3/4/2015

Central New Mexico Climate Change Scenario Planning Project

Final Report

Prepared by:

Ecosystem Management, Inc.

Stephanie Lee
Mike Tremble
Justine Vaivai

The University of New Mexico

Dr. Gregory Rowangould
Mohammad Tayarani
Amir Poorfakhraei

Prepared on Behalf of:

U.S. Department of Transportation's
Volpe National Transportation Systems Center

U.S. Federal Highway Adminstration

Middle Rio Grande Council of Governments (MRCOG)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support and technical assistance of many individuals and organizations for this project. We would like to extend our thanks to Ben Rasmussen and James Andrew of the U.S. Department of Transportation John A. Volpe National Transportation Systems Center; Aaron Sussman, Kendra Watkins, and Caeri Thomas of the Middle Rio Grande Council of Governments; and Tina Hodges of the U.S. Federal Highway Administration.

LIST OF ACRONYMS

ABCWUA	Albuquerque Bernalillo County Water Utility Authority
AMPA	Albuquerque Metropolitan Planning Area
AMAFCA	Albuquerque Metropolitan Arroyo Flood Control Authority
CH_4	Methane
CMIP3	Coupled Model Intercomparison Project Phase 3
CO_2	Carbon Dioxide
EMI	Ecosystem Management Inc.
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FRCC	Fire Regime Condition Class
GIS	Geographic Information System
GHG	Greenhouse Gas
GMCs	General Circulation Models
HOT	High Occupancy Toll
ITS	Intelligent Transportation System
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MRCOG	Mid Region Council of Government
NMDOT	New Mexico Department of Transportation
NO_2	Nitrogen Dioxide
SSCAFCA	Southern Sandoval County Arroyo Flood Control Authority
TAZ	Transportation Analysis Zone
UNM	University of New Mexico
US DOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
VHT	Vehicle Hours Traveled
VMT	Vehicles Miles Traveled
Volpe Center	John A. Volpe National Transportation Systems Center
WUI	Wildland Urban Interface

TABLE OF CONTENTS

Table of Tables

Table of Figures

EXECUTIVE SUMMARY

From 2013 to 2015, the U.S. Department of Transportation (US DOT) John A. Volpe National Transportation Systems Center (Volpe Center) and the Federal Highway Administration (FHWA) partnered with the Mid Region Council of Governments (MRCOG) and other agencies in the region to evaluate how the central New Mexico region could develop in a way that minimizes greenhouse gas (GHG) emissions and increases resiliency to climate change, which for this project was measured in terms of development foot print, wildfire risk, flood risk, and impacts to crucial wildlife habitat. MRCOG is the metropolitan planning organization for the central New Mexico region and is charged with regional transportation planning. The climate change scenario planning project coincides with MRCOG's process for updating the region's long range transportation plan, which identifies transportation investments and policies through the year 2040. The long range transportation plan is expected to incorporate strategies identified by the climate change scenario planning project. The project focused on identifying changes to land-use plans and policies and transportation system investments that could help meet these objectives. MRCOG, in consultation with stakeholders within the metropolitan planning area and through a series of public meetings, developed land-use and transportation planning scenarios for the region as well as a list of performance measures to comparatively evaluate each scenario.

Facilitated by the Volpe Center, a group of representatives from several federal, state, and local agencies provided input and guidance over the course of the project. With the assistance of the University of New Mexico (UNM) and Ecosystem Management, Inc. (EMI) consultant team (collectively the "project team"), MRCOG evaluated these scenarios using an integrated land-use and travel demand modeling system that allowed MRCOG to evaluate how land-use and transportation strategies could work together. MRCOG and the project team evaluated performance measures including regional mobility, accessibility, GHG emissions, and resiliency to climate change for each scenario using this modeling system.

The scenario analysis portion of the project began in March of 2014. The project was divided into three active phases of scenario development and one final phase of reporting the overall outcome of the project. During each scenario development phase, MRCOG developed a set of alterative land-use and transportation strategies MRCOG and the project team evaluated each of the preliminary scenarios for their transportation performance, GHG mitigation potential, and resiliency to climate change and presented the results to stakeholders at two workshops during the summer of 2014.

ES.1 Scenario Development and Evaluation

The preliminary set of scenarios included three future, year 2040, scenarios: a trend, "emerging lifestyles" and "jobs/housing balance." The emerging lifestyles scenario was designed to promote additional infill, transit oriented, and mixed use development while the jobs/housing balance scenario focused on allowing more housing near employment centers or more employment near housing, particularly on Albuquerque's west side. The trend scenario represents current land-use policies and historical development patterns. The two alterative scenarios performed better than the trend but generally there were only small differences between the three future scenarios. Given that the region's population is projected to grow 52 percent to 1,362,000 by 2040, each scenario would consume a large amount of new land, worsen traffic congestion, and increase GHG emissions.

During phase II, MRCOG created two new refined scenarios based on the evaluation of the preliminary scenarios and feedback from workshop participants: the preferred and the fiscally constrained preferred (constrained) scenarios. These two scenarios have the same land-use zoning and incentives but have different transportation networks. The fiscally constrained scenario represents a future roadway network and transit system where less transportation funding is available than expected. These alterative scenarios were designed to drive larger changes from the trend than either the emerging lifestyles or jobs/housing balance scenarios achieved. To do this, the alternative scenarios change zoning from the trend to allow even more mixed use near transit stops and activity centers, greater multi-family density near activity centers, and greater commercial intensity near west side commercial centers. These changes generally represent a combination of the zoning changes from the emerging lifestyles and job/housing balance scenarios from phase I along with incentives to achieve greater infill, mixed use, and transit oriented development. Similar to phase I, there were relatively small differences between each of the future scenarios but there are some notable differences. The new scenarios still consume a large amount of land and increase regional GHG emissions; however, the alterative scenarios do noticeably better than the trend. Transit accessibility and mode share also increases significantly over current levels in the alternative scenarios. The trend and the alternatives also result in less driving per capita, which when combined with more efficient vehicles in the future, results in a relatively large decrease in per capita GHG emissions, although the differences between scenarios are not large. The small differences between scenarios led the project team to conclude that none of the scenarios would improve the resiliency of the region to climate change in the context of significant population growth.

The final set of scenarios developed in phase III are refined versions of the three scenarios developed in phase II. MRCOG developed the final scenarios in response to feedback from the second workshop participants that generally included a desire for even greater reductions in travel and emissions and more concentrated infill and mixed use development in high priority centers and corridors. The final set of scenarios showed larger changes from the trend scenario (or "allowable uses" in phase I) than in the prior phases. While some of the changes are still relatively modest, they drew much clearer distinctions between the trend and the alternatives in key performance measures (Figure ES- 1). While land consumption continues to increase, the alternatives consume significantly less new land than the trend (30 percent less), result in less water consumed, and place less development in flood and wildfire risk areas and crucial habitat areas. The amount of driving, congestion and GHG emissions, including per capita GHG emissions, are also clearly lower than the trend. However, like prior scenarios, addressing river crossings remains a challenge; there were only small differences in the number of river crossings between the scenarios. The alterative scenarios also make significant improvements in access to transit, which results in a 51 percent increase in transit mode share over current (2012) levels in the preferred scenario. However, given the small baseline mode share, this large increase does not have a large impact on the key performance measures.

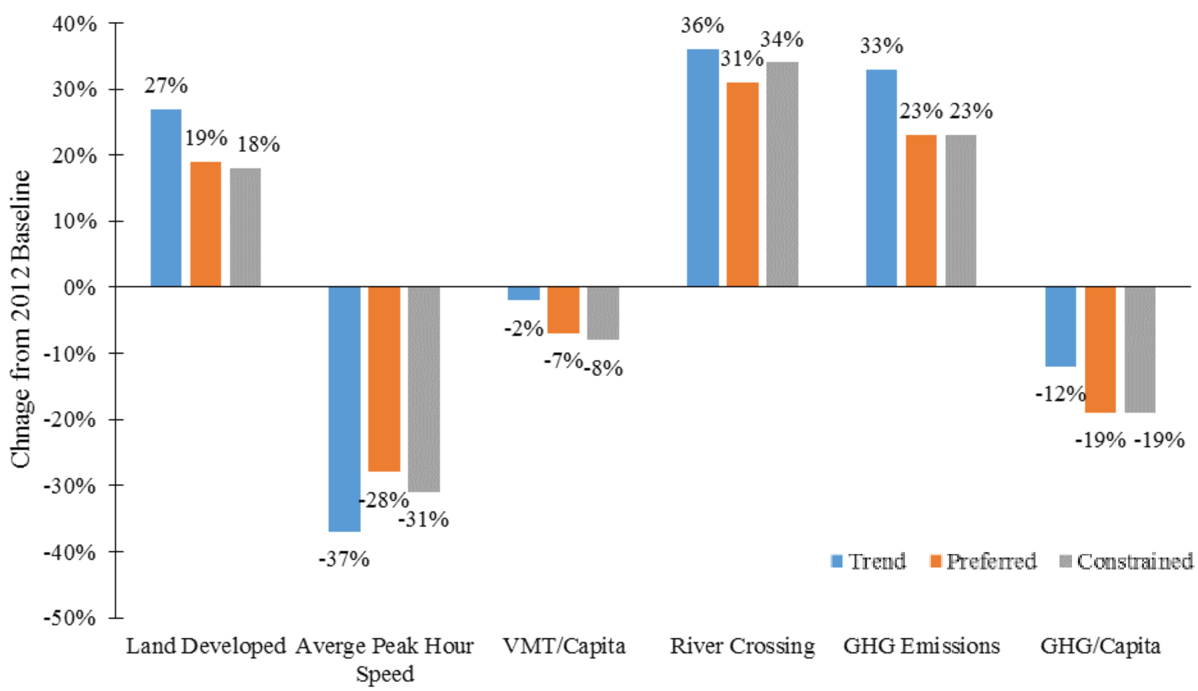

Figure ES- 1. Summary of Phase III Scenario Modeling Outcomes (Key Performance Measures).

ES.2 Conclusions

The scenario planning project identified two alterative scenarios that if adopted would put the region on a more sustainable development path than business as usual (the “trend” scenario). While the differences between alterative scenarios are small, they perform better than the trend scenario in almost every performance measure. Overall, the preferred and constrained scenarios also perform better than the other scenarios developed for the first two workshops. The greater development in core activity centers, key corridors, and increased transit investments under the preferred and constrained scenarios result in the least amount of driving and the smallest urban footprint, in-turn leading to less congestion, fewer GHG emissions, and less water consumption than other future scenarios. If funding constrains the development of the preferred scenario, the constrained scenario performs equally, and in some cases better (e.g., less water consumption, land development, and VMT per capita) than the preferred scenario.

While the alterative scenarios would decrease the growth in GHG emissions and reduce GHG emissions per capita, they would not keep them from growing beyond today’s level. The region’s growth will therefore continue to contribute to global climate change. The changes in regional development patterns and water consumption under the alterative scenarios will also make the region more resilient to climate change than business as usual; however, the region will become generally less resilient than it is today. The region’s development footprint will continue to grow, increasing urban heat, putting additional pressure on crucial habitat, and pushing new development in to areas at higher flood and wildfire risk. Water consumption will also continue to grow as the region’s population grows and new development also decreases the ability of rain to recharge ground water resources.

These conclusions highlight the regional benefits of adopting one of the alterative scenarios but they also highlight the challenge of accommodating a projected 52 percent increase in population by 2040. In the face of this population growth, more needs to be done to mitigate GHG emissions and increase resiliency. The project team identified additional GHG mitigation measure that the region or state could adopt that would further reduce transportation GHG emissions. The region could also mitigate climate change effects to urban heat, flooding, crucial habitat, and wildfire risk through a number of measures that could be implemented by individuals and governmental agencies.

1 INTRODUCTION

From 2013 to 2015, the U.S. Department of Transportation (US DOT) John A. Volpe National Transportation Systems Center (Volpe Center) and the Federal Highway Administration (FHWA) partnered with the Mid Region Council of Governments (MRCOG) to evaluate how the central New Mexico region could develop in a way that minimizes greenhouse gas (GHG) emissions and increases resiliency to climate change. MRCOG is the metropolitan planning organization for the central New Mexico region and is charged with regional transportation planning. The climate change scenario planning project coincides with MRCOG's process for updating the region's long range transportation plan, which identifies transportation investments and policies through the year 2040. The long range transportation plan is expected to incorporate strategies identified by the climate change scenario planning project. The project focused on identifying changes to land-use plans and policies and transportation system investments that could help meet these objectives. MRCOG, in consultation with stakeholders within the metropolitan planning area and through a series of public meetings, developed land-use and transportation planning scenarios for the region as well as a list of performance measures to comparatively evaluate each scenario. Facilitated by the Volpe Center, a group of representatives from several federal, state, and local agencies provided input and guidance over the course of the project.[1] With the assistance of the University of New Mexico (UNM) and Ecosystem Management, Inc. (EMI) consultant team (collectively the "project team"), MRCOG evaluated these scenarios for their effect on several of the performance measures including regional mobility, accessibility, GHG emissions, and resiliency to climate change. The project team's main tasks were assisting MRCOG with transportation and emission modeling and evaluating the performance and resiliency of each scenario using the output of several simulation and forecasting models.

The scenario analysis portion of the project and the project team's involvement began in March of 2014 (Figure 1). The project was divided into three active phases of scenario development and one final phase of reporting the overall outcome of the project. During each scenario development phase, MRCOG developed a set of alterative land-use and transportation strategies. The first phase also included developing a framework for evaluating each of the scenarios, including the models that would be used and the performance measures that would be calculated from their output. MRCOG created three preliminary year 2040 scenarios during Phase I. MRCOG and the project team evaluated the preliminary scenarios for their transportation performance, GHG mitigation potential, and resiliency to climate change and the results were presented to stakeholders at a workshop in July 2014. During phase II, MRCOG created a new set of refined scenarios based on the evaluation of the preliminary scenarios and feedback from workshop participants. MRCOG and the project team evaluated the new set of scenarios and presented the results at a second workshop in August 2014. Participants at the second workshop provided additional feedbacks that ultimately lead MRCOG to a final set of scenarios in Phase III. MRCOG and the project team evaluated the final set of scenarios during Phase III along with several additional GHG mitigation strategies not previously considered.

[1] A forthcoming guidebook, being prepared by the Volpe Center, discusses the role of this group in detail.

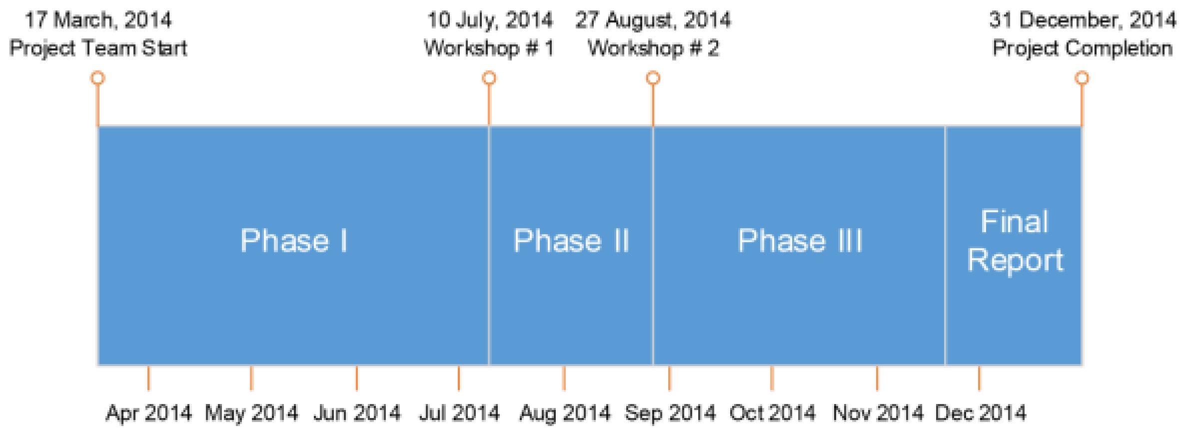

Figure 1. Project Timeline.

This report describes the development of the scenarios, modeling system, and other evaluation methods as they evolved through the course of the project. The report also summarizes the conclusions reached from the evaluation of the final set of scenarios. How are GHG emissions likely to change? Is the region likely to become more resilient? The final report draws on a series of technical memos created by the project team and reviewed by the Volpe Center, FHWA, and MRCOG to reach its final conclusions. To provide focus on the most important lessons learned and scenario outcomes, the full range of performance measures that were estimated and methodological details are left to the individual task memos and only the most critical information and details are included in this report.

2 METHODS

MRCOG with the assistance of the project team translated the conceptual land-use and transportation scenarios from phase I into an integrated land-use and travel demand modeling system. MRCOG and the project team then used the modeling system to evaluate how each scenario performed against a set of accessibility, mobility, safety, regional GHG emission, and climate change resiliency performance measures. The project team also used the modeling system to evaluate the GHG mitigation potential of several additional GHG reduction strategies that could be added to any of the land-use and transportation scenarios to achieve greater GHG mitigation.

2.1 Overview of MRCOG Modeling System

MRCOG and the project team used three primary modeling tools to evaluate changes in GHG emissions, mobility, accessibility and land development for each land-use and transportation planning scenario (Figure 2). Many of these metrics were then used to evaluate climate change resiliency. The modeling system contains a land-use simulation model, a travel demand forecasting model, and a vehicle air pollutant emission model. The output of each model serves as one of the primary inputs to the next model in the chain of models depicted in Figure 2. The links between each of the models creates an integrated modeling system that captures the dynamics between how changes in land-use patterns affect travel demand and how the transportation system affects land-use development, all of which ultimately determines accessibility, traffic congestion, and GHG emissions. Translating a conceptual land-use and transportation scenario into the modeling system requires providing data and specifying parameters for each of the individual sub-models as shown in Figure 2. The following sections describe the function of each sub-model component in more detail and how features of each scenario are carried over into the modeling system.

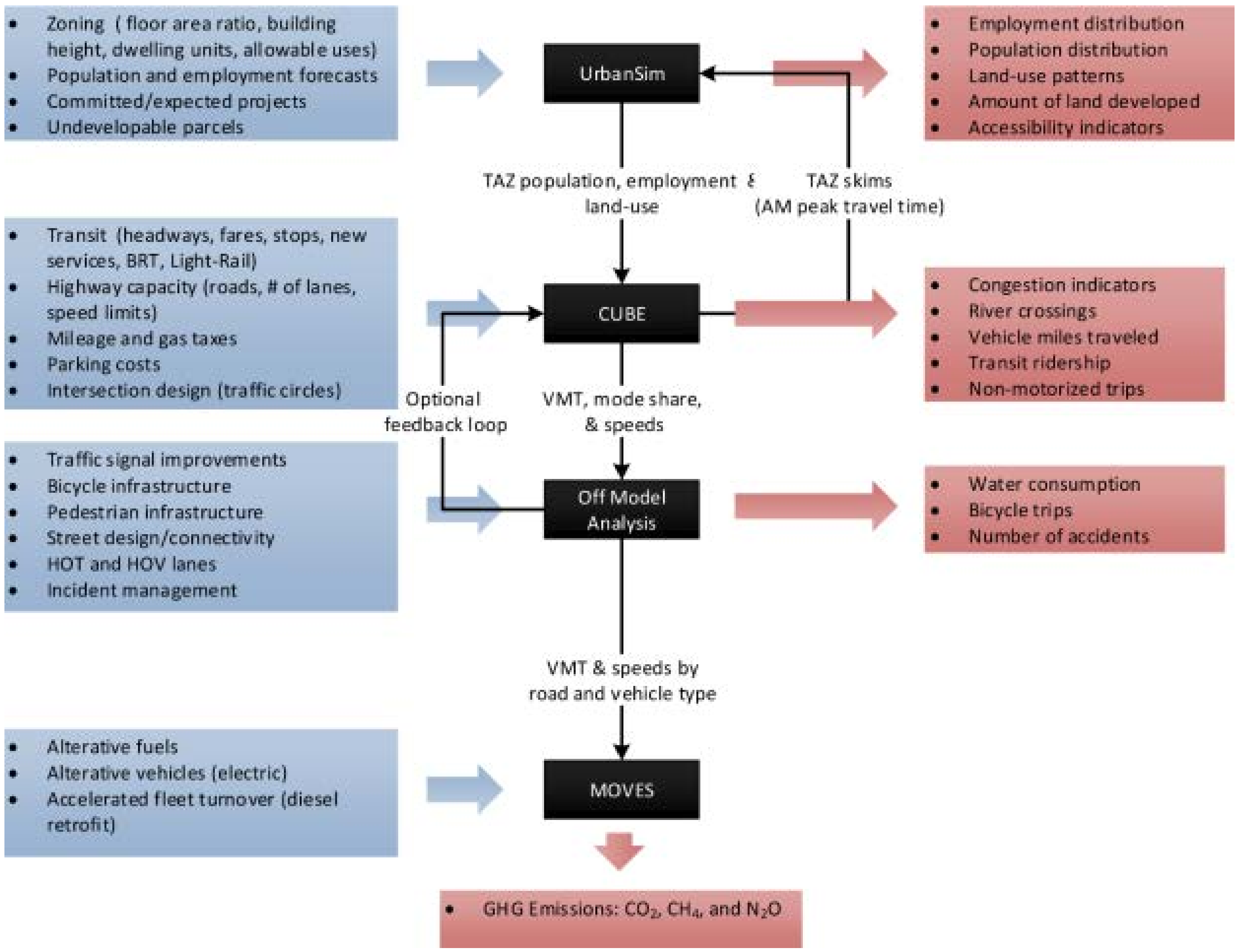

Figure 2. MRCOG Modeling System Overview and Scenario Inputs (blue) and Performance Measure Outputs (red).

2.1.1 Land-use Simulation Model—UrbanSim

The first step in this analysis uses UrbanSim, an agent based land-use model, to determine the future population, employment, and land-use mix in each parcel and transportation analysis zone[2] (TAZ). UrbanSim predictions are driven by estimates of land and housing values that depend on accessibility, land-use regulations (e.g., zoning), land availability, and the expected population and employment growth in the region. For example, parcels with greater accessibility are more attractive but will also tend to be more expensive; UrbanSim considers these types of dynamics in determining the probability of development for each parcel in the region.

To model the effect of accessibility, UrbanSim requires data from an external travel demand model (described in section 2.1.2). This dependence is indicated in Figure 2 by the feedback loop from CUBE to UrbanSim. Accessibility is derived from travel demand model network "skims" which provide a matrix of travel costs within and between each TAZ. MRCOG's current implementation of UrbanSim uses morning peak hour travel times as the cost input to measure accessibility. Initializing the modeling chain indicated in Figure 2 requires first running the CUBE model with the base year (2012) population, employment, and land-use mix for each TAZ to produce initial travel times. Subsequent year population,

[2] TAZs are geographical units similar to census tracks that are used to aggregate trip, land-use, and household characteristics for travel demand modeling

employment, and land-use mix are then simulated by UrbanSim to evolve the land-use and transportation system forward through the year 2040 forecasting horizon.

UrbanSim requires land-use regulations, land availability, and expected population and employment growth as inputs. MRCOG defined land-use regulations and land availability at the parcel level based on county tax records and other land-use data collected from local municipalities. MRCOG also provided future year population and employment growth projections. UrbanSim requires these projections to calibrate its own simulation of population growth. UrbanSim does not predict future regional population or employment but it models where this growth will occur and how it affects the mix of land-use.

Scenarios that aim to increase in-fill development, mixed use development, or transit oriented development, for example, are defined in the model system by changing UrbanSim land-use inputs. Municipal zoning allowances such as the maximum density, allowable uses (e.g., single family residential, commercial, industrial, etc.), or floor to area ratio (FAR) can be changed at the individual parcel level to promote these development objectives and evaluate their effect on MRCOG's performance measures, GHG emissions, and climate change resiliency.

Land-use and development can also be influenced by various policies and incentives; for example, reduced development fees for in-fill projects or reduced parking requirements. MRCOG's UrbanSim model cannot directly model the influence of specific policies and incentives on land-use and development. Instead, the model user can define "shifters" within UrbanSim that either increase or decrease the attractiveness of individual parcels. The magnitude of the shifters is ideally set to estimate the expected effectiveness of potential policies or incentive programs that may be considered. Policies and incentives could include expedited approvals, reduced permitting fees, density bonuses, reduced parking requirements, relaxed design criteria, tax increment financing districts, shared infrastructure costs, and reduced impact fees. MRCOG used shifters in this project to increase the relative attractiveness of parcels near activity centers, transit stops, and key transportation corridors over parcels located elsewhere. MRCOG staff set the shifter values at a level to reflect what they believe is achievable from a strong set of incentives that has not yet been defined. The logic in this approach was that MRCOG itself cannot create incentives or policies, which is up to municipal, county, and state governments, but they can demonstrate the relative level of incentive that would be required to achieve different land-use and development outcomes.

