University of Nevada, Reno

# Interpreting Global Emissions Scenarios into a Local Scale Urban Growth Model: Truckee Meadows Metropolitan Region, NV, USA

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# ABSTRACT

Scenario-based studies are used in a number of disciplines to better understand future uncertainties and help governments, organizations, and industries make plans that can withstand a wider range of potential future states. This research presents four distinct urban growth scenarios and modeled impacts for the Truckee Meadows metropolitan region in Nevada, USA. The urban growth scenarios are interpreted from the Special Report on Emission Scenarios (SRES) published by the Intergovernmental Panel on Climate Change (IPCC). Interpreting the SRES emissions scenarios into urban growth or land use change scenarios has been done in many regions of the world and at various sub-global scales, but this process has seen limited application at the local scale or in North America. The methodology for interpreting these scenarios to the local scale is discussed, along with how the scenarios are used to drive a cellular automata urban growth model. The urban growth impacts are assessed on the region's urban land use, housing, water use, and wastewater at 2029 and 2049. This impact analysis indicates the region could face significant resource challenges, and their timing and extent will likely be partially influenced by the driving forces explored in these scenarios. The SRES interpretation methodology presented in this research also provides a framework for future work to join SRES-linked urban growth and environmental models in order to conduct integrated climate change impact assessments at the local scale. Local scale analyses combining interrelated socio-economic and environmental issues will enable communities to make resilient plans which can adapt to and help mitigate a changing climate.

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# 1.0 INTRODUCTION

Water resources, urban growth, and climate change are key issues facing many parts of the world today. To best manage land and water resources now and into the future, governmental agencies at all levels must make policies, decisions, and plans that can account for, mitigate, and adapt to a changing climate. However, in order to manage resources these agencies must use tools which can consider the complex interaction of present and future climatic and socio-economic conditions affecting their region. In recent decades, scenarios have been effectively used as a tool (Schwartz, 1991) for land use planning (Myers and Kitsuse, 2000; Shearer, 2005) and climate change research (Nakicenovic et al., 2000; Berkhout et al., 2002; Arnell et al., 2004). In the context of land use planning and climate change research, scenarios can improve the understanding of future uncertainties, interactions, and linkages between multiple systems, and the implications of policies, adaptation, and mitigation (Moss et al., 2010).

Since the Intergovernmental Panel on Climate Change's (IPCC) publication of global emissions scenarios in the Special Report on Emission Scenarios (SRES) (Nakicenovic et al., 2000), a great deal of work has considered how these global scenarios can be used for climate change impacts and policy research and at finer spatial scales (UKCIP, 2000; 2002; Carter et al., 2004; Adger et al., 2005; van Vuuren et al., 2007). One particular way that this has been accomplished is through the interpretation of the SRES emission scenarios into future urban growth or land use scenarios. Several studies have demonstrated methods to create urban growth or land use change scenarios from the SRES scenarios and conduct subsequent impact analyses at regional, national, and large metropolitan scales (Solecki and Oliveri, 2004; Abildtrup et al., 2006; Rounsevell et al., 2006a; 2006b; Hansen, 2010). These studies used the results of their urban growth or land use models to conduct integrated climate change impact analyses on a variety of other systems. This is done through the use of the SRES emissions scenarios in downscaled global circulation models (GCM) to create outputs (e.g. temperature or precipitation), which can feed into environmental models. Combining the outputs of the urban growth or land use model with the outputs from the environmental model(s) allows for a joint assessment of potential future socio-economic and climate change impacts at the desired scale. Using the SRES scenarios as a framework provides consistency between the socio-economic and policy forces driving the scenarios in the urban growth or land use change models and the global emissions causing climate change and driving the environmental model(s) (Abildtrup et al., 2006). Examples of these integrated socio-economic and climate change assessments have focused on future impacts on coastal flooding (Hansen, 2010), inland flooding (Feyen et al., 2009), air quality and public health (Solecki and Oliveri, 2004), biodiversity (Rounsevell et al., 2006b), agricultural land use and crop productivity (Ewert et al., 2005), and agricultural prices (Abildtrup et al., 2006).

This research will build upon this previous research by developing SRES-derived urban growth scenarios at the local scale. Four SRES-derived urban growth scenarios were developed and spatially modeled using a cellular automata model for the Truckee Meadows, a small metropolitan region (less than 500,000 people) in northwestern Nevada, USA. The methods for interpreting the SRES emissions scenarios into urban growth scenarios at the local level and driving a cellular automata growth model will be discussed, along with potential future impacts on the region's urban land use, housing, water use, and wastewater. An integrated climate change impact assessment for the region was not within the scope of this study; however, future work can join SRES-derived urban growth scenarios with SRES-derived environmental scenarios to create consistent and integrated scenarios for exploring socio-economic and climate change-caused impacts at the local level. A great amount of completed and ongoing research has strengthened resource planning under a changing climate at the regional, national, and large metropolitan scales, and the goal of this study is to contribute to expanding these benefits to the local level.

## 2.0 BACKGROUND

### 2.1 Scenarios as a Tool

For several decades businesses, governments, and researchers have been using scenarios to help illustrate and explore potential future states of the world (Berkhout et al., 2002). Unlike other future-oriented methods such as forecasting or projecting, "the goal of working with scenarios is not to predict the future, but to better understand uncertainties in order to reach decisions that are robust under a wide range of possible futures" (Moss et al., 2010, p. 747). Scenario planning pioneer Peter Schwarz describes scenarios as “a tool for ordering one’s perceptions about alternative future environments in which one’s decisions might be played out” (Schwartz, 1991, p. 4). One useful way to consider scenarios is by the general principles they are comprised of. Shearer (2005, p. 68) defines these principles as:

> (1) scenarios are fictional (where fictional is understood to mean unverifiable but plausible, not fanciful) accounts which represent a process of change over some duration;
> (2) scenarios describe situations, actions, and consequences which are contingently related;
> (3) scenarios are understood to be predictive judgments which describe what could happen, not predictions which describe what will happen, or even what is likely to happen; and
> (4) scenarios organize information within explicitly defined frameworks

Scenarios are a very distinct approach for exploring the future and making plans, policies and decisions in the present. They help show a process of change over time with the interaction of various forces, display the contingent relationships between the forces, describe a potential future, and use a specific framework captured through a written narrative to display and guide the information.

Central to the scenario approach is the concept that scenarios offer several equal alternative futures to consider, therefore, an important principle of scenarios is choice. This contrasts other methods such as projections or forecasts, which may offer a ‘best’ or ‘preferred’ choice. Offering a range of scenarios allows the people or group(s) using the scenarios to consider a broad range of potential futures. Or, the choice in scenarios can allow them to be a testing ground for understanding the implications of different policy decisions (Shearer, 2005). The scenario creation process generally attempts to eliminate a large amount of the personal judgment because this can limit the range of uncertainty addressed in the scenarios (Metzger et al., 2010). Regardless of the desired use of the scenarios, the scenario users can treat all well-constructed scenarios as equally possible futures that facilitate exploration of changes and consequences.

Scenarios can be constructed in a variety of ways that can be adapted to meet the resources and objectives of the study. Several of the most recognized construction methods include through a process involving stakeholders (e.g. Shearer et al., 2009), interpretation (e.g. Solecki and Oliveri, 2004) or downscaling (e.g. Verburg et al., 2006) of existing scenarios, or through expert judgment (e.g. Abildtrup et al., 2006). There are valid reasons for each construction method and advantages and disadvantages to each approach (Mahmoud et al., 2009).

Scenarios always have quantitative and qualitative components. The quantitative components are used as inputs to drive models to come up with numerical or spatial future conditions (Mahmoud et al., 2009). The qualitative component comes in the form of scenario narratives, which are an effective medium to help link past to present to future states and convey complex problems in a holistic manner (Shearer, 2005). The narratives have been shown in numerous studies to have great “value as problem-solving and decision-making tools” (Berkhout et al., 2002, p. 87). These narratives, as Schwartz (as cited in Myers and Kitsuse, 2000) writes, “have a psychological impact that graphs and equations lack. Stories are about meaning; they help explain why things could happen in a certain way. They give order and meaning to events – a crucial aspect of understanding future possibilities” (p. 227).

Faced with a need to understand and plan for a highly uncertain future, climate change researchers and land use planners have found the scenario approach a useful method. The method provides a framework suitable for addressing the complex relationships in human and natural systems in a way that is acceptable to both the researchers, policy makers, and the general public.

## 2.2 IPCC SRES Emissions Scenarios

Greenhouse gas (GHG) emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) have been an integral part of climate change research since their first iteration in 1990. Since the first publication, the scenarios have gone through two other revisions in 1992 and most recently in 2000 (Nakicenovic et al., 2000). The most recently published emissions come from a report called the Special Report on Emissions Scenarios (SRES), which have been described as the “most prominent” (Berkhout et al., 2002, p. 86) use of scenarios in climate change research. The SRES scenarios have taken a fundamentally different approach to scenarios than that of its predecessors, SA90 and IS92. Unlike the earlier versions, the SRES frames the scenarios by using four narratives which serve to “describe consistently the relationships between emission driving forces and their evolution and add context for the scenario quantification” (Nakicenovic et al., 2000). In the SRES, the four scenario narratives each briefly describe a “demographic, social, economic, technological, environmental, and policy future” (Nakicenovic et al., 2000) at the global scale which guide emissions into four particular scenarios, labeled, A1, A2, B1, and B2.

For researchers assessing climate change, the SRES scenarios offer more than a wide range of quantitative emissions data that can be used for inputs to global circulation models (GCM). By using scenarios, the SRES lends itself for use in "wider scientific and policymaking communities […] for developing mitigation and adaptation measures and policies" (Nakicenovic et al., 2000). Moss et al. (2010) expand on this point, noting that, "when applied in climate change research, scenarios help to evaluate uncertainty about human contributions to climate change, the response of the Earth system to human activities, the impacts of a range of future climates, and the implications of different approaches to mitigation […] and adaptation" (p. 747).

### 2.3 Urban Growth Modeling

There is a wide range of urban growth models available today that are used to help study, understand, and predict urban growth. Cellular automata (CA) models are a prominent type of these models and they have been used in the simulation of urban growth for a number of years (Barredo et al., 2003; Sante et al., 2010). CA models vary greatly in the complexity of the required inputs and options available as model outputs (Sante et al., 2010). More complex models can require multiple land uses or data inputs such as employment and economic forecasts (e.g. Waddell, 2002). These models can create much more detail outputs such as the spatial location of multiple urban land uses (e.g. Landis and Zhang, 1998; Dietzel and Clarke,

2006) or economic and household indicators (e.g. Waddell, 2002). Other more simplistic models require only existing urban/non-urban land uses and spatial rules (e.g. Li and Liu, 2006).

Although the models may vary significantly, the purpose of each model is generally to capture spatially five distinct urban activities for the region being modeled. These activities include environmental characteristics (i.e. constraints), local-scale neighborhood characteristics (past and present patterns), spatial characteristics (large-scale patterns), urban and regional planning policies, and factors related to human decision making processes (Barredo et al., 2003). The urban activities are accounted for in the CA model through parameters such as exclusion zones (where future growth cannot occur) and attraction zones (where spatial and socio-economic factors would attract growth) (Kahyaoglu-Koracin et al., 2009). Since the CA model's goal is to simulate or predict future urban activities and growth, these models often use historic information to calibrate the model to the specific region (see for example Barredo et al., 2003; Solecki and Oliveri, 2004; Hansen, 2010). Calibration itself is an ongoing discussion in the CA research, so methods and metrics for testing the 'accuracy' of a CA model range greatly (Jantz and Goetz, 2005). Ultimately, each CA model has strengths and weaknesses that make the model more or less suitable for specific studies because of factors such as the extent of the region being modeled, data availability, time constraints, desired outputs, resolution of the analysis, flexibility of the model, and desired accuracy (Sante et al., 2010).

### 2.4 Interpreting SRES Scenarios into Land Use or Urban Growth Scenarios

One specific way that has expanded climate change research and the usefulness of scenarios is by interpreting the SRES emissions scenarios into future land use or urban growth scenarios at a finer spatial scale. In such an approach, future scenarios for a study region can be created and assessed to see how climatic and socio-economic changes may interact and impact various systems in a given region. Several studies have demonstrated a variety of methods to create land use change or urban growth scenarios from the SRES scenarios and conduct impact analyses at regional, national and large metropolitan scales (e.g. UKCIP, 2000; 2002; Carter et al., 2004; Solecki and Oliveri, 2004; Abildtrup et al., 2006; Rounsevell et al., 2006a). These studies have pioneered the concept of taking a more interdisciplinary approach to the range of impacts considered and deriving land use scenarios from the SRES.

In one of the first studies, conducted by the UK Climate Impact Programme, the research team created four scenarios for the UK based upon the drivers of the SRES to assess potential future economic, social and political changes for that region. These scenarios were used to complement the climate change scenarios done for the UK. While specific land use scenarios were not directly created from the SRES in this study, it became a leading example of an integrated approach to a regional impact assessment study and an illustration of using the SRES for something beyond only inputs for a GCM (UKCIP, 2000; 2002; Berkhout et al., 2002). Several other studies based in Europe soon followed suit and built upon the process by adding a specific land use component: The ATEAM study interpreted the four SRES scenarios into land use change scenarios for Europe to assess potential climate change impacts on land use in Europe (Ewert et al., 2005; Rounsevell et al., 2006a). Similarly, the ACCELERATES study developed SRES-derived scenarios to assess the medium and long-term impact of climate change on agricultural land use in Europe (Abildtrup et al., 2006). One of the only US-based studies incorporating emissions scenarios into land use change scenarios was done for the 31 county New York Metropolitan Region as part of the New York Climate & Health Project in an attempt to study the impacts of climate change, land use changes and air quality changes in the study region (Solecki and Oliveri, 2004).

The existing studies that have downscaled and interpreted the SRES emissions scenarios into land use scenarios have done so through a variety of methods. Some studies were conducted with the researchers using expert input to downscale driving forces and interpret the SRES emissions scenarios into narratives and land use model parameters (Solecki and Oliveri, 2004; Abildtrup et al., 2006; Rounsevell et al., 2006a). Others such as the UKCIP, sought stakeholder participation and collaboration to create narratives that were derived from the SRES emissions scenarios (Berkhout et al., 2002). Once narratives were created, all of the studies used Geographic Information System (GIS) to model the land use scenarios and assess the development or land use change impacts.

These studies then used the results of their urban growth or land use models to conduct integrated climate change impact analyses on a variety of other systems.

This is done by using the SRES emissions scenarios in downscaled GCMs to create outputs (e.g. temperature or precipitation) which can feed into environmental models. Combining the outputs of the urban growth or land use model with the outputs from the environmental model(s) allows for a joint assessment of potential future socio-economic and climate change impacts at the desired sub-global scale. Using the SRES scenarios as a framework provides consistency between the socio-economic and policy forces driving the scenarios in the urban growth or land use change models and the global emissions causing climate change and driving the environmental model(s) (Abildtrup et al., 2006). Examples of these integrated socio-economic and climate change assessments have looked at future impacts on coastal flooding (Hansen, 2010), inland flooding (Feyen et al., 2009), air quality and public health (Solecki and Oliveri, 2004), biodiversity (Rounsevell et al., 2006b), agricultural land use and crop productivity (Ewert et al., 2005) and agricultural prices (Abildtrup et al., 2006).

## 3.0 METHODS AND DATA

### 3.1 Study Area

The Truckee Meadows metropolitan region in northwestern Nevada is an exceptional location to demonstrate the interpretation of the SRES emission scenarios into urban growth scenarios for three main reasons: its fine spatial scale, rapid historical population and urban growth, and dry climate with limited water resources. First, the Truckee Meadows metropolitan region is smaller than most other study areas where this methodology has been applied, so it allows for assessment of its application at a finer spatial scale. The Truckee Meadows region is comprised of a portion of the southern end of Washoe County, Nevada, and is defined in the study as having a total size of 160,451 hectares. The region includes two incorporated cities, Reno and Sparks, as well as several unincorporated and rural communities (Fig. A.1).

Second, like many places in the western United States, this region has experienced rapid population growth as illustrated by this region's population more than doubling from 1979 to 2009. During this thirty year time span, the study region's population grew from 178,757 to 398,300 and averaged an annual growth rate of 2.63% (USCB, 1981; Hardcastle, 2010b). However, during the past few years of the economic recession, the population has slowed and even began to reveal a slight decline (Hardcastle, 2010a). This economic and population slowdown makes the future increasingly uncertain, which makes it even more valuable to consider future scenarios for the region.

Lastly, the region's dry climate makes water a limited and vital resource that must be carefully planned for and managed. The region's primary water source is the Truckee River, which flows in a general northeast direction from its origin at Lake Tahoe and ends in the large terminus Pyramid Lake (Thomas, 2009). Several reservoirs throughout the river's hydrologic basin help manage the river's flow and water delivery timing (USBR, 2011). Ultimately, most of the water flowing through the Truckee River comes from snowpack in the Sierra Nevada Mountains which are located to the immediate west of the Truckee Meadows. With the region's water resources dependent primarily upon snowpack, future climate change is a serious concern that must be incorporated in the present day and future planning of water resources to allow for sufficient water to meet the urban, agricultural, and environmental needs (Lea, 2010).

