax Assessor, ID
Address: 605 N. Capital Ave.
Idaho Falls, ID 83402
Phone: (208) 529-1320
Contact Person: Geri Keele

Name: Franklin County Tax Assessor, ID
Address: 51 W. Oneida
Preston, ID 83263
Phone: (208) 852-1091
Contact Person: Rich Umbel

Name: Fremont County Tax Assessor, ID
Address: 151 W. 1st N. # 2
St. Anthony, ID 83445
Phone: (208) 624-7984
Contact Person: Ivel Burrell

Name: Madison County Tax Assessor, ID
Address: County Courthouse
P.O. Box 389
Rexburg, ID 83440
Phone: (208) 359-3020 ext.317
Contact Person: Craig Rindlesbacher
<table>
<thead>
<tr>
<th><strong>Name:</strong></th>
<th>Teton County Tax Assessor, ID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Address:</strong></td>
<td>County Courthouse</td>
</tr>
<tr>
<td></td>
<td>P.O. Box 756</td>
</tr>
<tr>
<td></td>
<td>Driggs, ID 83422</td>
</tr>
<tr>
<td><strong>Phone:</strong></td>
<td>(208) 354-3507</td>
</tr>
<tr>
<td><strong>Contact Person:</strong></td>
<td>Danny Thomas</td>
</tr>
</tbody>
</table>
STATSGO SUITABILITY FOR AGRICULTURE

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains a coarse scale rating of the soil for agricultural use. Higher numbers (range: 1-500) indicate progressively fewer limitations and greater choices for agricultural use.

DATA SOURCE(S): U.S. Department of Agriculture
Soil Conservation Service

DATE OF SOURCE: 1994

SCALE OF ORIGINAL: 1:250,000

DATA LINEAGE SUMMARY:

Data for MT, WY, and ID were downloaded from the following website:
http://www.essc.psu.edu/soil_info/index.cgi?soil_data&statsgo
The mapunit polygons were downloaded for each state, as well as the relate table containing component information. In the component table several records correspond to a single map unit. For example, several components, each with their respective agricultural ratings, make up a single map unit. Therefore, the agricultural rating for a map unit is the average rating weighted by the proportion of the map unit that each component occupies. The data were converted to raster format using ARC/INFO polygrid.

Full documentation for the agricultural rating (land capability classification) are presented at http://soils.usda.gov/procedures/handbook/content/622.htm#02.

DATA SOURCES CONTACT(S):

Name: U.S. Department of Agriculture
Soil Conservation Service
National Cartography and GIS Center
Abbr. Name: USDA
Address: U.S. Department of Agriculture
Soil Conservation Service
National Cartography and GIS Center
P.O. Box 6567
Fort Worth, Texas 76115
Phone: 817 334 5559
Fax: 817 334 5469
GIS data: http://www.essc.psu.edu/soil_info/index.cgi?soil_data&statsgo
ROAD DENSITY

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the density of roads in a circular neighborhood around every location/cell within the Greater Yellowstone Area. The radius of the circular neighborhood is one kilometer. Density is measured in kilometers per square kilometers.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000 - roads

SCALE OF ORIGINAL: 1:100,000 - roads

DATA LINEAGE SUMMARY:

All roads were reselected from the 2000 TIGER/line coverages. MT, ID, and WY roads were appended and then clipped to the GYE study area boundary. The ARC/INFO linedensity command was used to calculate distance values. The "simple" option was selected for the type of density interpolation. 1000 was selected as the unit scale factor.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
          Tiger Mapping Service
          4700 Silver Hill Road, Stop 7400
          Washington, D.C. 20233
Phone: (301) 457-1128 (Geography)
       (301) 457-4100 (Customer Service)
Web site: http://www.census.gov/ftp/pub/geo/www/tiger
GIS gateway: http://www.census.gov/geo/www/gis_gateway.html
E-mail: Tiger@census.gov
Contact Person: Products and Services Staff, Geography Division
TRAVEL CAPACITY

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains travel capacity index values for all locations in the Greater Yellowstone Area. The index is based on road type and density.

DATA SOURCE(S): United States Census Bureau - roads

DATE OF SOURCE: 2000 - roads

SCALE OF ORIGINAL: 1:100,000 - roads

DATA LINEAGE SUMMARY:

Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" as described by the table below:

<table>
<thead>
<tr>
<th>Value</th>
<th>Road Type</th>
<th>Travel Speed</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited Access Highway</td>
<td>75</td>
<td>(2/75) * 100 = 2</td>
</tr>
<tr>
<td>2</td>
<td>Primary Road</td>
<td>65</td>
<td>(2/65) * 100 = 3</td>
</tr>
<tr>
<td>3</td>
<td>Secondary Road</td>
<td>30</td>
<td>(2/30) * 100 = 7</td>
</tr>
<tr>
<td>4</td>
<td>Local Road</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>6</td>
<td>Special Road Features</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>7</td>
<td>Driveway or Service Road</td>
<td>10</td>
<td>(2/10) * 100 = 20</td>
</tr>
<tr>
<td>0</td>
<td>Other</td>
<td>2</td>
<td>(2/2) * 100 = 100</td>
</tr>
</tbody>
</table>

Road density (km per sq. km) was multiplied by the inverse of the “travel cost” surface in order to obtain the travel capacity index.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
          Tiger Mapping Service
          4700 Silver Hill Road, Stop 7400
          Washington, D.C. 20233
Phone: (301) 457-1128 (Geography)
        (301) 457-4100 (Customer Service)
Web site: http://www.census.gov/ftp/pub/geo/www/tiger
          GIS gateway:
          http://www.census.gov/geo/www/gis_gateway.html
E-mail: Tiger@census.gov
Contact Person: Products and Services Staff, Geography Division
DISTANCE FROM MAJOR ROADS

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the Euclidian distance from major roads from 2000 TIGER/Line Files.

DATA SOURCE(S): United States Census Bureau - roads
DATE OF SOURCE: 2000 - roads
SCALE OF ORIGINAL: 1:100,000 - roads

DATA LINEAGE SUMMARY:

The following roads were reselected from the TIGER/Line files in ARC/INFO Arc:
CFCC Census Feature Class Code
A11-A18 Primary Road with Limited Access or Interstate Highway
A21-A28 Primary Road without Limited Access, US Highway
In ARC/INFO Grid, the Euclidian distance from this subset of roads was calculated.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
Tiger Mapping Service
4700 Silver Hill Road, Stop 7400
Washington, D.C. 20233
Phone: (301) 457-1128 (Geography)
(301) 457-4100 (Customer Service)
Web site: http://www.census.gov/ftp/pub/geo/www/tiger
GIS gateway:
http://www.census.gov/geo/www/gis_gateway.html
E-mail: Tiger@census.gov
Contact Person: Products and Services Staff, Geography Division
AIRPORT ACCESSABILITY

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the travel time in minutes to the nearest airport for all locations in
the Greater Yellowstone Area.

DATA SOURCE(S): U.S. Geological Survey - airports
United States Census Bureau - roads


SCALE OF ORIGINAL: Unknown – airports; 1:100,000 – roads

DATA LINEAGE SUMMARY:

The original airports dataset was obtained from the Department of Transportation. Only those airports with
passenger enplanement of greater than or equal to 250 passengers per year were selected to create a point
coverage to which the following attributes were attached: airport location identifier, name of airport, name
of state, state FIPS code, Air Carrier Activity Information System airports, Large Certified Air Carrier
Enplanement, Commuter Enplanement, Air Taxi Enplanement, Foreign Flag Air Carrier Enplanement, In-
Transit Enplanement and Total Enplanement. For use in the airport accessibility analysis, only those
airports with total enplanement greater than or equal to 3000 passengers were selected. This excluded the
West Yellowstone airport from the analysis.

Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads
were assigned a "travel cost" (See table presented in Travel Capacity documentation). The airports with
total enplanement greater than or equal to 3000 passengers and the "travel cost" datasets served as inputs
into a costdistance grid function. The grid resulting from the analysis describes travel time or accessibility
to airports from all locations in the Greater Yellowstone Area.

DATA SOURCES CONTACT(S):

Name: UNITED STATES GEOLOGICAL SURVEY
Address: 521 National Center
          Reston, VA 20192
Phone: 703-648-4528
Email: bwright@usgs.gov
Contact Person: Bruce Wright

Name: UNITED STATES CENSUS BUREAU
E-mail: Tiger@census.gov
See Road Density documentation for further details.
HOSPITAL ACCESSABILITY

Geodataset Type:      GRID
Geodataset Feature:   GRID

GENERAL DESCRIPTION:

This dataset contains values representing the travel time in minutes to the nearest hospital for all locations in the Greater Yellowstone Area.

DATA SOURCE(S):            United States Census Bureau - hospitals
United States Census Bureau - roads


SCALE OF ORIGINAL:        1:100,000 – hospitals; 1:100,000 – roads

DATA LINEAGE SUMMARY:

Census 2000 TIGER/Line files were acquired for the study area. All files were unzipped converted to ARC/INFO coverages using the TIGERARC command. Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" as described by the table below:

<table>
<thead>
<tr>
<th>Value</th>
<th>Road Type</th>
<th>Travel Speed</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited Access Highway</td>
<td>75</td>
<td>(2/75) * 100 = 2</td>
</tr>
<tr>
<td>2</td>
<td>Primary Road</td>
<td>65</td>
<td>(2/65) * 100 = 3</td>
</tr>
<tr>
<td>3</td>
<td>Secondary Road</td>
<td>30</td>
<td>(2/30) * 100 = 7</td>
</tr>
<tr>
<td>4</td>
<td>Local Road</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>6</td>
<td>Special Road Features</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>7</td>
<td>Driveway or Service Road</td>
<td>10</td>
<td>(2/10) * 100 = 20</td>
</tr>
<tr>
<td>0</td>
<td>Other</td>
<td>2</td>
<td>(2/2) * 100 = 100</td>
</tr>
</tbody>
</table>

The hospital locations as specified by the TIGER/Line files and the "travel cost" datasets served as inputs into a costdistance grid function. The grid resulting from the analysis describes travel time or accessibility to hospitals from all locations in the Greater Yellowstone Area.

DATA SOURCES CONTACT(S):

Name:                    UNITED STATES CENSUS BUREAU
E-mail:                  Tiger@census.gov
See Road Density documentation for further details.
TOWN ACCESSIBILITY
TRAVEL TIME FROM CENSUS DESIGNATED INCORPORATED PLACES

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

These datasets contains values representing the travel time in minutes to the nearest town for all locations in the Greater Yellowstone Area. Several population cut-offs were used to generate these datasets, including 100, 500, 1000, 5000, 10,000, 15,000, and 20,000.

DATA SOURCE(S): United States Census Bureau - towns
United States Census Bureau - roads


SCALE OF ORIGINAL: 1:100,000 – towns; 1:100,000 – roads

DATA LINEAGE SUMMARY:

2000 Incorporated Places/Census Designated Places for MT, WY, and ID were downloaded from http://www.census.gov/geo/www/cob/pl2000.html in ARC/INFO Export (.e00) format. The data were reprojected from Geographic (Lat/Lon) Nad83 to UTM Nad27, mapjoined, and clipped to the Greater Yellowstone Ecosystem. Incorporated places recognized in decennial census data products are those reported to the U.S. Census Bureau as legally in existence on January 1, 2000, under the laws of their respective states, as cities, boroughs, towns.

Census 2000 TIGER/Line files were acquired for the study area. All files were unzipped converted to ARC/INFO coverages using the TIGERARC command. Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" as described by the table below:

<table>
<thead>
<tr>
<th>Value</th>
<th>Road Type</th>
<th>Travel Speed</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited Access Highway</td>
<td>75</td>
<td>(2/75) * 100 = 2</td>
</tr>
<tr>
<td>2</td>
<td>Primary Road</td>
<td>65</td>
<td>(2/65) * 100 = 3</td>
</tr>
<tr>
<td>3</td>
<td>Secondary Road</td>
<td>30</td>
<td>(2/30) * 100 = 7</td>
</tr>
<tr>
<td>4</td>
<td>Local Road</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>6</td>
<td>Special Road Features</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>7</td>
<td>Driveway or Service Road</td>
<td>10</td>
<td>(2/10) * 100 = 20</td>
</tr>
<tr>
<td>0</td>
<td>Other</td>
<td>2</td>
<td>(2/2) * 100 = 100</td>
</tr>
</tbody>
</table>

Town locations and the "travel cost" datasets served as inputs into a costdistance grid function. This process was repeated for several population cut-offs, including 100, 500, 1000, 5000, 10,000, 15,000, and 20,000. The grids resulting from the analysis describe travel time or accessibility to towns of various sizes from all locations in the Greater Yellowstone Area.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
E-mail: Tiger@census.gov
See Road Density documentation for further details.
SCHOOL ACCESSABILITY

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the travel time in minutes to the nearest school for all locations in the Greater Yellowstone Area.

DATA SOURCE(S): United States Census Bureau - schools
United States Census Bureau - roads


SCALE OF ORIGINAL: 1:100,000 – schools; 1:100,000 – roads

DATA LINEAGE SUMMARY:

Census 2000 TIGER/Line files were acquired for the study area. All files were unzipped converted to ARC/INFO coverages using the TIGERARC command. Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" as described by the table below:

<table>
<thead>
<tr>
<th>Value</th>
<th>Road Type</th>
<th>Travel Speed</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited Access Highway</td>
<td>75</td>
<td>((2/75) \times 100 = 2)</td>
</tr>
<tr>
<td>2</td>
<td>Primary Road</td>
<td>65</td>
<td>((2/65) \times 100 = 3)</td>
</tr>
<tr>
<td>3</td>
<td>Secondary Road</td>
<td>30</td>
<td>((2/30) \times 100 = 7)</td>
</tr>
<tr>
<td>4</td>
<td>Local Road</td>
<td>25</td>
<td>((2/25) \times 100 = 8)</td>
</tr>
<tr>
<td>6</td>
<td>Special Road Features</td>
<td>25</td>
<td>((2/25) \times 100 = 8)</td>
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</tr>
<tr>
<td>0</td>
<td>Other</td>
<td>2</td>
<td>((2/2) \times 100 = 100)</td>
</tr>
</tbody>
</table>

The school locations as specified by the TIGER/Line files and the "travel cost" datasets served as inputs into a costdistance grid function. The grid resulting from the analysis describes travel time or accessibility to schools from all locations in the Greater Yellowstone Area.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
E-mail: Tiger@census.gov
See Road Density documentation for further details.
EDUCATIONAL ATTAINMENT (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

The education attainment table describes the proportion of the population 25 years and over within each town of the GYE that had attained a Bachelor’s degree or higher in 2000.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Census 2000 “Table DP-2: Profile of Selected Social Characteristics” were downloaded for all towns of population greater than 100 within the Greater Yellowstone Area from:
http://censtats.census.gov/pub/Profiles.shtml
The percent of the population of 25 years and over with a bachelor’s degree was compiled from the DP-2 tables for each town.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
4700 Silver Hill Road, Stop 7400
Washington, D.C. 20233
Email: hhes-info@census.gov
Web site: http://censtats.census.gov/pub/Profiles.shtml
PROFESSIONAL EMPLOYMENT (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