2.1.2 Travel Demand Forecasting Model—CUBE

MRCOG maintains a traditional 4-step trip based travel demand model implemented in Citilab's CUBE software. The travel demand model has four basic steps as the name implies. The first step predicts the number of trips produced in each TAZ based on the TAZ's population and housing characteristics and the number of trips attracted to each TAZ based on its employment and other non-residential land-uses such as retail and schools. The second step allocates the trips generated by each TAZ to other TAZs with the goal of matching supply (production) with demand (attraction). A gravity model distributes trips between TAZs based on the number of trips produced and attracted in each TAZ (i.e., the mass in the gravity analogy) and the generalized cost of travel between TAZs (i.e., the distance in the gravity analogy). The generalized cost of travel considers both out of pocket costs (e.g., parking and automobile operating costs) and travel time costs. The third step determines the mode(s) by which trips between each TAZ will take place using a nested logit model. The nested logit model is based on data from MRCOG's 1992 regional household travel survey, which provides information one the transportation modes used by individuals to make trips. The nested logit model predicts the probability of choosing each mode based primarily on vehicle ownership (none, 1, 2, 3+), which itself is estimated from household size and income, trip distance, and trip cost. The final step assigns trips to the physical transportation network and then calculates the resulting travel speed and traffic volume for each network link. Speeds are based on volume delay functions, which define the expected speed on a roadway link given its designed capacity, the predicted travel demand, and traffic control devices. The assignment procedures attempt to find a solution where no shorter paths are available for any trip accounting for the fact that travel times change as additional trips are added to each link.

MRCOG and the project team defined the elements of each scenario that include changes to the physical transportation system (e.g., adding new roadways or transit lines) or policies that affect travel costs (e.g., taxes and fees) in CUBE. CUBE contains a geographic information system that allows users to define new roadways and transit systems or change their attributes (e.g., number of lanes, speed limit, service frequency, etc.). Changes to the cost of using various transportation modes can also be changed. For example, the per mile cost of driving can be changed as can the cost of parking in different areas of the region. Bus fares can also be changed.

2.1.3 Integrated Land-use and Travel Demand Modeling

As indicated in Figure 2 and explained above, UrbanSim and the CUBE travel demand model can work together to model the interaction between land-use and transportation systems. Many elements of the climate change planning scenarios developed through the Central New Mexico Climate Change Scenario Planning Project are modeled by altering the input or parameters of these two models as indicated by the blue boxes in Figure 2. Zoning and other land-use regulations can be changed to accommodate infill and transit oriented development and urban growth boundaries can be implemented by restricting land-uses around the periphery of the urban area. These land-use policies can be modeled by changing input files provided to UrbanSim. UrbanSim will simulate new distributions of population, employment and land-use mix by TAZ, which then become the basis of traffic forecasts made in the CUBE model. The physical roadway and transit networks in the CUBE model can be edited to include new or expanded roadways or transit systems as well as changes to those systems such as speed limits, transit headways, and basic traffic control systems. Changes to these parameters affect mode choice, trip routing, and trip length calculations, which influences congestion levels but not the overall number of trips. When the model skims from the current CUBE modeling run are fed back to the UrbanSim model, updated population, employment, and land-use data is generated that are then fed back into the CUBE model for the next time period, which then affects the number of trips generated by CUBE.

The interaction between the land-use and travel models captures the complex dynamics between the two systems. In the first phase of this project, the two modeling systems were not fully integrated. CUBE was run first using the base year (2012) scenario to initialize UrbanSim, which then projected population, employment, land-use, and development from 2012 out to the year 2040. The 2040 model results, aggregated by TAZ, were then used by CUBE to estimate 2040 travel demand. The lack of iteration, that is running the model for at least one interim year between 2012 and 2040, in the first phase means that rising congestion levels and changes made to the transportation network over time are not accounted for in the calculations made by UrbanSim to determine the relative attractiveness of each parcel. Since congestion is expected to increase, this limitation biases the modeling results towards a forecast that has relatively greater fringe development because the cost of longer trip distances is under estimated. Phases II and III included an intermediate iteration step for the year 2025. Testing by MRCOG indicates that the iteration step had the expected effect; development was more concentrated in the center of the region, particularly in eastern Albuquerque where there is the least amount of traffic congestion. A greater number of iterations would likely improve the analysis; however, each iteration also requires defining a roadway network specific to the iteration year. With the exception of a 2025 network, additional intermediate year networks were not available and there was not enough time to create these for this project.

2.1.4 Off Model Analysis

The current implementation of the MRCOG model in CUBE includes only limited functionality for modeling bicycle or pedestrian trips. While the model does consider walk trips necessary to complete a transit trip and lumps other walk and bicycle trips into a single non-motorized category, it is not sensitive to any of the bicycle or pedestrian strategies being considered by MRCOG. These strategies include expanding the bicycle facility network (bicycle lanes, multi-use paths and bicycle boulevards), a potential bike share program, increasing street connectivity, and a complete streets policy. Improving the modeling system would require developing new discrete choice models, which would require collecting new survey data, extensive data analysis, and re-coding CUBE modeling scripts. These tasks are far outside the scope and timeframe of the current project. Similarly, the current MRCOG travel demand model has only limited ability to consider different types of traffic signal controls. Modeling of various intelligent transportation strategies (ITS) strategies is not possible. The current MRCOG travel demand model is also not well suited for analyzing high occupancy toll (HOT) lanes and other managed lane strategies. While CUBE can model these, it would require extensive model development work and data collection efforts that fall outside the scope of work and time frame for this project.

While some transportation system attributes, travel modes, and policies cannot currently be modeled in CUBE, they can be considered in an "off-model" analysis or "post-processing" as shown in Figure 2. The project team used off-model and post-processing to evaluate several additional GHG mitigation strategies that were not included in the scenarios developed by MRCOG. Off-model analysis and post-processing refer to various analytical methods and supplemental modeling that may be necessary to make up for limitations in MRCOG's current travel demand model or further process the results to estimate the desired performance metrics. For example, the number of trips estimated on each link can be adjusted to account for trips that are likely to be made by bike based on application of mode choice elasticities derived from prior studies. Similarly, the predicted travel times can be adjusted to account for improvements made by implementing various ITS strategies. The amount of improvement could be estimated by applying adjustment factors based on prior research findings or the region's own experience on Alameda Boulevard. There are many options available for off-model and post-processing analysis of specific network design features and policies. The application of specific off-model and post processing methods depend on data availability, time constraints, and the specific policies or strategies that each scenario includes.

1. Integrated off-model analysis. In this approach the existing modeling system is supplemented with additional calculation steps. These additional calculations adjust for known model limitations. Intermediate modeling results are intercepted and adjusted using correction factors derived from prior case studies and the scientific literature and then inserted back into the modeling system.

2. Post-processing. In this approach, model output is adjusted to correct for a known limitation, usually the lack of sensitivity to the strategy being considered. The modeling system is not supplemented in any way but more simply the final output is adjusted using correction factors derived from prior case studies and the scientific literature. This is generally a less robust method than integrated off-model analysis but in some cases necessary given the modeling system, data limitations, and the project timeline. Post-processing methods are very common and correction factors (elasticities) are widely available. Post processing is also used to estimate additional project performance measures from the model output; for example, water consumption.

3. For some strategies, the modeling system is completely insensitive to the strategy and there is also not enough scientific evidence available to perform integrated off-model analysis or post-processing. In these cases, the expected efficiency (magnitude of effect) and effectiveness (direction of effect or likelihood of success) of the strategy is discussed qualitatively or with a small hypothetical example based on a review of currently available scientific literature.

2.1.5 Vehicle Emission Modeling—MOVES

At the outset of the project, MRCOG did not have a vehicle emission model for the region. The project team set up the United States Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) model to estimate GHG emissions for each scenario. The main factors affecting vehicle emission rates are traffic volume and speed as well as the type of vehicles that make up the regional vehicle fleet. Traffic volume and speed data are provided by the travel demand model output.

Currently, there is no local information to define a regional vehicle fleet for the MRCOG region or New Mexico. While MRCOG and the project team did eventually gain access to New Mexico vehicle registration records, there was not enough time left in the project to evaluate them and update the MOVES model. As a substitute for this local information, the Austin, Texas, metropolitan area vehicle fleet is used. The Austin vehicle fleet was chosen based on consultation with the City of Albuquerque's Environmental Health Department, which has used this dataset in its previous regional air quality studies. The dataset was created by Sonoma Tech for the city to evaluate the air quality impact of its vehicle inspection and maintenance program.

The project team ran the MOVES model to provide output that includes the gram per mile emission rate for carbon dioxide (CO2), methane (CH4), and nitrogen dioxide (N2O) for a range of speeds for each roadway type (limited access/unrestricted access rural and urban roadways) for typical winter and summer weather conditions. The project team averaged the summer and winter modeling results to estimate annual average emission rates. The project team then formatted the MOVES model output into a lookup table. Based on roadway type and average speed, the project team assigned emission rates from the lookup table to each roadway link in the travel demand model output and multiplied by the link's traffic volume to calculate the total daily quantity of emissions for each roadway link. The project team then calculated a regional emission inventory by summing up the link level emissions.

The MOVES model could also be used to evaluate how changes in the vehicle fleet or the use of lower carbon fuels affect GHG emissions. These changes can be accomplished by defining alterative vehicle fleets or changing the pace at which the models replace older vehicles with newer and more efficient vehicles. The project team did not consider these strategies in this project, which was focused on land-use and transportation planning strategies that are generally within the control of regional and local governments.

2.2 Additional GHG Mitigation Strategies

MRCOG provide the project team with a descriptive list of potential GHG reduction strategies. Some of these strategies became features of the scenarios that were developed by MRCOG. The project team considered additional strategies separately using a range of post processing and off model analysis, which are described in more detail in section 4.

2.3 Resiliency Evaluation

Resiliency refers to the ability of a system to withstand a shock. A recent executive order defines resiliency to climate change more specifically as the "…ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."[3] During the first phase of the project the project team performed a literature review to determine how climate change may affect the region and what actions could be performed to increase the region's resiliency to potential climate change impacts.

While the task 1.2 memo provides a long list of resiliency considerations, only a subset were used to evaluate each scenario's climate change resiliency. The reason for this limited assessment of resiliency is

[3] 11/1/2013 Executive Order --Preparing the United States for the Impacts of Climate Change

that the scenarios are largely conceptual and regional in scope and therefore do not provide detail about specific design considerations that may make particular scenarios more or less resilient to climate change. For example, the scenarios do not indicate if permeable pavements will be used to reduce runoff and improve ground water recharge or if new bridges may be designed to withstand larger floods. The resiliency analysis of each scenario is based solely on the features of each scenario defined by MRCOG and what can be measured with the modeling system. Accordingly, the resiliency evaluation is an assessment of how regional land-use plans and major transportation infrastructure decisions affect resiliency; for example, how much land is developed in areas at greater risk of floods and wildfires that could become more frequent and severe. While not a comprehensive assessment of the region's climate change resiliency, evaluating how large scale, long-term plans, and long-lived infrastructure projects affect the region's resiliency can help identify scenarios that place the region on a more resilient foundation going into the future.

MRCOG and the project team also evaluated the resiliency of each scenario with respect to the predicted change in the metropolitan area's climate. The Volpe Center provided analysis based on downscaled coupled model intercomparison project phase 3 (CMIP3) climate data and divided the model runs into five "climate futures" (Figure 3). This analysis indicates that the region is likely to become warmer with more frequent and longer heat waves. The modeling was less certain about precipitation. The region is slightly more likely to receive less precipitation but is also expected to become drier even if there is more precipitation because of higher temperatures, which will increase evapotranspiration. Greater precipitation could, however, still increase flood risk even if it does not increase water supply. Figure 4 shows estimated temperature and precipitation changes for each of the five potential climate futures.

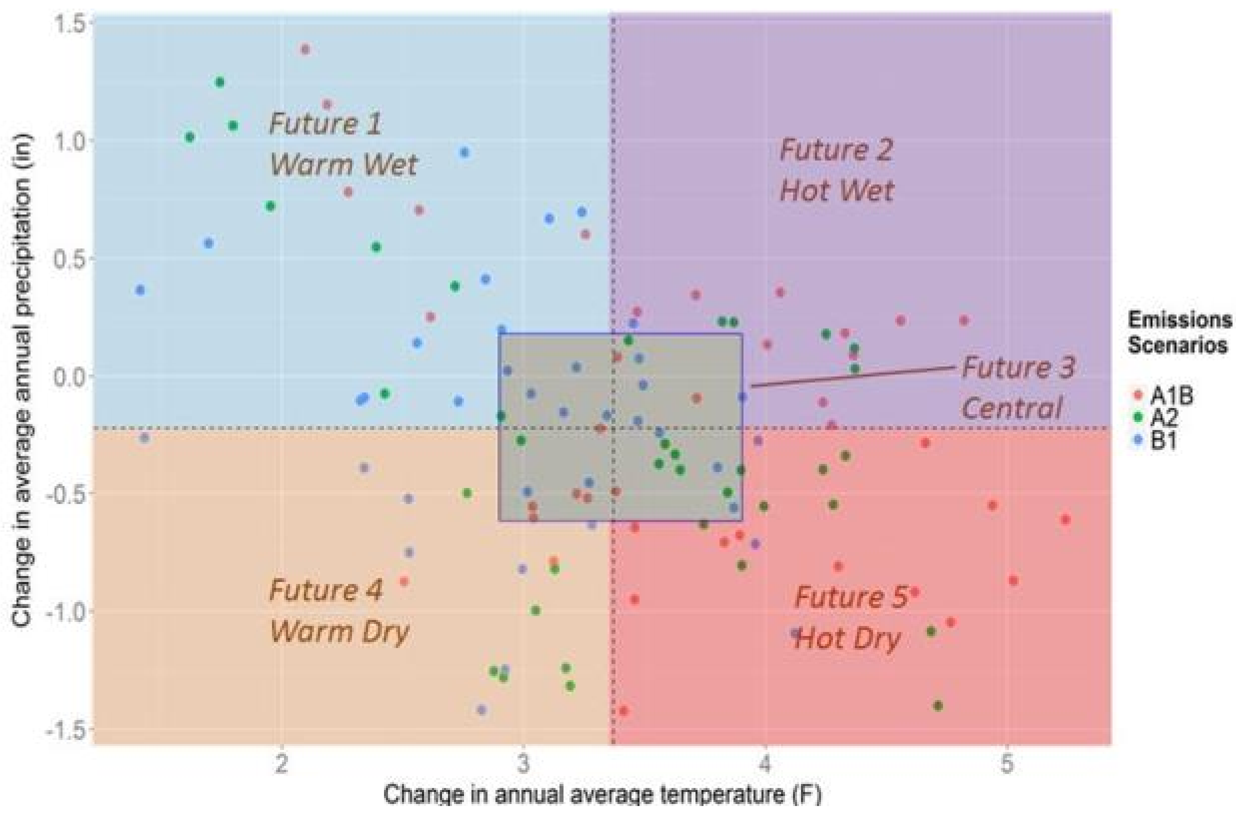

Figure 3. Summary of Global Climate Model Runs for the Year 2040 for Central New Mexico. (Source: Volpe Center).

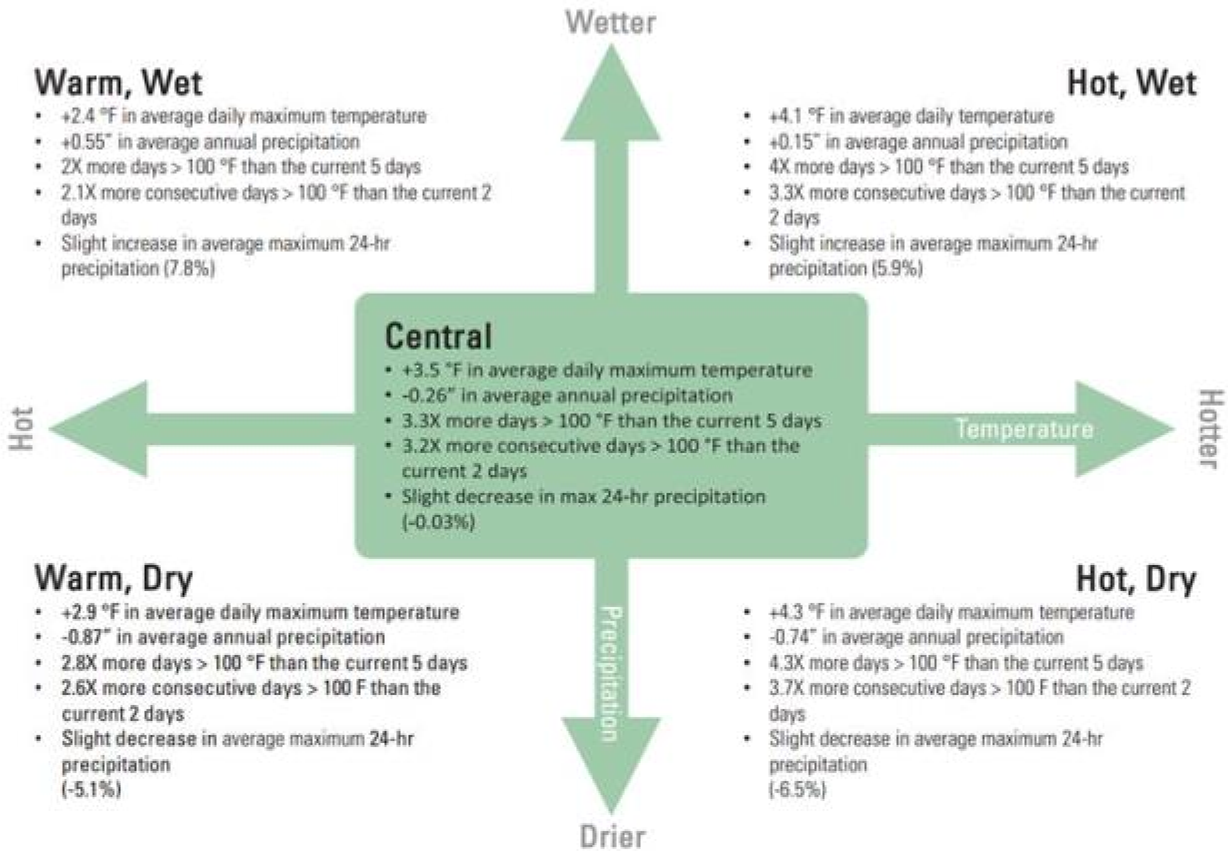

Figure 4. **Summary of Climate Change Futures for the Year 2040 for Central New Mexico. (Source: Volpe Center).**

Figure 4 provides a summary of climate change futures for the Year 2040. The project team evaluated each land-use scenario for its resiliency to an expected increase in temperature and the potential for a drier climate where there will be prolonged drought and also the potential for greater precipitation that could increase flood risk. The project team considered resiliency along five dimensions: flooding, drought, urban heat, wildfire, and crucial wildlife habitat. Mitigation strategies for risks associated with each of these dimensions are listed in text boxes as part of each of the following discussions.

2.3.1 Flood Risk

Decisions about the location of development and the design of transportation facilities and buildings in addition to the density of development will affect flood damages and therefore flood resilience. Flooding in Albuquerque, the most populous part of the region, originates from the Rio Grande and/or from high-intensity short-duration thunderstorms, which create relatively high peak flows but low volumes of water (New Mexico Floodplain Managers Association 2003). Flood risks in Sandoval and Torrance Counties are also generally related to extreme rainfall events. Valencia County had historical problems caused by the Rio Grande, but these have been resolved following levee construction. Flood risk is greatest in low lying areas and areas near arroyos.

Evaluating how changes in land-use and development and the location of transportation infrastructure will affect flood risk was one of the most challenging tasks the project team faced. While climate change may increase the frequency and intensity of rainfall events, how these events change flood risks in any particular location is extremely complex and subject to many uncertainties. In most parts of the region, developed areas are protected by various flood control infrastructure. If climate change results in more intense rainfall events, there may be little change in flood risk if the existing infrastructure can accommodate the change in intensity. The ability of flood control infrastructure to protect against more intense storms is very likely to vary across the region. In fact, some areas experience periodic flooding under existing conditions.

The project team held a meeting with the region's water resources and flood control experts[4] to gain a better understanding of how to consider flood risks on a regional scale. Two major research tasks were identified. The first task requires developing rainfall event predictions from the climate models that reflect the type of events the region designs its infrastructure to accommodate–high intensity short duration storms. The CMIP3 climate model used by the Volpe Center estimates the intensity of 24 hour rainfall events while the region evaluates and designs for flood risks against the 100 year 6 hour event. The CMIP3 model is useful for generating a general view of how climate change may affect the region, but is insufficient for a detailed analysis of flood risks. The second task involves translating higher intensity rainfall events into flood inundation forecasts using hydraulic models developed by each flood control agency. This analysis requires detailed modeling of each stream, channel, and flood plain on a case by case basis. The resources to complete this level of flood risk assessment is well beyond what could be accomplished within this project so the project team in consultation with the flood risk experts developed a simplified approach.

The simplified approach considers how much development and transportation infrastructure is developed within existing flood plains. Existing flood plains were defined as FEMA 100-year floodplains. Without being able to actually model the hydraulics of individual streams and channels, and with a large amount of uncertainty surrounding the intensity of future precipitation events, this approach provides the most justifiable approach. FEMA floodplains are defined to represent areas that are at higher flood risk. Logically, these are areas that would be at even higher risk should climate change bring more intense rainfall events or other outcomes that increase flood risk such as more rapid melting of mountain snowpack. All other approaches considered by the project team, such as estimating flood risk based on distance from a flood plain, required assumptions that were determined to be indefensible and unreliable. One major limitation of using existing floodplain maps is that more intense rainfall events could result in floods occurring beyond existing floodplain boundaries. Unfortunately, there was no reliable way to predict where this could occur. Additionally, 100-year floodplain maps do not indicate which areas are at relatively higher or lower flood risk.

The project team used 100-year FEMA floodplain maps to evaluate each scenario by overlaying floodplain boundaries with UrbanSim land-use predictions and calculating the amount of new development occurring in existing floodplains. Scenarios with more development in flood plains are considered less resilient.

While a more robust flood risk approach was beyond the scope of our analysis, the Southern Sandoval County Arroyo and Flood Control Authority (SSCAFCA) provided MRCOG and the project team with an example of what a more detailed analysis would look like (Schoener, n.d.). SSCAFCA modeled the change in the peak flows and inundation that would occur along the upper Calabacillas Arroyo (Figure 5) if rainfall for the 24-hour 100-year design storm increased by 10 percent and 25 percent. These increases are hypothetical since SSCAFCA, like the project team, did not have the resources to complete a robust analysis of how global climate change may affect the 100-year design storm. Using these assumptions, SSCAFCA modeled the change in peak flows and inundation using a hydrologic model recently developed by SSCAFCA and the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA). The results indicated that a 10 percent increase in precipitation from the 24-hour 100-year design storm results in a 25 percent increase in peak flows in the arroyo while a 25 percent increase in

[4] Dr. Mark Stone (UNM), Dr. Ricardo Gonzalez-Pinzon (UNM), Dagmar Llewellyn (Bureau of Reclamation), and Dr. Jesse Roach (Sandia National Laboratory at the time of the project)

precipitation from the 24-hour 100-year design storm results in a 75 percent increase in peak flows. In the Calabacillas arroyo, the large increase in peak flows would result in larger flood plains that could inundate nearby homes and Southern Boulevard (Figure 6). These results demonstrate the type of analysis that is possible with more resources and how a relatively small change in extreme precipitation events can sometimes cause a disproportionally large increase in flooding. It is important to note that each watershed, arroyo, and flood control channel would respond differently to changes in precipitation due to local conditions such as topography and hydraulic structures (e.g. culverts and bridges) and that generalizations should not be drawn from this example. Instead, each watershed, arroyo, and channel would need to be evaluated individually.