## 3.2 Scenario Development

Four scenarios were developed for the Truckee Meadows study region to drive an urban growth model and assess impacts on urban land use, housing, water use, and wastewater at two time periods (2029 and 2049). These local scale growth scenarios were based upon the four existing global emissions scenarios from the IPCC SRES (Nakicenovic et al., 2000). The creation of these scenarios was completed through the following three steps:

1. Qualitatively interpreting the four global IPCC SRES scenarios into a framework for creating local urban growth scenarios and adapting this framework to the study region through an understanding of the local driving forces and past and present conditions in the region.
2. Creating the four scenario narratives which describe alternative futures of the region from 2010 through 2049.
3. Quantitatively deriving population projections and urban growth trends from historical data to establish baseline and parameter values for the local urban growth scenarios.

### *3.2.1 Interpretation of SRES Emission Scenarios*

The SRES emission scenario narratives describe four different potential future states of the world caused by varying interactions, policies, and attitudes among the driving forces of population, technology, society, economy, and the environment. These four potential states of the world produce broad and overlapping ranges of global greenhouse gas (GHG) emissions (Nakicenovic et al., 2000). The four scenario narratives are labeled A1, A2, B1, and B2. In terms of general differences between the scenario narratives, the "A" scenarios are more economically-focused, while the "B" scenarios are more environmentally-focused, and the scenarios with a "1" suffix are driven by global decision-making, while the "2" scenarios are driven by regional and local decision-making. One important nuance is that the A1 scenario actually has three subgroups which describe distinct energy uses that create three different emission ranges for the A1 scenario. These three subgroups are the A1FI (fossil fuel intensive), A1T (non-fossil energy sources), and A1B (balanced fuel sources). The A1B scenario was selected for this study and will hereafter be referred to as the A1 scenario for naming consistency with the other three scenarios. This version of the A1 scenario was selected because it was determined to most closely represent a trend scenario when interpreted into a local urban growth scenario.

The four SRES scenario narratives are brief and lack any overt descriptions of policies or patterns of the world's future urban growth. However, the narratives and emissions ranges for the scenarios imply policies and preferences which would influence urban growth. Using a matrix approach as a framework (Carter et al., 2004; Abildtrup et al., 2006), the driving forces considered to be the most directly influential on urban growth were identified for each of the four SRES scenarios. These driving forces include Population, Social Emphasis (economy or environment), Decision-making Structure, rate of Economic Development, and the level of the GHG Emissions range (Table 1). The next step was to interpret these global driving forces from the SRES down to driving forces affecting growth at the local scale. The goal in doing this interpretation was to keep true to the future states of the world presented in the SRES scenarios while adapting these scenarios to the historical context, existing conditions, political structure, and present policies of the study region.

This local scale adaptation was aided through two steps which provided better understanding of the local driving forces and key uncertainties in the region. First, actors (i.e. key figures) from local governmental planning agencies in the Truckee Meadows were informally consulted through one-on-one meetings or phone calls. The purpose of these discussions was to uncover the role of the actor’s agency in the region’s planning process and his or her perspectives on the recent history, actors, trends, policies, and uncertainties affecting urban growth in the Truckee Meadows. These discussions provided an opportunity to develop a better understanding of the driving forces affecting urban growth in the region from the local practitioner’s point of view.

Second, research was conducted to gather and analyze the published policies and regulations from local, state, and federal agencies which most directly influence the driving forces affecting urban growth in the Truckee Meadows. Since there is a seemingly unlimited amount of policies that could potentially affect the many aspects of urban growth, special attention was paid to several long-range planning documents from local governmental or public planning, transportation, and water agencies (City of Reno, 2011; City of Sparks, 2007; TMRPA, 2007; TMWA, 2010; RTC, 2008). These documents provided an opportunity to further understand the initiatives, policies, and issues that these agencies are focusing on. In conjunction with the information gained from discussions with the regional actors, these documents and policies offered insight into the range of driving forces affecting urban growth in the Truckee Meadows region.

With this understanding of the local conditions and forces affecting urban growth, the matrix was completed (Table 1). The bottom section of the matrix shows the key driving forces affecting urban growth in the Truckee Meadows and each category's status under the four scenarios. Many of the driving forces categories were the same for the SRES emissions scenarios and the Truckee Meadows urban growth scenarios. This included the categories of Population, Social Emphasis, Decision-making Structure, and Economic Development rate. For these categories, the status under the scenarios was generally passed directly down from the global to the local level when applicable. For example, under the Population category, the high population in the A2 SRES emissions scenario was interpreted to also mean a high population in the A2 urban growth scenario in the Truckee Meadows. There were several exceptions to this direct pass-down of category values. These exceptions were based upon using knowledge of the local region to adapt the global futures of the SRES to local futures for the Truckee Meadows. For example, the A1B SRES emissions scenario was interpreted to be the scenario most closely relating to the global trend. Interpreting this scenario at the local level to resemble the trend meant using a medium rather than a low population projection.

Some driving forces affecting urban growth in the Truckee Meadows were not overtly accounted for in the SRES scenarios; however, these driving forces could be interpreted from the SRES categories. For example, the Growth Patterns and Transport categories were identified as key forces affecting urban growth in the Truckee Meadows, but these forces were not explicitly addressed at the global scale under the SRES. Instead, the Social Emphasis and GHG Emissions driving forces discussed in the SRES were interpreted to influence urban growth patterns and transport decisions. At the local level this meant that scenarios with a Social Emphasis valuing the environment over economy were interpreted to mean that urban policies would be sought to promote more compact development patterns, while scenarios emphasizing economy over the environment would have urban policies allowing more diffuse development (Reginster and Rounsevell, 2006). The level of GHG Emissions for the SRES scenarios was interpreted by considering how emissions ranges might be reflective of Transport decisions at the local level. For example, high global emissions would mean a combination of local preferences and urban policies such as strong dependence on cars and future development of major road infrastructure (Solecki and Oliveri, 2004). These policies would in turn affect spatial patterns of growth by encouraging and enabling more diffuse development (i.e. urban sprawl). The completed matrix illustrates the complete interpretation of the scenarios from the global to the local scale and highlights some key elements of the four local urban growth scenarios. Additionally, this matrix provided the foundation for creating the four scenario narratives.

**Table 1: Scenario interpretation framework from SRES (Nakicenovic et al., 2000) to Truckee Meadows.**

| Driving Forces | A1B | A2 | B1 | B2 |
|---|---|---|---|---|
| | **IPCC SRES Scenarios** | | | |
| *Population* | Low | High | Low | Medium |
| *Social Emphasis* | Economic Growth | Economic Growth | Environmental Sustainability | Environmental Sustainability |
| *Decision-making structure* | Global | Regional | Global | Regional |
| *Economic Development* | High - globally | Wide ranging - dependent on region | Medium - globally; shift to service and information | Medium - globally |
| *GHG Emissions* | Trend | Higher than trend | Much lower than trend | Slightly lower than trend |
| | **Truckee Meadows Urban Growth Scenarios** | | | |
| *Population* | Medium | High | Low | Medium |
| *Social Emphasis* | Economic Growth | Economic Growth | Environmental Sustainability | Environmental Sustainability |
| *Decision-making structure* | Federal | State and Local | Federal | State and Local |
| *Economic Development* | Medium: Introduction of some new industries | High: Strengthening of past industries and introduction of some new industries | Low: Inability to strengthen old industries or introduce new industries | Medium: Introduction of several new industries |
| *Growth Patterns:* | | | | |
| *Infill Rate* | Low | Low | Med | High |
| *Density Change* | Historic avg. | Slight increase from historic avg. | Moderate decrease from historic avg. | Significant decrease from historic avg. |
| *Spatial pattern* | Moderately Diffuse | Highly Diffuse | Moderately Compact | Highly Compact |
| *Transport:* | Utilization of existing major road network, some expansion of minor road network. No expansion of public transportation. | Significant expansion of major and minor road networks. No expansion of public transportation. | No expansion of major or minor roads networks. Some expansion of public transportation. | Minimal expansion of major and minor roads to reduce pollution. Significant expansion of public transportation. |

### *3.2.2 Scenario Narratives*

The scenario narratives were constructed to utilize the existing organizations and political structure in the Truckee Meadows, as well as the SRES-derived framework, local driving forces, and the region's quantitative land use and population values. The goal for the narratives was to present a plausible pathway for change in the Truckee Meadows under each of the four scenarios, and allude to the patterns and assumptions utilized when the scenarios were converted into parameters used for the urban growth model. It is important to remember that these scenarios only offer a range of potential future states of the region, not predictions or necessarily even preferred futures.

While the four scenarios are unique, they all share common attributes. First, each scenario used the same basic exclusions for designating where future urban growth cannot occur (Table 2). These included Geographic Information System (GIS) layers such as existing urban land, water bodies, protected open space, and slopes greater than 20%. However, the individual scenarios also added additional GIS layers as exclusions depending on the focus of the scenario. The GIS layers were used to determine the land that would be available for future development under the four scenarios (Fig. A.2). The variation between exclusions shows how the more environmentally-focused scenarios (B1 and B2) constrained the region's buildable lands and how the more economically-focused scenarios (A1 and A2) opened additional lands for development. The primary differences between the buildable lands for the scenarios are that the A1 scenario opened up a large contiguous area of university-owned agricultural lands in the east-central region for future development. The A2 also made available these agricultural lands, and additionally allowed wetland regions to be developed and what are currently public lands in the north-central and east-central parts of the region. The north-central public lands were only allowed to be developed after the rest of the region's buildable area was exhausted by 2039. Policies in the narrative explain this land decision, which was based upon precedent from southern Nevada (USBLM, 2011). The A2 growth scenario was interpreted from the SRES scenarios to have the highest population, economic growth rate, and the lowest influence from environmental policies, which were the reasons for having this scenario build on sensitive lands (wetlands) and what are currently public lands.

**Table 2: Exclusions used in the growth model for the four scenarios. These were used to create GIS layers designating which land would be available for future development (see Fig. A.4-A.X).**

| | **A1 - Diffuse Arterial** | **A2 - Diffuse Perimeter** | **B1 - Moderate Compact** | **B2 - TOD Compact** |
|---|---|---|---|---|
| **Exclusions** | Existing urban | Existing urban | Existing urban | Existing urban |
| | Roads | Roads | Roads | Roads |
| | Railroad tracks | Railroad tracks | Railroad tracks | Railroad tracks |
| | Slopes > 20% | Slopes > 20% | Slopes > 20% | Slopes > 20% |
| | Water bodies | Water bodies | Water bodies | Water bodies |
| | Open space - existing parks | Open space - existing parks | Open space - existing parks | Open space - existing parks |
| | Protected federal, state, county, &local lands | Protected federal, state, county, &local lands | Protected federal, state, county, &local lands | Protected federal, state, county, &local lands |
| | Non-protected state lands | Non-protected state lands | Non-protected state lands | Non-protected state lands |
| | Non-protected federal lands | | Non-protected federal lands | Non-protected federal lands |
| | Wetlands | | Wetlands | Wetlands |
| | | | UNR farm | UNR farm |

Second, all of the scenarios used a GIS layer of eight sub-regions as the basis for the zones where urban growth would be allocated into the future (Fig. A.3). Seven of the sub-regions are used as planning regions by local government agencies

(TMRPA, 2007; TMWA, 2010; NNWPC, 2011). The eighth sub-region (Rural) refers to all of the remaining area in the Truckee Meadows not covered by the seven planning sub-regions. Note that the sub-region geographically representing the west and central portions of Reno is also called Truckee Meadows, which is different than the whole study area that has the same name. Each of the scenarios also incorporated additional zones to allow for adjusting the finer spatial allocation of the urban growth to correspond to the details of the scenario (Table 3, Fig. A.4-A.7). These additional zones included large identified master planned development (MPD) sites, which are discussed in greater detail in the section 3.3.2. One special note is that the B2 scenario actually used two different zone layers. The same zone layer as A1 was used for years 2010-2019, and for 2020-2049 the zone layer shown in Fig. A.7 was used to allow a change in the spatial pattern of growth in response to a significant compact development policy shift in that scenario. Finally, the last commonality between the scenarios is that they all run for the span of 40 years from 2010 to 2049; utilizing 2009 as the baseline year.

**Table 3 Complete listing of the sub-regions, master planned developments (MPD), and other scenario-specific zones used in the growth model for the four scenarios. The zone numbers are referenced in Fig. A.X-A.X.**

| Zone # | A1 - Diffuse Arterial | A2 - Diffuse Perimeter | B1 - Moderate Compact | B2 - TOD Compact |
|---|---|---|---|---|
| **1** | Rural | Rural | Rural | Rural |
| **2** | Truckee Meadows (Reno) | Truckee Meadows (Reno) | Truckee Meadows (Reno) | Truckee Meadows (Reno) |
| **3** | Sun Valley | Sun Valley | Sun Valley | Sun Valley |
| **4** | So. Truckee Meadows (STM) | So. Truckee Meadows (STM) | So. Truckee Meadows (STM) | So. Truckee Meadows (STM) |
| **5** | Stead/Lemmon | Stead/Lemmon | Stead/Lemmon | Stead/Lemmon |
| **6** | Sparks | Sparks | Sparks | Sparks |
| **7** | Spanish Springs | Spanish Springs | Spanish Springs | Spanish Springs |
| **8** | Cold Springs | Cold Springs | Cold Springs | Cold Springs |
| **9** | Truckee Meadows MPD | Truckee Meadows MPD | Truckee Meadows MPD | Truckee Meadows MPD |
| **10** | So. Truckee Meadows MPD | So. Truckee Meadows MPD | So. Truckee Meadows MPD | So. Truckee Meadows MPD |
| **11** | Stead/Lemmon MPD | Stead/Lemmon MPD | Stead/Lemmon MPD | Stead/Lemmon MPD |

| | | | | |
|---|---|---|---|---|
| **12** | Sparks MPD | Sparks MPD | Sparks MPD | Sparks MPD |
| **13** | Spanish Springs MPD | Spanish Springs MPD | Spanish Springs MPD | Spanish Springs MPD |
| **14** | Cold Springs MPD | Cold Springs MPD | Cold Springs MPD | Cold Springs MPD |
| **15** | | Sun Valley MPD | Urban Core | Redevelopment Center |
| **16** | | Winnemucca Ranch MPD | | South Virginia Corridor |
| **17** | | BLM E | | TOD Corridor |
| **18** | | BLM N | | Urban Core |
| **19** | | | | 2mi Buffer around Urban Core |
| **20** | | | | 4mi Buffer around Urban Core |

The four scenario narratives are presented below along with spatial representations of the modeled future urban growth under the scenarios (Fig. A.8). In order to more easily distinguish the scenarios, they have been given a descriptive name in addition to keeping the alpha-numeric names from the SRES scenarios. Table 4 displays the Urban ha/person and Population values for each of the scenarios at 2029 and 2049, along with a tabular representation of the region's new urban growth allocation.

**Table 4: Urban hectares/person, population, and spatial allocation of future urban growth into the sub-regions at 2029 and 2049 for the four scenarios.**

| | **A1 - Diffuse Arterial** | | **A2 - Diffuse Perimeter** | | **B1 - Moderate Compact** | | **B2 - TOD Compact** | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **2029** | **2049** | **2029** | **2049** | **2029** | **2049** | **2029** | **2049** |
| **Urban ha/person** | 0.079 | | 0.093 | | 0.074 | | 0.053 | |
| **Population** | 522,068 | 589,070 | 490,316 | 717,584 | 391,476 | 430,993 | 522,068 | 589,070 |
| **Sub-region** | Allocation of New Urban Growth | | | | | | | |
| RURAL | 6.3% | 6.2% | 8.0% | 35.3% | 7.1% | 1.8% | 5.1% | 4.2% |
| TRUCKEE MEADOWS | 28.2% | 20.7% | 26.3% | 11.2% | 37.4% | 40.8% | 30.7% | 20.7% |
| SUN VALLEY | 2.9% | 1.9% | 3.2% | 1.0% | 3.4% | 3.3% | 4.1% | 2.8% |
| STM | 18.6% | 21.1% | 21.0% | 14.5% | 15.1% | 18.8% | 22.5% | 27.6% |
| STEAD / LEMMON | 10.8% | 15.7% | 9.4% | 8.4% | 11.6% | 4.2% | 13.2% | 22.8% |
| SPARKS | 16.2% | 14.3% | 18.3% | 16.3% | 17.6% | 24.4% | 17.4% | 13.2% |
| SPANISH SPRINGS | 10.1% | 7.2% | 10.4% | 3.7% | 5.0% | 5.4% | 4.6% | 4.3% |
| COLD SPRINGS | 6.9% | 12.9% | 3.4% | 9.6% | 2.8% | 1.3% | 2.3% | 4.3% |
| | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** |

### 3.2.2.1 Scenario A1 – Diffuse Arterial

A growing nationwide demand for renewable energy helps garner widespread support for the drafting and adoption of the 2015 Nevada Clean Energy Act. The act updates the state's Renewable Portfolio Standard by creating a 30-40-50 rule, which mandates that energy providers in the state procure up to 30% of their energy from eligible renewable resources by 2030, 40% by 2040, and 50% by 2050. The act coincides with a revamping of state and federal programs for incentivizing both large-scale and small-scale renewable energy growth. Tax credits and consumer rebates, combined with climbing prices for most nonrenewable energy sources, make it cost-effective and attractive for an unprecedented number of individual property owners and companies to implement renewable energy generation technologies on homes, businesses, and public and private land. This creates a steep rise in the investments, technological advancements, and jobs in the renewable energy sector. Nevada's renewable energy potential, combined with recognition for several large and successful renewable energy projects, helps the state become a globally renowned leader in renewable energy. While this renewal energy boom helps pull Nevada out of the national recession, it's not before major budget shortfalls drive support for the region's university to sell the university-owned agricultural lands in the east-central portion of the Truckee Meadows to private developers.