The professional employment table describes the proportion of the population 16 years and over within each town of the GYE with management, professional, and related occupations in 2000.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Census 2000 “Table DP-3: Profile of Selected Economic Characteristics” were downloaded for all towns of population greater than 100 within the Greater Yellowstone Area from: http://censtats.census.gov/pub/Profiles.shtml

The percent of the population of 16 years and over with an occupation in professional, scientific, management, administrative, or waste management services was compiled from the DP-3 tables for each town.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
4700 Silver Hill Road, Stop 7400
Washington, D.C. 20233
Email: hhes-info@census.gov
Web site: http://censtats.census.gov/pub/Profiles.shtml
UNEMPLOYMENT STATUS (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

The unemployment status table describes the proportion of the population 16 years and over within the labor force but unemployed within each town of the GYE in 2000.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Census 2000 “Table DP-3: Profile of Selected Economic Characteristics” were downloaded for all towns of population greater than 100 within the Greater Yellowstone Area from: http://censtats.census.gov/pub/Profiles.shtml

The percent of the population of 16 years and over within the labor force, but unemployed was compiled from the DP-3 tables for each town.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
4700 Silver Hill Road, Stop 7400
Washington, D.C. 20233
Email: hhes-info@census.gov
Web site: http://censtats.census.gov/pub/Profiles.shtml
PER CAPITA INCOME (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

This table describes the per capita income within each town of the GYE in 2000.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Census 2000 “Table DP-3: Profile of Selected Economic Characteristics” were downloaded for all towns of population greater than 100 within the Greater Yellowstone Area from: http://censtats.census.gov/pub/Profiles.shtml

The per capita income was compiled from the DP-3 tables for each town.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
4700 Silver Hill Road, Stop 7400
Washington, D.C. 20233
Email: hhres-info@census.gov
Web site: http://censtats.census.gov/pub/Profiles.shtml
SEASONAL HOUSING (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

This table describes the proportion of total housing units used for seasonal, recreational, or occasional use within each town of the GYE in 2000.

DATA SOURCE(S): United States Census Bureau

DATE OF SOURCE: 2000

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Census 2000 “Table DP-1: Profile of Selected Demographic Characteristics” were downloaded for all towns of population greater than 100 within the Greater Yellowstone Area from: http://censtats.census.gov/pub/Profiles.shtml
The proportion of seasonal housing was compiled from the DP-3 tables for each town.

DATA SOURCES CONTACT(S):

Name: UNITED STATES CENSUS BUREAU
Abbr. Name: USCB
Address: United States Census Bureau
          4700 Silver Hill Road, Stop 7400
          Washington, D.C.  20233
Email: hhes-info@census.gov
Web site: http://censtats.census.gov/pub/Profiles.shtml
SPORTING GOODS RETAIL INDEX (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

This table describes the per capita number of businesses listed in the online yellow pages under sporting goods retail within each town of the GYE in 2001.

DATA SOURCE(S): YellowPages.com, Inc.

DATE OF SOURCE: 2001

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Using the search option available at the OnLine Yellow Pages (http://www.yellowpages.com/Index.aspx), the number of businesses per town listed under the “sporting goods stores and bicycle shops” category was recorded. These figures were divided by the 2000 population of each town in order to adjust for town size.

DATA SOURCES CONTACT(S):

Name: YellowPages.com, Inc., a Delaware Corporation
Address: YellowPages.com, Inc.
2501 North Green Valley Parkway #101
Henderson, Nevada 89014
United States of America
Email: support@yellowpages.com
GUIDES AND RESORTS INDEX (TOWN SCALE)

Dataset Type: RELATIONAL TABLE
Dataset Feature: NA

GENERAL DESCRIPTION:

This table describes the per capita number of businesses listed in the online yellow pages under guide services and resort hotels within each town of the GYE in 2001.

DATA SOURCE(S): YellowPages.com, Inc.

DATE OF SOURCE: 2001

SCALE OF ORIGINAL: Town Level Data

DATA LINEAGE SUMMARY:

Using the search option available at the OnLine Yellow Pages (http://www.yellowpages.com/Index.aspx), the number of businesses per town listed under the “guide and outfitter services” and “resort hotels” categories was recorded. These figures were divided by the 2000 population of each town in order to adjust for town size.

DATA SOURCES CONTACT(S):

Name: YellowPages.com, Inc., a Delaware Corporation
Address: YellowPages.com, Inc.
2501 North Green Valley Parkway #101
Henderson, Nevada 89014
United States of America
Email: support@yellowpages.com
ACCESSIBILITY TO YELLOWSTONE AND GRAND TETON NATIONAL PARKS

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the travel time to the nearest entrance gate of either Yellowstone N.P. or Grand Teton N.P. for every location within the Greater Yellowstone Area.

DATA SOURCE(S):
- Montana Natural Heritage Program – public lands
- University of Wyoming, Spatial Data Center – public lands
- United States Census Bureau – roads

DATE OF SOURCE:
- MT – 2002
- WY – December 1996
- 2000 – Roads

SCALE OF ORIGINAL: 1:100,000 and 1:24,000

DATA LINEAGE SUMMARY:

Lineage for Montana -
The public lands database was maintained weekly by the Montana Natural Heritage Program until it was acquired by LBL in January 2002. Most attribute data is from the June 1998 version of the GAP Project 'stewardship' layer.

Lineage for Wyoming -
Information on land ownership was derived from two sources, digital land ownership files provided by the BLM state office in Wyoming (about 35% of the state) and paper Surface Management Status maps which were digitized in house by WY-GAP (65% of the state). Land ownership digitized by WY-GAP was edge-matched with polygons digitized by the BLM. In most cases, there was a close match along the edges, requiring only minor shifts in lines. Larger discrepancies (usually the result of differences in scale of the data sources) were closed off without an attempt to force a match.

The Landscape Biodiversity Laboratory converted the coverages of public lands for each state into one grid. No inaccuracies were found where boundaries between public lands did not align. National parks were reselected from the grid. The ARC/INFO eucdistance command was used to calculate distance values. Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" as described by the table below:

<table>
<thead>
<tr>
<th>Value</th>
<th>Road Type</th>
<th>Travel Speed</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited Access Highway</td>
<td>75</td>
<td>(2/75) * 100 = 2</td>
</tr>
<tr>
<td>2</td>
<td>Primary Road</td>
<td>65</td>
<td>(2/65) * 100 = 3</td>
</tr>
<tr>
<td>3</td>
<td>Secondary Road</td>
<td>30</td>
<td>(2/30) * 100 = 7</td>
</tr>
<tr>
<td>4</td>
<td>Local Road</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>6</td>
<td>Special Road Features</td>
<td>25</td>
<td>(2/25) * 100 = 8</td>
</tr>
<tr>
<td>7</td>
<td>Driveway or Service Road</td>
<td>10</td>
<td>(2/10) * 100 = 20</td>
</tr>
<tr>
<td>0</td>
<td>Other</td>
<td>2</td>
<td>(2/2) * 100 = 100</td>
</tr>
</tbody>
</table>

The national park boundaries and the "travel cost" datasets served as inputs into a costdistance grid function. The grid resulting from the analysis describes travel time or accessibility to national parks from all locations in the Greater Yellowstone Area.
DATA SOURCES CONTACT(S):