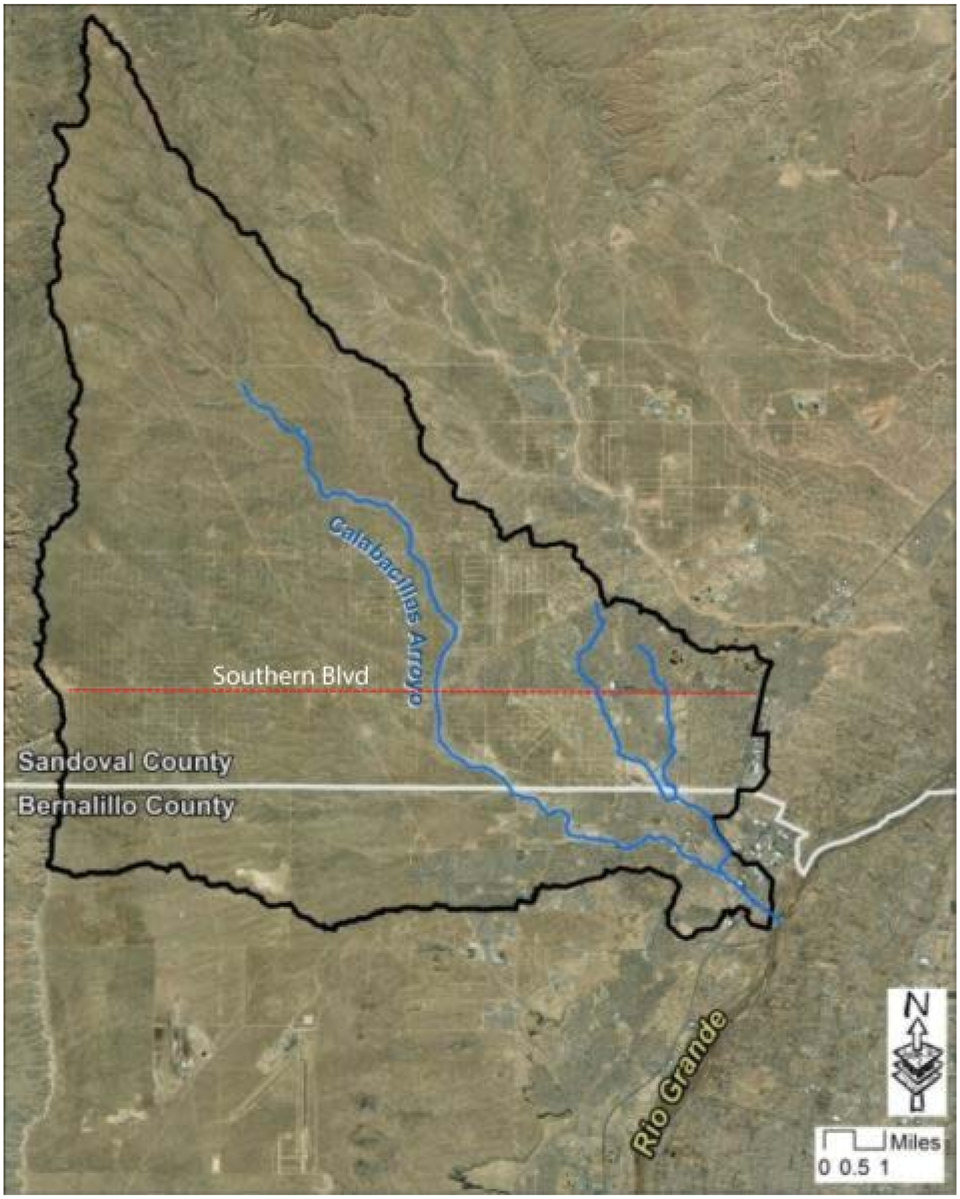

Figure 5. The Calabacillas Watershed (black outline) drains to the Rio Grande from the west. (Source: Schoener, n.d.).

Figure 6. Existing 100-year floodplain (blue) in the Calabacillas Arroyo north of Southern Blvd. Yellow and red lines indicate the estimated flood plain extents for 10 percent and 25 percent higher precipitation in a 24-hour period. (Source: Schoener, n.d.).

The project team also evaluated which roads within the Albuquerque Metropolitan Planning Area (AMPA) are currently built in or over existing 100-year flood plains. The project team used the New Mexico Department of Transportation's (NMDOT) geographic information system (GIS) roadway network layer to evaluate flood risks. Future road networks developed for each of the scenarios were not evaluated since they are a simplified representation of the actual road network and would therefore not accurately align with the many narrow flood plains in the region. There is also very little difference between each of the scenario road networks. This analysis indicates which roadway segments may be at greater flood risk if climate change results in more precipitation or more extreme precipitation events. One limitation of this analysis is that it does not distinguish between roads in flood plains and those built on structures (bridges) above them. Furthermore, not all road segments in a flood plain are at equal risk. Flood risk mitigation strategies are listed in the textbox below.

Flood Risk Mitigation Strategies

- Do not build in the floodplain to improve flood resiliency.
- Acquire land or conservation easements to allow for stormwater absorption and arroyo channel adjustments.
- Direct mitigation of peak flows and volumes using stormwater retention (wet ponds), detention (dry ponds), and subsurface stormwater storage.
- Increase the number of communities participating in the Community Rating System (CRS). The CRS reduces flood insurance rates in exchange for a community conducting certain flood hazard reduction activities that are beyond the minimum national standard for floodplain management.
- Reduce fuel loads in critical watersheds to lessen frequency and severity of wildfires that cause floods and debris flows that enhance flooding.
- Utilize green infrastructure techniques including permeable pavements, bioswales, and downspout connections.
- Plant vegetation that can tolerate inundation.
- Repair bridges, culverts and levees.

Table 1 shows the percent change in development in the floodplain in the scenarios versus development in 2012. There is a decrease in buildings in the preferred scenario compared to the trend scenario and an increase in households and employment in the preferred scenario compared to the trend scenario.

Table 1. Scenario Development in Floodplain vs. 2012 Percent Change.

Scenario	Households	Household Population	Employment	Total Units	Non-residential Square Feet	Buildings	Total
Trend	49.3%	49.6%	37.8%	50.2%	45.1%	44.2%	53.0%
Constrained	51.7%	52.0%	44.2%	51.4%	50.2%	36.9%	50.0%
Preferred	50.6%	50.9%	44.0%	49.5%	50.7%	37.4%	47.0%

The project team calculated the average population density of the floodplain area per acre for each scenario by dividing the total number of people projected to be living in the floodplain area under each scenario by the total number of acres in the floodplain area (Figure 7). The trend scenario has 0.0006 more people per acre living in the floodplain area compared to the preferred scenario.

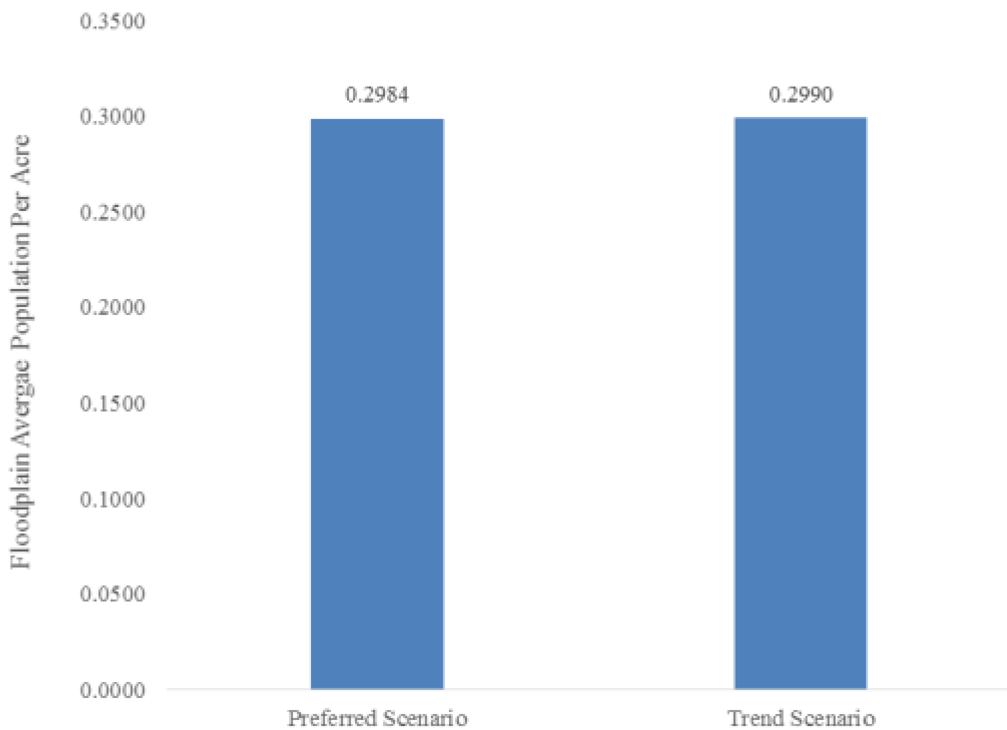

Figure 7. Floodplain Average Population per Acre.

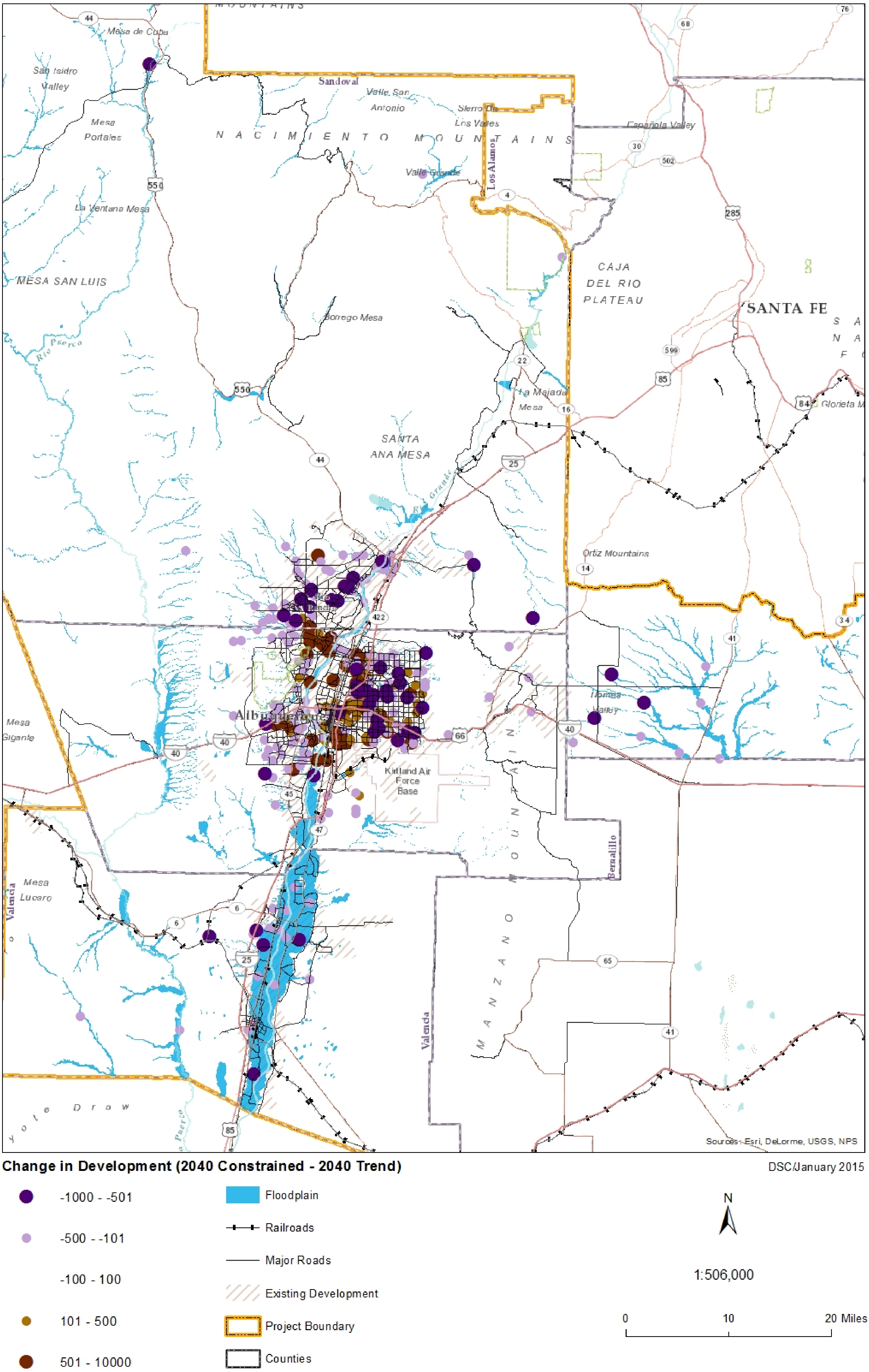

Figure 8. Floodplains Constrained vs. Trend Map.

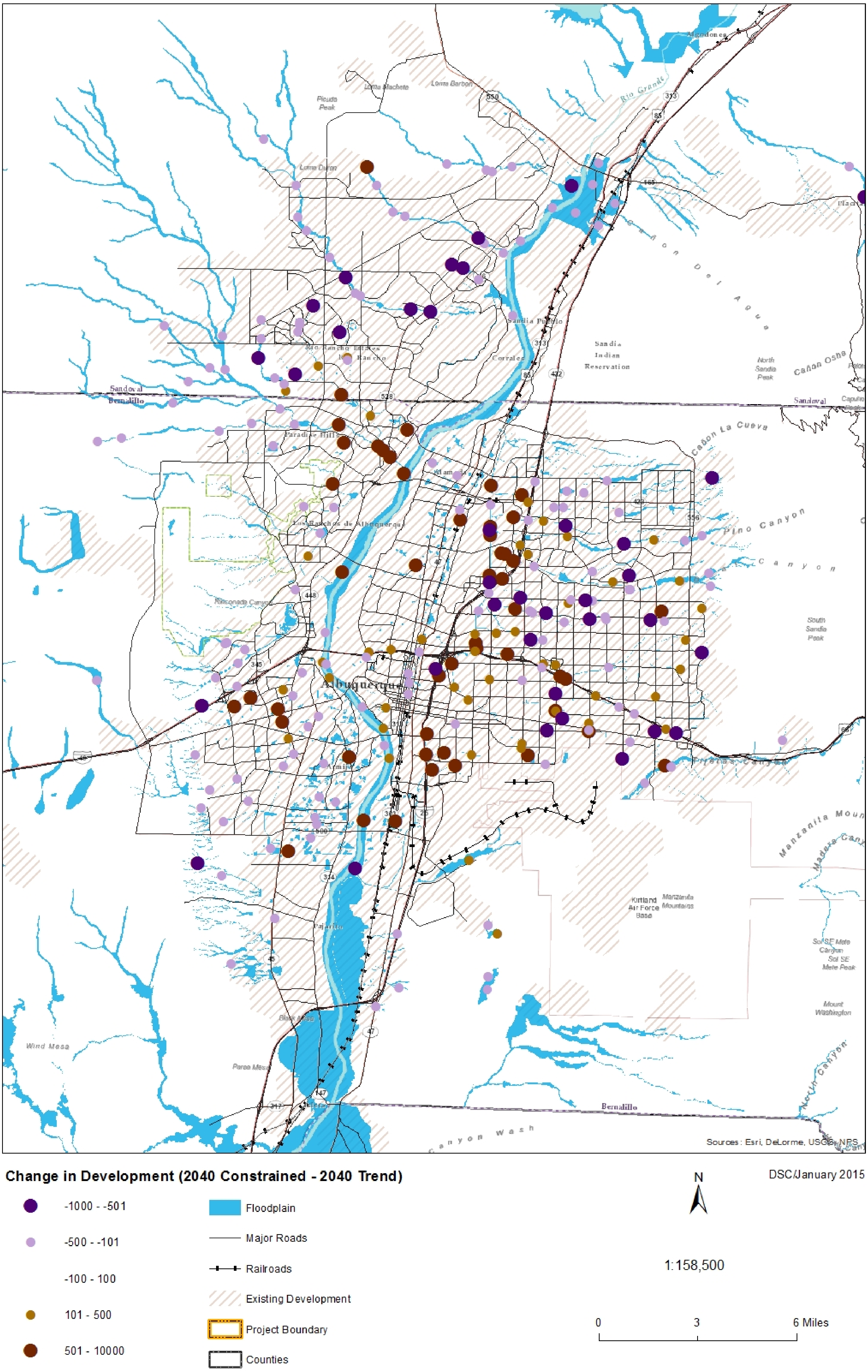

Figure 9. Floodplains Constrained vs. Trend Map Focusing on Albuquerque, NM.

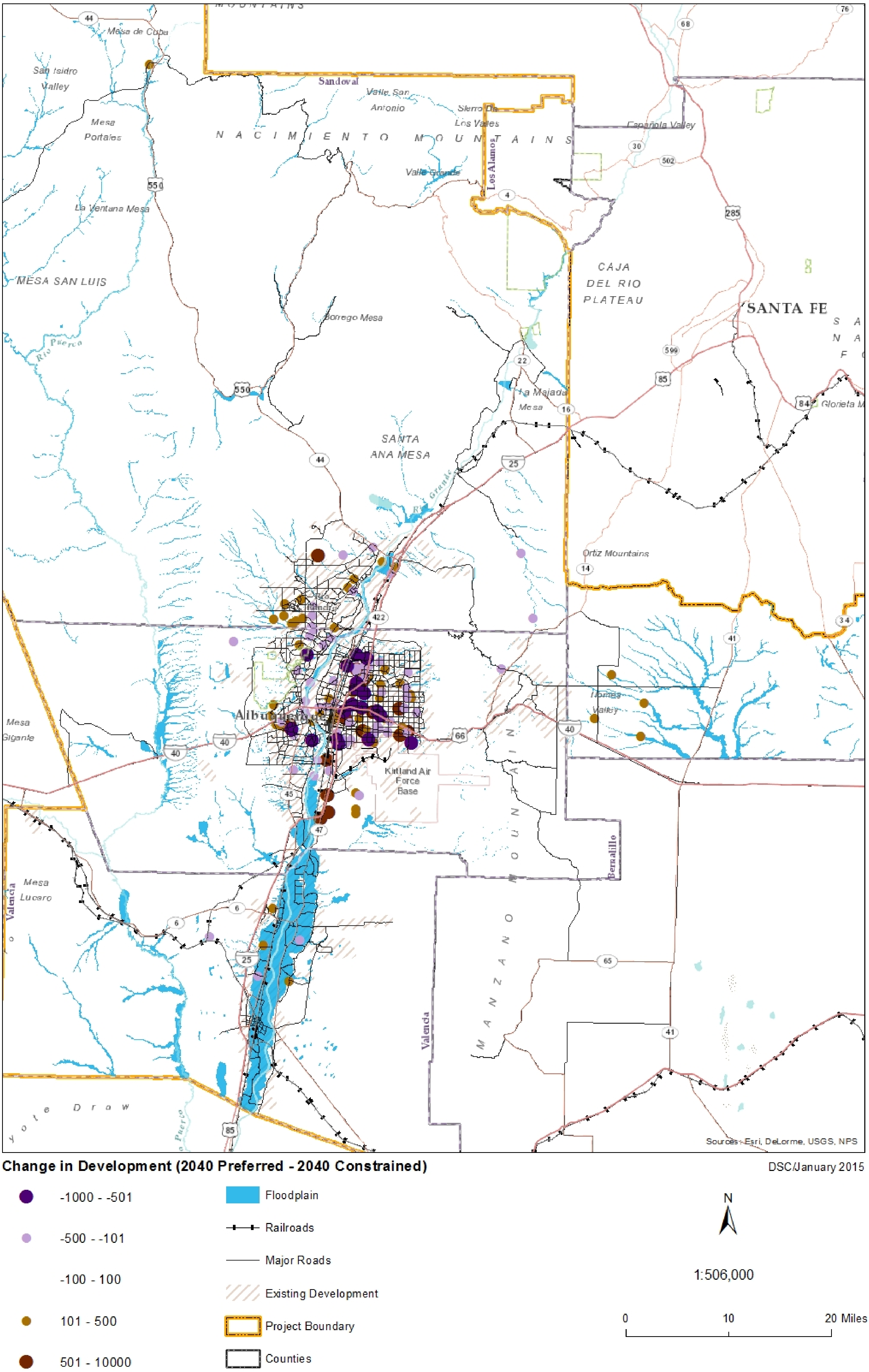

Figure 10. Floodplains Preferred vs. Constrained Map.

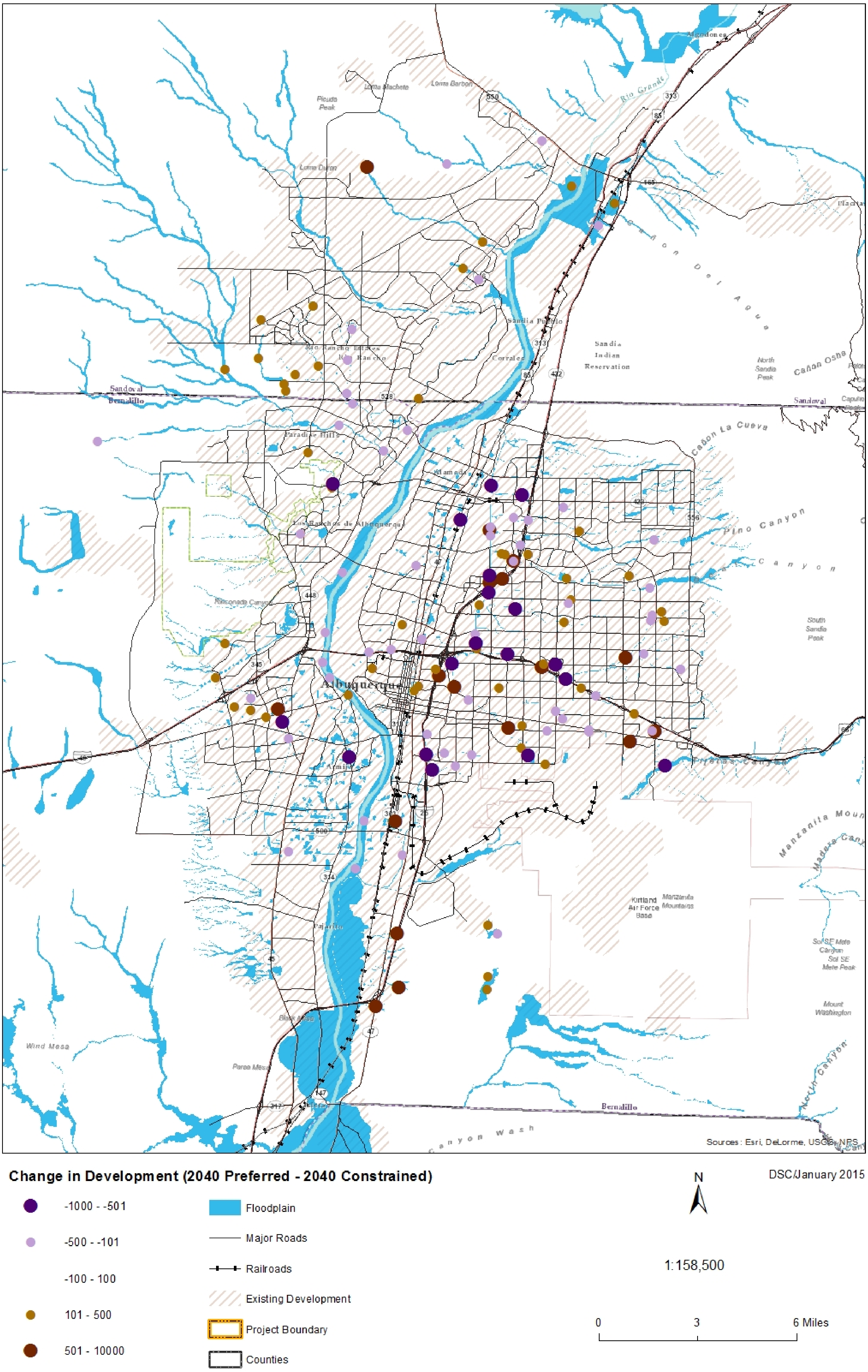

Figure 11. Floodplains Preferred vs. Constrained Map Focusing on Albuquerque, NM.