The local governments in the Truckee Meadows are able to attract new businesses and jobs from this growing renewable energy sector coming into the state. Population growth maintains a steady rate as additional skilled workers move into the region. With support from politicians and constituents concerned about unconstrained sprawl, local planning agencies are able to encourage growth into the seven designated planning sub-regions through steep impact fees for growth occurring outside these bounds. Average residential densities remain relatively similar to historic densities, but the economic prosperity and relatively affordable land prices contribute to a continuous increase of the population demanding low-density single-family housing over alternatives. New development continues in line with the historic pattern, contributing to the largest growth in the northwest, northeast, and south central portions of the region. The only significant change in the growth in the region is the addition of several large master planned communities and commercial areas in the east-central part of the region on the former university-owned agricultural lands.

#### 3.2.2.2 Scenario A2 – Diffuse Perimeter

After several years of stagnant economic growth, the governments in the Truckee Meadows make a concerted effort to grow and expand the existing economic bases in tourism, business and financial services, logistics and transportation. Aggressive tax incentive policies create a business friendly environment to attract new and relocating businesses and development to the region. The Truckee Meadows region especially has great success in attracting companies leaving California to avoid the regulations brought about by the California Global Warming Solutions Act of 2006 and the more stringent revision of

2024. The large amount of new growth reestablishes the construction sector as an important part of the region's economy.

The region's population grows at a high rate with a steady influx of workers attracted by the growing jobs and retirees drawn by the relatively affordable housing and recreational opportunities. In order to help pull the region out of the recession, new residential and commercial growth is aided and encouraged through the relaxation of zoning and density regulations. Once out of the recession, the prosperity from the booming growth weakens the local planning agencies' authority to enforce regional planning efforts. The recession also leads to the auctioning of the university-owned agricultural lands in the east-central part of the region to private developers. This is done to help fix the state's higher education budget deficits without cutting more university programs and services.

Densities for residential and commercial buildings slightly decrease from the historical average. The region's increasing average household income level leads to consistent growing preference for single-family housing. With pressure from the increasing population in the region and an exhaustion of available developable private lands, the Northern Nevada Public Land Management Act is passed to allow the sale of portions of the public land in the north central portions of the region. Growth pushes outward in all directions, with the northern area receiving the most growth due to the opening of several new satellite communities on the large developable sections of private and formerly public land.

#### 3.2.2.3 B1 – Moderate Compact

Despite efforts by federal, state, and local authorities across the nation to revive the economy, it takes several years before the U.S. economy begins a slow rebound. The effects of the recession linger on even longer in Nevada, where the historically strong sectors of tourism, gaming, and construction struggle to rebound. With the state government and local governments in the Truckee Meadows suffering from declining tax revenue sources, cuts to infrastructure, services, and education contribute to an unfavorable climate for any new economic growth in the region. After two decades of population levels below the historic high in 2008, the region finally sees a slight increase in the population in 2033 after the expansion of several large distribution and customer service centers which help bring in a modest amount of new jobs. The businesses are attracted by the region's rail and interstate access, inexpensive land, and favorable tax structure.

With population growth and tax revenue now increasing at a very low rate, local governments adopt stringent regulations affecting growth in order to make sure infrastructure and services costs are kept to a minimum. These policies are strengthened by local support calling for the protection of sensitive lands and reduction of diffuse growth in the region. A flat household income rate prevents an increase in the demand for single-family housing relative to multi-family housing options. Average densities increase slightly from historic averages as a restructured property tax system encourages the majority of growth to occur as infill projects within the existing urban cores in Reno and Sparks.

#### 3.2.2.4 B2 – TOD Compact

Continuous instability in the middle-east sends oil prices climbing to new record highs and helps bolster support for a comprehensive national approach to reducing oil dependency at the household level.  Combined with growing concern for reducing traffic pollution and improving air quality, the Federal Transit Administration significantly increases funding to support transit projects which meet the several criteria including reducing transport pollution, improving development opportunities, significantly reducing vehicle miles traveled, and making communities better places to live.  In the Truckee Meadows, growing concern about congestion and air pollution in the region bolsters support for an improved public transportation system.  Local transportation and land use planning agencies work with businesses and community groups to design and propose a streetcar project along the Virginia St. corridor and integrated bus rapid transit network.  The region secures federal funding and acquires the remainder of the necessary funds through special taxes and assessments from businesses who will benefit directly from the transit system.  The local planning agencies receive priority funding due to the approval by the International Olympic Committee for the Reno-Tahoe area to host the 2022 Olympics.

The construction of the streetcar line and network of bus rapid transit routes are implemented along the region's transit oriented development corridors per the 2007 regional plan.  These transit corridors provide a catalyst for significant high density residential and commercial development within the immediate proximity of the transit lines.  The transit system upgrades are coordinated with the new facilities and infrastructure required for the Olympics so the athletes, workers, and visitors can move easily between the various event sites, hotels, airport, and other attractions in the region. The region’s tourism sees steady growth following the global recognition as a successful Olympics host and the tourism-friendly transit connecting the region to local attractions and the new transit system around Lake Tahoe. Additionally, the region attracts a growing number of companies in the software, pharmaceuticals, life sciences, financial services, and renewable energy technology sectors. The job growth, combined with an increase in the number of retirees moving to the area, leads to steady population growth in the Truckee Meadows.

With the transit system continuing to act as an attractor for new high density growth, average residential and commercial densities increase significantly as growth clusters around the transit corridors. Additionally, a region-wide implementation of high impact fees for outlying development is used to deter sprawl while incentives for infill and high density development in the urban core are coordinated through a strong regional redevelopment plan. Demand for these types of development grows as a larger number of families, working professionals, students, and retirees seek close proximity to the transit network and an improved urban bike and pedestrian lifestyle in the urban core of the region. As the urban core fills up with new development, some medium density growth occurs in the north central and south central portions of the region near the ends of the transit system.

### *3.2.3 Population Projections and Urban Growth Trends*

The scenario framework for the Truckee Meadows indicated the need for a range of high, medium, and low population projections. An analysis of the available projections for the Truckee Meadows was conducted, and three out of the several projections available were selected. The low and high projections were both selected from the State Demographer's recent projections (Hardcastle, 2010a). The medium projection was selected from a projection completed by a local water agency (TMWA, 2010). The criteria for selecting the projections were based upon two factors. First, three distinct population projections that offered a range of populations at 2049 were sought in order to provide the low, medium, and high projections required for the scenarios. Second, with the economic recession having significant impacts on the population and growth of the Truckee Meadows region in the past few years, preference was given for projections which utilized the most current data and reflected this current population slowdown. With the three population projections selected, several modifications were made in order to prepare them for use in the scenarios.

First, an annual historic population time series from 1979-2009 was created using the state demographer's historic estimates for 1986-2009 (Hardcastle, 2010b) and the U.S. Census estimate for 1980 (Forstall, 1995), and interpolating population estimates for the missing years of 1979 and 1981-1985. However, these annual estimates show population for Washoe County, and not population estimates for the Truckee Meadows region, which is an area residing within Washoe County. In order to determine the population estimates for the Truckee Meadows region, spatial and tabular block group data (USCB, 2001) for Washoe County were overlaid with the Truckee Meadows region to determine the percentage (95.6%) of the county population residing within the Truckee Meadows region. Table 5 shows the Washoe County Population, Truckee Meadows population, growth rate, and people per household (USCB, 1981; 1991; 2011).

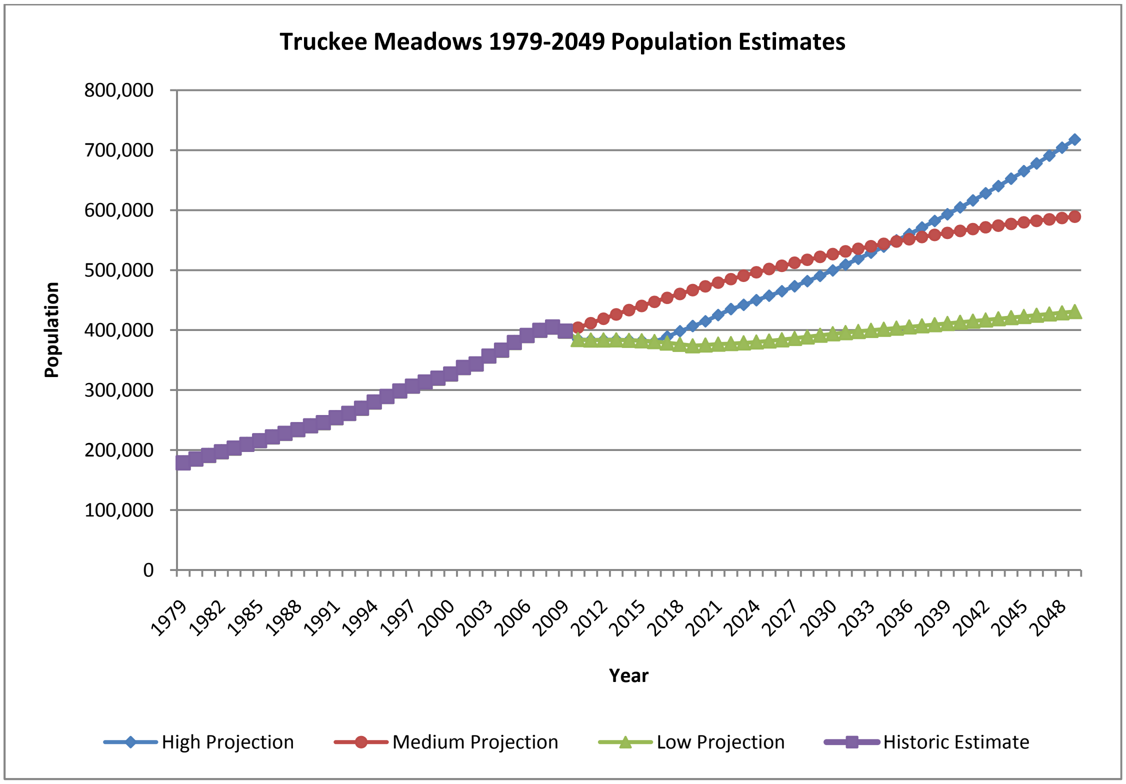
**Table 5: Historic population data for Washoe County and Truckee Meadows**

| Year | Washoe County Population | Truckee Meadows Population | TM Annual Population Change | Annual Population Growth Rate | People Per Household |
|---|---|---|---|---|---|
| **1979** | 186,984 | 178,757 | | | 2.46 |
| **1980** | 193,623 | 185,104 | 6,347 | 3.43% | 2.46 |
| **1981** | 199,876 | 191,081 | 5,978 | 3.13% | 2.46 |
| **1982** | 206,322 | 197,244 | 6,162 | 3.12% | 2.45 |
| **1983** | 212,768 | 203,406 | 6,162 | 3.03% | 2.45 |
| **1984** | 219,214 | 209,569 | 6,162 | 2.94% | 2.45 |
| **1985** | 225,660 | 215,731 | 6,162 | 2.86% | 2.44 |
| **1986** | 232,270 | 222,050 | 6,319 | 2.85% | 2.44 |
| **1987** | 238,360 | 227,872 | 5,822 | 2.55% | 2.44 |
| **1988** | 244,890 | 234,115 | 6,243 | 2.67% | 2.43 |
| **1989** | 251,580 | 240,510 | 6,396 | 2.66% | 2.43 |
| **1990** | 257,120 | 245,807 | 5,296 | 2.15% | 2.43 |
| **1991** | 265,762 | 254,068 | 8,262 | 3.25% | 2.44 |
| **1992** | 273,178 | 261,158 | 7,090 | 2.71% | 2.45 |
| **1993** | 282,214 | 269,797 | 8,638 | 3.20% | 2.46 |
| **1994** | 293,141 | 280,243 | 10,446 | 3.73% | 2.47 |
| **1995** | 302,748 | 289,427 | 9,184 | 3.17% | 2.48 |
| **1996** | 312,366 | 298,622 | 9,195 | 3.08% | 2.49 |
| **1997** | 320,828 | 306,712 | 8,090 | 2.64% | 2.50 |
| **1998** | 327,899 | 313,471 | 6,760 | 2.16% | 2.51 |
| **1999** | 334,601 | 319,879 | 6,407 | 2.00% | 2.52 |
| **2000** | 341,935 | 326,890 | 7,011 | 2.14% | 2.53 |
| **2001** | 353,271 | 337,727 | 10,837 | 3.21% | 2.53 |
| **2002** | 359,423 | 343,608 | 5,881 | 1.71% | 2.53 |
| **2003** | 373,233 | 356,811 | 13,202 | 3.70% | 2.53 |
| **2004** | 383,453 | 366,581 | 9,770 | 2.67% | 2.53 |
| **2005** | 396,844 | 379,383 | 12,802 | 3.37% | 2.53 |
| **2006** | 409,085 | 391,085 | 11,702 | 2.99% | 2.53 |

| | | | | | |
|---|---|---|---|---|---|
| **2007** | 418,061 | 399,666 | 8,581 | 2.15% | 2.53 |
| **2008** | 423,833 | 405,184 | 5,518 | 1.36% | 2.53 |
| **2009** | 416,632 | 398,300 | -6,884 | -1.73% | 2.53 |

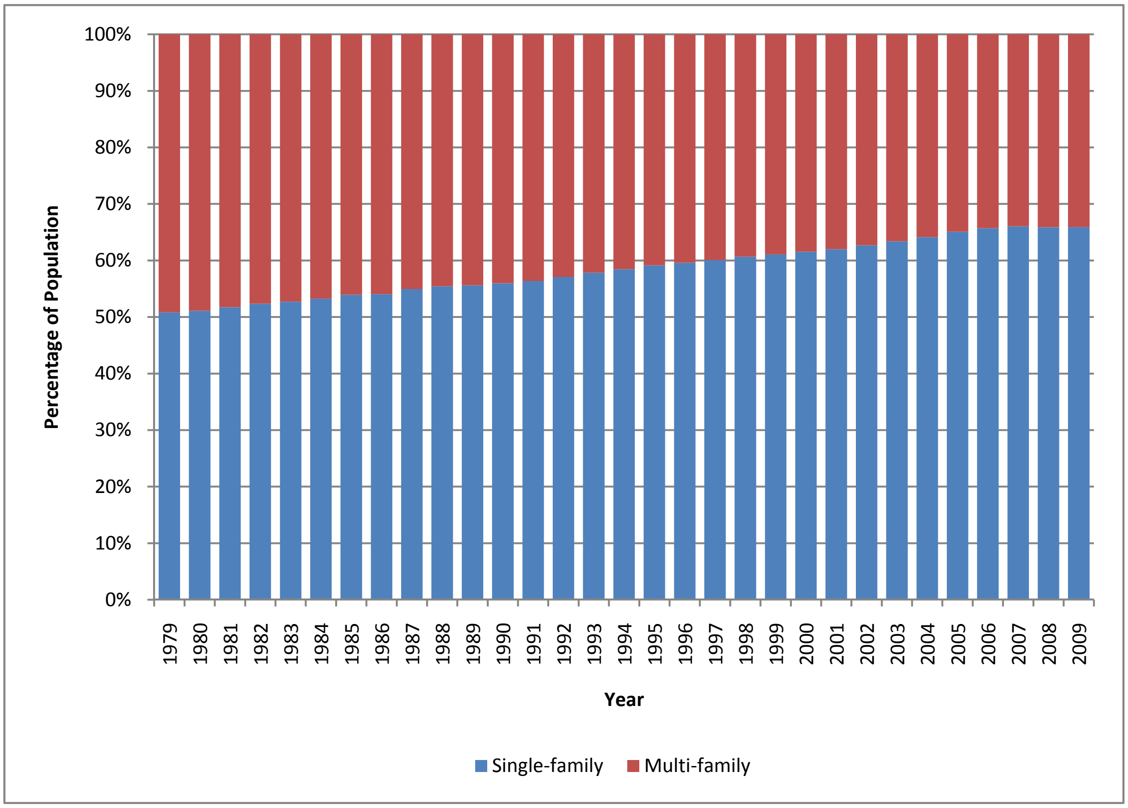
Next, the 2009 population total of 398,300 from the Truckee Meadows historic estimates was used as the base population, and all three future projections were calibrated to this start population. This calibration was done by using the annual growth rates for 2010-2049 from the three projections and applying them to the 2009 base population to come up with a new annual future population estimate for 2010-2049. Since the high and low populations only had projections from 2010-2030, the years 2031-2049 needed to be estimated. For the high projection this was done by taking the average of the annual growth rate for years 2017-2030 and applying this as the growth rate for years 2031-2049 to calculate a population estimate. For the low projection this was done by taking the average of the annual growth rate for years 2020-2030 and applying this as the growth rate for years 2031-2049 to calculate a population estimate. Those years were selected to determine the growth rate from 2031-2049 because they were the first years in those two projections where annual population growth became continuously positive. Fig. 1 displays the historic population estimate along with the three projections that were used in the future scenarios.