<table>
<thead>
<tr>
<th>Name:</th>
<th>MONTANA NATURAL HERITAGE PROGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address:</td>
<td>PO BOX 201800</td>
</tr>
<tr>
<td></td>
<td>Helena, MT 59620-1800</td>
</tr>
<tr>
<td>Phone:</td>
<td>(406) 444-2817</td>
</tr>
<tr>
<td>Web site:</td>
<td><a href="http://nris.state.mt.us/nsdi/nris/ab105/ownerse.html">http://nris.state.mt.us/nsdi/nris/ab105/ownerse.html</a></td>
</tr>
<tr>
<td>Email:</td>
<td><a href="mailto:cjones@state.mt.us">cjones@state.mt.us</a></td>
</tr>
<tr>
<td>Contact Person:</td>
<td>Cedron Jones, Mapping/GIS Specialist</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th>SPATIAL DATA AND VISUALIZATION CENTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address:</td>
<td>Box 4008 University Station</td>
</tr>
<tr>
<td></td>
<td>Laramie, WY 82071</td>
</tr>
<tr>
<td>Phone:</td>
<td>307-766-2751</td>
</tr>
<tr>
<td>Web site:</td>
<td><a href="http://www.sdvc.uwyo.edu/24k/landown.html">http://www.sdvc.uwyo.edu/24k/landown.html</a></td>
</tr>
<tr>
<td>Contact Person:</td>
<td>Data Manager</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th>UNITED STATES CENSUS BUREAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbr. Name:</td>
<td>USCB</td>
</tr>
<tr>
<td>Address:</td>
<td>United States Census Bureau</td>
</tr>
<tr>
<td></td>
<td>Tiger Mapping Service</td>
</tr>
<tr>
<td></td>
<td>4700 Silver Hill Road, Stop 7400</td>
</tr>
<tr>
<td></td>
<td>Washington, D.C. 20233</td>
</tr>
<tr>
<td>Phone:</td>
<td>(301) 457-1128 (Geography)</td>
</tr>
<tr>
<td></td>
<td>(301) 457-4100 (Customer Service)</td>
</tr>
<tr>
<td>Web site:</td>
<td><a href="http://www.census.gov/ftp/pub/geo/www/tiger">http://www.census.gov/ftp/pub/geo/www/tiger</a></td>
</tr>
<tr>
<td>GIS gateway:</td>
<td><a href="http://www.census.gov/geo/www/gis_gateway.html">http://www.census.gov/geo/www/gis_gateway.html</a></td>
</tr>
<tr>
<td>E-mail:</td>
<td><a href="mailto:Tiger@census.gov">Tiger@census.gov</a></td>
</tr>
<tr>
<td>Contact Person:</td>
<td>Products and Services Staff, Geography Division</td>
</tr>
</tbody>
</table>
DISTANCE FROM MAJOR RIVERS AND WATER BODIES

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset represents the Euclidian distance from major rivers and water bodies.

DATA SOURCE(S): U.S. Geological Survey in cooperation with U.S. EPA

DATE OF AUTOMATION OR SOURCE: 1999

SCALE OF ORIGINAL SOURCE MAPS: 1:100,000

DATA LINEAGE SUMMARY:

The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that comprise the nations surface water drainage system. It is based initially on the content of the U.S. Geological Survey 1:100,000-scale Digital Line Graph (DLG) hydrography data, integrated with reach-related information from the U.S. Environmental Protection Agency Reach File Version 3.0 (RF3). More specifically, it contains reach codes for networked features and isolated lakes, flow direction, names, stream level, and centerline representations for aerial water bodies. Reaches are also defined to represent water bodies and the approximate shorelines of the Great Lakes, the Atlantic and Pacific Oceans, and the Gulf of Mexico. The NHD also incorporates the National Spatial Data Infrastructure framework criteria set out by the Federal Geographic Data Committee.

The data were downloaded from http://nhd.usgs.gov/data.html, regionpoly'ed, reprojected, and mapjoin'ed in ARC/INFO. Major water bodies were reselected from the NHD database if they satisfied one of the following criteria: (1) ftype = 'STREAM/RIVER'; (2) sq_km > 0.10 and ftype cn 'CHANNELS'; or (3) sq_km > 0.75 and ftype = 'LAKE/POND'. The reservoirs did not need to be identified separately because they were classified as lake/pond. Linear features representing major rivers were reselected from the NHD database if the name attribute contained either the words 'River' or 'Henry's Fork'. The resulting coverage was visually compared to road maps & atlases that show only major water features, and matched closely.

Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost" (See table presented in Travel Capacity documentation). The major water body dataset and the "travel cost" dataset served as inputs into a costdistance grid function. The resulting grid describes travel time or accessibility to major water bodies from all locations in the GYE.

DATA SOURCES CONTACT(S):

Name: UNITED STATES GEOLOGICAL SURVEY
Abbr. Name: USGS
Address: 521 National Center
          Reston, VA 20192
Phone: 703-648-4528
Email: nhd@usgs.gov

Name: UNITED STATES CENSUS BUREAU
E-mail: Tiger@census.gov
See Road Density documentation for further details.
VARIATION IN ELEVATION PER SQ MILE NEIGHBORHOOD

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing variation of elevation in the surrounding square mile neighborhood for all locations in the Greater Yellowstone Area. When the standard deviation is small there is relatively little variation in the terrain. In other words, the terrain is relatively flat. Conversely, when the standard deviation is large, there is a high degree of variation in elevation; thus, the terrain is relatively steep.

DATA SOURCE(S): U.S. Geological Survey (USGS), EROS Data Center

DATE OF SOURCE: 1999

SCALE OF ORIGINAL: 1:24,000

DATA LINEAGE SUMMARY:

The U.S. Geological Survey has developed a National Elevation Dataset (NED). The NED is a seamless mosaic of best-available elevation data. The 7.5-minute elevation data for the conterminous United States are the primary initial source data. In addition to the availability of complete 7.5-minute data, efficient processing methods were developed to filter production artifacts in the existing data, convert to the NAD83 datum, edge-match, and fill slivers of missing data at quadrangle seams. One of the effects of the NED processing steps is a much-improved base of elevation data for calculating slope and hydrologic derivatives.

The original DEMs that went into the National Elevation Dataset were classified as Level 1 or Level 2. Level 1 DEMs have elevations whose root mean square accuracy could be as poor as 15 meters. Level 2 DEMs have been smoothed by the USGS for consistency and edited to remove identifiable systematic errors.

The DEMs were downloaded by LBL from the following websites:
http://inside.uidaho.edu/asp/theme.asp#Physical
http://www.sdvc.uwyo.edu/24k/dem.html
http://nris.state.mt.us/ndsi/nris/el10/utmdems.html

Missing data resulting from edge-matching problems occurred only in the Wyoming dataset. The slivers were filled in using ARC/INFO Grid commands, Nibble and Focalmean. For a full description of the commands involved in merging the WY, ID, and MT datasets please refer to create_dem.aml. The "focalstd" ARC/INFO command was used to calculate the variation in elevation.