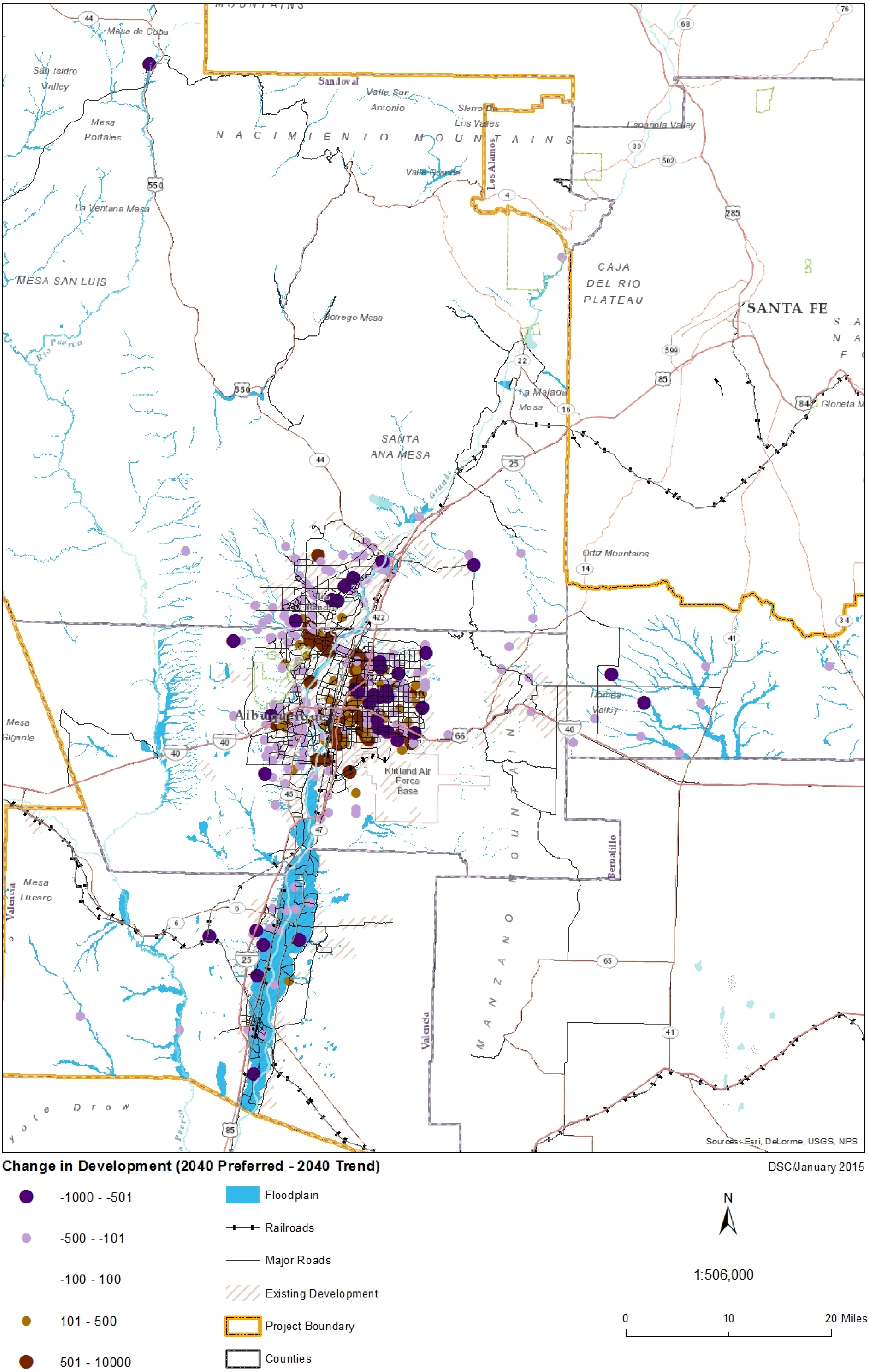

Figure 12. Floodplains Preferred vs. Trend Map.

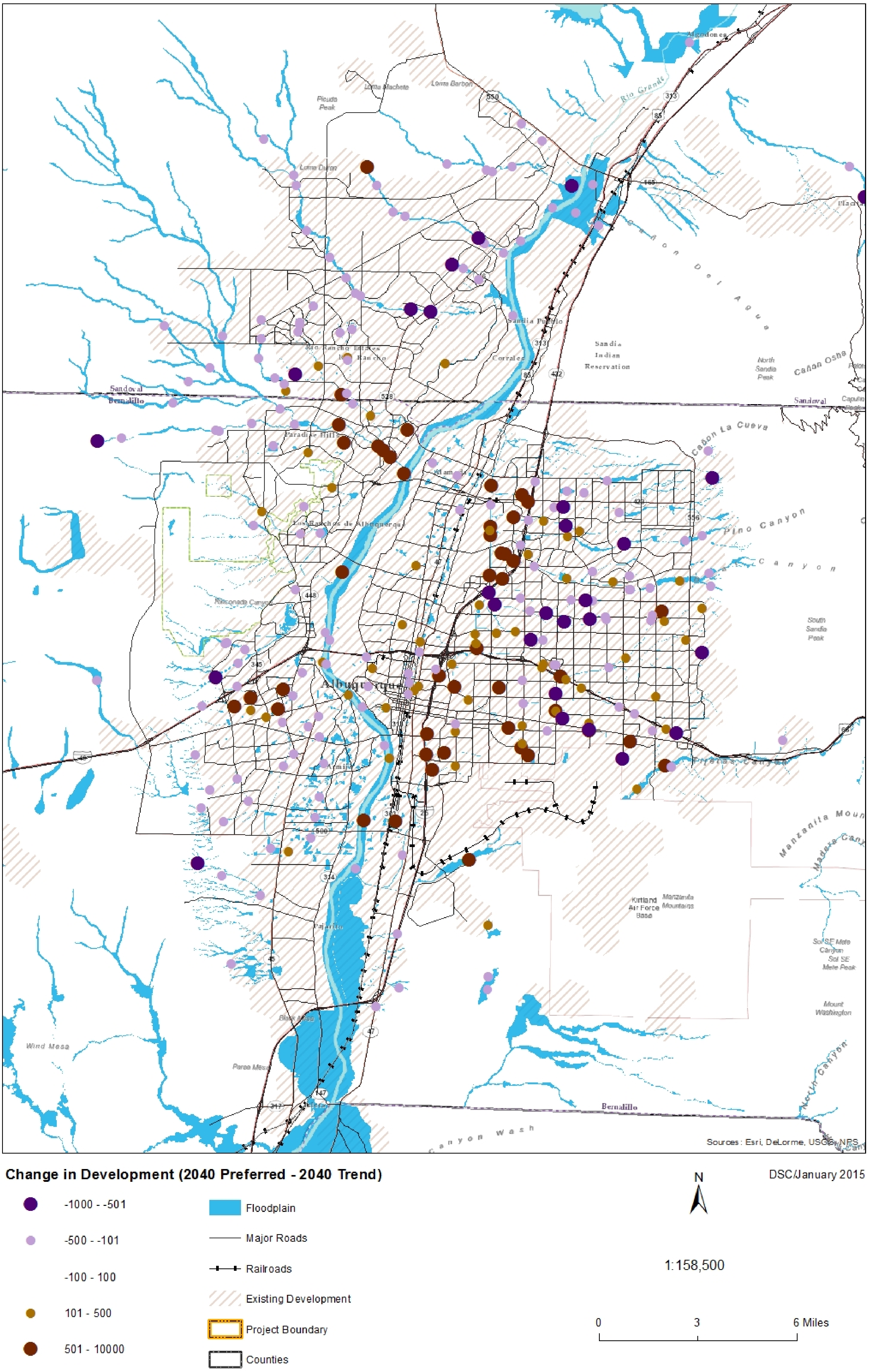

Figure 13. Floodplains Preferred vs. Trend Map Focusing on Albuquerque.

2.3.2 Drought

While less precipitation is slightly more likely than more precipitation in future years, increasing temperatures are likely to increase drought conditions and limit water availability under any of the potential climate futures. In spite of the uncertainties regarding precipitation trends, streamflows on rivers that supply a large portion of the region's water are expected to decrease dramatically as increased temperatures accelerate the evapotranspiration of the landscape and the evaporation of water bodies. A report by the Bureau of Reclamation concludes that by the year 2100, flows in the Rio Grande are expected to drop by approximately one-third and water supplied via the San Juan-Chama Diversion Project is expected to drop by approximately one-quarter (Llewellyn and Vaddey 2013). A reduction in surface water supplies will likely result in greater demand on ground water resources; however, historically ground water use in the region has been unsustainable as the volume being withdrawn far exceeded the rate at which aquifers were recharged. As land development continues, a greater extent of impervious surfaces (e.g., paved surfaces and buildings) will further limit the rate that ground water resources can be replenished by rainfall.

Each of the future land-use scenarios can be evaluated for their resiliency to drought in two ways: their effect on water supply and their effect on water consumption. The main land-use factor affecting water supply is the development footprint of the metropolitan area. Impervious surfaces such as buildings and paved roadways decrease the amount of land-area available for rain water to penetrate the surface and replenish ground water resources. At the scale of this analysis, there is no information describing parcel level features that may decrease or increase ground water resources, such as permeable pavements or rainwater catchment or retention systems (e.g., bioswales). Additional drought mitigation strategies are listed in the textbox below. Resiliency to drought as it relates to changes in water supply is therefore evaluated by the amount of land developed in each scenario. Scenarios with more acres of developed land are considered to be less resilient since they will place greater limits on ground water recharge.

Drought Mitigation Strategies

- Use permeable pavements
- Design roads and storm water infrastructure to slow water run off speeds
- Landscape with native , drought tolerant, vegetation
- Implement water harvesting techniques
- Repair leaks in irrigation systems
- Avoid outdoor watering during hottest part of the day
- Eliminate runoff from property and reduce overspray from sprinkler systems
- Convert high-water using plumbing and fixtures with low-flow fixtures
- Avoid washing sidewalks and parking lots
- Require restaurants to provide water only upon request.
- Reuse dishwater, show water and rinse water for watering plants.

The main factor affecting water consumption is land-use. Commercial, industrial, agricultural, and residential land-uses consume more water than unirrigated range lands and undeveloped land. The project team evaluated water consumption data from the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) and the New Mexico Office of the State Engineer to create water consumption rates for each major category of land-use. These water consumption rates were then used to estimate the total water consumption of each scenario based on the amount of land developed by each land-use category that was predicted by UrbanSim.

The agriculture water consumption rate was obtained from the Task 1.1 memo and is based on the total reported year 2010 irrigated agricultural water withdrawals from the New Mexico Office of the State Engineer for Bernalillo, Sandoval, and Valencia counties. The amount of irrigated agricultural land in each of these counties is estimated from parcel level land-use data provided by MRCOG. Torrance County is excluded because the land-use data was previously determined to be unreliable (see Task 1.1 memo for details). The water consumption rates for the remaining land-uses are based on year 2013 water uses account data provided by the ABCWUA.

The project team evaluated the database of water use accounts provided by ABCWUA which was linked to parcel level land-use data by MRCOG to determine how water consumption varied by land-use, lot size, and year of construction. One limitation of the ABCWUA database is that data describing the year that structures were built is very sparse and only available for certain date ranges. More complete data is available about the date that the water system serving each parcel was built; these are the date data used in the following analysis. The water consumption rate of industrial, institutional, and commercial land-uses were not evaluated by date because there were too few data points to reliably investigate differences over time.

Figure 14 summarizes the water consumption data from the ABCWUA database. There are three main observations. Residential land-uses use much more water than the other land-uses, there is a very large range of water consumption rates, particularly for residential uses, and the distribution of water consumption rates for the non-residential land-uses is highly skewed towards higher values. The ABCWUA data indicate a very wide range of water consumption rates, which is expected given the wide range of potential industrial, commercial, and institutional activities that can take place on each parcel. This range is apparent in Figure 14, most non-residential land-uses appear to use relatively little water while a few consume much more. The wide range of residential water consumption rates is likely driven by differences in the amount of irrigated landscaping around each residential structure as well as the number of residents in each household. Differences in the efficiency of water-using appliances could also explain some of the range observed in the data.

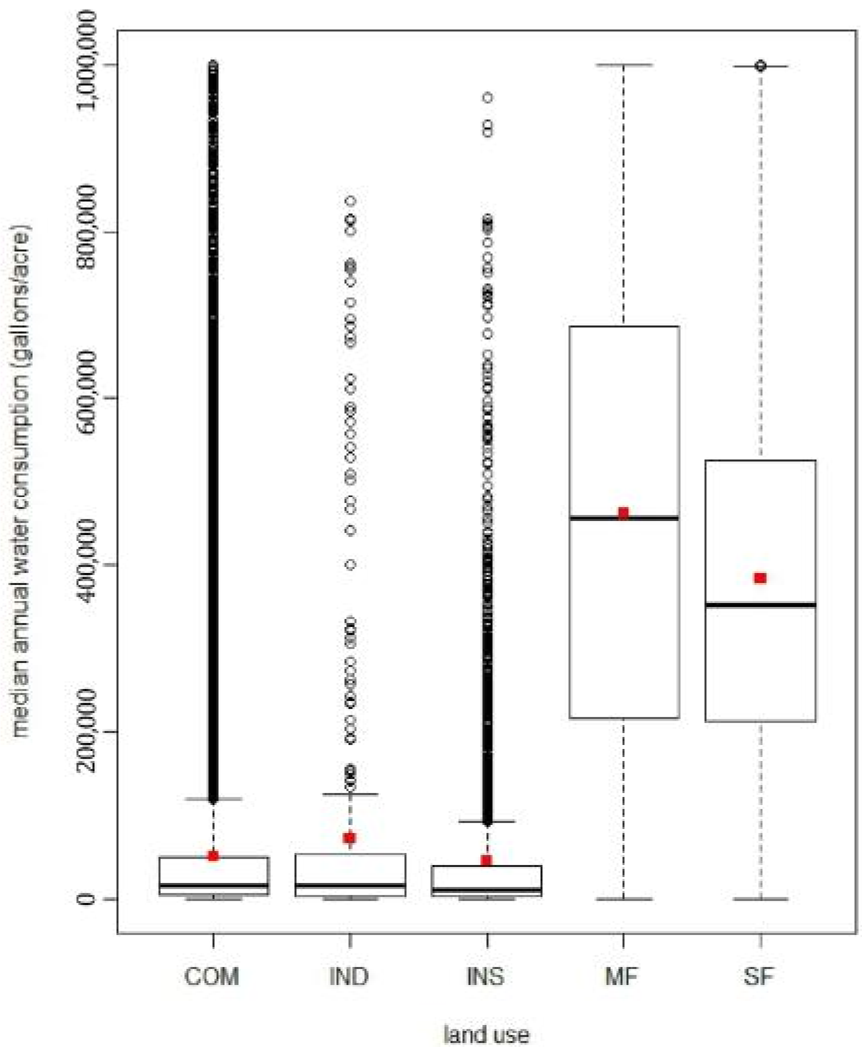

Figure 14. Boxplots for year 2013 median annual water consumption by land-use type in Bernalillo County (COM = commercial, IND = industrial, INS = institutional, MF = multi-family residential, SF = single family residential, lines in boxes = 25th, 50th, and 75th percentiles from bottom to top, dashed lines extend to +/- 1.5 times the interquartile range (distance between the 25th and 75th percentiles) and dots are any remaining data points, red box = mean).

The project team evaluated residential water consumption rates in more detail since there were many more data available. Figure 15 shows that residential water consumption per housing unit increases as lot sizes increase.[5] The trend is most notable for single family homes with less than half acre lot sizes. There is little association between lot size and water consumption for lots above one half acre. One possible explanation for the trend observed for smaller lots may be that very small lots are unlikely to have any irrigated landscaping; there is just no space for it. As lots become bigger there is more space that allows a

---

[5] The data in Figure 1515 are limited to lot sizes less than 1 acre. Larger lot sizes are uncommon in urban areas. The larger lots in the ABCWUA database had an extremely large range of values which obscured the trend in the much more common smaller lots. The full range of data were used in estimating the median water use rates while the truncated data were used to display trends.

homeowner to add a yard or irrigated landscaping. At larger lot sizes where there is likely always space for a yard or irrigated landscaping, the trend breaks down possibly because not every homeowner chooses to have irrigated landscaping or the same amount or type of irrigated landscaping; at this point lot size is not a constraint on water use like it may be for the smaller lots. Figure 15 also indicates that single family housing units use far more water than multi-family housing units. This likely occurs because multi-family housing developments have less irrigated landscaping per housing unit than single family homes. There is less of a trend between multi-family water consumption rates and multi-family housing development lot size. This observation is expected since the number and size of housing units in a multi-family development can vary widely for a particular lot size which results in more or less land available for more water intensive uses such as irrigated landscaping.

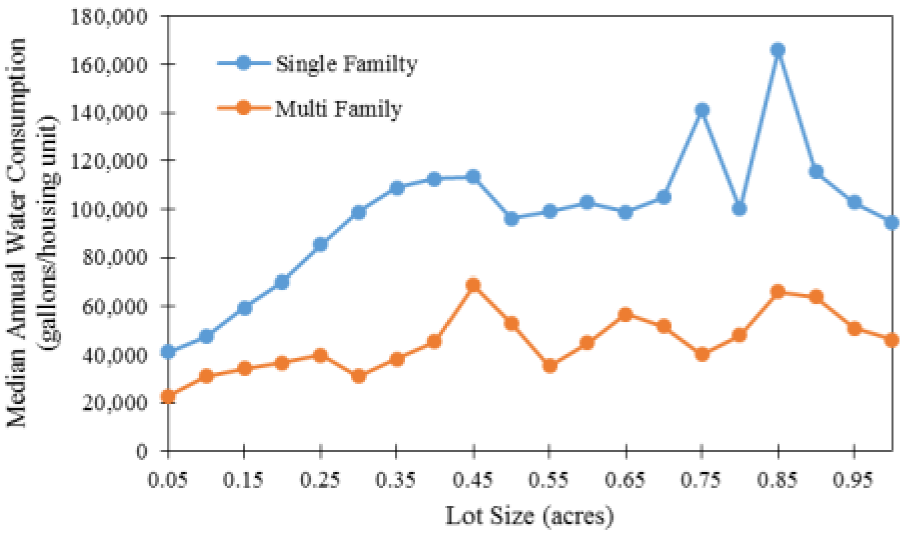

Figure 15. Bernalillo County Residential Water Consumption Rate by Lot Size.

Figure 16 shows the trend in residential water use per housing unit by the year that the water distribution system was built. This date is used as a proxy for the date the housing structure or subdivision was built. The data indicate a general trend of lower consumption for new single-family homes, except for homes built during the late 1980s and early 1990s which have much higher consumption rates. There is also a very sharp drop in water consumption rates for single-family homes built after 2009. The multi-family water consumption data is more variable and with no apparent trend. The trends in Figure 16 may be the result of homes being built with different types of landscaping or other water using (saving) features over time and also differences in average lot sizes over time. Figure 17 controls for lot size by plotting the trend in water consumption per housing unit per acre. These data show that single family housing units built since 1984 consume more water per acre than older homes and those built since 2009. The difference in the trends seen in Figure 16 and Figure 17 indicate that while homes built from the mid-1990s through the 2000s have lower per housing unit water consumption, per acre the rate is actually still relatively high.

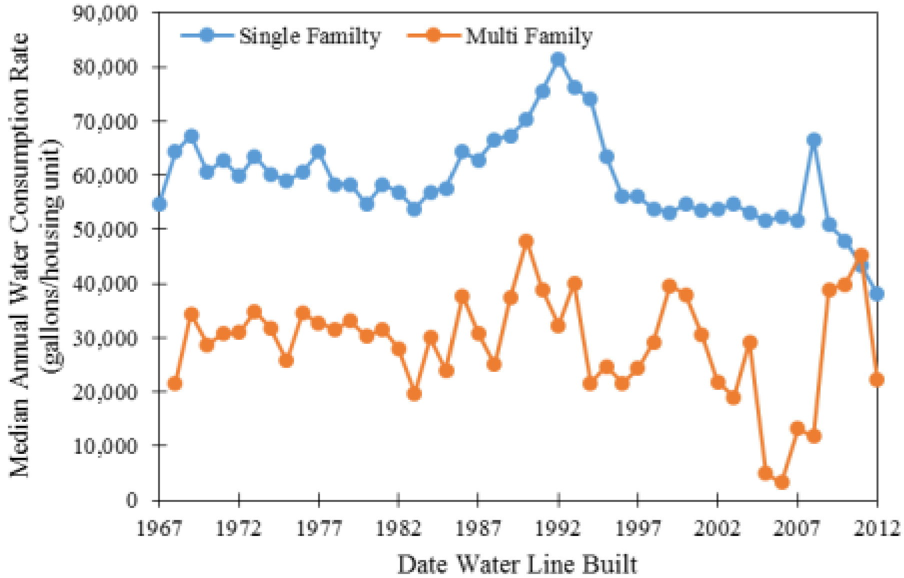

Figure 16. Bernalillo County Residential Water Consumption Rate by Date of Water System Construction.

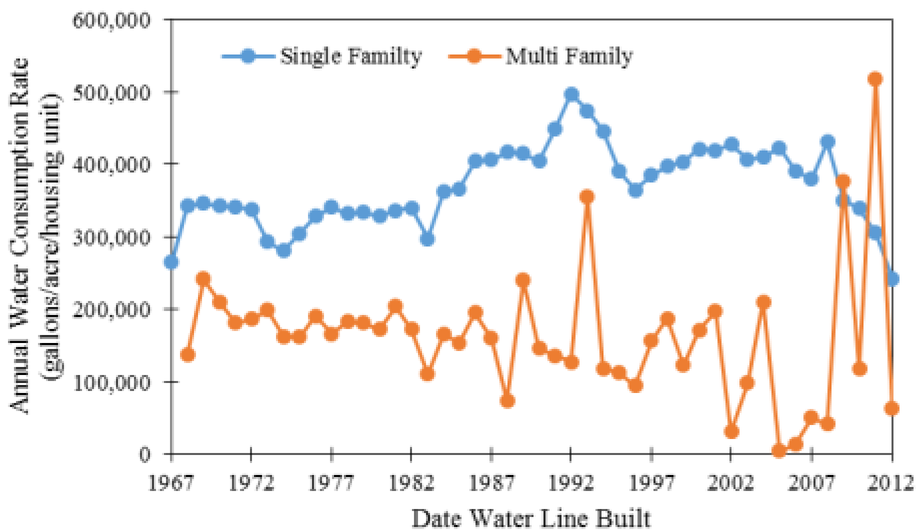

Figure 17. Bernalillo County Residential Water Consumption Rate per Acre by Date of Water System Construction.

The project team considered the above residential data analysis when developing a regional residential water consumption rate for the scenario analysis. In the absence of additional data, the data from Bernalillo County was assumed to represent water consumption rates across the entire study area which also includes parcels in Sandoval, Torrance, Valencia, and Santa Fe Counties. The residential water consumption rate equals the median annual water use per housing unit per acre and is shown in Table 2. The project team created a per-acre water consumption rate (rather than per-housing unit) to correspond with the other water consumption rates and because a per-acre water consumption rate results in less residential water consumption in scenarios with greater housing density (smaller lot sizes) while a per-unit rate would not have this sensitivity. The project team estimated a single water consumption rate for single and multi-family housing units even though they have very different consumption rates because data describing the development of each type of housing structure in each future scenario is not available[6]. Since water consumption rates also vary with the date that housing units (or water distribution lines) were built, the project team estimated the water consumption rate with data from housing units built only within the past 10 years. The project team did not use a smaller range since there has been little development (or little available date data) in recent years leading to small sample sizes. The small sample sizes along with the short duration of the recent downward trend reduced the project team's confidence in using the most recent data alone. The water consumption rate can therefore be thought of as relatively conservative. Finally, the project team used median water consumption rates since most of the data were highly skewed and the means were affected by a large number of very large outliers. Under these conditions, the median provides a more robust estimate of central tendency. Table 2 provides the estimated median water consumption rate for each type of land-use for the year 2013.

Table 2. Water Consumption Rates by Land-Use Category.

Land-Use	Median 2013 Water Consumption Rate (gallons/acre/year)
Agriculture	2,418,012
Industrial	15,987
Institutional	11,117
Residential	421,085
Commercial	16,111

The project team combined the water consumption rates in Table 2 with the amount of land estimated by UrbanSim to be developed in each land-use category for each scenario in Phase III. Development by land-use category was not available in phases I and II and the water consumption rates were not completed until Phase III. Like other aspects of the resiliency analysis, due to the lack of parcel-level detail, the scope of the water consumption analysis is limited. For example, the size of families in households is not considered nor is the presence of drought tolerant landscaping. Similarly, the type of industrial or commercial activity is not considered even though water use depends heavily on the type of business activity. Future industrial and commercial land-uses may involve business activities that use significantly more or less water than present activities. Additionally, only information on current year water use data is available; without data describing the trend in water use over time, there is little basis for evaluating how water use rates may change in the future. Given these limitations, water use estimates derived from these water use rates are not expected to be very accurate in an *absolute* sense. They are expected to provide a reasonable method for comparing the *relative* water consumption of each scenario. Scenarios that have lower water use estimates based on these water use rates are expected to be more resilient to drought driven by climate change.