**Fig. 1: Truckee Meadows historic population estimates 1979-2009 and future projections 2010-2049.**



Parcel-level land use and building data (TMWA, 2010) was used to obtain historic averages and baseline data for the urban growth scenarios regarding the land use, roads, housing, and spatial allocation of the population into sub-regions within the Truckee Meadows region. Several intermediate steps were needed to create a comprehensive parcel-level database which contained detailed records on land use and buildings in the region. First, the parcels database was simplified by removing unnecessary fields and duplicate parcel records. Then a field was added to reclassify the land use for each record into one of six general categories: agriculture, park, single family, multi-family, commercial, and vacant. The Assessor's buildings database was then simplified by removing unnecessary fields, summing the total number of buildings and units for records for each parcel, and removing all duplicate

**Fig. 2: Historic allocation of population between single-family and multi-family housing (1979-2009).**



records for each parcel except for the record containing the earliest built year. The purpose of keeping only the record with the earliest built year was to have a way of identifying at what year each parcel was urbanized. The building dataset was then joined to the parcel dataset using the unique parcel numbers. This master dataset was then joined to the spatial file containing the parcels for all of Washoe County to create a GIS layer to be used for spatial analysis of historic growth.

The GIS layer was used to analyze land use and building totals annually from 1979-2009 to identify trends and averages to help establish quantitative baseline values. Key metrics assessed at the annual level included: area for each of the land use classes, road area, single-family and multi-family units, and commercial buildings. A linear regression established that the areas of the urban land use classes were all positively correlated with population, so coefficients were derived to determine the hectares per person for each of the six land use classes. The single-family and multi-family unit data was used to establish the historical average and trend of population allocation between the two housing types (Fig. 2). The values for the urban area per person in hectares and single-family vs. multi-family allocation percentage for the years 1979-2009 are illustrated in Table 6 along with these values for the four future scenarios. These are used to calculate a final weighted average hectares person, which simply means that for every person gained in the Truckee Meadows from 1979-2009, an average of 0.077 hectares of urban area was added. The historic values were used in the calibration of the growth model which will be described in more detail in section 3.3.2. The values for the four future scenarios are a quantitative representation the different policies, preferences, and assumptions affecting urban land uses and were used as parameters in the growth model to provide the future spatial representations.

**Table 6: Historic and scenario values for the urban land uses, allocation of population between single family and multi-family, and a weighted urban land use per person value.**

| | Urban Land Use Class | | | | | Allocation of Population | | Urban per Person |
|---|---|---|---|---|---|---|---|---|
| | **Single-family** | **Multi-family** | **Commercial** | **Park (urban)** | **Road** | **Single-family** | **Multi-family** | **Weighted Average** |
| **1979-2009** | 0.057 | 0.008 | 0.022 | 0.002 | 0.016 | 58.54% | 41.46% | **0.077** |
| **A1** | 0.055 | 0.008 | 0.022 | 0.002 | 0.015 | 71.00% | 29.00% | **0.079** |
| **A2** | 0.063 | 0.009 | 0.023 | 0.002 | 0.017 | 77.55% | 22.45% | **0.093** |
| **B1** | 0.054 | 0.008 | 0.020 | 0.002 | 0.014 | 65.90% | 34.10% | **0.074** |
| **B2** | 0.039 | 0.006 | 0.016 | 0.002 | 0.011 | 55.00% | 45.00% | **0.053** |

Values in ha/person

## 3.3 Growth Model

### *3.3.1 Model Overview*

The modeled growth maps show a spatial representation of potential future urban growth under the four scenarios (Fig. A.8). These representations of growth were developed through the use of a deterministic cellular automata (CA) urban growth model which was used in previously published studies by Steinitz et al. (2003) and Kahyaoglu-Koracin et al. (2009). CA models have been used in the simulation of urban growth for a number of years (Barredo et al., 2003; Sante et al., 2010) and can vary greatly in the complexity of the required inputs and options available as model outputs (Sante et al., 2010).

The growth model used for this study was selected based upon two factors. First, the model's straightforward interface allows it to be accessible to a wider audience and easily modified to be run with different parameters in place. Second, the model output (i.e. cells representing urban growth) is simple yet sufficient enough to conduct an impact assessment on the region's urban land uses, housing, water use, and wastewater. While a more complex model could show urban land uses at the parcel scale, this model is able to show urban growth at a high resolution, and the quantities of new urban land uses, and housing can be calculated at the sub-region level, which was adequate for this impact analysis.

The model used in this study required three key GIS input layers each utilizing a 20m x 20m cell size: buildable land, existing urban land, and user-specified zones layers which divide the Truckee Meadows into sub-regions for the allocation of future growth. The 20m x 20m cell size was selected because it nested well within the average size of residential lots and because it could capture a greater amount of the region’s many small undeveloped parcels scattered throughout urbanized areas, which are important potential development sites for the scenarios which focus on urban infilling.

The buildable layer instructs the model which land is available for future urban development. As discussed in section 3.2.2, the buildable layers in the study varied to allow for differences between which lands would be protected under each scenario. The urban layer represents the urban footprint of the region at the given time step, and the same urban extent from 2009 was used at the start of the modeling run for each of the four scenarios. The model uses this urban layer to create a Euclidean distance layer which assigns a value for each buildable cell depending on its proximity to urban cells. This Euclidean distance layer is used by the model to prioritize where to put future growth. The cells with the lowest Euclidean distance value (those cells closest to existing urban cells) have a higher attractiveness for urbanization than those with higher Euclidean distance values (those cells furthest from existing urban cells). The zones layer can represent any number of geographical sub-regions that the model user wants to define, and are used to spatially allocate the growth. In this study, the zones layer used the same eight sub-regions as a base and joined this with the region’s identified master planned developments. Additional zones were added to meet the policies of the individual scenarios (Table 3, Fig. A.4-A.7).

The model also has several quantitative parameters that were adjusted based upon the scenario. These parameters include the start population, growth rate for the time step, urban hectares per person, and the percentage allocation of the growth for each of the individual region's zones. The parameters quantitatively represented the different policies, preferences, and assumptions affecting urban land uses in the region as described in the scenario narratives.

### *3.3.2 Model Calibration*

To know how well the model could produce future urban growth outputs for the Truckee Meadows the model was first calibrated using historic data (Barredo et al., 2003; Solecki and Oliveri, 2004; Hansen, 2010). Utilizing the historic data, the model was run several times to try to emulate the observed growth that occurred from 1980-2009 (Fig. A.9). During that thirty year time period, the region experienced an astonishing amount of urban growth, expanding from 10,819 hectares in 1979 to 27,975 hectares in 2009, a 158.6% increase. These values exclude the urban area for roads since historical data on this urban land use was not available. The calibration was focused solely on comparing the modeled and actual urban growth that occurred from 1980-2009, so the urbanized lands pre-1980 were not included in the quantitative comparison between how well modeled and actual urban growth agreed because this would have led to overly-inflated values. Additionally, while data was available at annual time steps from 1980-2009, the calibration was more focused on emulating the growth as it was represented at the end of the 30 year time period, rather than considering the calibration accuracy at smaller time steps.

When using the growth model to model this thirty year period of historic growth, initial calibrations had a cell overlap rate around 53%. The cell overlap rate value reflects the percentage of times that the modeled cells spatially intersected the actual cells urbanized from 1980-2009. Having a high percentage of exact matching cells in calibrating a CA model for a regional scale assessment is not very probable or even necessary (Jantz and Goetz, 2005; Hansen, 2010). Additionally, higher resolution models tend to have lower cell overlap rates (Jantz and Goetz, 2005). However, comparing the modeled output to the actual growth it was clear that the model had not sufficiently captured the region's spatial pattern of urban growth. Using the annual growth data, it was determined that during 1980-2009, large master planned developments that were disconnected from existing urban areas became a dominant pattern for growth in the region. After including these large outlying parcels of land into the zone layer, the cell overlap rate improved to 57%, and more importantly, the pattern of modeled growth looked much closer the observed growth.

To quantitatively test if the model was now calibrated to sufficiently capture the region's growth pattern a method similar to that used by Hansen (2010) was employed. In this process the cells for the modeled and actual growth layers for 1980-2009 were expanded by one cell in all directions and then their overlap rate was measured. This process showed how often the modeled growth agreed with the actual growth within one cell (20m) in all directions. The overlap rate with this one cell expansion increased to 66%. When the cells were expanded by three cells for the modeled and actual layers the overlap rate increased to 75%. Even though it was not apparent from the initial cell-to-cell overlap comparison test, the pattern agreement tests helped confirm that the model was calibrated to the region's observed growth pattern. With the model successfully calibrated to the region, the future scenarios were run per the parameters and inputs as described in section 3.2.3.

## 3.4 Water and Wastewater Estimates

**Table 7: Water use coefficients (NNWPC, 2011).**

| Water Service Type | Use Coefficients |
|---|---|
| Single-family on municipal | 0.51 |
| Single-family on well | 1.00 |
| Multi-family | 1.33 |
| Commercial | 2.17 |
| Metered Irrigation Service | 3.12 |

Units in AF/YR

With spatial outputs of future urban growth obtained from the growth modeling process, the total number of residential units and commercial buildings was calculated for the scenarios at 2029 and 2049. Based upon historic ratios (TMWA, 2010), the total number of single-family units was then broken into two categories: units on wells and units on municipal water. All of the residential units and commercial buildings were spatially disaggregated to the sub-regions based upon each region's growth rate over the model run. With a spatial distribution of the region's future housing and commercial buildings for each of the scenarios at 2029 and 2049, an analysis of future water use and wastewater outputs was calculated.

To calculate future water use and wastewater outputs a method was employed that was utilized by the Northern Nevada Water Planning Commission (NNWPC, 2011) and based upon models constructed by the Truckee Meadows Water Authority (TMWA, 2010). First the units and buildings were converted to water services for five categories: single-family on municipal water, single-family on well water, multi-family, commercial, and metered irrigation service (MIS). The single-family and commercial categories tied directly to the existing buildings already disaggregated to sub-regions, while the MIS was calculated based upon a statistical relationship to multi-family and commercial services (TMWA, 2010). The multi-family coefficient is based upon usage per multi-family meter, which is roughly equivalent to one meter per multi-family building. Using a known historical value of average multi-family units per building, the number of future multi-family units was converted to multi-family buildings in order to apply the water use coefficient. The five categories of water services were then multiplied by the published water use coefficients (Table 7) and the 6% system loss factor (NNWPC, 2011) was applied to determine total water use per sub-region under each of the scenarios. This calculation provided a single annual estimated water use value at 2029 and 2049 for each sub-region under the four scenarios.

**Table 8: Wastewater ratios (NNWPC, 2011).**

| Sub Region | Wastewater Ratio |
|---|---|
| RURAL | 0.47 |
| COLD SPRINGS | 0.46 |
| SPANISH SPRINGS | 0.48 |
| SPARKS | 0.44 |
| STEAD / LEMMON | 0.44 |
| STM | 0.47 |
| SUN VALLEY | 0.40 |
| TRUCKEE MEADOWS | 0.49 |

In order to take into account any potential changes to water use due to future uncertainties such as climate change (e.g. increasing temperatures causing higher evapotranspiration rates) or socio-economic influences (e.g. conservation measures), a simple sensitivity analysis was also conducted. In this analysis, water use coefficients were adjusted in increments of 5 ranging from +15 to -15 percent from the baseline coefficients. Using these adjusted coefficients, water use outputs were calculated again by sub-region at 2029 and 2049 for the four scenarios. These water use reduction coefficients are conservative when considering that in Las Vegas, from 2002 to 2009, gallons per capita per day were reduced 25% and there is a goal to reduce this another 20% by 2035 (SNWA, 2011). Additionally, in the Truckee Meadows region, conservation efforts during historic droughts have shown water use reductions in the 15-20% range (TMWA, 2007). The result of these calculations yields a range of water use and wastewater outputs. This is helpful for determining each sub-region's capacity to accommodate a wider range of possible future water use outputs.

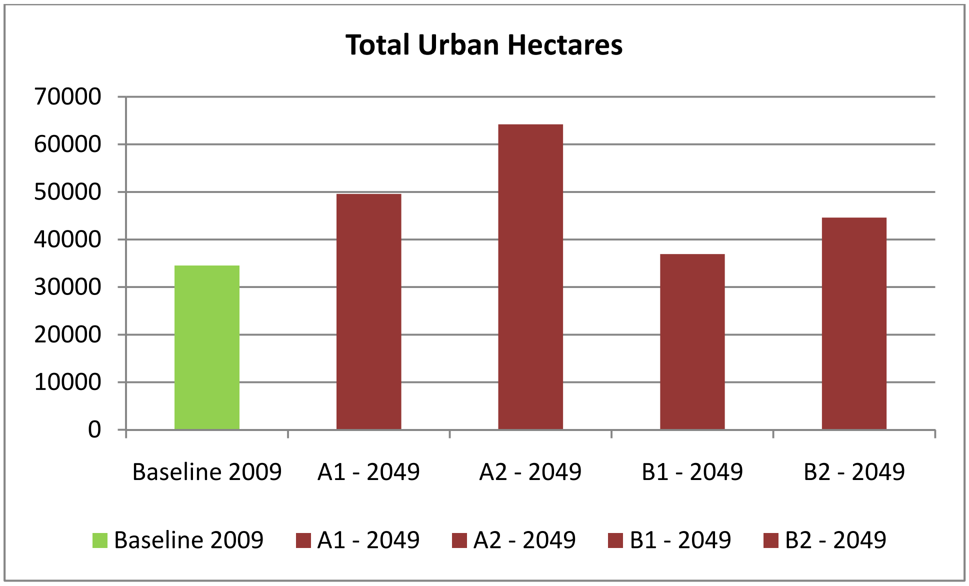
The ranging water use values by sub-region were then used to calculate the wastewater outputs by sub-region. The same method utilized by the Northern Nevada Water Planning Commission (NNWPC, 2011) was used for the calculations. The calculated water use estimates for the four scenarios were multiplied by the wastewater ratios (Table 8) to determine wastewater outputs for the sub-regions. The ratios represent the percentage of the water used which remains in the system as wastewater, which varies based upon the characteristics of each sub-region. The calculated wastewater outputs were then aggregated to the five wastewater sub-regions to align with how wastewater is currently spatially managed.

## 4.0 RESULTS

### 4.1 Land Use Impacts

In the Truckee Meadows, the four modeled scenarios yielded a wide range of values for the region's growth. Table 9 compares the population, urban land uses, and housing/buildings for the four scenarios. As to be expected, the B scenarios generally display a more compact urban growth future for the region compared to the A scenarios (Fig. 3). This is due to the population estimates used and parameters adjusted to account for local policies emphasizing more compact growth occurring in and near the urban core of the region.

**Fig. 3: Total urban hectares for the Truckee Meadows. Comparison of the 2009 baseline to the four scenarios at 2049.**



Some of the key outputs to consider from the model include the housing units, buildings, and urban area totals. When comparing these scenario outputs at 2029 against the observed values from 2009, A1 experienced the largest gain in total urban area of 9,778 ha, or 28%, to bring the total urban area to 44,290 ha. For housing units and buildings, the A1 scenario added the most new single-family units and B2 added the most multi-family units. Since commercial units were based upon population and the A1 and B2 scenarios shared the same population projection, both scenarios added the highest number of commercial buildings. The low values for urban area, housing, and buildings were all claimed by B1 since that scenario had not experienced any modeled growth from 2010-2029.

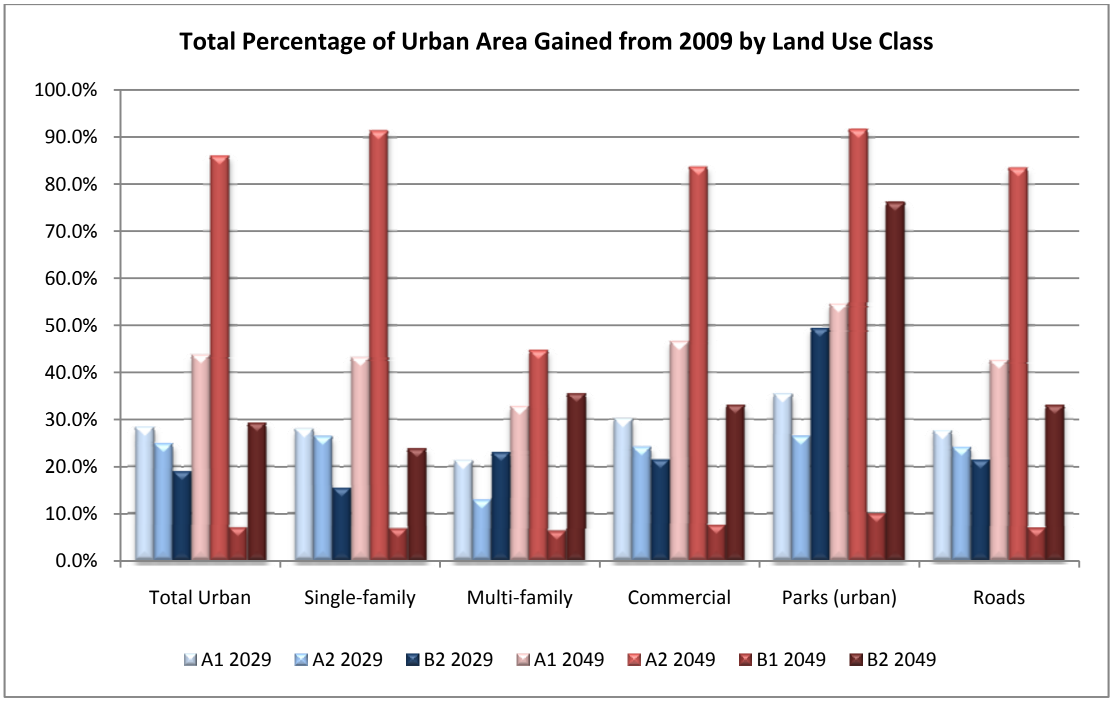
Comparing the 2049 output totals to 2009, the A2 scenario far surpassed all other scenarios by adding 29,694 ha of urban land, an 86% increase, to bring the total urban extent to 64,206 ha. To give some additional context to this large increase in urban area over the forty year time span, this increase is still only slightly over half the percentage increase in urban area (158.6%) that occurred historically in the thirty year time span from 1980-2009. The B1 scenario added the least amount of urban area, 2,420 ha or a 7% increase, resulting in 36,932 ha total. For housing units and buildings, the A2 scenario added the most single-family units, the B2 scenario added the most multi-family units, and the A2 scenario added the most commercial buildings. The B1 scenario, with the lowest population growth, added the least amount of housing units and commercial buildings.