DATA SOURCES CONTACT(S):

Name: UNITED STATES GEOLOGICAL SURVEY
Address: 521 National Center
          Reston, VA 20192
Phone: 703-648-4528
Email: bwright@usgs.gov
Contact Person: Bruce Wright
Website: http://mcmcweb.er.usgs.gov/sdts/geocomm.html
http://data.geocomm.com/dem/

Name: MONTANA STATE LIBRARY
Address: PO Box 201800
         Helena, Montana 59620-1800
Phone: (406) 444-5358
Email: gdaumiller@state.mt.us
Contact Person: Gerry Daumiller
Website: http://nris.state.mt.us/ndsi/nris/el10/utmdems.html

Name: SPATIAL DATA AND VISUALIZATION CENTER
Address: Box 4008 University Station
          Laramie, Wyoming 82071
Phone: 307-766-2751
Contact Person: Data Manager
Website: http://www.sdvc.uwyo.edu/24k/dem.html

Name: UNIVERSITY OF IDAHO LIBRARY
Address: Moscow, ID 83844-2350
Phone: 208-885-6344
Email: lwai@uidaho.edu
Contact Person: Lily Wai
Website: http://inside.uidaho.edu/asp/theme.asp#Physical
FORESTED AREAS TRAVEL TIME

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

This dataset contains values representing the travel time in minutes to the nearest large forested patch for all locations in the Greater Yellowstone Area.

DATA SOURCE(S): U.S. Geological Survey and U.S. Environmental Protection Agency – land cover
U.S. Census Bureau – roads


SCALE OF ORIGINAL: 1:24,000 – land cover; 1:100,000 – roads

DATA LINEAGE SUMMARY:

Forested areas were taken from the land cover data set produced by the U.S Geological Survey (USGS) as part of a cooperative project between the USGS and the U.S. Environmental Protection Agency (USEPA) to produce a consistent, land cover data layer for the conterminous U.S. based on 30-meter Landsat thematic mapper (TM) data. National Land Cover Data (NLCD) was developed from TM data acquired by the Multi-resolution Land Characterization (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies that produce or use land cover data. Partners include the USGS (National Mapping, Biological Resources, and Water Resources Divisions), USEPA, the U.S. Forest Service, and the National Oceanic and Atmospheric Administration.

The TM multi-band mosaics were processed using an unsupervised clustering algorithm. Both leaves-off and leaves-on data sets were analyzed. The resulting clusters were then labeled using aerial photography and ground observations. Clusters that represented more than one land cover category were also identified and, using various ancillary data sets, models developed to split the confused clusters into the correct land cover categories. The base data set for this project was leaves-off Landsat TM data, nominal-1992 acquisitions. Other ancillary data layers included leaves-on TM, USGS 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief, Bureau of the Census population and housing density data, USGS land use and land cover (LUDA), and National Wetlands Inventory (NWI) data if available. For more detailed information on procedures and methods refer to: http://landcover.usgs.gov/mapping_proc.html

The NLCD data were downloaded: from http://landcover.usgs.gov/natlandcover.html, resampled, and reprojected. The original 21 classes were reclassified into forested and non-forested areas. Large forested patches were reselected (those patches containing greater than 250 sq. km of contiguous forest), and smoothed using the focalmin GRID function with a 5 by 5 cell neighborhood. These rules were chosen somewhat arbitrarily in order to reselect only large contiguous forested areas.

Census 2000 TIGER/Line files were acquired for the study area. All files were unzipped converted to ARC/INFO coverages using the TIGERARC command. Using the attribute data provided in the United States Census Bureau TIGER/Line roads database, all roads were assigned a "travel cost".

The locations of large forested patches and the "travel cost" datasets served as inputs into a costdistance grid function. The grid resulting from the analysis describes travel time or accessibility to hospitals from all locations in the Greater Yellowstone Area.
### DATA SOURCES CONTACT(S):

<table>
<thead>
<tr>
<th>Name</th>
<th>UNITED STATES GEOLOGICAL SURVEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>521 National Center</td>
</tr>
<tr>
<td></td>
<td>Reston, VA 20192</td>
</tr>
<tr>
<td>Phone</td>
<td>605) 594-6114</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:leac@edcmail.cr.usgs.gov">leac@edcmail.cr.usgs.gov</a></td>
</tr>
<tr>
<td>Contact Person</td>
<td>NLCD project members</td>
</tr>
<tr>
<td>Website</td>
<td><a href="http://landcover.usgs.gov/nationallandcover.html">http://landcover.usgs.gov/nationallandcover.html</a></td>
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<tr>
<td></td>
<td><a href="http://landcover.usgs.gov/classes.html">http://landcover.usgs.gov/classes.html</a></td>
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</thead>
<tbody>
<tr>
<td>E-mail</td>
<td><a href="mailto:Tiger@census.gov">Tiger@census.gov</a></td>
</tr>
</tbody>
</table>

See Road Density documentation for further details.
ENCROACHING DEVELOPMENT
EXISTING RURAL HOUSING DENSITY

Geodataset Type: GRID
Geodataset Feature: GRID

GENERAL DESCRIPTION:

These datasets contain values representing the number of rural homes in a radius around each section at a given point in time. Radii of 1, 2, 3, 5, 10, 20, 30, 40, 50, 100, and 200 miles were used to generate several maps of rural housing density.

DATA SOURCE(S): U.S. Geological Survey (USGS), EROS Data Center

DATE OF SOURCE: 1999

SCALE OF ORIGINAL: 1:24,000

DATA LINEAGE SUMMARY:

Refer to the documentation for the Tax Assessor Rural Homes Database for a description of housing data collection and contacts. In ARC/INFO GRID, the “pointstats” function was used to calculate the total number of rural homes within surrounding neighborhoods of various sizes.

DATA SOURCES CONTACT(S):

Refer to the documentation for the Tax Assessor Rural Homes Database for a list of contacts for the housing data.
ZONING DISTRICTS

Geodataset Type: COVER
Geodataset Feature: POLYGON

GENERAL DESCRIPTION:

This dataset describes the location and attributes of zoning districts for the twenty counties of MT, WY, and ID within the GYE. The data were collected from the individual counties in digital and hard copy formats, and digitized by the Landscape Biodiversity Laboratory, Department of Ecology, Montana State University, May, 2002.

FEATURE ATTRIBUTE TABLE CODES AND VALUES:

<table>
<thead>
<tr>
<th>Zone</th>
<th>MPS Acres</th>
<th>Description</th>
<th>Max Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone = Name of zone designation</td>
<td>MPS Acres = Minimum parcel size in acres</td>
<td>Description = Brief description of ZONE if necessary</td>
<td>Max Homes = Maximum number of homes per square mile allowed by the zoning district</td>
</tr>
</tbody>
</table>

DATA SOURCE(S): Planning and Zoning departments of the twenty counties within the GYE.

DATE OF AUTOMATION OR SOURCE: May 2002

SCALE OF ORIGINAL SOURCE MAPS: Variable

DATA LINEAGE SUMMARY:

Wyoming Counties (6)
- Fremont County. No data collected because there is no zoning outside town areas.
- Hot Springs County. No data was collected because the land use plan is individually based and ruled upon by public hearing.
- Lincoln County. Provided a hard copy map.
- Park County. Provided digital maps in map info format.
- Sublette County. Provided digital map in shapefile format.
- Teton County. Provided digital map in shapefile format.

Idaho Counties (8)
- Bear Lake County. No data collected because the land use plan is still in the process of development.
- Bonneville County.
- Caribou County. No data collected because the county is zoned all Agriculture. The rules are confusing regarding parcel division, allowing a one time division of forty acres (the minimum parcel size able to be divided) by non-family members but unlimited divisions by family members.
- Clark County. The zoning is extremely limited occurring only in town areas and in small size industrial zones.
- Franklin County. The county is zoned primarily Agricultural with a minimum parcel size for subdivision as one acre per home.
- Fremont County. No data was collected because the county uses performance based standards instead of zoning. The standards address several factors including wildlife areas, stream and river channels and sensitive areas before building is allowed.
- Madison County. Downloaded the map from the website in PDF format.
- Teton County. Provided hardcopy map.