2.3.3 Urban Heat

Increased heat exposure can lead to increased heat-related mortality, and these impacts are likely to be inequitably distributed across communities (McGeehin and Mirabelli 2001). The very young and the elderly are known to have a decreased ability to regulate body temperature (Kovats and Hajat 2008). Additionally, low-income residents of a city are less likely to have access to cooling and may have other complicating medical factors (Kovats and Hajat 2008). These patterns are likely to hold across different US cities (Uejio et al. 2011), although the impacts of the increment of additional heat are determined in relation to the starting temperature in a region (Pincetl et al. 2013). In other words, the difference between

[6] UrbanSim forecasts for phases I and II did contain separate estimates of single and multi-family homes but the models within UrbanSim that predicted the split was later determined by MRCOG staff to be unreliable and was not used in the phase III analysis.

the heat wave temperature and the starting temperature is more closely linked to health outcomes than the absolute temperature.

Paved urban surfaces, buildings, and other materials located in a city store heat that is re-radiated throughout the day. As a result, core urban areas tend to be hotter than surrounding suburban and rural areas; this effect is known as the urban heat island effect. The effect is more pronounced in the nighttime hours, mediated by wind speed, cloud cover, and vegetation (Souch and Grimmond 2006). As a result of this effect, urban areas are likely to see increasing rates of heat-related morbidity and mortality under increasing temperature scenarios (McGeehin and Mirabelli 2001).

As noted by Hart and Sailor (2009), differences in urban forms are likely to have important effects on the urban heat island. These include: building density and building height to width ratio, roads and traffic density, building and surface materials whose thermal properties differ from the surrounding rural environment, the use of green space, and sky view factor [quantity of visible sky when viewed from the ground ranging from 0 to 1]. A city's canyon geometry [the layout of artificially created "canyons" resulting from the construction of tall buildings], building density and the materials used can absorb and store more incoming solar radiation due to a reduction in surface albedo or conversely store less energy due to shading. Canyon geometry causes the city surface to emit less long-wave radiation due to reduced sky-view factor. Urban surface characteristics can result in a reduction in evapotranspiration due to lack of vegetation and surface moisture. Urban areas are also sources of waste heat emissions due to anthropogenic activity (p. 398, citations omitted).

Very few studies have empirically investigated the relative importance of these effects in different locales. One exception is an empirical study of small-scale variation in urban heat island effects in Portland, Oregon which found that canopy cover was the single most important variable affecting urban temperatures in that city (Hart and Sailor 2009). Areas with more vegetative cover had lower temperatures. Industrial and commercial land uses were associated with higher temperatures, even exceeding temperatures in some areas of the downtown core. The authors hypothesized that shading due to high rise buildings reduces the uptake of solar radiation. Finally, some of the warmest areas in the city were above arterial road surfaces. This effect was more pronounced on weekdays than weekends due to vehicle-related heat emissions.

The net effects of any particular residential, commercial, or industrial development are not easily summarized and depend on site-specific considerations. In the Southwest, Phoenix has been extensively studied for urban heat island effects (Brazel et al. 2007, Uejio et al. 2011), due in part to its already high ambient temperatures and historically low-density land uses. Brazel et al. (2007) found that the urban core in Phoenix was approximately 2.2 degrees Celsius warmer than the rural countryside. Comparatively less attention has been paid to urban heat island effects in Albuquerque or other central New Mexico cities. While findings in Phoenix may provide some indication of what is possible in cities in the Southwest, heat island effects in central New Mexico would likely differ somewhat from Phoenix because of the region's lower starting temperatures, differences in urban form, and the realization that most temperature increases in central New Mexico that will occur will be due to regional climate change effects as opposed to urbanization itself (Mishra and Lettenmaier 2011, Pincetl et al. 2013). Although there is uncertainty regarding the magnitude of heat island effects in central New Mexico, measures to mitigate the effects could be taken as more data is developed and evaluated.

Efforts taken to mitigate urban heat islands can have an overall reductive effect on heat in cities. Land use decisions that consider not only density, but also building height, building materials, paved surface area, and vegetation could help improve the region's resilience to heat island effects. Different types of land cover can affect the severity of urban heat islands and overall temperature. Increasing vegetation can result in local cooling; white surfaces and roofs can be used to reflect, rather than absorb, heat; and less paved area overall can reduce the citywide effects of the urban heat island. Green roofs, which involve planting vegetation on rooftops, can reduce the energy consumption of a building used for cooling by reducing its thermal gain (Saiz et al. 2006). Some work has also evaluated or hypothesized about the effect of green roofs on urban heat island mitigation. There is almost certainly a reduction in ambient temperature above the green roof (Wong et al. 2003), but the effects of implementing green roofs on a citywide scale have yet to be tested. According to Saiz et al. (2006), studies in Toronto, Canada indicate that one third of the city area would experience a 1 degree Celsius drop in temperature with 50 percent penetration of green roofs. In central New Mexico, planting additional vegetation requires additional water use, so implementing some forms of urban heat island mitigation could actually increase water consumption. The use of white roofs and ground-level and green roof vegetation would mitigate this effect somewhat as green roof vegetation relies on drought tolerant plants (rather than high water use plants). When temperatures do climb, creating local cooling centers where people and families without access to cooling can go can also be an effective strategy for increasing the population-wide resilience to severe heat events by reducing the risk of death, especially for elderly residents.

These findings have implications for land use planning in central New Mexico. As development density increases, the same number of people and activities can be accommodated with fewer square feet of paved area. Reducing paved area reduces urban heat island effects, but the larger buildings that would be required to accommodate high-density housing in the urban core may have a countervailing effect, as their absorption of heat would be greater. At the same time, tall buildings may help maintain lower temperatures due to localized shading, depending on urban canyon geometry (Hart and Sailor 2009). The net effects of higher density development on urban heat are site- and design-specific. Locating new housing growth within the urban core would have the added benefit of making cooling centers easily accessible to large numbers of people. For any urban form developed, adding green space, canopy cover, and converting vacant lots into vegetated areas may also marginally reduce high temperatures.

Two factors are expected to drive increasing temperatures: climate change driven by increasing concentrations of GHGs and an increasing urban heat island driven by development of currently undeveloped land. Each of the future scenarios will increase the region's development footprint by 18 percent to 27 percent over year 2012 levels (Table 2) and each scenario also includes an increase in roadway lane miles. This growth represents a significant increase in development and is likely to lead to a larger and more intense urban heat island in the greater Albuquerque area. The alternative scenarios, which result in approximately 30 percent less land development than the trend scenario, will help slow the increase in urban heat. Maintaining present levels of urban heat or further slowing its growth will require additional mitigation measures (see textbox).

Urban Heat Mitigation Strategies

- Develop more compactly
- Plant vegetation along roads and parking lots
- Minimize roadway length and width
- Remove unused parking lots, minimize new parking lot demand
- Use reflective/white roofs on buildings

Table 3. Change in Regional Development Footprint.

Scenario	Development Footprint (acres)	Change from 2012	Change from Trend
2012 Baseline	215,660		
Trend	273,495	57,836 (27%)	
Preferred	255,936	40,276 (19%)	-17,599 (-6%)
Constrained	254,859	39,199 (18%)	-18,636 (-7%)

One of the main threats of increasing urban heat is public health. Extreme temperatures and prolonged heat waves which, climate modeling suggests the region will likely experience, are associated with an increase in deaths and other negative health outcomes[6]. Each of the scenarios will result in increased urban heat and therefore an increased threat to public health. Since each scenario is expected to experience similar increases in urban heat and each scenario has the same population, the difference in the population's resiliency to urban heat health impacts between trend and alterative scenarios will be small.

The other main threat of urban heat is damage to transportation infrastructure. Increasing temperatures can cause failure (buckling) of railway tracks and accelerate the deterioration of roadway and parking lot pavements. The failure of railway tracks and deterioration of pavements represents an increase in transportation infrastructure maintenance costs. Since each of the future scenarios are expected to increase urban heat and more extreme temperature and longer heat waves are expected, transportation system maintenance costs are expected to increase over today's level. The alterative scenarios may be slightly cooler and therefore be slightly more resilient to increasing temperature. Additionally, the smaller development footprint of the alterative scenarios will likely result in fewer paved surfaces and therefore lower expected pavement maintenance costs.

2.3.4 Wildfire Risk

As the climate changes, the severity and frequency of wildfires is expected to increase in central New Mexico (USDOI 2013, Weiss 2014). Some analysts predict that a temperature increase of 1.8° Fahrenheit due to climate change will result in a 470 percent increase in acreage burned by wildfires in the New Mexico foothills of the Rockies and a 656 increase in acreage burned in the southern Rockies of New Mexico (Funk et al. 2014). Lightning strikes, a major cause of wildfires, are predicted to increase 12 ± 5 percent per degree Celsius of global warming and about 50 percent over this century (Romps et al. 2014).

In 2013, 221,951 acres (five percent of all acreage burned in the U.S.) burned in New Mexico (estimated from National Interagency Fire Center 2014). Of the twenty largest wildfires observed in New Mexico's recorded history, nineteen of them have occurred since the year 2000. Three of the most damaging fires include the Cerro Grande fire of 2000, the Las Conchas fire in 2011, and the Whitewater-Baldy fire in 2012. These three fires together burned over 495,000 acres. The Las Conchas fire also threatened to encroach on Los Alamos National Laboratories, a facility that lies upstream of the Cochiti Dam and Reservoir and holds radioactive materials. A loss of containment in this facility that might have been caused by the fire and the subsequent leakage of this material into the Rio Grande watershed could have resulted in heightened levels of radioactive isotopes within the region's largest water supply.

The increased frequency, severity, and size of wildland fires in the watershed jeopardize the reliability of water supply. Burn scar material from fires can be mobilized by monsoon rain events and washed into the stream systems that feed the Rio Grande basin, disrupting both the natural ecology of the system as well as human drinking water supplies. In 2011, the cities of Albuquerque and Santa Fe ceased the use of river water for municipal needs for 40 and 20 days respectively, demonstrating the significant impact of wildfire and post-fire debris flow on municipal water users.

In addition, with drier soils, more sudden precipitation events, and more destructive fires, the risk of land slides in the wildfire area will increase. In 2011, storms over areas burned by the Las Conchas fire caused debris and flooding that damaged 79 structures and roads caused erosion on the Santa Clara Pueblo. The Federal Emergency Management Administration (FEMA) declared two disasters in a month for Santa Clara Pueblo because of flooding (Indian Country 10/25/2013).

Smoke from wildfires will continue to cause a safety problem, especially along travel routes. Indications from the Las Conchas fire emissions analysis is that wildfires contribute more to air pollution and global warming than previously predicted (Department of Energy/Los Alamos National Laboratory 2013). The resulting smoke significantly degrades air quality, damages human and wildlife health, as well as interacts with sunlight to cause substantial warming (Department of Energy/Los Alamos National Laboratory 2013).

The costs of fire protection and fire damage can be significant when high-value structures are at risk or are burned. There can also be costs associated with a loss of property value in areas that are adjacent to fire damage, for example recently burned areas are less attractive to potential buyers. Residents of central New Mexico may experience greater rates of injuries and mortality from direct contact with fires. Previous studies evaluating the health impacts of fire in the Southwest have found that wildfire smoke leads to respiratory and eye-related symptoms but not necessarily mortality, while the majority of deaths are related to burns (Brown et al. 2013).

Agricultural areas and dry rangeland are at risk for increased fire damage. Fires can affect crops and livestock, structures and outbuildings, irrigation infrastructure, perennial crops (such as tree crops), and as a result, compromise the economic returns of these lands.

The impacts of increasing wildfire risk on support infrastructure (natural drainage and utilities) are not generally discussed in the climate impacts literature. Speculatively, natural drainage facilities may experience changes in vegetation and increased sediment deposition as a result of wildfires. When floods follow fire damage in drainage facilities or on upstream land, sediment deposition may compromise the functionality of natural drainage areas. Aboveground utilities (e.g., electrical lines, transformers, and distribution stations) could be directly damaged by fires and power lines can experience damage from fire retardants and capacity reductions due to smoke or heat (Tidwell et al. 2013). Power lines may also experience outages due to preventive shutdowns, arcing or soot buildup caused by smoke (Tidwell et al. 2013).

Increasing frequency and severity of wildfires can cause damage to roads, road closures, and reduced visibility (Camp et al. 2013, National Research Council 2008, Niemeier et al. 2013). Freight traffic may be delayed by fires (Camp et al. 2013) and travelers may experience increased safety risks from fires. Bus service may be suspended or rerouted to avoid road closures (FTA 2011); where alternate routes are not available, compromised transit service can have significant impacts for transit dependent populations. Mudflows can cause damage similar to that of floods, with additional risks and cleanup associated with debris carried by mudflows.

Transportation infrastructure located in the wildland urban interface (WUI) is at a greater risk of being damaged by wildfire. The most sensible transportation strategy for increasing wildfire resilience would be to not locate transportation infrastructure in the WUI zone beyond what is needed to provide mobility and evacuation needs for existing WUI residents. At the same time, roads and their rights-of-way can be used as additional defensive space to separate homes from wilderness, increasing the development's resiliency to wildfire (Brzuszek et al. 2010). Proper signage and multiple wide, well-maintained ingress and egress points for a development for both evacuation and emergency services purposes can improve wildfire resiliency for both individual homes and the community as a whole (DeGomez 2011). Additional wildfire mitigation strategies are listed in the textbox at the end of this section.

Other wildfire impacts to transportation infrastructure include:

- Bike and pedestrian facilities and travelers will experience similar impacts as road infrastructure and travelers including greater damages from fire, mudflows, facility closures, reduced visibility, and increased safety risks.
- Rail infrastructure will also experience greater damages, closures, and delays due to fires, mudflows, and reduced visibility. Wooden rail bridges are at particularly high risk of damage from wildfires (Camp et al. 2013).
- Wildfires can reduce airplane visibility (National Research Council 2008, Niemeier et al. 2013), which can lead to delays and cancellations at some airports (Koetse and Rietveld 2009). Wildfires can also directly damage airport facilities (Niemeier et al. 2013), especially those that are adjacent to fire-prone undeveloped land, increasing costs and safety risks.
- Sediment and debris from upstream areas that have been damaged by fire can damage and settle in drainage facilities, increasing maintenance costs and reducing their functionality.

The project team used the wildfire risk model/GIS data developed by the New Mexico Nature Conservancy for the statewide natural resource assessment. The model/GIS data combined three modeled fire behavior parameters (rate of spread, flame length, crown fire potential) and one modeled ecological health measure (fire regime condition class) with WUI areas and ignition probability. The fire behavior parameters were modeled using FlamMap; fire regime condition class was modeled using the Fire Regime Condition Class tool; wildland urban interface areas were created combining the USFS Silvis Lab WUI and the community wildfire Protection plans WUI within the state; and ignition probabilities were derived using fire history locations from 1987–2008. For a detailed description of each parameter, refer to the data atlas found at All about Watersheds information Clearinghouse (http://allaboutwatersheds.org/).

The maps identify wildfire risk areas from low to high and the development change in the WUI. The intent of these maps is to identify where areas of wildfire risk are located in proximity to development changes and the change of development within the WUI. The project team defined the unit used to analyze the change in development as the sum of the number of household population and employment for each scenario. The USFS Silvis Lab WUI area in Figure 19 is based on a study from Radeloff et al. (2005) that categorized the WUI into WUI intermix and WUI interface zones. WUI intermix zones are areas with more than one housing unit per 40 acres where wildland vegetation dominates the landscape, while WUI interface zones are areas with higher density housing adjacent to areas with heavy vegetation (1.5 miles of a large, contiguous block of wildland vegetation). In other words, the interface is where wildland vegetation is adjacent to houses or other developments and the intermix is where houses and wildland vegetation intermingle (see Figure 19 for planning area WUI).

Figures 20 to 25 show two concepts for each scenario: 1) the change of development in the WUI and 2) wildfire risk in the planning area. The units describing the development change in the WUI and wildfire risk areas are at the subzone level, which are geographical units that are created by MRCOG to analyze the future travel demand in the region as well as land use planning. The preferred scenario has the least amount of development occurring within the WUI compared to the trend scenario (Tables 4 and 5). Under the preferred scenario, increased development in the WUI occurs primarily within the existing road network in already developed areas of Albuquerque and within low to medium wildfire risk areas (Figure 23). Additionally, there is a decrease in development or no development in high wildfire risk areas for the preferred and constrained scenarios compared to the trend scenario (Tables 4 and 5; Figure 20 to Figure 23). Consequently, the preferred scenario will be more resilient to wildfire than the trend scenario.

Table 4. Scenario Development in WUI Intermix vs. 2012 Percent Change.

Scenario	Households	Household Population	Employment	SF Units	MF Units	Non-residential Square Feet	Buildings	Total
Trend	42.8%	40.9%	51.7%	39.5%	62.3%	57.4%	36.1%	41.4%
Constrained	38.2%	36.2%	43.0%	34.2%	69.4%	54.4%	30.6%	36.7%
Preferred	38.6%	36.6%	40.8%	34.4%	68.9%	54.4%	31.1%	37.2%

Table 5. Scenario Development in WUI Interface vs. 2012 Percent Change.

Scenario	Households	Household Population	Employment	SF Units	MF Units	Non-residential Square Feet	Buildings	Total
Trend	20.9%	19.1%	25.9%	16.6%	35.7%	23.7%	14.6%	19.6%
Constrained	19.4%	17.5%	24.1%	12.4%	41.6%	24.7%	11.2%	18.1%
Preferred	19.5%	17.6%	22.7%	12.7%	40.6%	23.4%	11.5%	18.2%

The project team calculated the average population density of the WUI per acre for each scenario by dividing the total number of people projected to be living in the WUI area under each scenario by the total number of acres in the WUI area (Figure 18). The trend scenario has 0.0063 more people per acre living in the WUI area compared to the preferred scenario.

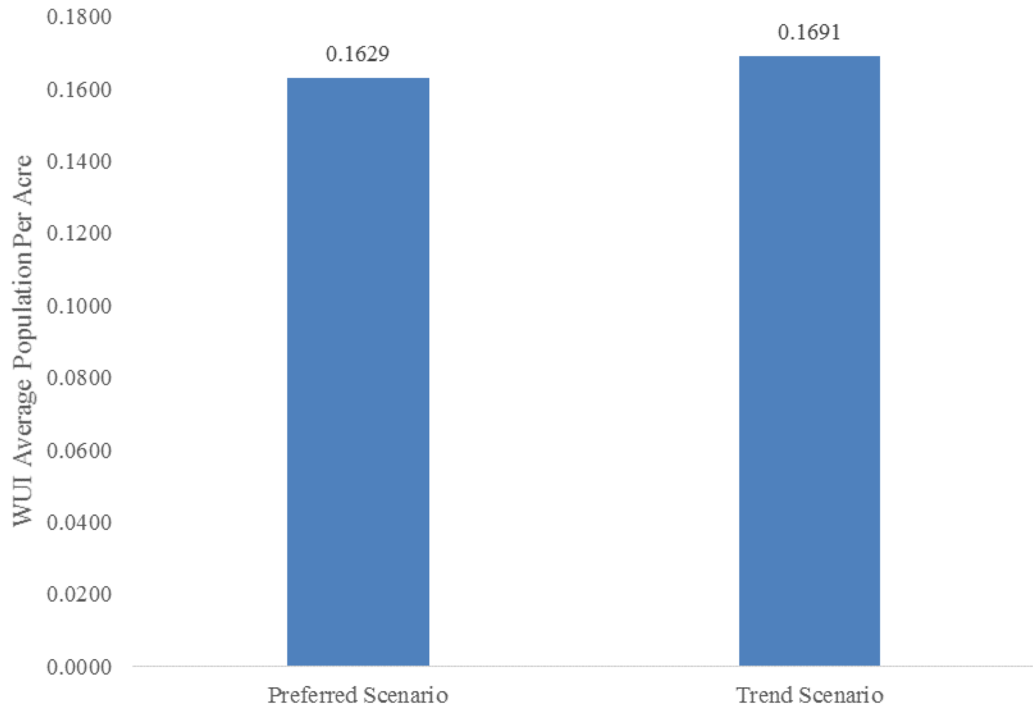

Figure 18. WUI Average Population per Acre.

Wildfire Risk Mitigation Strategies

- Create "defensible space": Requirements for buffer zones between development and wildland areas. These requirements could include recommendations for "firescaping"—surrounding the building with vegetation that is less likely to combust.
- Reduce combustible fuels around critical facilities such as power stations, power lines transformer sites, major transportation routes and critical watersheds.
- Produce a Community Wildfire Protection Plan and Homeowners Guide and distribute to residents
- Allow free greenwaste disposal and free assistance to move brush away from houses
- Facilitate greenwaste removal by picking up and hauling away slash
- Encourage participation of local neighborhoods with Firewise. Firewise is a program that involves homeowners, local leaders, developers, agricultural producers and others for an effort to protect people, property and natural resources from wildfires.
- Provide defensible space workshops
- Deed restrictions or covenants placed on new developments that require the establishment of defensible space.
- Vegetation management plans: Site-specific analyses of vegetation and other features including schedules for fuel removal and cleanup.
- Pay special attention to fuel located downhill of houses sited on a slope.
- Do not locate transportation infrastructure in the WUI zone beyond what is needed to provide mobility and evacuation needs for existing WUI residents.
- Post proper signage and multiple wide, well-maintained ingress and egress points for a development for both evacuation and emergency services purposes
- Create ephemeral flooding in depressions in the bosque within the fuel breaks to encourage growth of less-flammable native riparian and wetland vegetation species
- Develop more compactly
- Plant vegetation along roads and parking lots
- Minimize roadway length and width
- Remove unused parking lots