**Table 9: Truckee Meadows population, land use, and housing/building values for 2009 and the four scenarios at 2029 and 2049.**

| | Observed | A1 - Diffuse Arterial | | A2 - Diffuse Perimeter | | B1 - Moderate Compact | | B2 - TOD Compact | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | 2009 | 2029 | 2049 | 2029 | 2049 | 2029 | 2049 | 2029 | 2049 |
| **Population** | | | | | | | | | |
| Population | 398,300 | 522,068 | 589,070 | 490,316 | 717,584 | 391,476 | 430,993 | 522,068 | 589,070 |
| Population Gained | N/A | 123,768 | 190,770 | 92,016 | 319,284 | -6,824 | 32,693 | 123,768 | 190,770 |
| People Per Household | 2.53 | 2.6 | 2.6 | 2.53 | 2.53 | 2.53 | 2.53 | 2.6 | 2.6 |
| **Urban Land Uses** | | | | | | | | | |
| Urban Development Per Person (ha/person) | 0.077 | 0.079 | 0.079 | 0.093 | 0.093 | 0.074 | 0.074 | 0.053 | 0.053 |
| Total Urban (ha) | 34,512 | 44,290 | 49,583 | 43,070 | 64,206 | 34,512 | 36,932 | 41,072 | 44,623 |
| Total Urban Density (people/ha) | 11.541 | 11.787 | 11.880 | 11.384 | 11.176 | 11.343 | 11.670 | 12.711 | 13.201 |
| Total Urban Gained (ha) | N/A | 9,778 | 15,071 | 8,558 | 29,694 | 34,512 | 2,420 | 6,560 | 10,111 |
| % Change from 2009 | N/A | 28.3% | 43.7% | 24.8% | 86.0% | 0.0% | 7.0% | 19.0% | 29.3% |
| Single-family (ha) | 17,110 | 21,899 | 24,491 | 21,616 | 32,744 | 17,110 | 18,269 | 19,754 | 21,185 |
| Single-family Gained (ha) | N/A | 4,789 | 7,381 | 4,506 | 15,634 | 0 | 1,159 | 2,644 | 4,075 |
| % Change from 2009 | N/A | 28.0% | 43.1% | 26.3% | 91.4% | 0.0% | 6.8% | 15.5% | 23.8% |
| Multi-family (ha) | 1,389 | 1,684 | 1,844 | 1,568 | 2,010 | 1,389 | 1,476 | 1,709 | 1,883 |
| Multi-family Gained (ha) | | 295 | 455 | 179 | 621 | 0 | 87 | 320 | 494 |
| % Change from 2009 | N/A | 21.2% | 32.8% | 12.9% | 44.7% | 0.0% | 6.3% | 23.0% | 35.6% |
| Commercial (ha) | 8,933 | 11,627 | 13,086 | 11,089 | 16,413 | 8,933 | 9,602 | 10,853 | 11,892 |
| Commercial Gained (ha) | | 2,694 | 4,153 | 2,156 | 7,480 | 0 | 669 | 1,920 | 2,959 |
| % Change from 2009 | N/A | 30.2% | 46.5% | 24.1% | 83.7% | 0.0% | 7.5% | 21.5% | 33.1% |
| Parks (urban) (ha) | 565 | 765 | 873 | 714 | 1,083 | 565 | 621 | 844 | 995 |
| Parks (urban) Gained (ha) | | 200 | 308 | 149 | 518 | 0 | 56 | 279 | 430 |
| % Change from 2009 | N/A | 35.4% | 54.5% | 26.4% | 91.7% | 0.0% | 9.9% | 49.4% | 76.1% |
| Roads (ha) | 6,515 | 8,314 | 9,289 | 8,083 | 11,955 | 6,515 | 6,964 | 7,911 | 8,667 |
| Roads Gained (ha) | | 1,799 | 2,774 | 1,568 | 5,440 | 0 | 449 | 1,396 | 2,152 |
| % Change from 2009 | N/A | 27.6% | 42.6% | 24.1% | 83.5% | 0.0% | 6.9% | 21.4% | 33.0% |
| **Housing/Buildings** | | | | | | | | | |
| Single-family Units | 118,278 | 152,076 | 170,373 | 146,483 | 216,145 | 118,278 | 126,794 | 144,460 | 158,633 |
| SFAM Units Gained from 2009 | N/A | 33,798 | 52,095 | 28,205 | 97,867 | 0 | 8,516 | 26,182 | 40,355 |
| % Change from 2009 | N/A | 28.6% | 44.0% | 23.8% | 82.7% | 0.0% | 7.2% | 22.1% | 34.1% |
| Multi-family Units | 61,183 | 74,988 | 82,461 | 69,348 | 89,515 | 61,183 | 65,589 | 82,604 | 94,201 |
| MFAM Units Gained from 2009 | N/A | 13,805 | 21,278 | 8,165 | 28,332 | 0 | 4,406 | 21,421 | 33,018 |
| % Change from 2009 | N/A | 22.6% | 34.8% | 13.3% | 46.3% | 0.0% | 7.2% | 35.0% | 54.0% |
| Commercial Buildings | 8,332 | 10,272 | 11,452 | 9,714 | 13,713 | 8,332 | 8,669 | 10,272 | 11,452 |
| COMM Buildings Gained from 2009 | N/A | 1,940 | 3,120 | 1,382 | 5,381 | 0 | 337 | 1,940 | 3,120 |
| % Change from 2009 | N/A | 23.3% | 37.4% | 16.6% | 64.6% | 0.0% | 4.0% | 23.3% | 37.4% |

Since the populations are different across each scenario, one value that is useful for cross-comparison is the total urban density which compares the total population to the urbanized area. Compared to the 2009 baseline of 11.54 people per urban hectare, all of the scenarios increase the region's density ratio at 2049 except for the A2 scenario, which decreases the density ratio to 11.18. The decreasing density for that scenario reflects the low density and sprawling parameters and policies guiding that scenario.

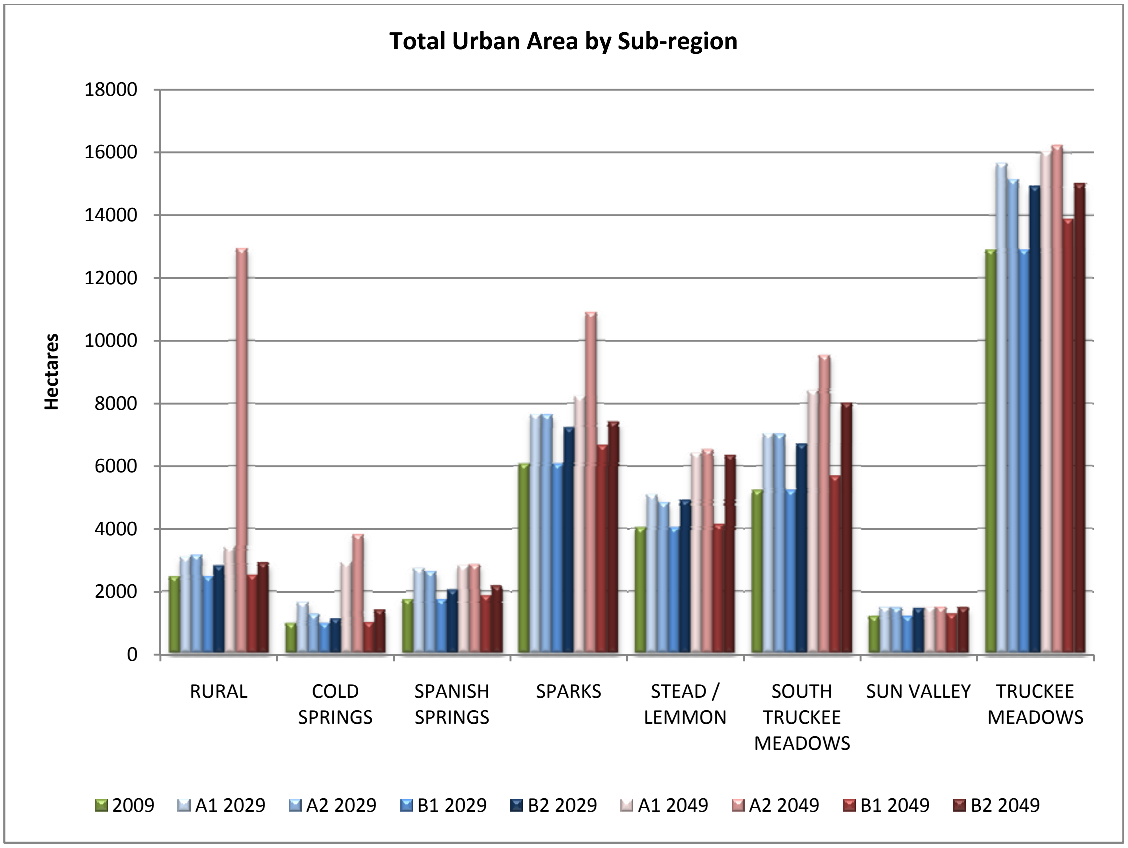
**Fig. 4: Total percentage of the urban land use area gained for the future scenarios at 2029 and 2049. The percentages refer to the increase from the 2009 baseline. (Note that the B1 scenario had not experienced any growth by 2029, so there is no data for that scenario and time period showing on the graph).**



Another telling comparison of the scenario outputs is to consider the percentage increase of area for all the urban land use classes (Fig. 4). The wide range of possible land use changes under the scenarios is evidenced by the difference between the A2 and B1 scenarios for the land use classes at 2049. For the most part the graph illustrates a higher increase in the urban area gained at 2049 for the A scenarios compared to the B scenarios. However, this does not hold true for the multi-family and park land uses, where the B2 scenario experiences more growth than the A1 scenario due to an increasing preference for multi-family housing and an increase in the hectares of parks added per person.

When comparing how the growth is allocated into sub-regions there is a generally much closer range between the scenarios (Fig. 5). Some sub-regions, such as Truckee Meadows (i.e. west and central Reno – not the entire study region), are closer to being fully developed than others, and this limits the possible range of growth for these regions going into the future. Other sub-regions, such as Rural, Sparks, South Truckee Meadows, and Cold Springs, contain lands that are farther removed from the existing urban concentrations in the region and have a larger share of developable land. These areas display a wider range in the amount of growth they experience and can play a significant role in the future urban shape, transportation network, and jobs and housing locations for the entire region.

**Fig. 5: Total urban area by sub-region in 2009 and for the four scenarios at 2029 and 2049.**



## 4.2 Water Use and Wastewater Impacts

For water use, under the scenarios about half of the regions are estimated to not experience water constraints by 2049 when compared to the identified supply capacity (NNWPC, 2011) (Fig. 6). Of the regions that have the greatest likelihood for supply and demand imbalances, the two which show the greatest possibility are Cold Springs and South Truckee Meadows. The Stead/Lemmon sub-region indicates some possible imbalances with supply and demand if water use coefficients were to increase from the historic averages.

In stark contrast, wastewater shows a much great possibility of imbalances between output and disposal capacity across all of the scenarios at 2049 (Fig. 7). In all of the scenarios except B1, wastewater outputs will exceed identified disposal capacities by 2049 in all of the wastewater sub-regions. In many of the scenarios the same is also true at 2029, which aligns with the findings from the region's water plan that cite wastewater imbalances in many sub-regions by 2030 (NNWPC, 2011).

**Fig. 6: Water use estimates by sub-region for the Truckee Meadows. The use estimates are compared to the identified supply capacity (NNWPC, 2011) and the bars represent the +15% to -15% change to the use coefficients to account for future use uncertainty.**

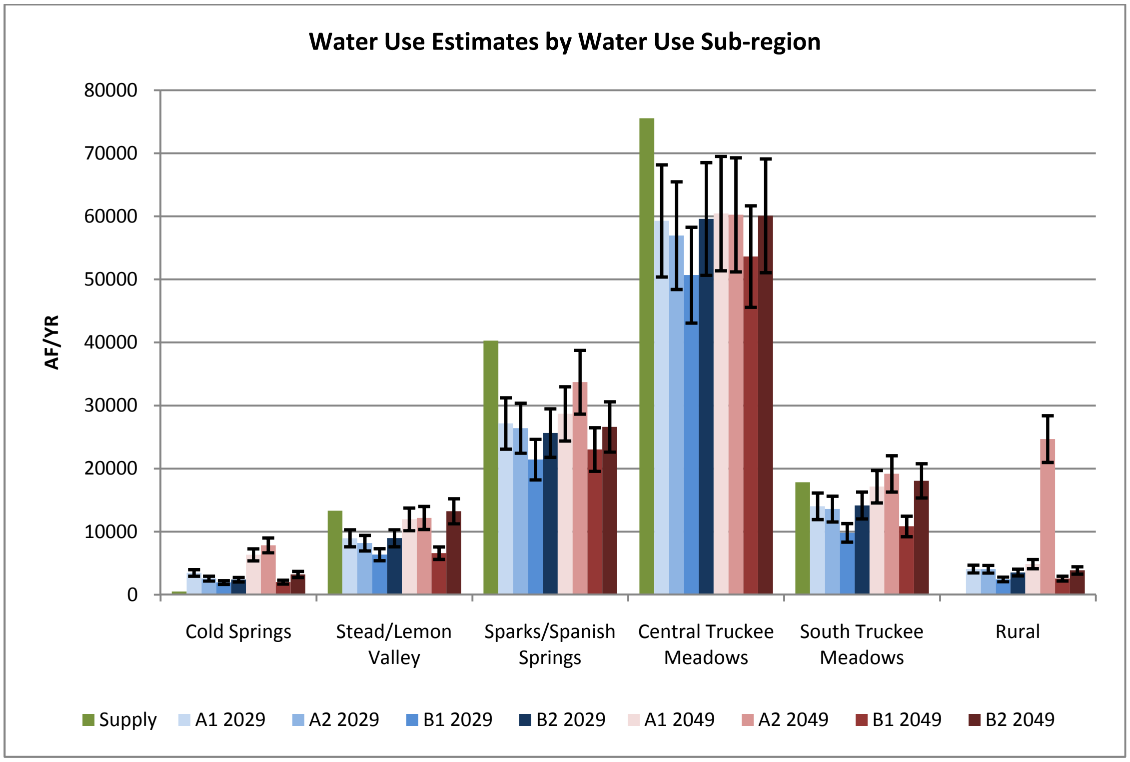
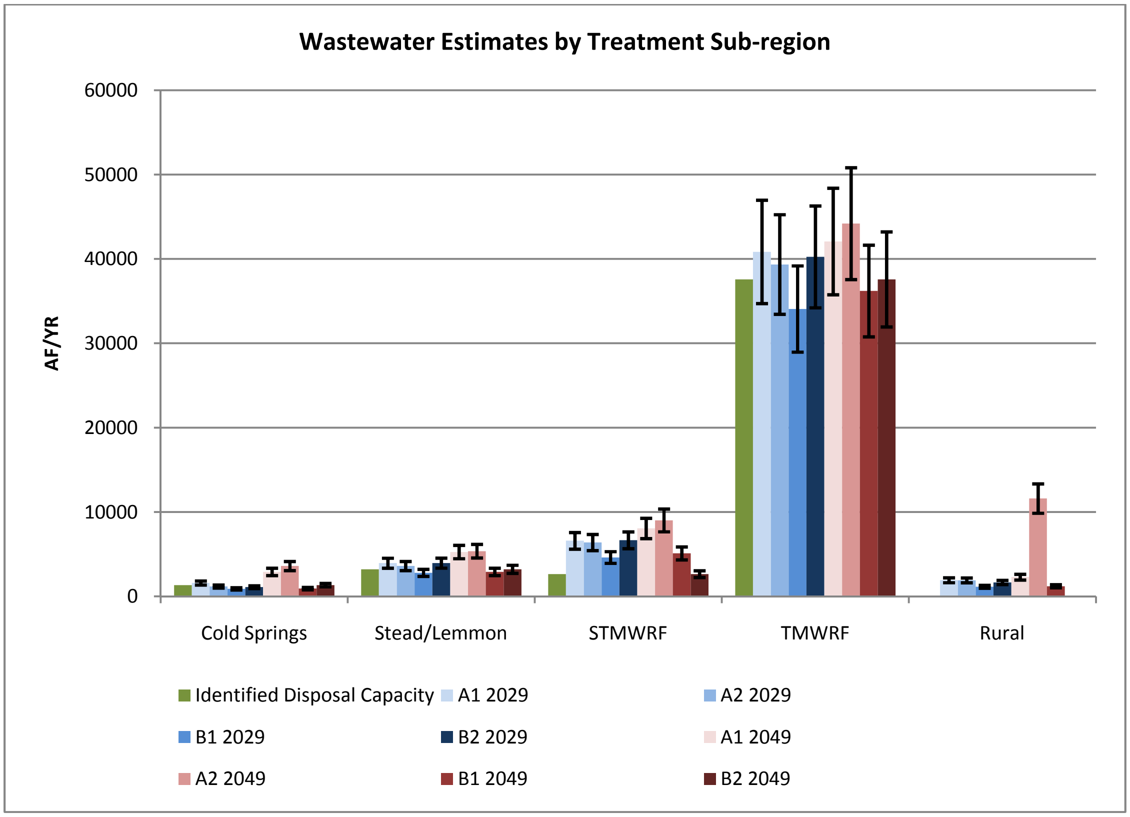