Montana Counties (6)
- Gallatin County. Provided digital and hardcopy maps.
- Madison County. No data was collected because the county has no zoning. The only restrictions are various floodplain setbacks which are smaller than one township range section.
- Park County. Provided hardcopy maps.
- Stillwater County. Provided hardcopy maps.
- Sweetgrass County. No data was collected because the only zoning district is for the town of Big Timber.

All hardcopy maps were digitized using ARC/INFO ArcEdit. Digital datasets received by counties were checked for label errors and merged to the overall Greater Yellowstone zoning coverage.

DATA SOURCES CONTACT(S):

Wyoming Counties (6)

Name: Fremont County Planning and Zoning Department
Phone: (307) 332-1077
Contact Person: County Planner

Name: Hot Springs County Planning and Zoning Department
Phone: (307) 864-2961
Contact Person: Dennis Adams

Name: Lincoln County Planning and Zoning Department
Phone: (307) 885-3106
Contact Person: John Woodward

Name: Park County Planning and Zoning Department
Phone: (307) 527-8540
Contact Person: Planning Coordinator

Name: Sublette County Planning and Zoning Department
Phone: (307) 367-6812
Contact Person: Pam Curry (GIS)

Name: Teton County Planning and Zoning Department
Phone: (307) 733-3959
Contact Person: County Planner

Idaho Counties (8)

Name: Bear Lake County Planning and Zoning Department
Phone: (208) 945-2333
Contact Person: Craig Thomas

Name: Bonneville County Planning and Zoning Department
Phone: (208) 529-1386
Contact Person: Steve Serr

Name: Caribou County Planning and Zoning Department
Phone: (208) 547-1780
Contact Person: Ralph Hupkins
Name: Clark County Planning and Zoning Department  
Phone: (208) 374-5271  
Contact Person: County Planner

Name: Franklin County Planning and Zoning Department  
Phone: (208) 852-9301  
Contact Person: John Burg

Name: Fremont County Planning and Zoning Department  
Phone: (208) 624-3148  
Contact Person: Karyn Ords

Name: Madison County Planning and Zoning Department  
Phone: (208) 356-8907  
Contact Person: Denel Jose

Name: Teton County Planning and Zoning Department  
Phone: (208) 354-2593  
Contact Person: Rachelle Fulmer

Montana Counties (6)

Name: Gallatin County Planning and Zoning Department  
Phone: (406) 582-3072  
Contact Person: Allen Armstrong (GIS)  
            Jennifer Koozer (Planner)

Name: Carbon County Planning and Zoning Department  
Phone: (406) 446-1694  
Contact Person: Greg McGann

Name: Madison County Planning and Zoning Department  
Phone: (406) 843-5250  
Contact Person: Dorris Fisher

Name: Park County Planning and Zoning Department  
Phone: (406) 222-4102  
Contact Person: County Planner

Name: Stillwater County Planning and Zoning Department  
Phone: (406) 322-8050  
Contact Person: Bo Bowman

Name: Sweetgrass County Planning and Zoning Department  
Phone: (406) 932-5470  
Contact Person: Betty Alexander
APPENDIX B

SAS STATISTICAL CODE
The following code is an example of the SAS commands and arguments used to specify the generalized linear models of growth in rural residential development. We made the assumption of a negative binomial distribution, and specified a log link in order to transform to linear relationships. To assess the goodness of fit between the predicted models and the observed data, Pearson’s chi-square statistics were used. For a true model, the Pearson's chi-square statistic divided by the degrees of freedom should asymptotically approach one. This value is provided by default in the output of the GENMOD procedure. When this value is much larger than one, the data are said to exhibit overdispersion (SAS Institute Inc., 1989). Area was incorporated in the models as an offset variable because the area of all sections was not exactly 2.59 square kilometers.

```sas
proc genmod data=dir.dataset;
model response = covariate1 covariate2 covariate3
    / offset=area dist=nb link=log lrci residuals pred;
run;
```

The following code is an example of the SAS commands and arguments used to generate the variogram for the Pearson’s residuals of the top models of growth in rural residential development. The lag distance of 8046.72m (1mi.) was specified due the resolution of the tax assessor homes dataset. The output included semivariance by lag distance, and was exported to a comma separated file using the EXPORT procedure.

```sas
proc variogram data=dir.dataset outvar=dir.output_file;
compute lagdist=8046.72 maxlags=10;
coordinates xcoord=xcoor ycoord=ycoor;
run;

proc export data=dir.output_file outfile="/directory_path /output_file"
dbms=csv;
run;
```
APPENDIX C

RDS SIMULATION SOURCE CODE
import phClasses.*;
import java.io.*;
import java.util.*;

public class RDS implements Serializable
{

public static void main(String[] args) throws Exception
//-----------------------------------------------------------------
{      //   initialize variables:

    boolean output ;    //   output to file (y,n) ?
    if (args[0].equals("y")) output = true ;
    else output = false ;

    boolean zoning ;    //   implement zoning (y,n) ?
    if (args[1].equals("y")) zoning = true ;
    else zoning = false ;

    String zn ;
    if (zoning)  zn = "z" ;
    else  zn = "x" ;

    double[] beta = {-3.5324,3.0083,-0.6478,0.0067,0.5217,-0.0643,-1.1226,1.7544,-3.3056,0.1395} ;
    double[] err = {0,0.4827,0.3067,0.0013,0.1141,0.0167,0.0187,0.1042,0.2728,0.0244} ;

    if (args[2].equals("u"))
    { for (int i = 0; i < 10; i++)  beta[i] += err[i] ; }
    if (args[2].equals("l"))
    { for (int i = 0; i < 10; i++)  beta[i] -= err[i] ; }

    int simYear = 2000 ;   //   start-up year default
    int NUMTRS = 24999 ;   //   number of TRS'
    double chg ;    //   change in number of homes

    SystemState system ;   //   initialize system of rural homes

    File f = new File("SystemState.dat") ;
    if (f.exists())
    {      //   if output from previous iteration exists, use 2010 as the starting point.
       FileInputStream fis = new FileInputStream("SystemState.dat") ;
       ObjectInputStream ois = new ObjectInputStream(fis) ;
       Object o = ois.readObject() ;
       system = (SystemState) o ;
       simYear += 10 ;
    }
    else
    {      //   if output from previous iteration doesn't exist, use default starting point: 2000.
       String inpName = "input/tax" + Integer.toString(simYear) + ".txt" ;
       if (zoning) system = new SystemState(new File(inpName), new File("input/zn_op.txt")) ;
       else system = new SystemState(new File(inpName)) ;
    }