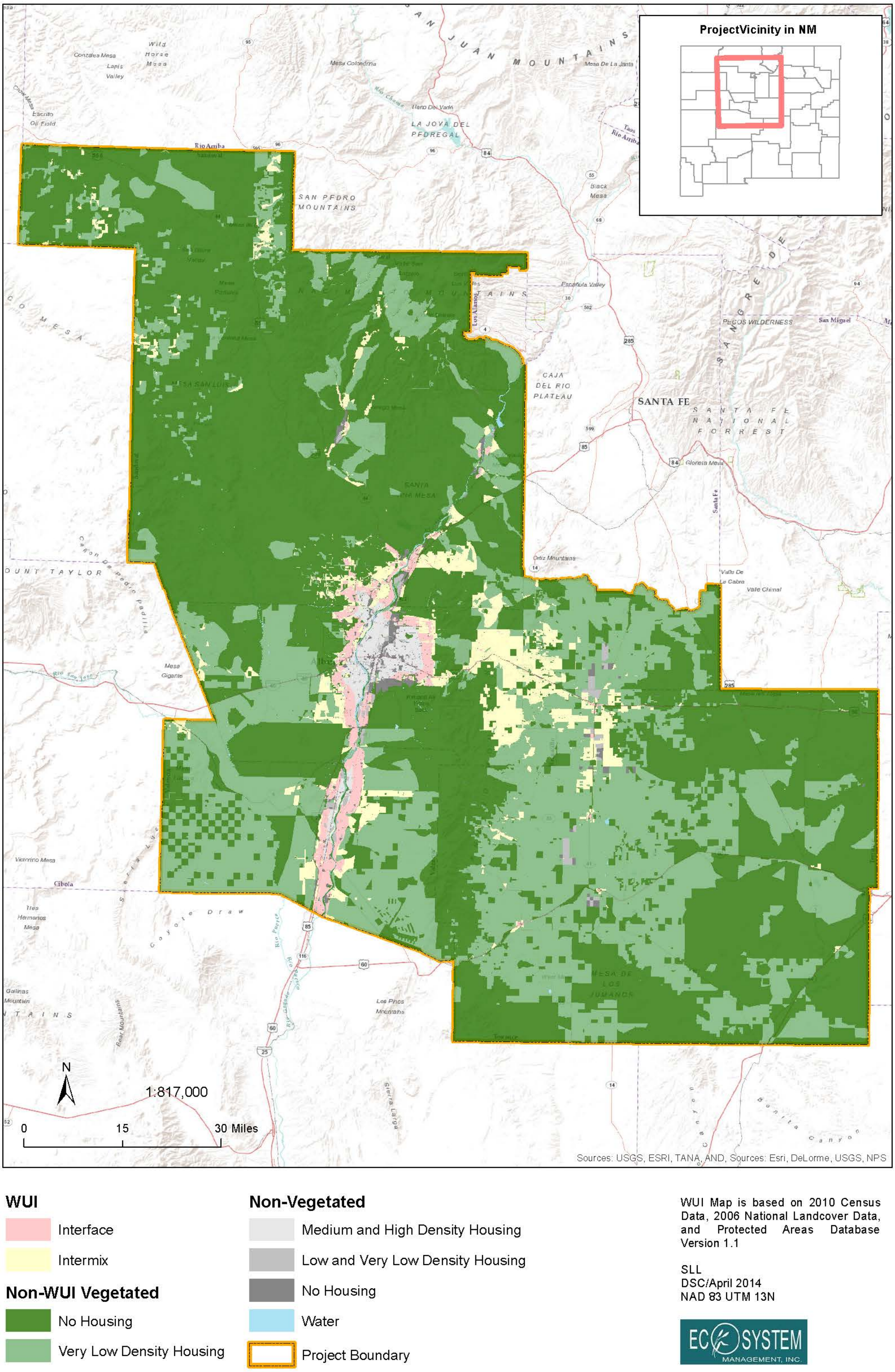

Figure 19. Wildland-Urban Interface

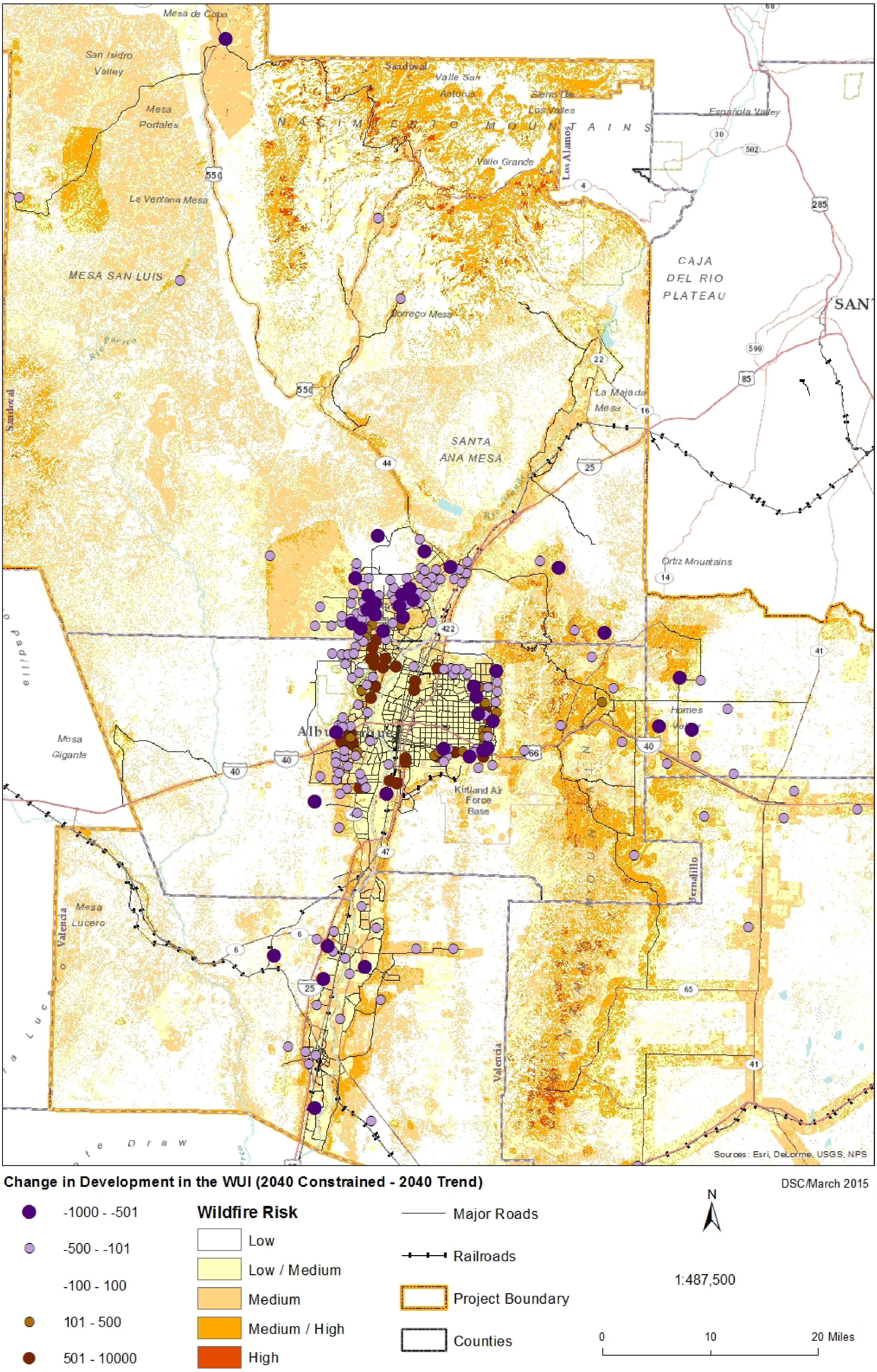

Figure 20. WUI Constrained vs. Trend Map.

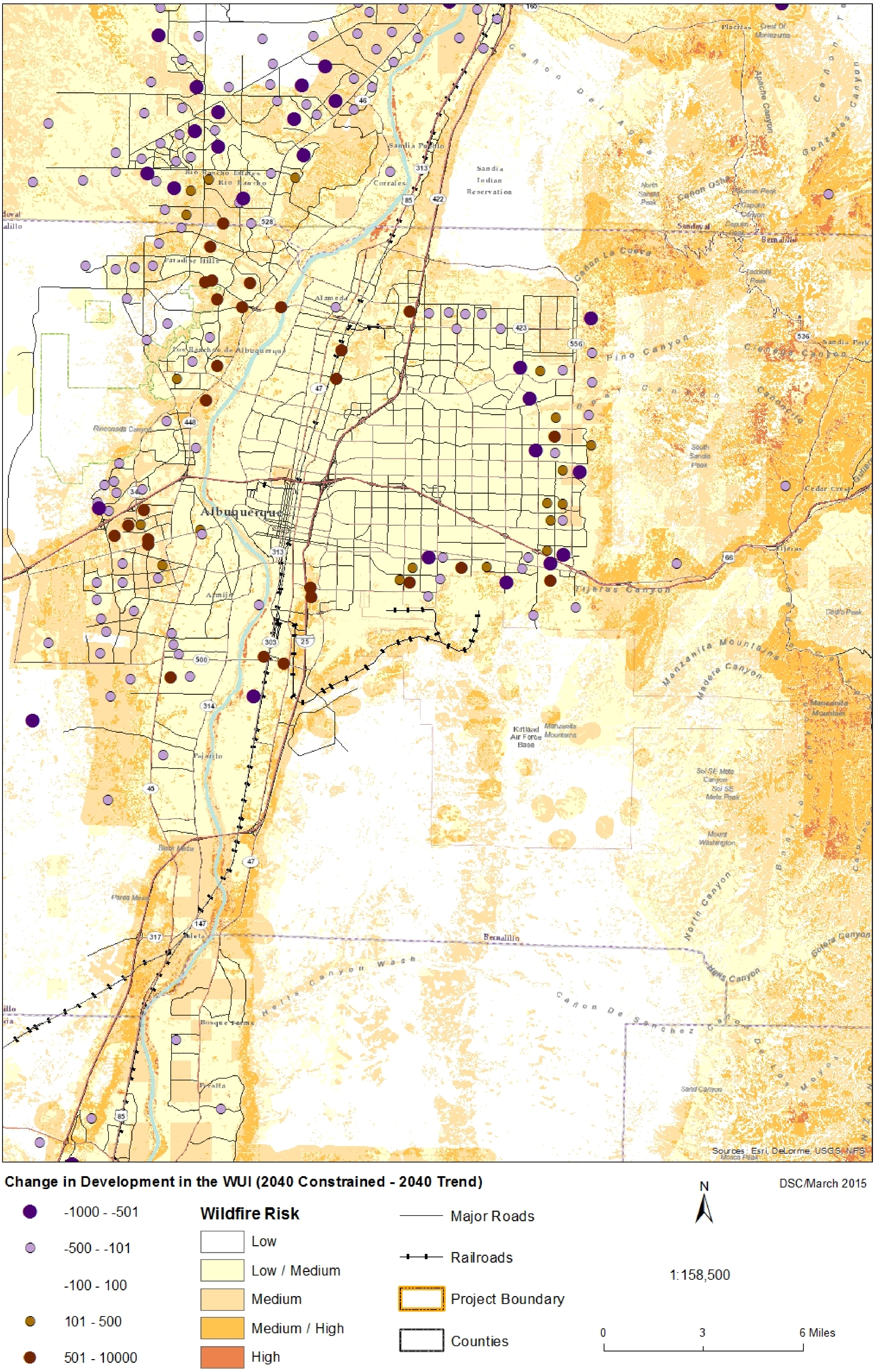

Figure 21. WUI Constrained vs. Trend Map Focusing on Albuquerque, NM.

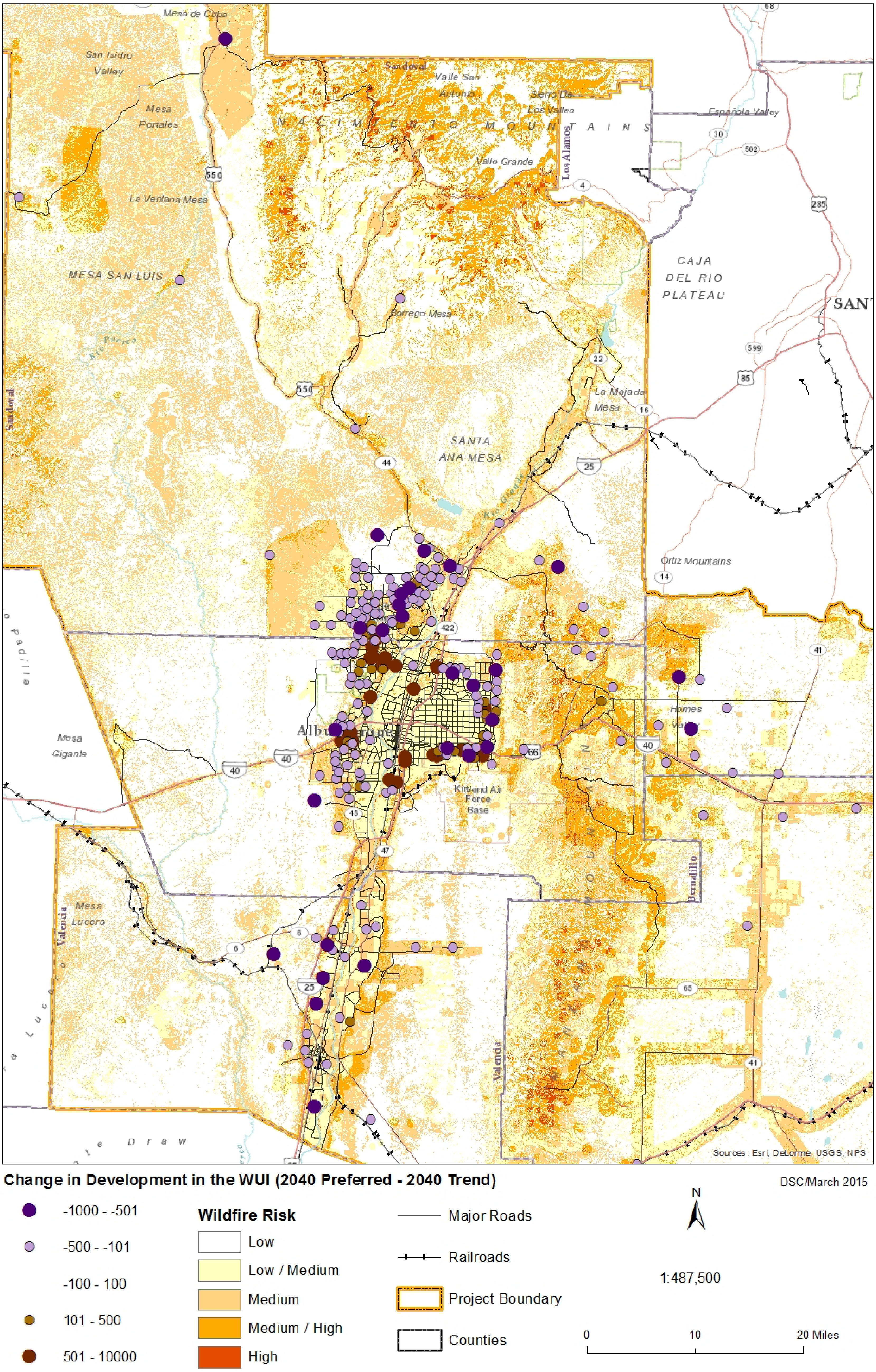

Figure 22. WUI Preferred vs. Trend Map.

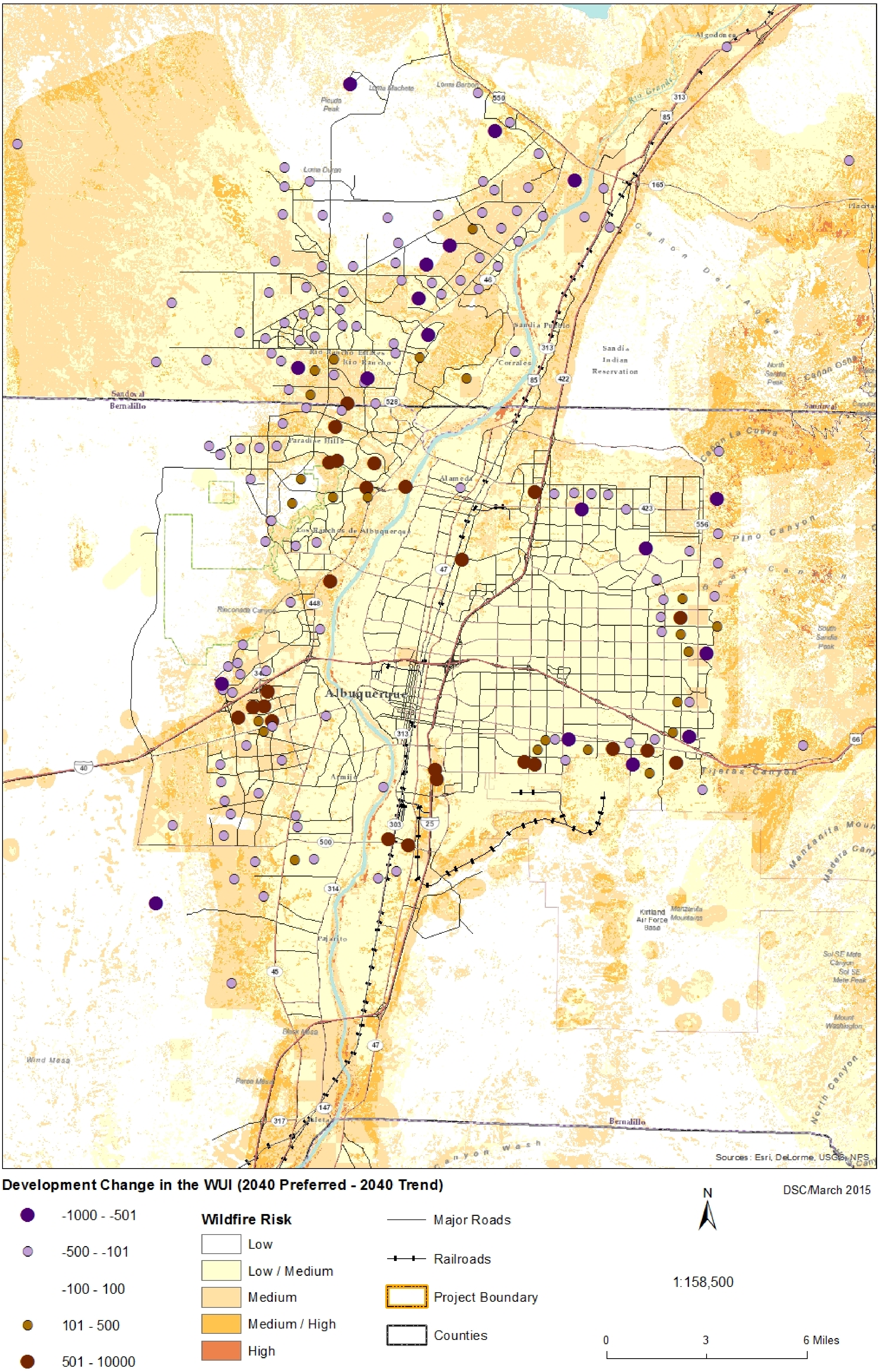

Figure 23. WUI Preferred vs. Trend Map Focusing on Albuquerque, NM.

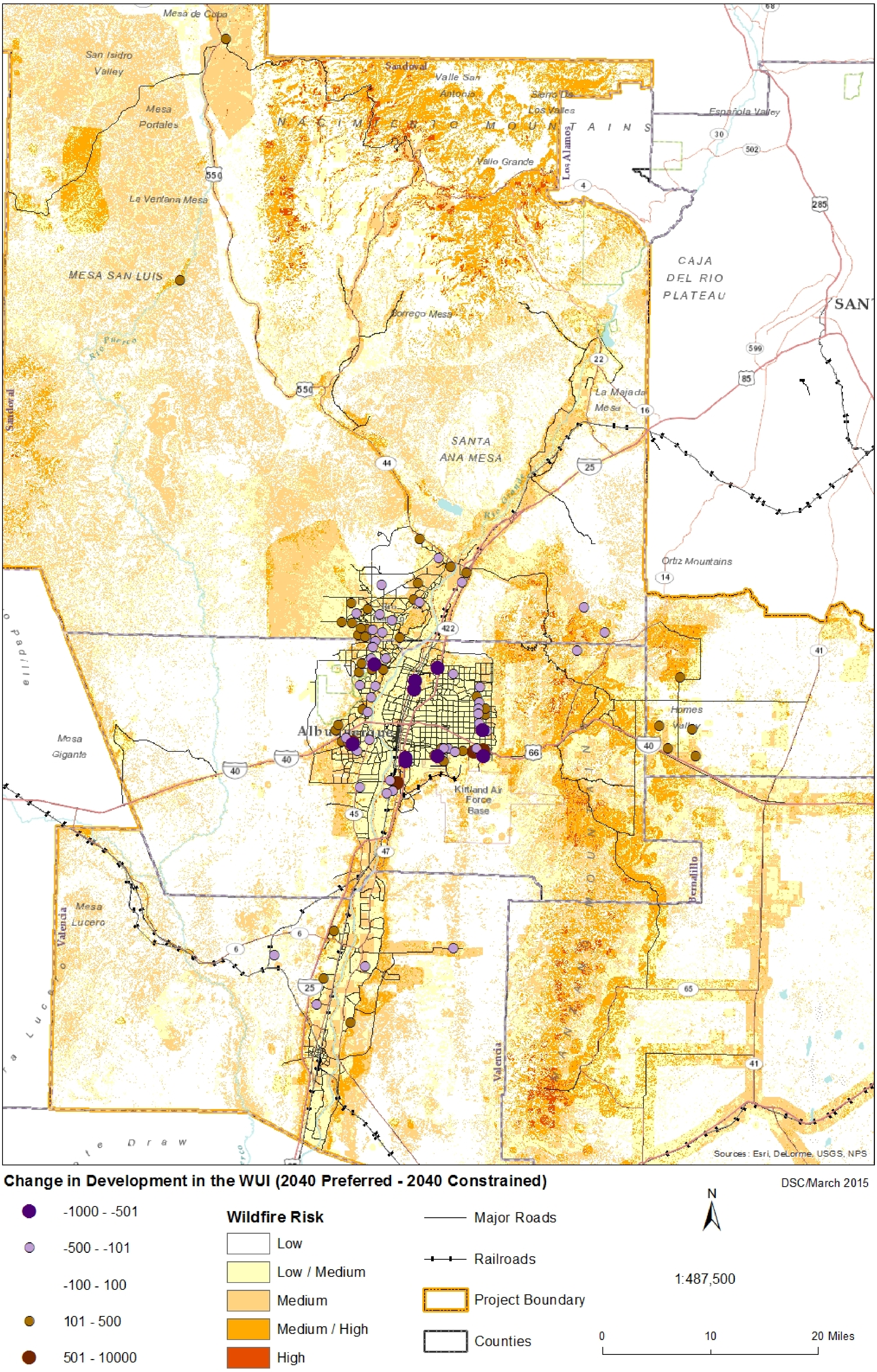

Figure 24. WUI Preferred vs. Constrained Map.

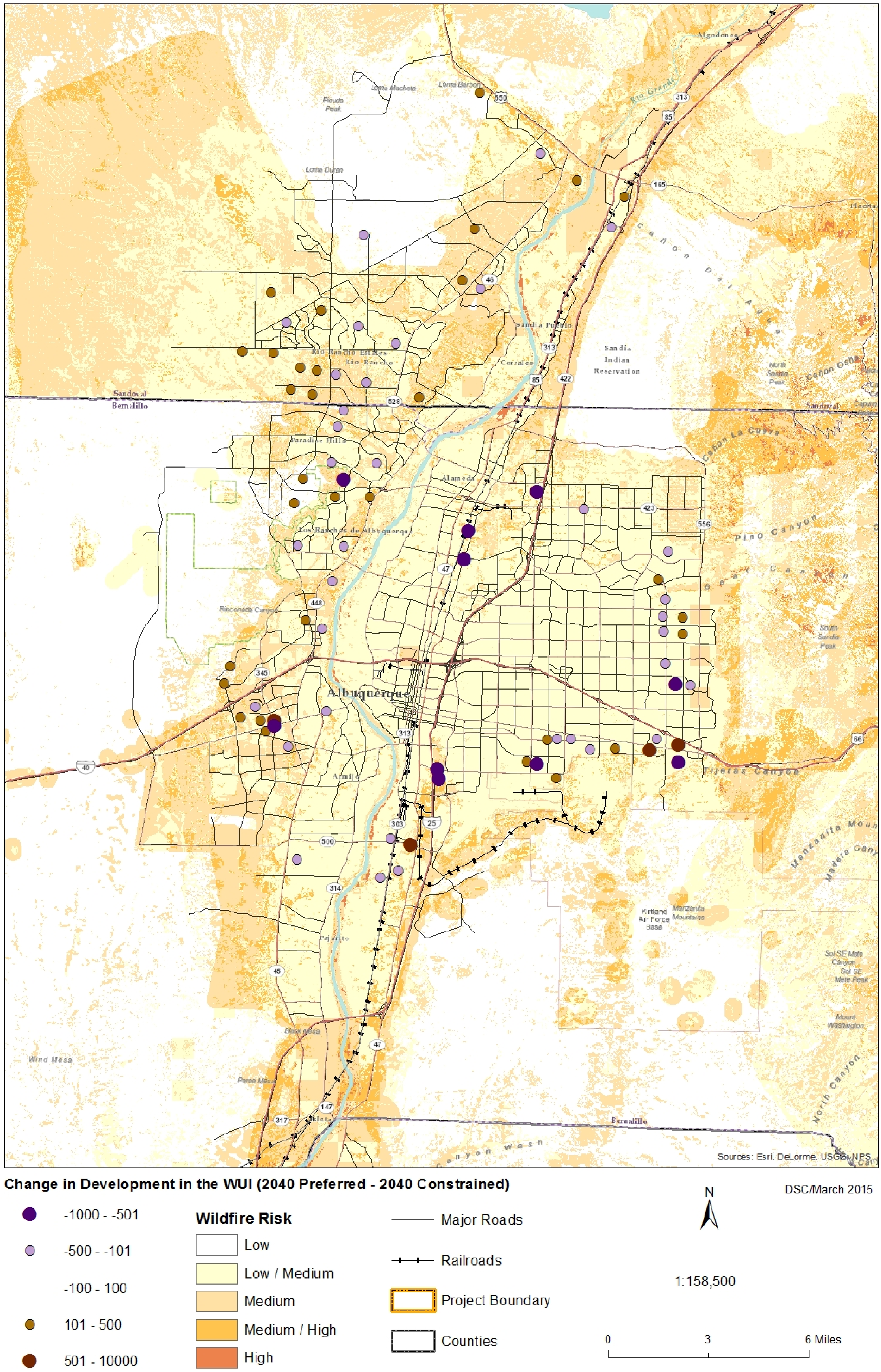

Figure 25. WUI Preferred vs. Constrained Map Focusing on Albuquerque, NM.

2.3.5 Key Natural Resources

2.3.5.1 Introduction

Key natural resources in the region are likely to be adversely affected by climate change. Precipitation and temperature strongly influence the distribution and abundance of species. The relatively warm and dry region will become increasingly arid and desert-like. In this region and globally, the effects of climate change on species, ecosystems, and ecosystem services include declines in species populations (Pounds et al. 2006), shifts in species distributions (Root et al. 2005), disruption of the synchronization of seasonal plant and animal life history events (Brown et al. 1997), increased invasion by exotics (Walther et al. 2002), spread of pathogens and pests (Brooks and Hoberg 2007), appearance of vegetation dieback (Breshears et al. 2005), and community-ecosystem reorganization (Brown et al. 1997). Additionally, growth of the region's human population will continue to result in water use conflicts with natural resources as well as habitat fragmentation (Finch 2012).