**Fig. 7: Wastewater estimates by treatment sub-region in the Truckee Meadows. The wastewater estimates are compared to the identified disposal capacity and the bars represent the +15% to -15% change to the use coefficients to account for future use uncertainty.**



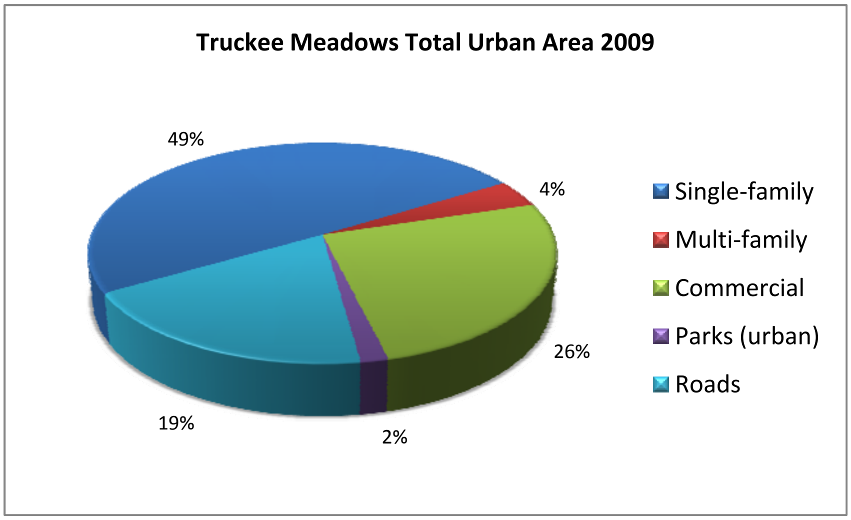
# 5.0 DISCUSSION

## 5.1 Implications for the Truckee Meadows Region

The Truckee Meadows region, like many places in the USA and throughout the world, is currently experiencing a significant recession where unemployment and foreclosures rates remain at record highs and state and local budgets continue to be cut. In contrast to the steady economic and population boom the region experienced for the past few decades, there currently seems to be a much greater sense of uncertainty about the region's socio-economic future. This study has attempted to address this uncertainty through an integrated study employing the construction of local-scale urban growth scenarios from the IPCC SRES emissions scenario narratives. The derived urban growth scenarios have been limited in this example to exploring only potential future urban land uses, housing, water use, and wastewater at the local level. Considering the results of this study, several important conclusions can be drawn about future land and water resources for the Truckee Meadows.

First, while the region does have a large amount of land available for development, it is not enough to support the A2 scenario of high population growth to 2049 without significant changes. In this scenario the existing buildable lands included the currently university-owned agricultural lands in the east-central part of the region and all of the region's wetlands – two lands that presently are not available for development. Despite these additions and even after filling some of the most remote buildable lands in the north and east, the available land was almost fully exhausted before 2049. Only by converting public lands currently managed by the federal government's Bureau of Land Management into private land available for development was the region able to hold the scenario's growth needs. This is important to consider because the average annual population growth rate in the A2 scenario is 1.47%. This is a very conservative rate compared to the 1979-2009 average annual population growth rate of 2.63%. Additionally, although this scenario's growth is able to fit into the region after policy changes are made, this study does not even consider the economic feasibility, consumer preferences, or the water availability for developing remote outlying areas.

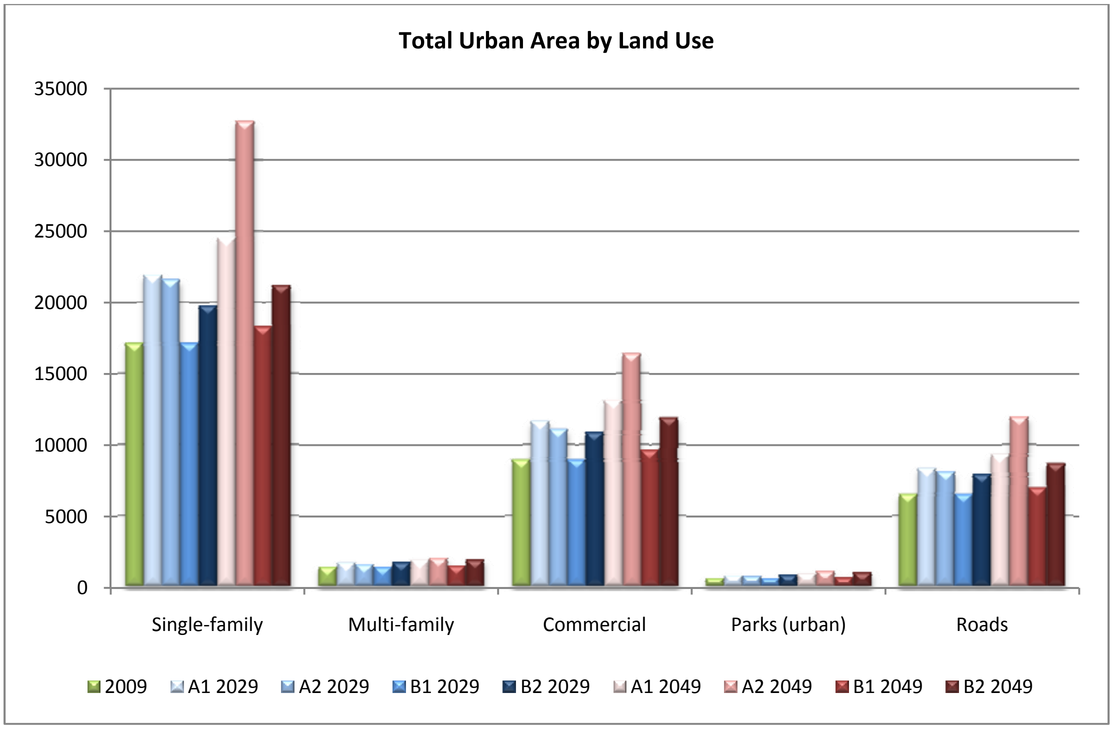
**Fig. 8: Contribution of the different urban land uses to the total urban area in 2009.**



Second, policies and preferences affecting the single-family, commercial, and road urban land uses will make the most difference spatially in the region since those uses currently comprise 94% of the region's urban area (Fig. 8) and this share will likely increase over time (Fig. 9). The A1 and B2 scenarios illustrate this point because both had very different changes in the growth of the urban area by 2049 while sharing the same medium population projection. A1 increased the total urban area of the region by 43.7%, while B2 increased the urban area by 29.3%. The difference between the scenarios was that the A1 scenario kept trend values for the percentage allocation between single-family and multi-family housing, and the single-family, commercial, and road land use values of hectares per person. The B2 scenario adjusted the single-family and multi-family allocation percentage back down to the 1979-1996 average, and decreased the hectares per person for the three key urban land uses by 30%.

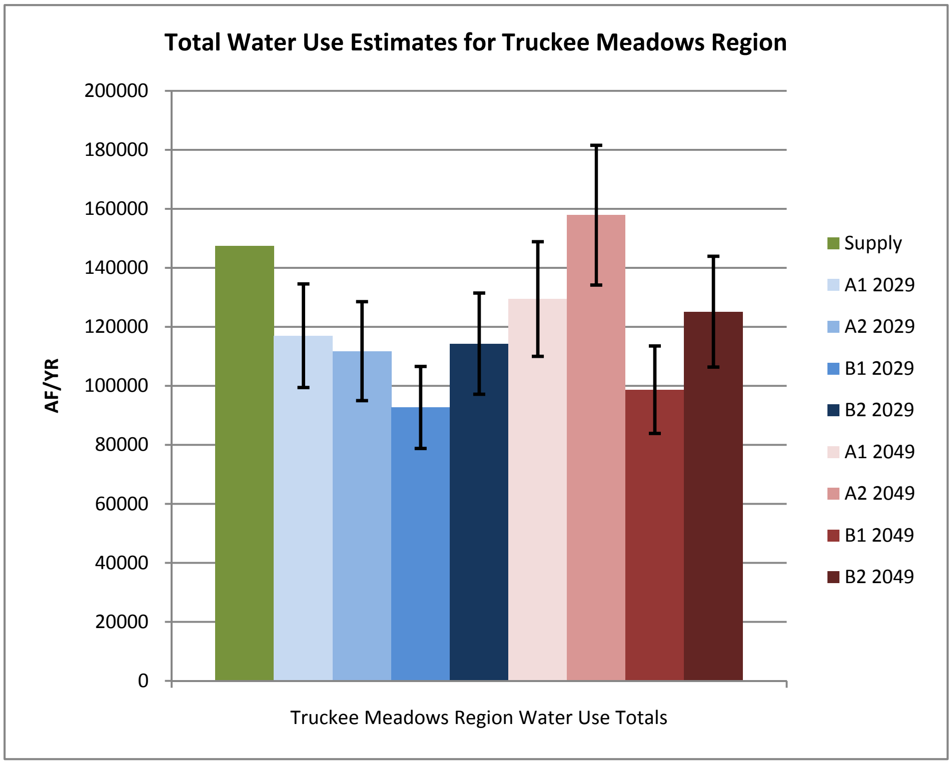
The A1 scenario most closely represents a trend of growth while the B2 scenario is similar in many regards to the current regional plan, which in general calls for higher density thresholds to reduce the spread of the urban footprint, encouraging more mixed-used development, and focusing growth into the region's traditional urban core and into transit-oriented development along regional corridors (TMRPA, 2007). It is hoped that seeing how these policies and preferences are spatially manifested will be useful for encouraging discussion and reviews of existing trends, policies, and regulations in the region. Having spatial representations of several modeled scenarios side-by-side can add a new element to the region's planning process as the possible consequences of policies can be seen and considered in time and space.

**Fig. 9: Total urban land area by sub-region for 2009 and the four future scenarios at 2029 and 2049.**



Lastly, policies and preferences affecting the spatial patterns of growth not only have important consequences for the region's land use, but also for the water use (Guhathakurta and Gober, 2007) and wastewater needs. When considering

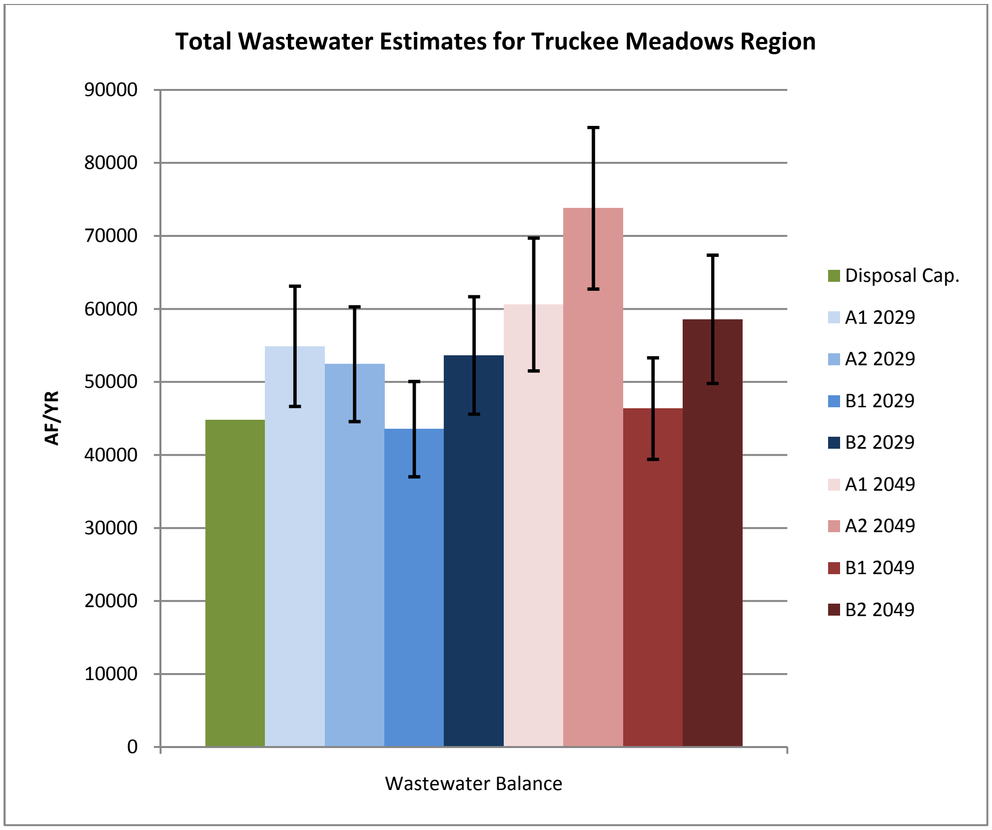
**Fig. 10: Water use estimates for the entire Truckee Meadows region compared to the region's existing total identified supply capacity (NNWPC, 2011).**



future water use by sub-region (Fig. 6), imbalances occur between identified supply capacity and water use for several sub-regions by 2049. However, when considering future water use for the entire Truckee Meadows region (Fig. 10), only the A2 scenario shows a regional imbalance at 2049 using the unadjusted water use coefficients. These results indicate that although a scenario of high population growth (A2) could create water supply and demand imbalances at the regional scale, the more immediate problem will be with supply and demand imbalances at the sub-regional level. These sub-regional imbalances indicate that the temporal and spatial distribution of future growth within the region will affect the location and timing of infrastructure implementation, and which agencies will bear responsibility for the costs of projects that will be needed to transfer potable water throughout the Truckee Meadows. Additionally, this study assumes future water supplies will remain stable in the future, but changes to water supply would certainly affect the region's water balance and should be considered in future research.

Wastewater shows an even greater prevalence of potential sub-regional imbalances (Fig. 7), which results in imbalances at the regional level (Fig. 11). Because many of the sub-regions are already close to current maximum capacity for wastewater treatment, rates and spatial patterns of growth will force local agencies to make decisions about wastewater disposal options in the immediate future. With spatially linked water and growth challenges, the Truckee Meadows region will be best served if further efforts are directed at addressing and planning for these issues jointly.

**Fig. 11: Wastewater estimates for the Truckee Meadows region compared to the region's total identified disposal capacity (NNWPC, 2011).**



## 5.2 Challenges in the Scenario Development

This study has shown that the SRES emissions scenarios can be interpreted into local scale urban growth scenarios. Spatially modeling these scenarios yields valuable information that can be used to conduct local scale impact assessments. The benefits of this scenario development process will be more fully realized when climate impact assessments are made at the local scale by joining the urban growth scenarios to other environmental models which are also linked to the SRES emissions scenarios. However, in addition to these benefits there are challenges and limitations to this scenario methodology which warrant further consideration.

The qualitative nature of interpreting the SRES emission scenarios into urban growth (or land use change) scenarios means that the scenarios could always be interpreted in a different manner (Reginster and Rounsevell, 2006). It also means that the biases of the person or groups interpreting the scenarios to the local scale are introduced into the process, which affects the scenario outcomes and changes the range of uncertainty that the scenarios cover (Metzger et al., 2010). However, this issue applies to scenarios-based studies in general. Scenarios contain qualitative components, which really distinguishes them from other future planning methods such as projecting or forecasting. The reason this is noteworthy is because in this particular scenario creation methodology the goal for the SRES-derived urban growth (or land use change) scenarios is to use them in additional studies utilizing environmental models. This means that the interpretation of the urban growth scenarios will affect not just urban growth results, but also the results of other environmental impacts being assessed (Rounsevell et al., 2006a).

Scale is also an important issue because of the difficulty in interpreting global trends and policies to a metropolitan region. The linkages between the global and local scales are much more tenuous compared to the linkages between, for example, the global and national scales. In order to make the connections between the global and local scenarios means that numerous assumptions must be made in order to simplify the process and maintain a level of transparency.

There is also a challenge with striking a balance between keeping the local scenarios true to the global SRES emissions scenarios while considering the conditions of the local region. In this study several driving force conditions were adjusted from the SRES scenarios to the local urban growth scenarios. The justifications for doing so were to make the global scenarios fit with the local conditions and were based upon knowledge of the study region. This becomes a very nebulous, although perhaps unavoidable, part in the interpretation process. For example, SRES-derived urban growth scenarios would necessarily differ from the ones created in this study if they were created for similarly sized metropolitan regions in interior China, coastal Brazil, or northeastern Europe.