    SystemState system ;   //   initialize system of rural homes
    File f = new File("SystemState.dat") ;
    if (f.exists())
    {      //   if output from previous iteration exists, use 2010 as the starting point.
       FileInputStream fis = new FileInputStream("SystemState.dat") ;
       ObjectInputStream ois = new ObjectInputStream(fis) ;
       Object o = ois.readObject() ;
       system = (SystemState) o ;
       simYear += 10 ;
    }
    else
    {      //   if output from previous iteration doesn't exist, use default starting point: 2000.
       String inpName = "input/tax" + Integer.toString(simYear) + ".txt" ;
       if (zoning) system = new SystemState(new File(inpName), new File("input/zn_op.txt")) ;
       else system = new SystemState(new File(inpName)) ;
    }
}
Predictor apVar = new Predictor(new File("input/ap.csv")); // instantiate predictor
Predictor rdVar = new Predictor(new File("input/rd.csv")); // variables
Predictor fsVar = new Predictor(new File("input/fst.csv"));
Predictor wtVar = new Predictor(new File("input/wt.csv"));
Predictor en1Var;
Predictor en2Var;
Predictor dvVar;
if (simYear == 2000)
{
    en1Var = new Predictor(new File("input/enc1" + Integer.toString(simYear) + ".csv"));
    en2Var = new Predictor(new File("input/enc20" + Integer.toString(simYear) + ".csv"));
    dvVar = new Predictor(new File("input/dev" + Integer.toString(simYear) + ".csv"));
}
else
{
    //en1Var = new Predictor(new File("input/enc1" + Integer.toString(simYear) + zn + args[2] + ".csv"));
    //en2Var = new Predictor(new File("input/enc20" + Integer.toString(simYear) + zn + args[2] + ".csv"));
    //dvVar = new Predictor(new File("input/dev" + Integer.toString(simYear) + zn + args[2] + ".csv"));
    en1Var = new Predictor(new File("input/enc12010om.csv"));
    en2Var = new Predictor(new File("input/enc202010om.csv"));
    dvVar = new Predictor(new File("input/dev2010om.csv"));
}
System.out.println();
System.out.println("______RDS OUTPUT________________________________")
System.out.println();
System.out.println("Total Homes in " + Integer.toString(simYear) + ": " + Integer.toString(system.getTotal()))
for (int trs = 0; trs < NUMTRS; trs++)
{
    chg = (beta[0] + (system.getTrsArea(trs)) + (beta[1] * rdVar.get(trs)) +
(beta[9] * system.getPastChg(trs)));
    chg = Math.exp(chg);
    system.update(trs, chg);
}
for (int trs = 0; trs < NUMTRS; trs++)
{
    System.out.println("Total Homes in " + Integer.toString(simYear + 10) + ": " + Integer.toString(system.getTotal()))
}
System.out.println("________________________________________________")
System.out.println();

/* if output is set to true, print the program output to a file that can
be linked to the gis. */
if (output) // output recNum & trsTotal
{
    // to an ascii file
    System.out.println("Storing RDS " + Integer.toString(simYear + 10) + " Output (takes approx. 4
    minutes)...") ;
    String filename ;
    //filename = "sim" + Integer.toString(simYear + 10) + zn + args[2] ;
    filename = "sim" + Integer.toString(simYear + 10) + "o" + args[2] ;
    PrintWriter pOut = new PrintWriter(new FileWriter(filename + "out")) ;
    pOut.println(system.toString()) ; // call the system's toString method
    pOut.close() ;
}

/* serialize the system instance in it's final state. */
FileOutputStream fos = new FileOutputStream("SystemState.dat") ;
ObjectOutputStream oos  = new ObjectOutputStream(fos) ;
oos.writeObject(system) ;
fos.close() ;
//} // [end output block]

} // [end main]

} // [end SimRRD class]
package phClasses;
import java.io.*;
import java.util.*;

public class SystemState implements Serializable {

    // SystemState constants
    public static final int NUMTRS = 24999;
    /* set NUMTRS variable to the number of township-range-sections (trs)
     within the EPA study area */

    // SystemState instance variables
    private int total = 0;  // total number of homes in the system
    private int[] recNum;  // number corresponding to GIS polygon
    private int[] trsTotal;  // number of homes in the trs
    private double[] trsArea;  // area of the trs (not always 1 sq mi.)
    private int[] pastChg;  // change in the number of homes during
                            // the previous time step
    private boolean zoning;  // true if zoning restrictions will be
                             // considered in the model
    private int cap = 640;  // number of homes per section never to
                         // exceed
    private int[] maxHomes;  // maximum number of homes that can be
                           // developed within the trs as set by
                           // zoning restrictions
    private int[] dispReg;  // region within which homes can be
                            // displaced due to zoning restrictions
    private int[] dispRegID;  // section identification number per region
    private int[] dispRegMax;  // number of sections per region
    private int[] dispSim;  // values describing areas with similar
                         // combinations of predictor variable
                         // values - used for zoning displacement
    private int totalDisp = 0;  // total number of homes displaced
    private int numDispFail = 0;  // for debugging: number failures
    private int sameReg = 0;
    private int difReg = 0;

    // SystemState constructor methods
}
public SystemState(File f) throws Exception
{
    /* no zoning data provided - set zoning to false */
zoning = false ;
    /* instantiate the instance variable arrays */
recNum = new int[NUMTRS] ;
trsTotal = new int[NUMTRS] ;
trsArea = new double[NUMTRS] ;
pastChg = new int[NUMTRS] ;
    /* open the file that was passed as the argument. the file should have 
        four columns corresponding to: 1. recNum, 2. trsTotal, 3. trsArea, 
        and 4. pastChg */
BufferedReader input = new BufferedReader(new FileReader(f)) ;
    /* populate the instance variables */
String str = input.readLine() ;  // read the 1st line of the file
int rec = 0 ;    // initialize the record counter
String next ;
while (str != null)    // while the next line has data
{     // parse the line
    StringTokenizer words = new StringTokenizer(str) ;

    next = words.nextToken() ;  // get the line's 1st token
    recNum[rec] = Integer.parseInt(next) ; // populate recNum[]

    next = words.nextToken() ;    // get the 2nd token
    trsTotal[rec] = Integer.parseInt(next) ; // populate trsTotal[]

    next = words.nextToken() ;    // 3rd token
    trsArea[rec] = Double.parseDouble(next) ; // populate trsArea[]

    next = words.nextToken() ;    // 4th token
    pastChg[rec] = Integer.parseInt(next) ; // populate pastChg[]

    str = input.readLine() ;   // read the next line
    rec++ ;     // augment the record counter
}
    /* calculate the total number of homes within the system */
for (int x = 0; x < NUMTRS; x++)
{ total += trsTotal[x] ; }
}

public SystemState(File f, File z) throws Exception
    /* second option for SystemState constructor 
    used if two file arguments are provided */
{
    /* zoning data provided - set zoning to true */
zoning = true ;
    /* instantiate the instance variable arrays */
recNum = new int[NUMTRS] ;
trsTotal = new int[NUMTRS] ;
trsArea = new double[NUMTRS] ;
pastChg = new int[NUMTRS] ;
maxHomes = new int[NUMTRS] ;
dispReg = new int[NUMTRS] ;
dispRegID = new int[NUMTRS] ;
dispRegMax = new int[NUMTRS] ;
dispSim = new int[NUMTRS] ;
/* open 1st file that was passed as the argument. the file should have
four columns corresponding to: 1. recNum, 2. trsTotal, 3. trsArea,
and 4. pastChg */
BufferedReader input = new BufferedReader(new FileReader(f)) ;
/* populate the instance variables */
String str = input.readLine() ; // read the 1st line of the file
int rec = 0 ; // initialize the record counter
String next ;
while (str != null) // while the next line has data
{
    // parse the line
    StringTokenizer words = new StringTokenizer(str) ;

    next = words.nextToken() ; // get the line's 1st token
    recNum[rec] = Integer.parseInt(next) ; // populate recNum[]

    next = words.nextToken() ; // get the 2nd token
    trsTotal[rec] = Integer.parseInt(next) ; // populate trsTotal[]

    next = words.nextToken() ; // 3rd token
    trsArea[rec] = Double.parseDouble(next) ; // populate trsArea[]

    next = words.nextToken() ; // 4th token
    pastChg[rec] = Integer.parseInt(next) ; // populate pastChg[]

    str = input.readLine() ; // read the next line
    rec++ ; // augment the record counter
}
/* populate zoning array with values for: 1. max number of homes per trs,
2. displacement regions, 3. displacement section id, 4. displacement max,
and 5. displacement combinations */
BufferedReader z_input = new BufferedReader(new FileReader(z)) ;
str = z_input.readLine() ; // read the 1st line of the file
rec = 0 ; // initialize the record counter
while (str != null) // while the next line has data
{
    // parse the line
    StringTokenizer words = new StringTokenizer(str) ;

    next = words.nextToken() ; // get the line's 1st token
    maxHomes[rec] = Integer.parseInt(next) ; // populate the array

    next = words.nextToken() ; // get the 2nd token
    dispReg[rec] = Integer.parseInt(next) ; // populate dispReg[]

    next = words.nextToken() ; // 3rd token
    dispRegID[rec] = Integer.parseInt(next) ; // populate dispRegID[]

    next = words.nextToken() ; // 4th token
    dispRegMax[rec] = Integer.parseInt(next) ; // populate dispRegMax[]