2.3.5.2 Crucial Habitat

The Western Governors' Wildlife Council is developing tools to assist western states in identifying and conserving crucial wildlife habitat and corridors across the region. While individual states are compiling information within their borders, they also are working with neighbouring states to improve the regional understanding of areas important to wildlife to better inform land use planning efforts. One tool developed by the Wildlife Council is the Western Governors' Crucial Habitat Assessment Tool (CHAT), a cooperative effort of 16 Western states to provide the public and industry a high-level overview of "crucial habitat" across the West. Crucial habitat is ranked on a relative scale of 1 to 6; areas most likely to contain natural resources that contribute to crucial habitat are ranked 1 on the scale with 6 representing areas considered least likely to contain those resources. Crucial habitat should be interpreted as the relative probability or risk that a high-priority habitat or species would be encountered in a given area. A weighted score was created by the project team taking the sum of the households and population in each category for ranks 1 to 3 and multiplying the sum by a value (3x for rank 1; 2x for rank 2; 1x for rank 3). The project team created a weighted score to provide a reference point for the differences in development patterns between the scenarios as the percentages alone are the same for the trend and constrained scenarios. A crucial habitat rank at a square-mile scale is based on:

- Species of concern (animals and plants)
- Wildlife corridors
- Terrestrial species of economic and recreational importance
- Aquatic species of economic and recreational importance
- Freshwater integrity (watershed status)
- Large natural areas
- Natural vegetation communities of concern

Data layers of crucial habitat, obtained from the Western Governors' Association, were overlaid with the change in development layer. Areas of crucial habitat at risk for each scenario are shown in Figures 28 to 33. Figure 26 shows the households (HH) plus employee (Emp) categories for the CHAT for each of the different scenario. The ranks for CHAT range from 1 to 6. The project team compared the three scenarios against the 2012 base line and the percent change is shown in the table. Within the context of 52 percent regional population growth by 2040, more development will occur in all CHAT ranks under all scenarios. The trend scenario has the most development in four ranks (ranks 1–3 and 5). The constrained scenario has the most development in one rank (rank 6). The preferred scenario has the most development in one rank (rank 4). The preferred scenario has less development than the other scenarios in CHAT ranks 1 and 2, which means that there would be less impact on higher priority habitat and species compared to the trend and constrained scenarios. In the preferred scenario, growth within CHAT ranks 1 and 2 would mainly occur in already developed areas (Figure 33). Growth within already developed and small areas will help to reduce potential impacts to crucial habitat and associated species, thus improving CHAT resiliency. Additional mitigation strategies for crucial habitat areas are listed in the textbox at the end of this section.

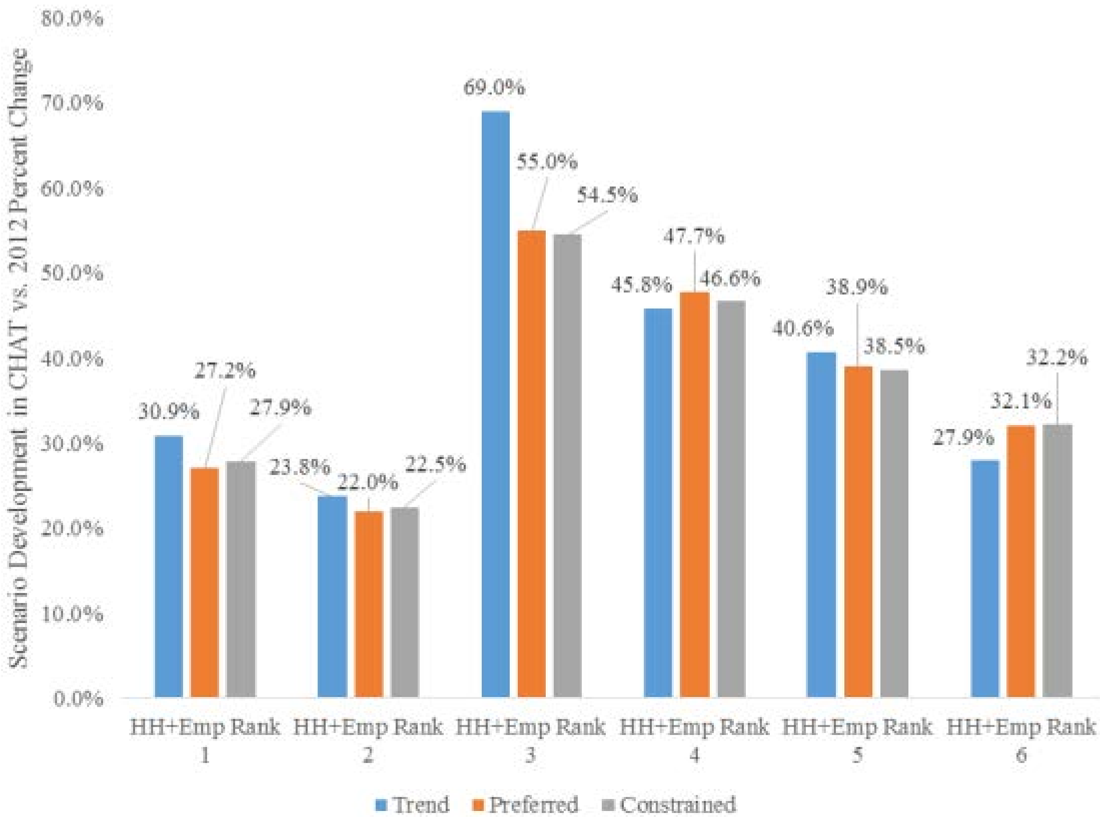

Figure 26. Scenario Development in CHAT vs. 2012 Percent Change.

The project team calculated the average population density of people living in the crucial habitat area per acre for each scenario by dividing the total number of people projected to be living in crucial habitat areas under each scenario by the total number of acres in the crucial habitat areas (Figure 27). The trend scenario has 0.0023 more people per acre living in crucial habitat areas compared to the preferred scenario.

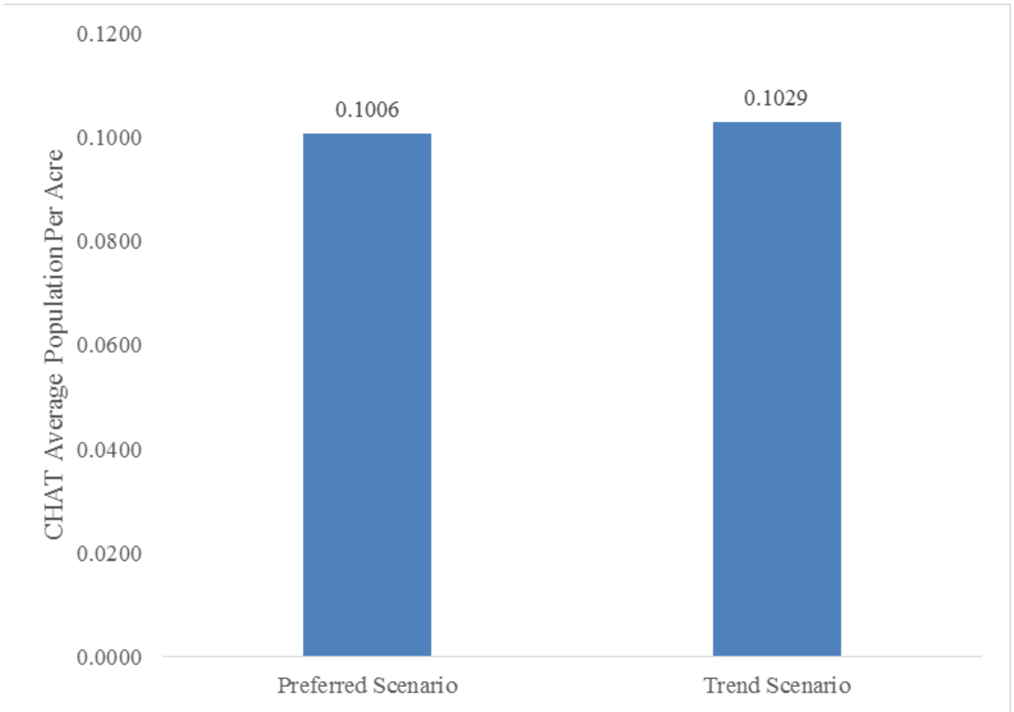

Figure 27. Crucial Habitat Average Population per Acre.

Mitigation Strategies for Crucial Habitat

- Coordinate Rio Grande water management activities to support and improve the bosque's riverine and terrestrial habitats, with special emphasis on mimicking typical natural hydrographs.
- Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.
- Protect, extend, and enhance the structure of aquatic habitat to the benefit of native communities.
- Integrate management of nonnative and native fish species in all aquatic environments in the Middle Rio Grande riparian ecosystem including wetlands, canals, and drains.
- Protect the geographic extent of the Rio Grande bosque and avoid further fragmentation of the riparian ecosystem and component habitats.
- Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.
- Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife habitat values, and maintain rural and semirural conditions.
- Prevent unmanaged fires in all reaches of the bosque.
- Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the bosque.
- Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.
- Sustain and enhance existing cottonwood communities, and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.
- Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone.
- Modify storm water outfalls to function as wetlands, increasing diversity of habitat.
- Install moist soil willow swales that would serve a dual purpose of reestablishing connectivity between the bosque and the river, as well as providing shrub, mid-canopy habitat.
- Clear exotic species in the bosque and replant areas with native species of cottonwood riparian gallery forest.
- Reduce fuel loads and develop wildfire fuel breaks to reduce risk of severe wildfires.
- Remove debris from floods and wildfires from streams and arroyos.
- Create refugia for species such as the Rio Grande silvery minnow.
- Preserve and protect wildlife corridors.

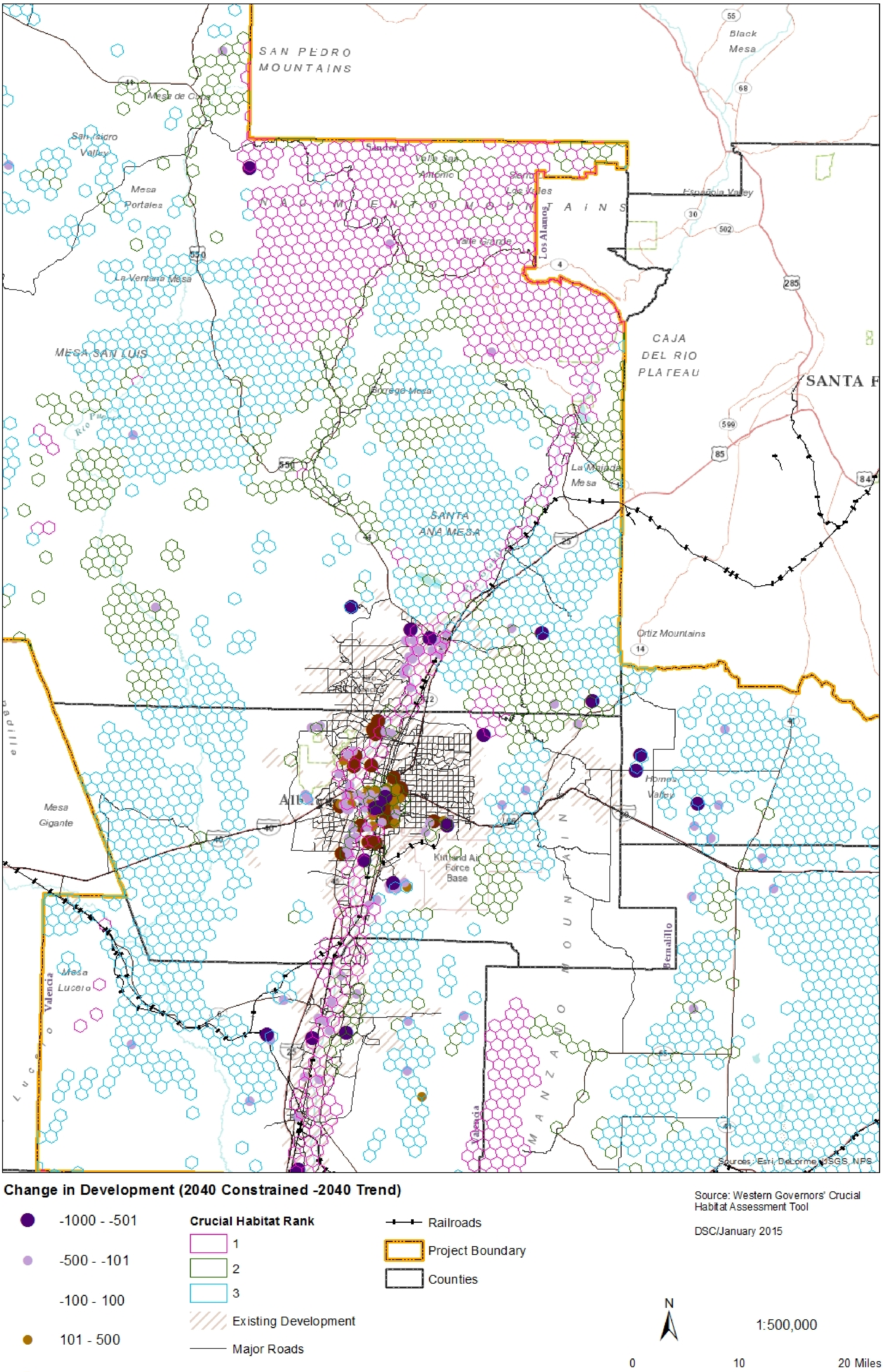

Figure 28. CHAT Constrained vs. Trend Map.

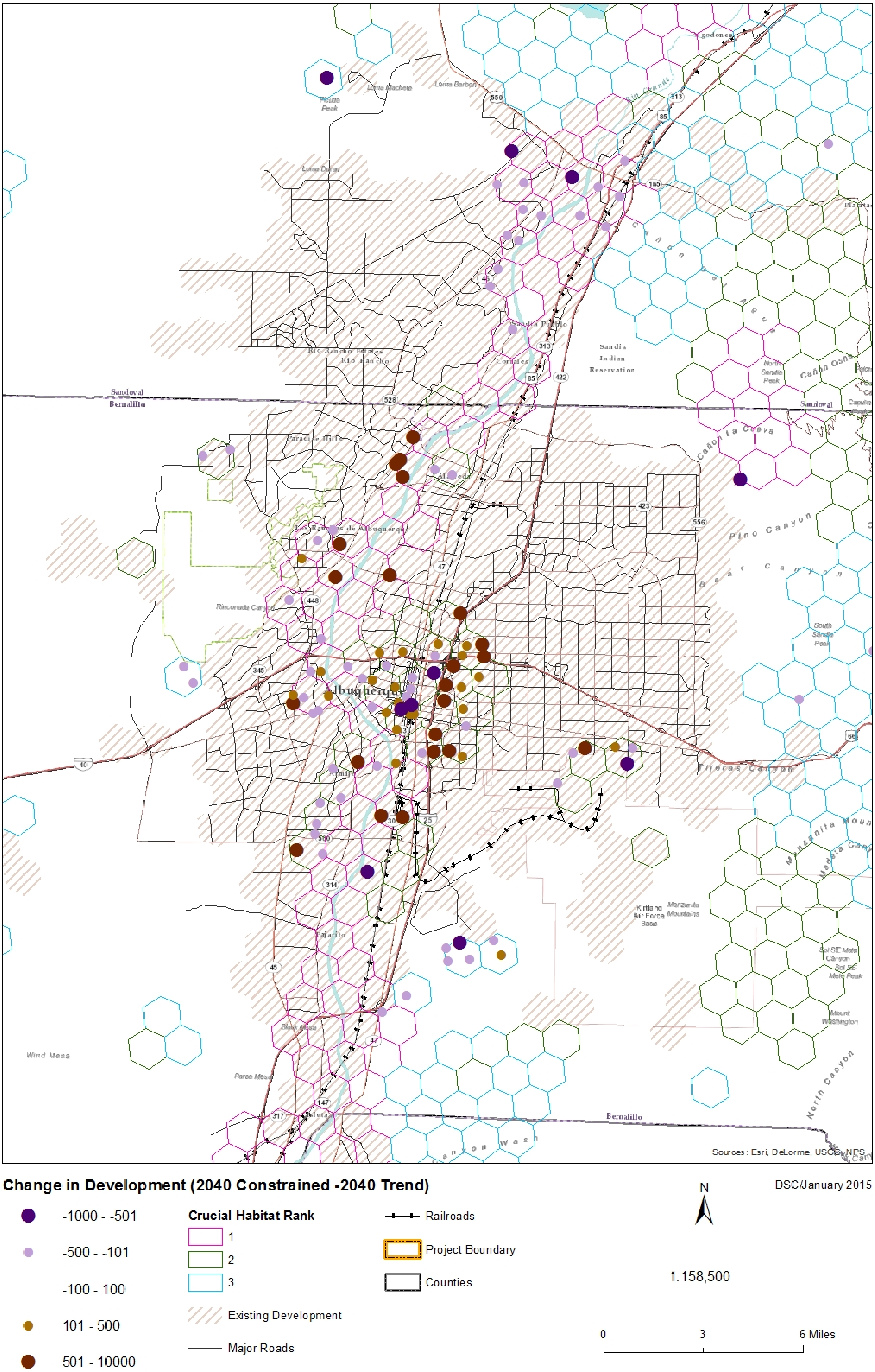

Figure 29. CHAT Constrained vs. Trend Map Focusing on Albuquerque, NM.

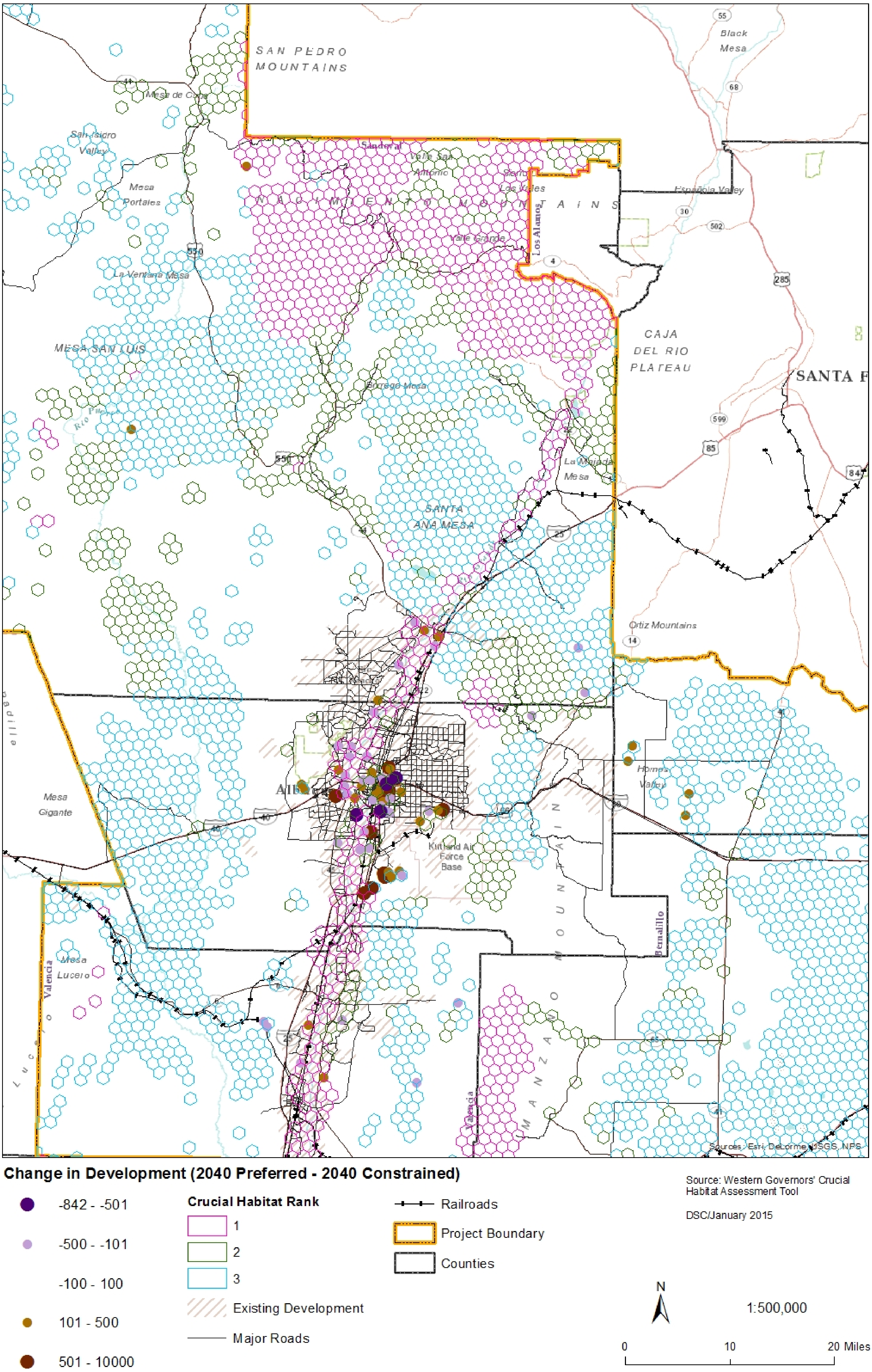

Figure 30. CHAT Preferred vs. Constrained Map.

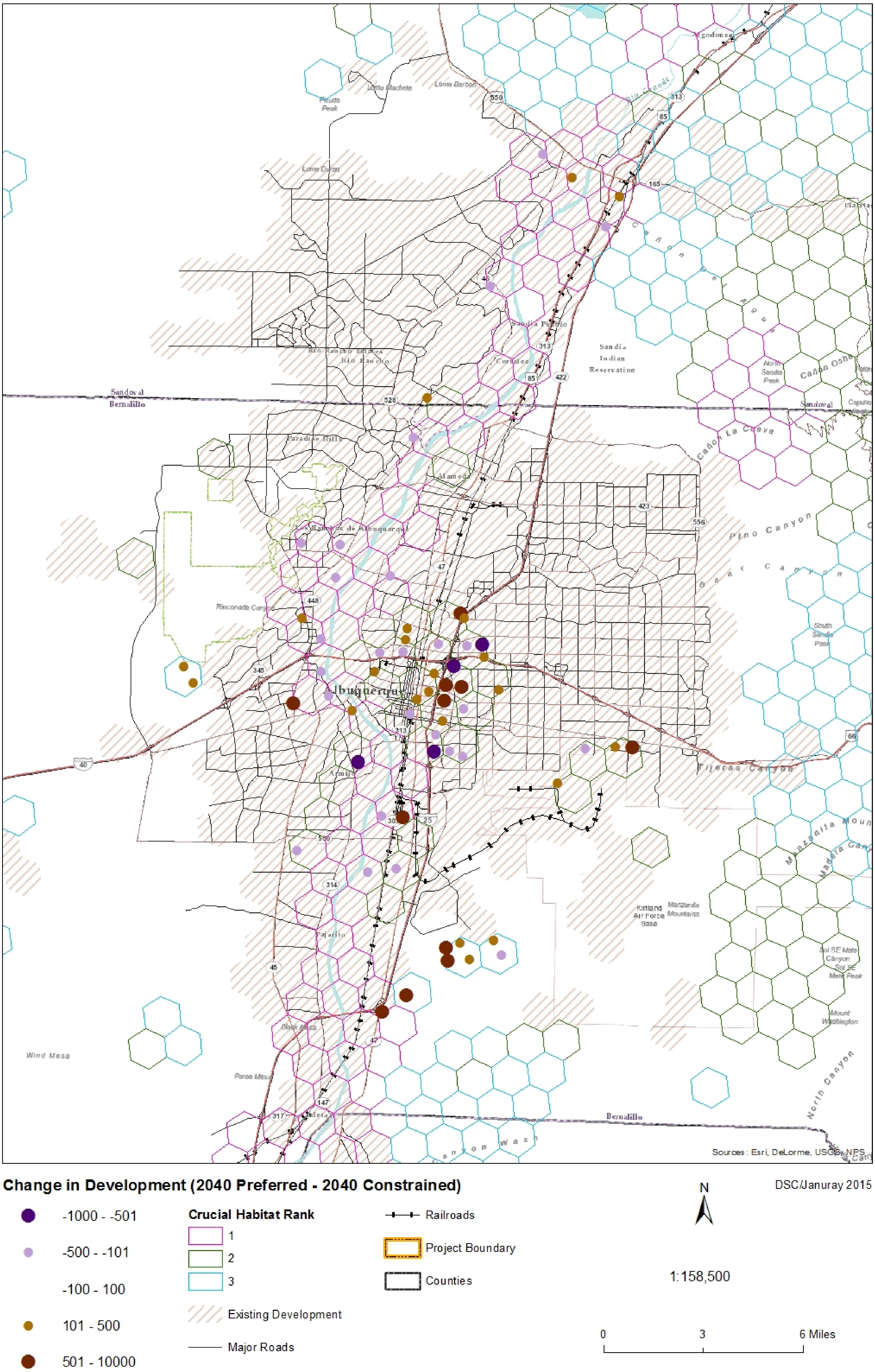

Figure 31. CHAT Preferred vs. Constrained Map Focusing on Albuquerque, NM.