These identified challenges in this methodology warrant consideration and can likely be improved upon by further research and application in case studies. Additionally, it is important to keep in mind that “the goal of working with scenarios is not to predict the future, but to better understand uncertainties in order to reach decisions that are robust under a wide range of possible futures” (Moss et al., 2010, p. 747), which this methodology facilitates.

### 5.3 Future Research

This research only considered the urban land use, housing, water use, and wastewater impacts under the four scenarios, but an obvious and important future addition to this work would be researching how the region’s water supply could be affected in the future, especially under climate change. For example, the region’s surface and ground hydrology could be modeled using precipitation and temperature outputs from the downscaled GCMs under the four major emissions scenarios. These future water supply estimates could be considered in combination with the four urban growth scenarios and demand estimates to develop a more complete analysis of the region’s land and water resources. Impact assessments with socio-economic and environmental models driven by scenarios that are linked to the SRES emission scenarios will help improve knowledge of climate change impacts at the local scale.

Additionally, future work can help contribute to the growing body of knowledge about the complex feedbacks between urban and environmental systems affected by climate change and how to best balance adaptation and mitigation plans. For example, Hamin and Gurran (2009) have noted the “density conundrum” caused by climate change, where urban density helps mitigate certain aspects of climate change (reducing VMTs and building energy use), but at the same time, open space is required to facilitate other mitigation (runoff management and urban cooling) and environmental needs (species mobility and habitat). Similarly, urban growth decisions affect local urban heat islands, which in turn affect water use (Guhathakurta and Gober, 2007). Expanding and improving the integrated approaches to climate research change across all scales will enable a better understanding of the complexities and feedbacks between environmental and urban systems. These advances will better enable decision makers and planners at all levels to introduce better mitigation and adaptation policies and make more resilient plans.

## 6.0 CONCLUSION

This study builds upon other projects which have used a similar methodology of downscaling and interpreting the IPCC SRES scenarios into urban growth or land use scenarios at a finer spatial scale. However, this study has shown the adaptation of this method to the local scale and demonstrated its application by creating scenarios for a small metropolitan region of less than 500,000 people, and then modeling growth at a high (20m x 20m cell) spatial resolution. Impact assessments were conducted for land, water use, and wastewater outputs to better understand how they might be affected by future urban growth in the region. While the results of this impact analysis have immediate relevance for the study region, the methodologies can be useful to researchers and local agencies throughout the world, especially in regions where urban growth, water resources, and climate change pose present and future concerns.

Future work can join SRES-derived urban growth scenarios with SRES-derived environmental scenarios for impact assessments at the local scale. This will enable stronger integrated assessments of socio-economic and climate change-caused impacts for communities and metropolitan regions. While future socio-economic conditions, let alone climate change, are uncertain in any region, a scenario-based approach is exactly the tool that can facilitate a greater understanding of uncertainties in order to help local planners and decision makers make more robust plans and decisions which can withstand a wider range of potential future states (Moss et al., 2010).

A better understanding of the potential impacts, trade-offs, and costs and benefits of adaptation and mitigation of climate change are important concerns in planning for climate change across all scales (Adger et al., 2005). It is hoped that future contributions to this line of research will bolster the understanding of complex climate change and socio-economic impacts, and strengthen the ability of government agencies to make plans that can help nations, regions, and communities mitigate and adapt to a changing climate.

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# APPENDIX

**Fig. A.1: Truckee Meadows study area.**

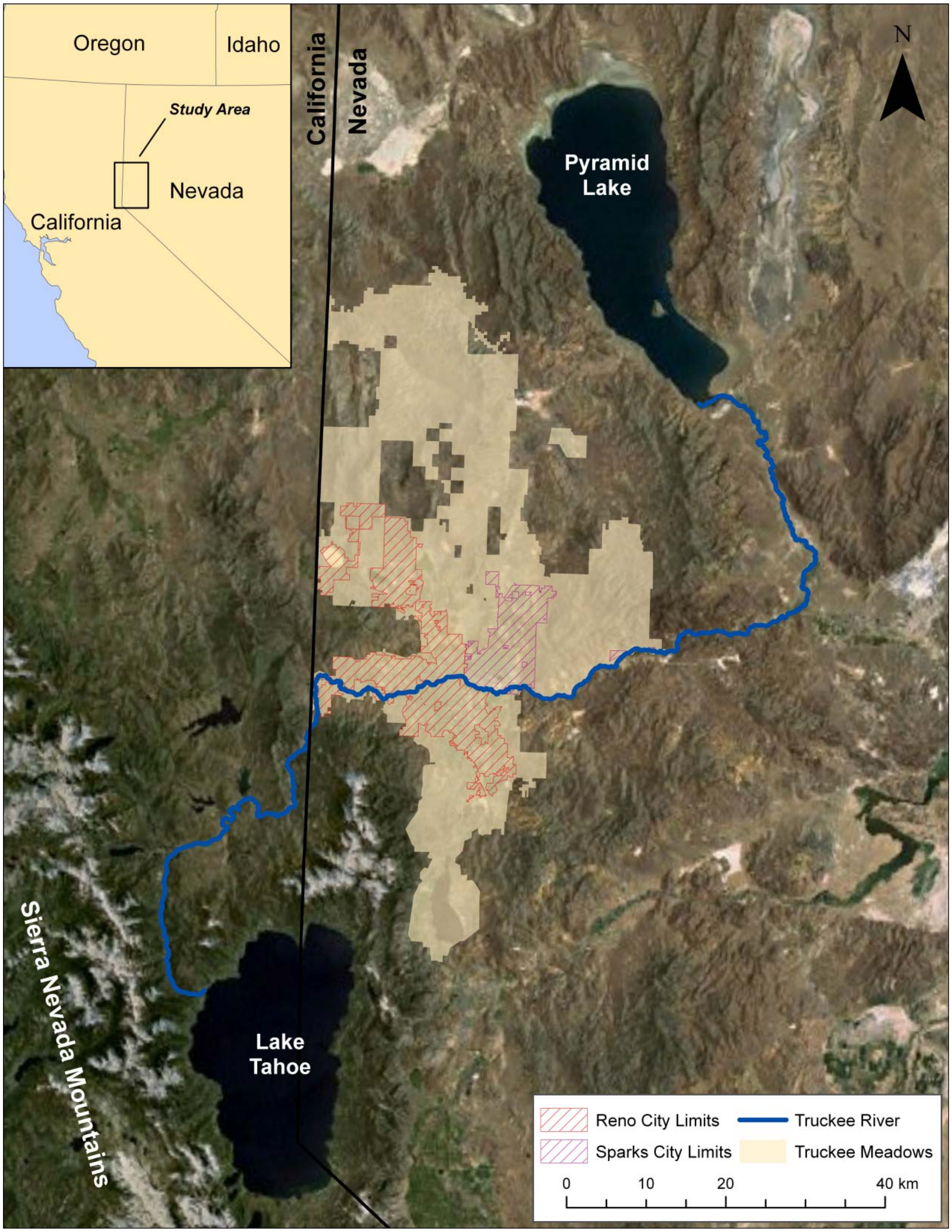

**Fig. A.2: Buildable land as of 2009 in the Truckee Meadows, NV, USA. Green indicates land that is available for future development in the four urban growth scenarios.**

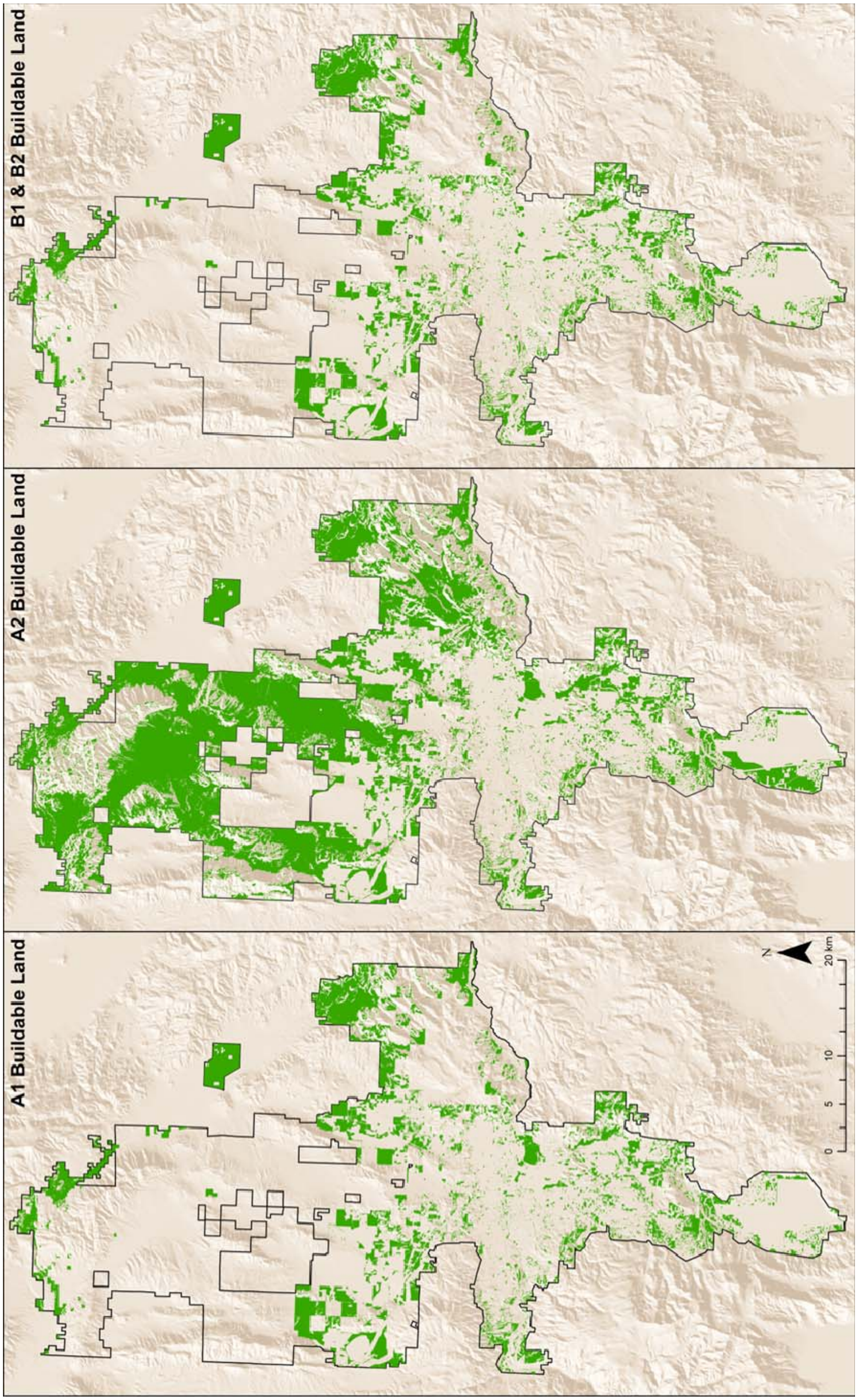

Fig. A.3: Sub-regions in the Truckee Meadows study area.

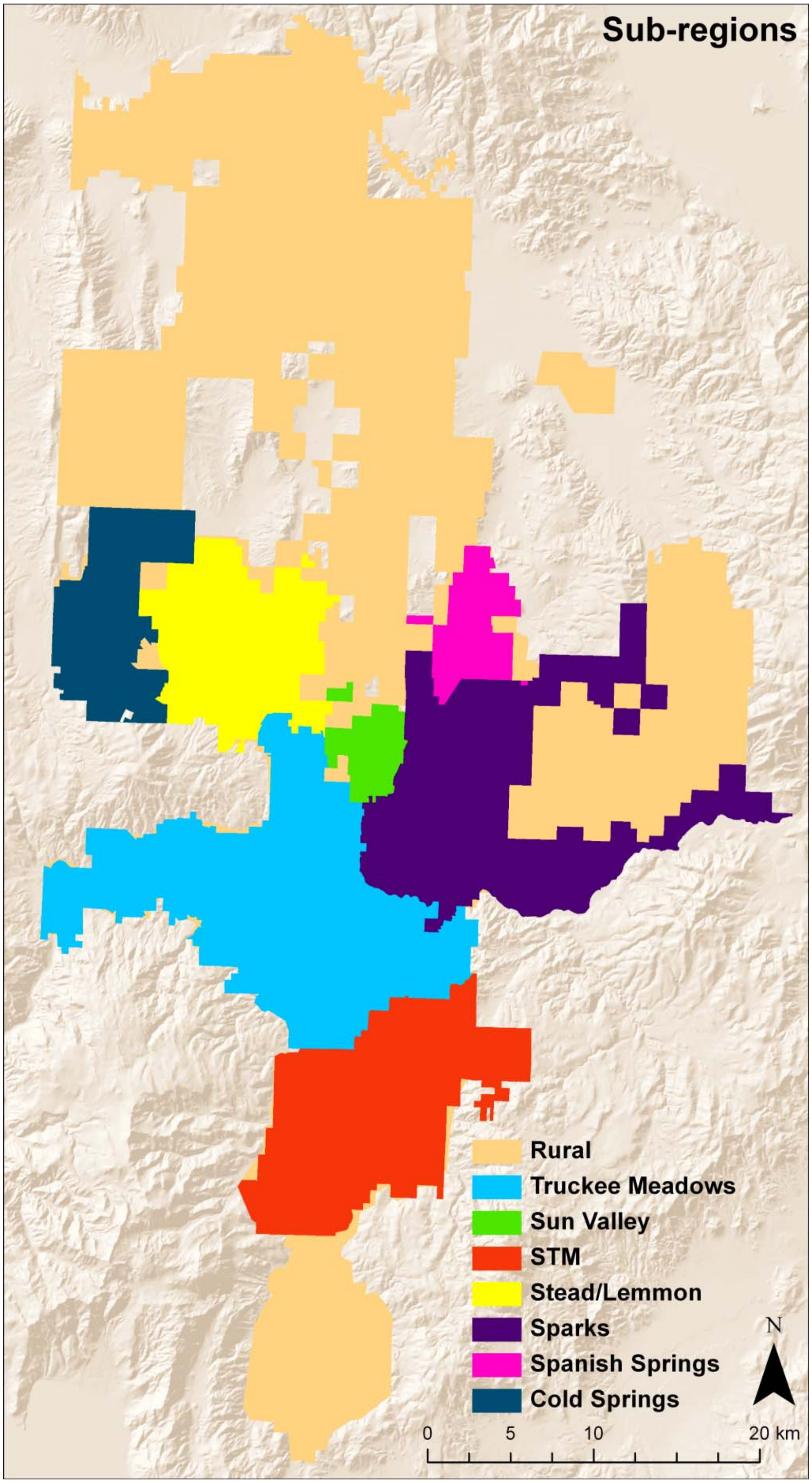

**Fig. A.4: Zones used in the growth model for the A1 scenario. The numbers correspond to the values under this scenario in Table 3.**

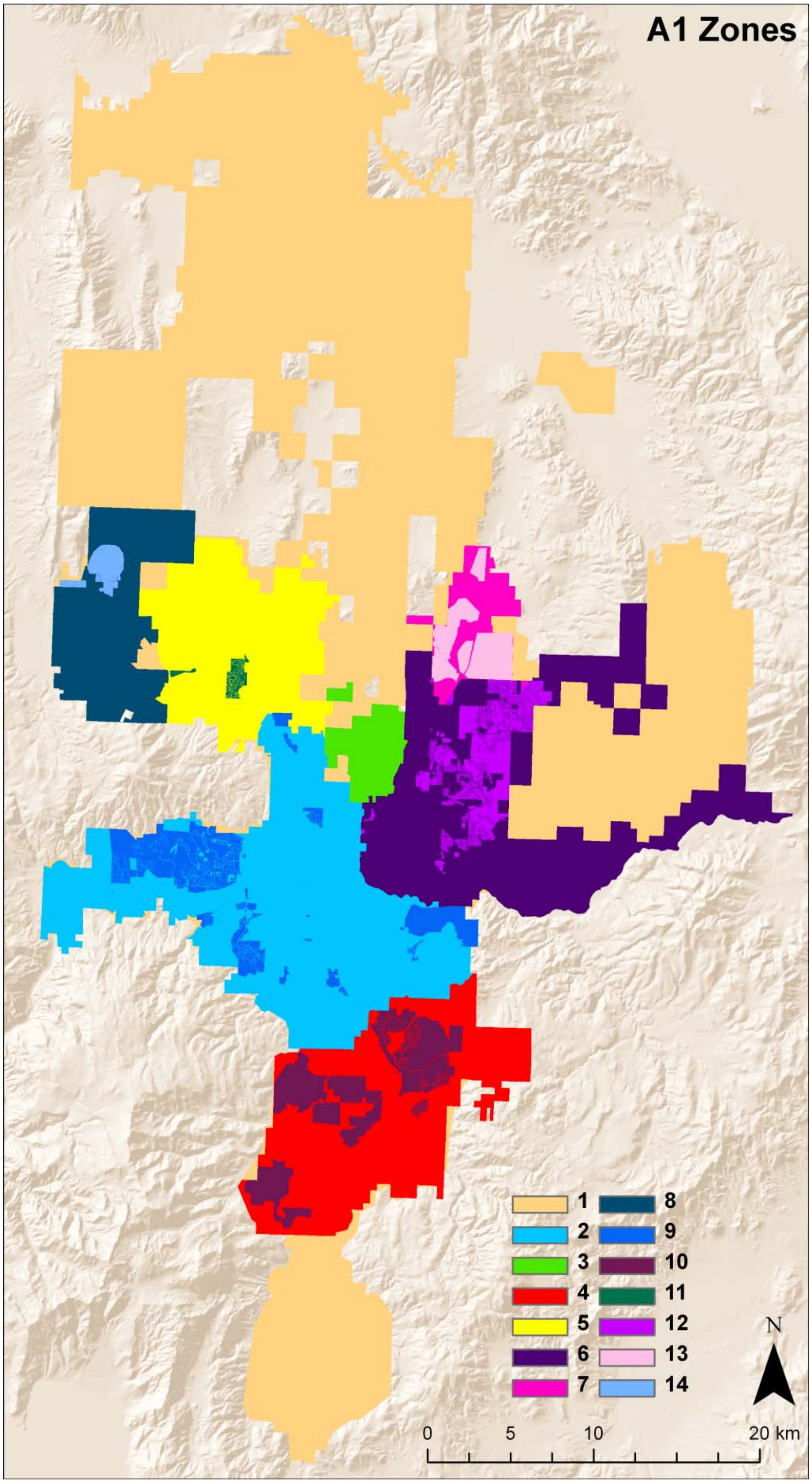

**Fig. A.5: Zones used in the growth model for the A2 scenario. The numbers correspond to the values under this scenario in Table 3.**