}
next = z_words.nextToken();       // 5th token
dispSim[rec] = Integer.parseInt(next); // populate dispSim[]

str = z_input.readLine();          // read the next line
rec++;                             // augment the record counter

/* calculate the total number of homes within the system */
int count = 0;
for (int x = 0; x < NUMTRS; x++)
{
    total += trsTotal[x];
    if (trsTotal[x] > maxHomes[x])
    {
        maxHomes[x] = trsTotal[x];
        count++;
    }
}
// for debugging:
// System.out.println("TRS' in which the present number of housing " +
// "exceeds the max:" + Integer.toString(count));

// SystemState methods
//--------------------
public int getTotal()
{ return total; }

public double getTrsArea(int i)
{ return trsArea[i]; }

public int getTrsTotal(int i)
{ return trsTotal[i]; }

public int getPastChg(int i)
{ return pastChg[i]; }

public int getTotalDisp()
{ return totalDisp; }

public int getDispFail()
{ return numDispFail; }

public int getSameReg()
{ return sameReg; }

public int getDifReg()
{ return difReg; }

public int calcTotal()
{
    for (int z = 0; z < NUMTRS; z++)
    { total += trsTotal[z]; }
    return total;
public void update(int i, double chg)
/* method to update the system state for a particular trs */
{
  int numNewHomes ;
  int dispHomes ;

  if (chg < 0)
  /* if no change in number of homes, don't change trsTotal or total */
  { numNewHomes = 0 ; }  
  else
  {
    int ptNumNewHomes = (int)Math.round(chg) ;
    int ptTrsTotal = trsTotal[i] + ptNumNewHomes ;
    if (zoning)
    /* if modelling zoning... */
    {
      if (ptTrsTotal > maxHomes[i])
      /* if the potential number of new homes exceeds the maximum number, as specified by the zoning restrictions... */
      {
        /* figure out the number of homes that are allowed 
        and assign them to the section */
        numNewHomes = maxHomes[i] - trsTotal[i] ; // number allowable homes
        trsTotal[i] = maxHomes[i] ;
        total += numNewHomes ;
        /* displace the leftover homes to similar sections 
        within the same region */
        dispHomes = ptNumNewHomes - numNewHomes ;  // number leftover homes
        int numLoops = 0 ;   // initiate number loops to zero
        int numDisp = 0 ;    // number homes displaced so far
        int x , dif ;
        boolean cont = true ;
        while (cont)
        {     // 1st generate a random number
          numLoops++ ;    // for selecting a random section
          double dispIDd = Math.random() * dispRegMax[i] ; // within the same region.
          int dispID = (int)dispIDd + 1 ;
          dif = dispRegID[i] - dispID ; // use the difference between
          x = i - dif ; // the current section id # and the 
          // random # to shift the pointer (x) 
          // to the other section.
          boolean notDispToZero = true ;
          if ((trsTotal[i] != 0) & (trsTotal[x] == 0)) // if the zoned section had homes
          { notDispToZero = false ; }
          // and the new section doesn't
          // cancel the displacement
          if (x < NUMTRS)  // make sure x is within the correct range
          {
            if ((dispReg[i] == dispReg[x]) & (dispSim[x] == dispSim[i]) &
                (trsTotal[x] < maxHomes[x]) & (notDispToZero))
if (dispReg[i] == dispReg[x]) sameReg++ ;  // and the section has not reached it's max
else difReg++ ;  // assign the home to that section.

trsTotal[x]++ ;
total++ ;
numDisp++ ;
totalDisp++ ;
}

if (numDisp == dispHomes)  // if all leftover homes have been displaced, break from loop.
{ cont = false ; }  // if too many loops (no success in finding a similar section),
if (numLoops > (5000 * dispHomes))  // break from loop and
{ cont = false ;
numDispFail += (dispHomes - numDisp) ;  // record the number of homes that failed to be displaced.
}
else if (ptTrsTotal > cap)
/* if the potential number of new homes exceeds the maximum number, as specified by the upper cap... */
{
/* set the number of new homes to the cap, & update the system state variables */
numNewHomes = cap - trsTotal[i] ;
trsTotal[i] = cap ;
total += numNewHomes ;
}
else
/* else if the potential number of new homes does not exceed the zoning restrictions or cap... */
{
/* update the system state variables */
numNewHomes = ptNumNewHomes ;
trsTotal[i] = ptTrsTotal ;
total += ptNumNewHomes ;
}
}  // [end if modelling zoning]
else
/* if not modelling zoning... */
{
if (ptTrsTotal > cap)
/* if the potential number of new homes exceeds the maximum number, as specified by the upper cap... */
{
/* set the number of new homes to the cap, & update the system state variables */
numNewHomes = cap - trsTotal[i] ;
trsTotal[i] = cap ;
}
total += numNewHomes ;
}

else
    /* else if the potential number of new homes does not exceed the
     * maximum number, as specified by the zoning restrictions... */
    {
        /* update the system state variables */
        numNewHomes = ptNumNewHomes ;
        trsTotal[i] = ptTrsTotal ;
        total += ptNumNewHomes ;
    }
    // [end if not modelling zoning]

    // [end else predicted change ne 0]

    /* set the past change equal to the modelled change */
    pastChg[i] = numNewHomes ;
    // [end update method]

public String toString()
/* method that converts SystemState to a string consisting of two columns:
recNum (for linking back the the GIS polygons), &
trsTotal (the modelled number of homes within each trs)
note: without this method the program runs multiple time steps within
seconds. the toString method takes approximately 4 minutes to run */
{
    String tmp = "" ;
    for (int z = 0; z < NUMTRS; z++)
    {
        tmp += (Integer.toString(recNum[z]) + "," +
                Integer.toString(trsTotal[z]) + "n") ;
    }
    return tmp ;
}
package phClasses;
import java.io.*;
import java.util.*;

public class Predictor {
    // Predictor constants
    //------------------------------
    public static final int NUMTRS = 25005 ;
    /* set NUMTRS variable to the number of township-range-sections (trs)
       within the EPA study area */

    // Predictor instance variables
    //------------------------------
    private double[] var ;

    // Predictor constructor methods
    //------------------------------
    public Predictor(File f) throws Exception {
        var = new double[NUMTRS] ;
        /* open the file containing the input data */
        BufferedReader input = new BufferedReader(new FileReader(f)) ;
        /* populate the var[] array */
        String str = input.readLine() ;
        int i = 0 ;
        while (str != null)   // until the end of the file
            {    // is reached,
                var[i] = Double.parseDouble(str) ; // populate the array
                str = input.readLine() ;
                i++ ;
            }
    }

    // Predictor methods
    //---------------------
    public double get(int i) {
        /* method to retrieve the value at the given array index */
        { return var[i] ; }
    }
}