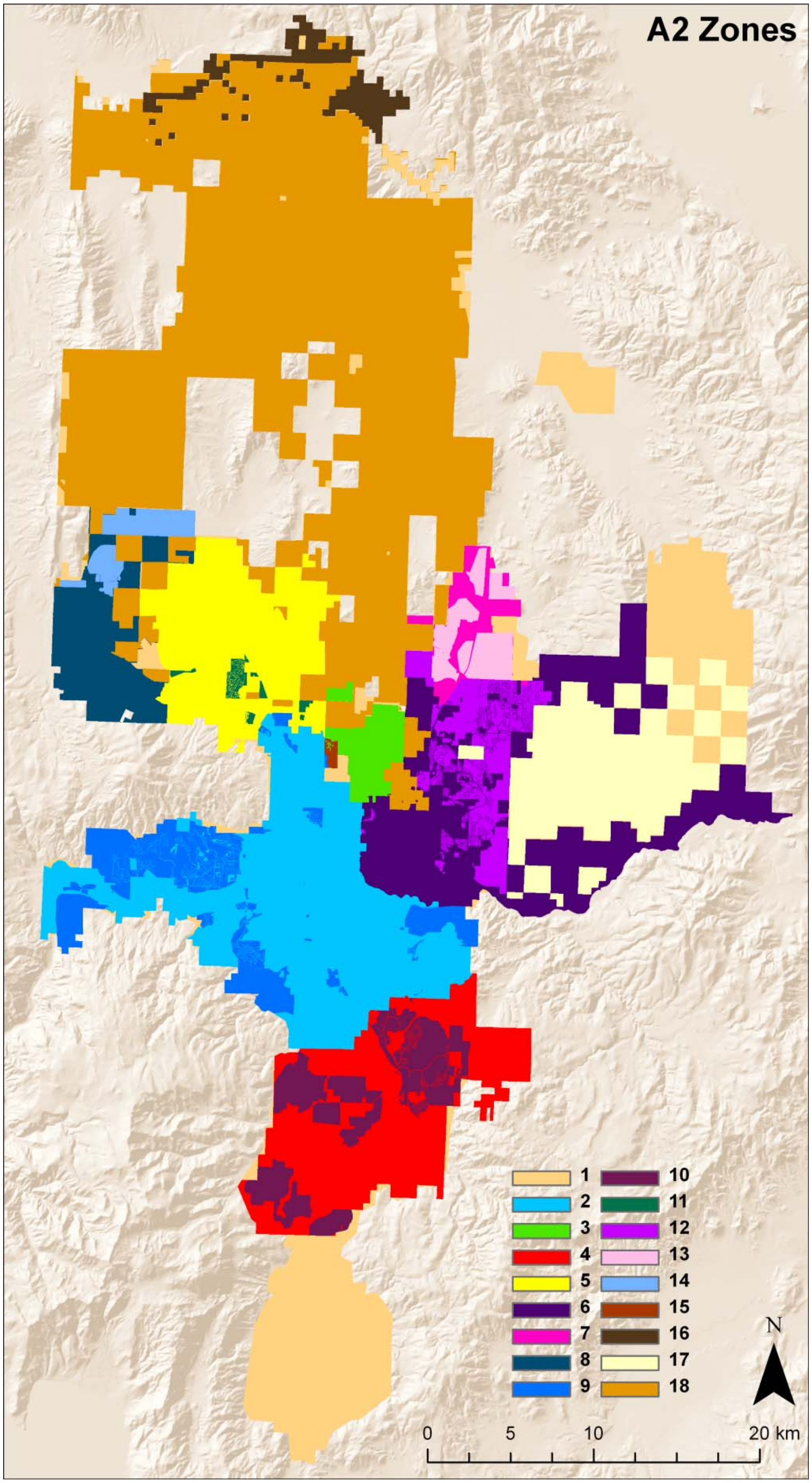

**Fig. A.6: Zones used in the growth model for the B1 scenario. The numbers correspond to the values under this scenario in Table 3.**

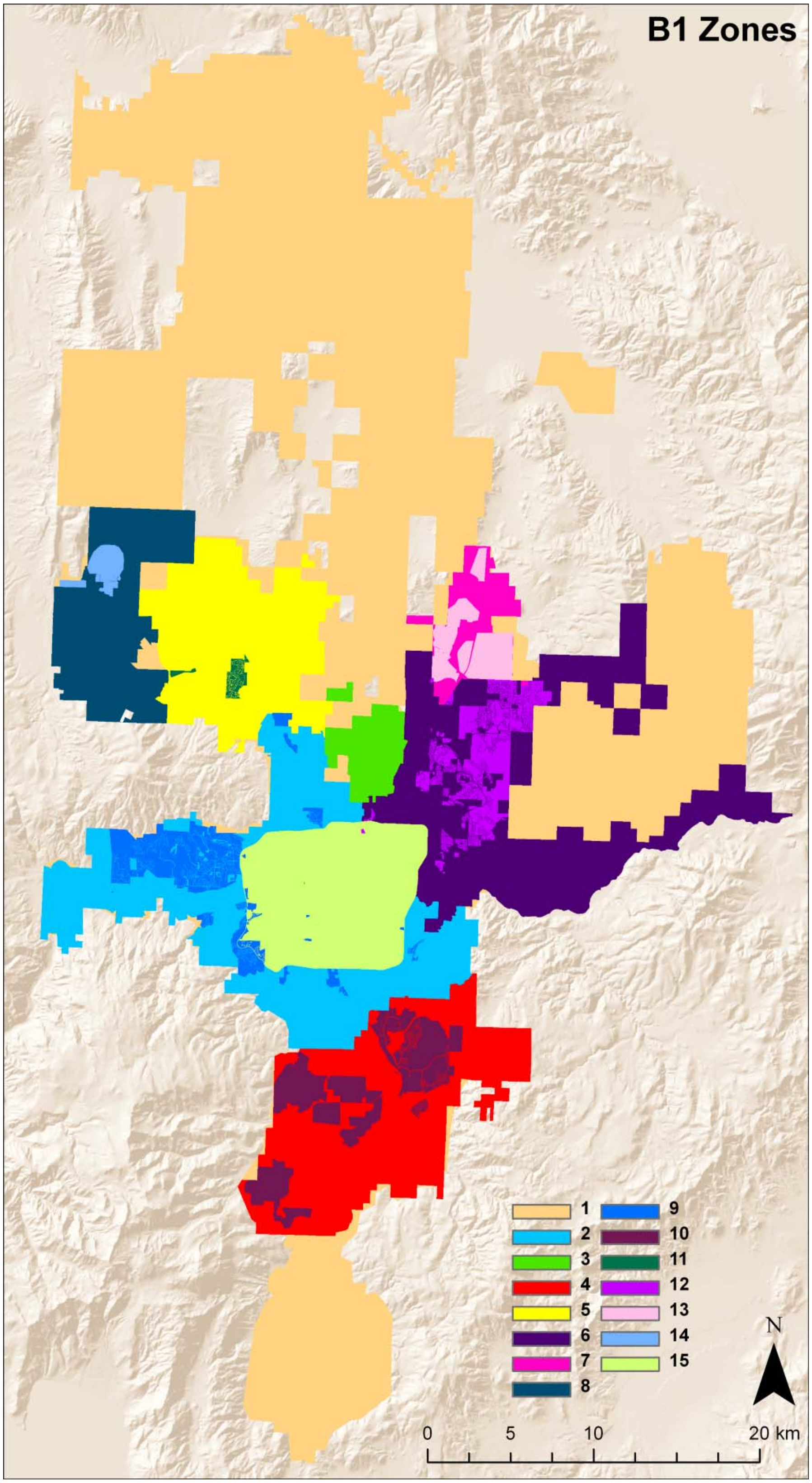

Fig. A.7: Zones used in the growth model for the B2 scenario. The numbers correspond to the values under this scenario in Table 3.

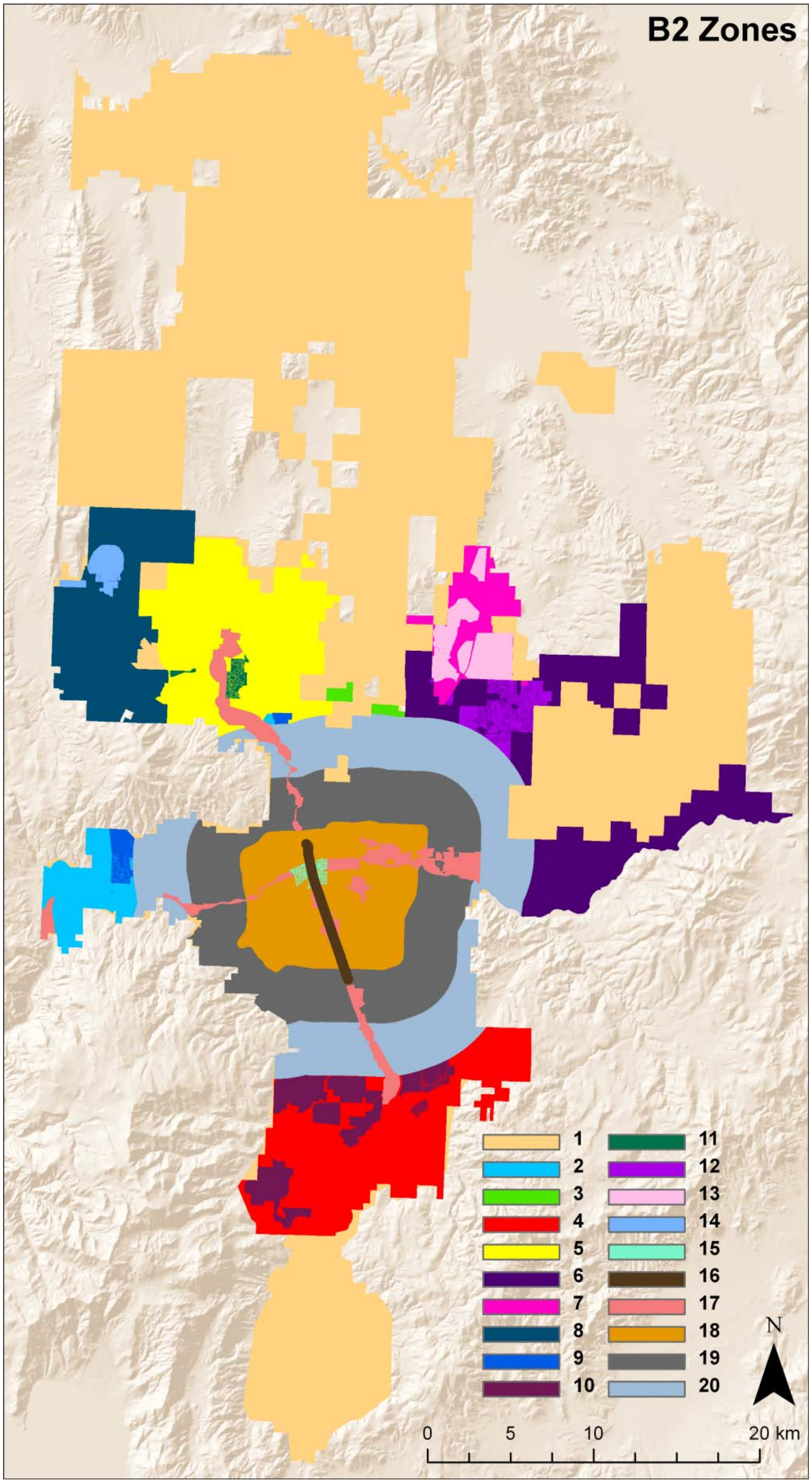

**Fig. A.8: Modeled urban growth scenarios from 2010-2049 for the Truckee Meadows, NV, USA. Orange is the urban footprint in 2009, red is the urban footprint in 2029, and blue is the urban footprint in 2049.**

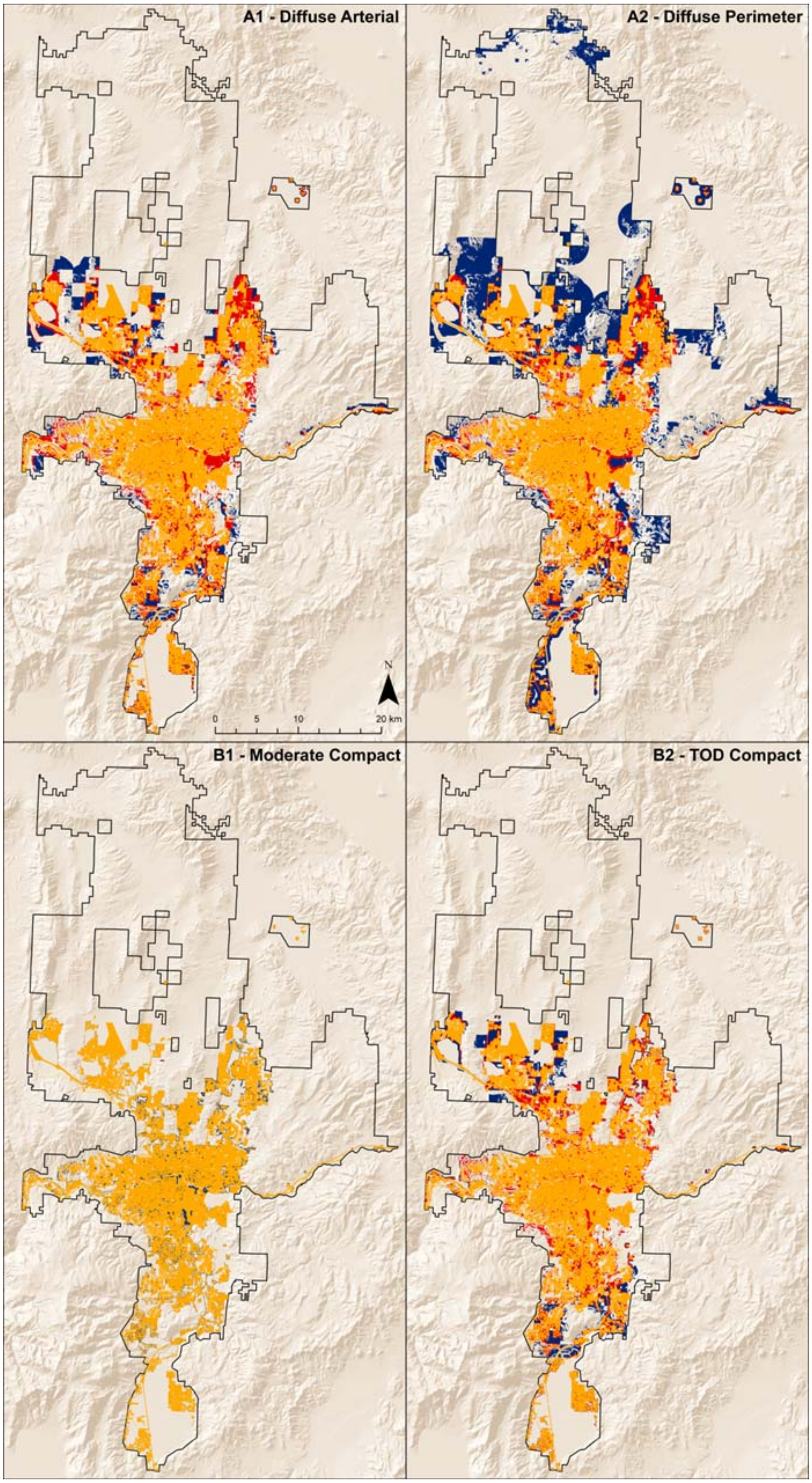

**Fig. A.9: Historic urban growth in the Truckee Meadows, NV, USA. Magenta is the urban footprint in 1979, orange is the urban footprint in 2009.**