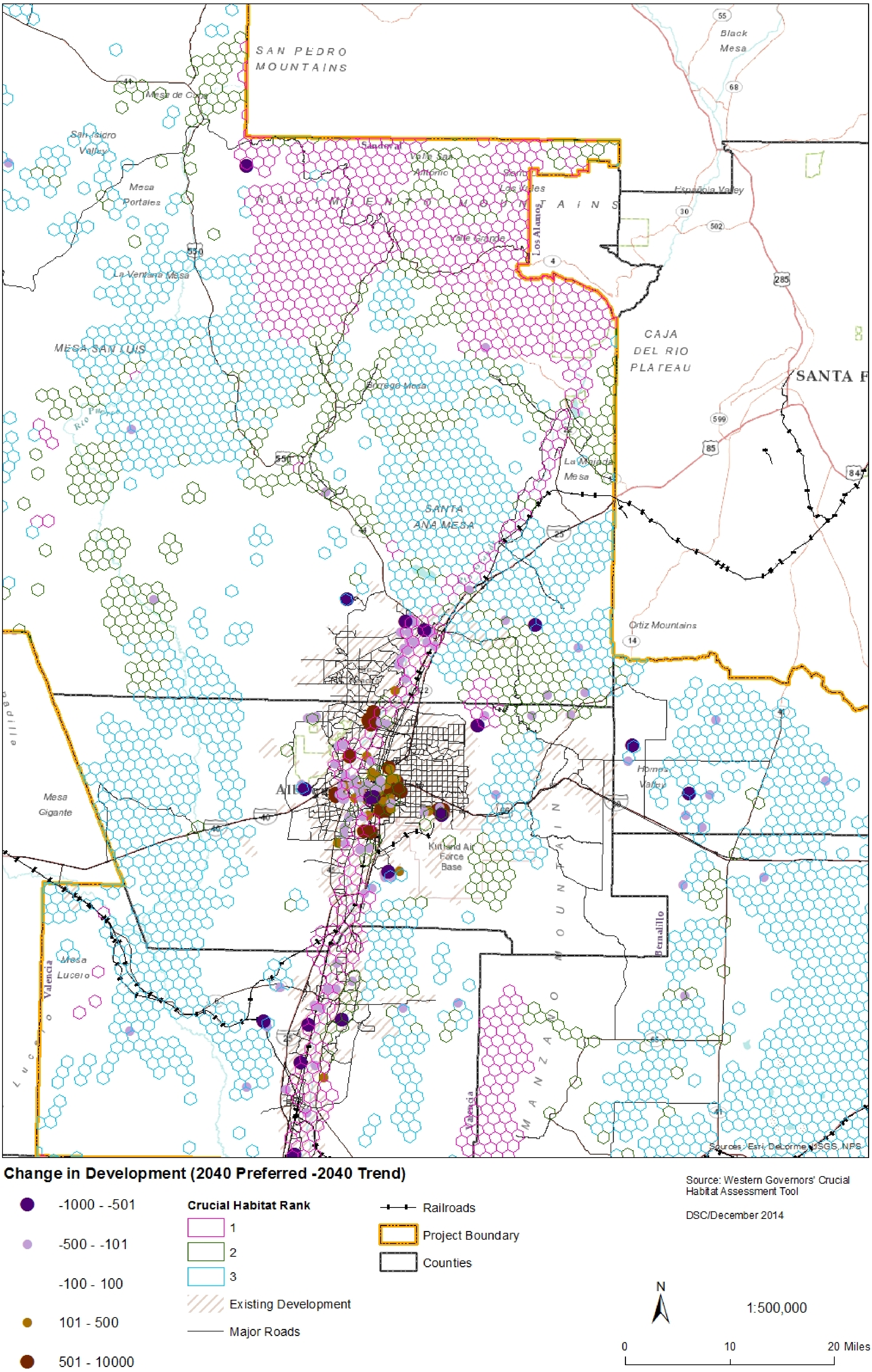

Figure 32. CHAT Preferred vs. Trend Map.

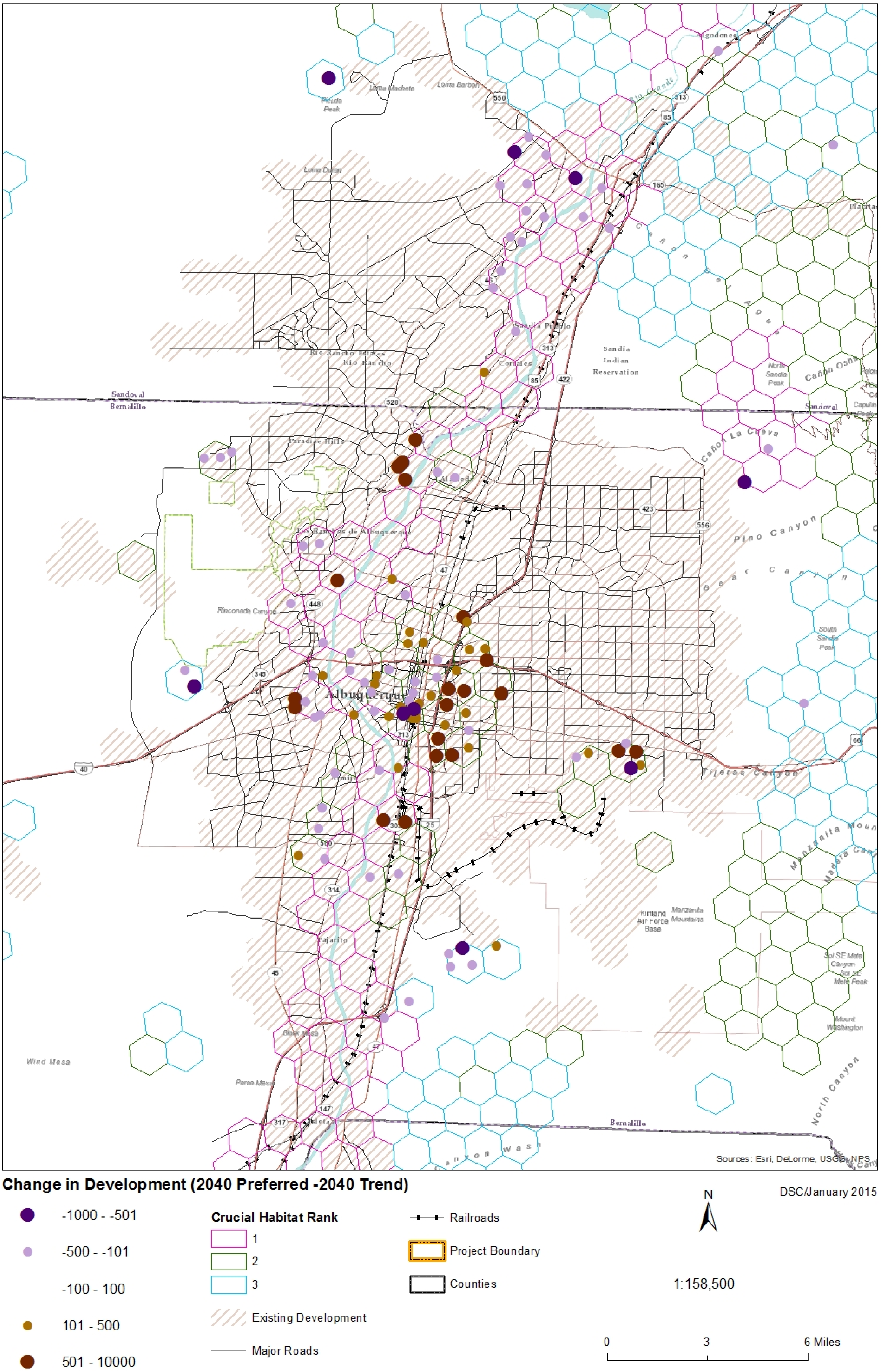

Figure 33. CHAT Preferred vs. Trend Map Focusing on Albuquerque, NM.

2.3.5.3 Vegetation

Like other regions of the Southwest, central New Mexico is expected to experience large temperature increases, increased severity and duration of drought periods, increased wildfire activity (both in size and severity), insect outbreaks, and overall reduction in river and stream flows. The current vegetation communities are shown in Figure 34. Projected changes in the plant communities in the central Rio Grande Valley are shown in Figure 35 (Friggens et al. 2013). The future community compositions are based in the IPCC IS92a scenario (1 percent increase in greenhouse gases per year after 1990) and two general circulation models (GCMs): the Hadley Center and the Canadian Center for Climate modeling and Analysis. Chihuahuan desert scrub is predicted to expand considerably. Creosote bush (*Larrea tridentata*) is the dominant plant species in the Chihuahuan desert scrub. This species is currently predominantly found in the desert regions to the south of central New Mexico.

Riparian habitat is the most critical habitat in the project area. Cottonwoods (*Populus fremontii* and *Populus deltoids*) and willows (*Salix exigua*) are the predominant native riparian species in the study area. Human development of wetlands has resulted in 80 percent of the wetlands being drained (Water Assembly and Mid-Region Council of Governments 2005). Climate change will result in increasing demand for water and decreased supplies. Experts predict decreasing availability of riparian habitat, including the loss of mature trees due to fire and insect and disease, which would directly and indirectly affect many species of birds and mammals (Llewellyn and Vaddey 2013).

Invasive species may well be the greatest challenge in managing riparian habitat. They often outcompete native vegetation, become quickly established, and are difficult to remove (since they are more salt, fire, and drought tolerant and resistant to water stress than native species). Climate change may lower the water table and increase the risk of fire, which favors invasive species over native riparian species as well. Invasive species are generalists that are able to thrive in a greater range of environmental conditions.

Salt cedar or tamarisk (*Tamarix spp.*) is an invasive species that has been a major focus of management and restoration in the Middle Rio Grande basin. The species is associated with water draw down, floodplain loss, and increased fire risk. The species has the capacity to establish in sites that are less suitable for native flora due to alteration of flows and grazing (Stromberg et al. 2009). As the climate changes, tamarisk is likely to spread and outcompete cottonwood species (Glick et al. 2011 and Friggens et al. 2013). Stress due to water limitations and increased fire will continue to favor the establishment of tamarisk. Tamarisk also shades areas, which reduces cottonwood recruitment (Obedzinski et al.2001).

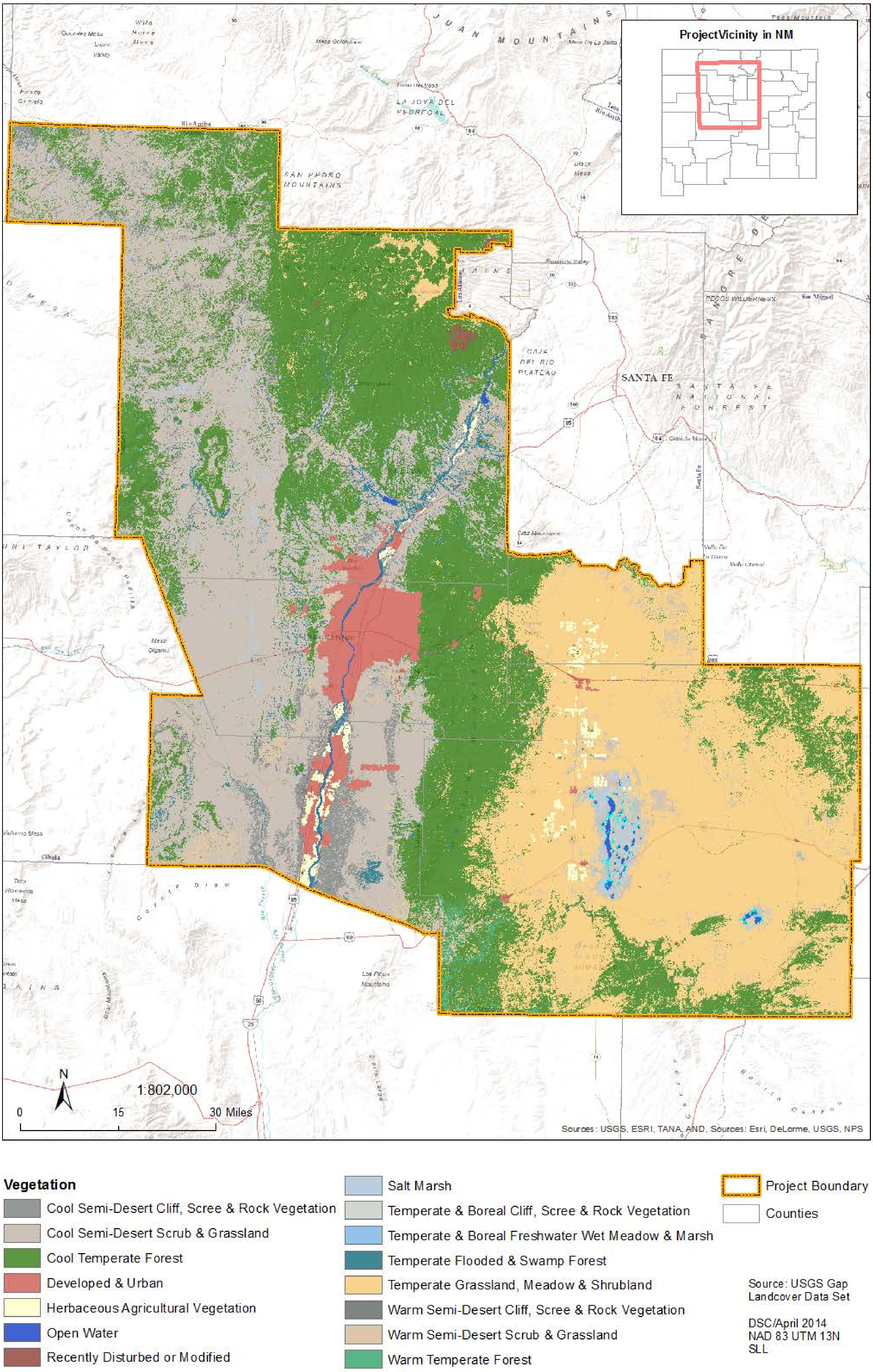

Figure 34. Current Vegetation Communities in Central New Mexico.

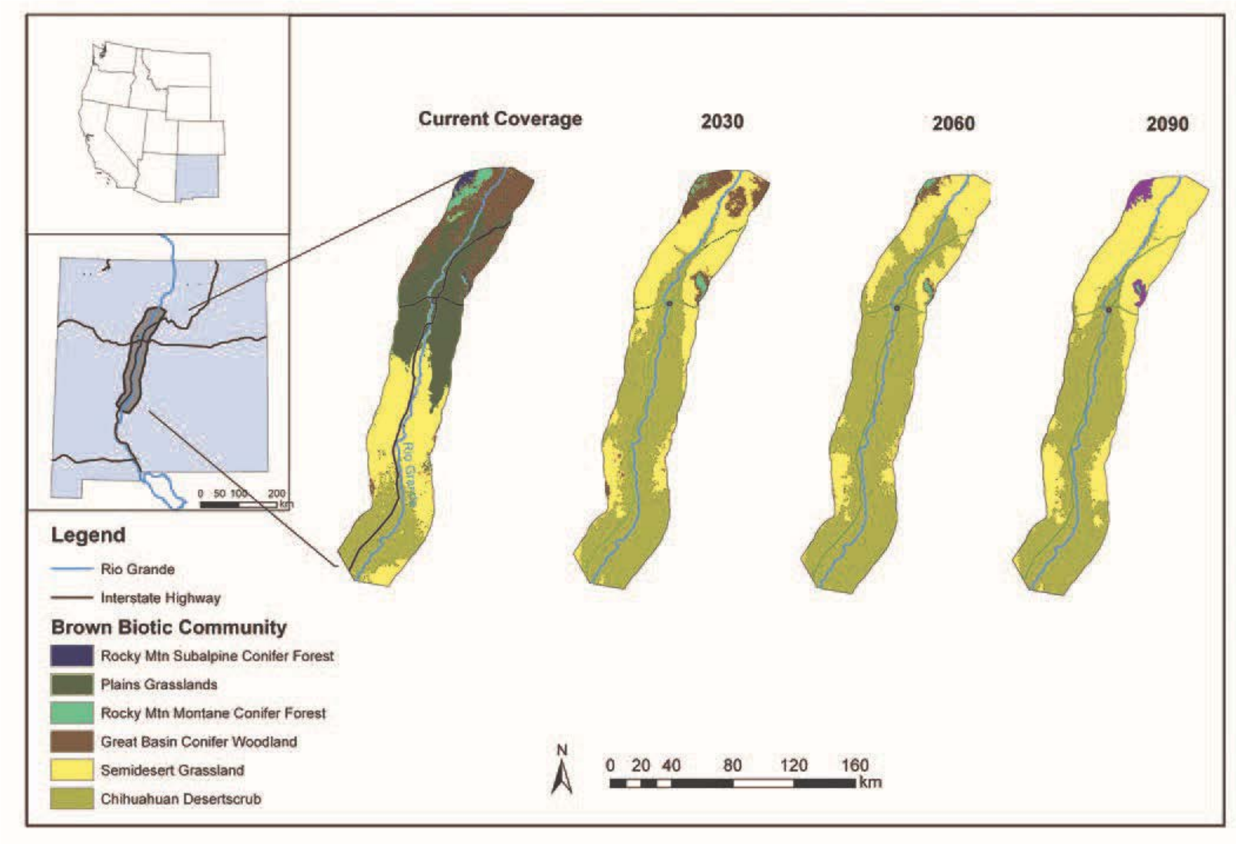

Figure 35. Projected Changes in Vegetation in Central Rio Grande Valley.

2.3.5.4 Threatened and Endangered Species

Historic development of the Upper Rio Grande has had impacts on the listed species and their habitats, and climate change promises to exacerbate those impacts, primarily through decrease in stream flows and available water to support riparian habitat (Llewellyn and Vaddey 2013). There are four listed endangered species, three threatened species, and one proposed threatened species in the study area.

- Currently the Rio Grande silvery minnow is endangered and believed to only occur in one reach of the Rio Grande in New Mexico, a stretch of river that runs the entire length of the planning area. Successful recruitment is strongly linked to the magnitude and duration of spring runoff. Population increases coincide with inundation of overbank habitats that support larval development. In the summer and fall, the drying river causes mortality to the silvery minnow. The decline in populations is mainly due to modification of its habitat, competition and predation by non-native species, and water quality degradation. Climate change is projected to reduce available water in the Upper Rio Grande system, making environmental flows in the river more difficult to maintain, and reducing the shallow groundwater available to riparian vegetation.

- The Southwestern Willow Flycatcher is listed as an endangered species. Nearly half (43 percent) of the endangered Southwestern Willow Flycatcher territories are found in riparian patches consisting primarily (greater than 90 percent) of native trees such as willow (*Salix* spp.) (New Mexico Biota Information System 2014). This species is known to nest in tamarisk as well. The greatest threats to the subspecies is modification of habitat, changes in flood and fire regimes, changes in water and soil chemistry, as well as establishment of invasive non-native plants (U.S. Fish and Wildlife Service 2002). This species is also vulnerable due to thermal tolerances and brood parasitism by brown-headed cowbirds. A vulnerability assessment of 117 vertebrate species that occur in the Middle Rio Grande Bosque identified the Southwestern Willow Flycatcher as the most vulnerable to climate change as it is restricted to a local food source during nesting season and the primary food source, insects, depends on water for some phase of their lifecycle. This species received the highest vulnerability rating for phenology (Friggens et al. 2013). The flycatcher is a migrant at risk of a timing mismatch between initiation of migration and availability of critical resources at the destination site.

- The Jemez Mountain salamander is listed as an endangered species. The Jemez Mountain salamander is endemic to north-central New Mexico in areas of tree canopy cover greater than 50 percent, elevation between approximately 7,000 and 11, 250 feet, and coniferous logs. The underground habitat is comprised of deep, fractured, subterranean igneous rock in areas of high moisture (Federal Register 2013). Climate change will cause changes in fire regime and forest structure that will constrict the distribution of the species and genetically isolate populations (Parmenter 2009).

- The New Mexico jumping meadow mouse is an endangered species. The New Mexico jumping meadow mouse is associated with tall, dense, herbaceous riparian vegetation, especially areas dominated by sedges. Of 37 mammals assessed for vulnerability to climate change in the middle Rio Grande valley, the New Mexico jumping meadow mouse was the most vulnerable based on habitat, physiology, and biotic interactions (Friggens et al. 2013).

- The Mexican Spotted Owl is listed as a threatened species. The Mexican spotted owl's preferred habitat is high canopy closure, high stand density, a multi-layered canopy, uneven-aged stands, numerous snags, and downed woody matter. This species is vulnerable to increased temperatures because it has a narrow and low thermal neutral zone. Population projections for this species in New Mexico, modeled under three IPPC scenarios, predict a substantial decline.

- The Pecos sunflower is listed as a threatened species. The Pecos sunflower is a wetland plant that grows on wet, alkaline soils at spring seeps, wet meadows, stream courses and pond margins. Populations are all dependent upon wetlands from natural groundwater deposits. Decreased groundwater and increased groundwater pumping as periods of drought increase could jeopardize populations of these species as climate changes.

- The western population of the yellow-billed cuckoo is listed as a threatened species. This species generally prefers mature riparian habitats and are most commonly associated with cottonwood or other native forests. Of 42 avian species assessed for vulnerability to climate change in the Middle Rio Grande area, the western yellow-billed cuckoo was ranked as the fourth most vulnerable. The species is vulnerable in all categories assessed: habitat, physiology, phenology, and biotic interactions (Friggens et al. 2013).

3 SCENARIOS

MRCOG developed an initial set of scenarios during the first phase of the project and these became the basis for more refined scenarios in phases II and III. Each set of scenarios included two common features: a current year scenario and a business as usual future year scenario that represents the expected development in the region following today's plans, policies, historical development trends, and projected population and employment growth. Population is expected to grow by 460,000 (a 52 percent increase) and employment by 183,000 (a 46 percent increase) by the year 2040. The current year was defined as the year 2012 and all future scenarios were developed for the year 2040. The project's 28 year planning horizon was set to align with MRCOG's update to its long range regional transportation plan. MRCOG plans to incorporate the scenarios and strategies identified from the climate change scenario planning project into the long range plan. Along with these common scenarios, each phase developed several alterative scenarios that were designed to alter the course of development from its historical trend in the region over the planning horizon with the aim of reducing GHG emissions and increasing resiliency to climate change. Addressing climate change concerns was the primary focus of the alterative scenarios; however, MRCOG also developed them to respond to other needs in the region such as reducing traffic congestion, increasing accessibility, and promoting economic growth. The scenario development process can therefore be thought of as a constrained optimization problem where alternatives were developed with the objective of minimizing GHG emissions and maximizing resiliency to climate change within constraints posed by available funding and the region's transportation and development needs, which are driven by the projected 52 percent increase in the region's population.

The next three sections describe the scenarios developed in each phase of the project, respectively. The objectives behind each scenario and the factors that influenced their designs are also discussed. Furthermore, while the scenarios evolved through the course of the project, so did the modeling methods. These changes are also described. In many ways, the project was more than just about developing and evaluating a series of land-use and transportation planning scenarios. It was also about developing a greater modeling capacity for MRCOG that would provide valuable analytical capabilities for this project and those that follow. The aim was to develop a capacity so that this project would not be a one-off effort but part of a continuous process of guiding the region to a more sustainable future. Inevitably, MRCOG and the project team refined the models and uncovered various bugs during each phase. This resulted in the creation of a refined and more robust modeling system. However, the changes also mean that metrics calculated for each phase of the project are not always directly comparable. With this limitation in mind, this section describes how MRCOG refined scenarios in the later phases to respond to the outcomes of earlier phases, yet it is not always possible to describe quantitatively how much better the refined scenarios are then the earlier scenarios.

The scenarios created in phases I to III are summarized by comparing several key outcomes. These include the amount of land developed, an indicator of sprawl and density; the change in peak hour average travel speeds, an indicator of regional congestion; the change in VMT per capita, an indicator of the region's dependence on vehicles for mobility; the change in regional GHG emissions; and the change in the number of river crossings, a key concern for many residents. The full range of performance measures for each scenario is included in the Appendix A. Performance Measure Summary Table. Notably, excluded from the key outcomes are accessibility and mode share metrics. While these are important performance measures for regional transportation planning, they are considered intermediate metrics by the project team for the purposes of summarizing the climate change scenario planning project's main findings; changes in these metrics drive the changes in the key metrics. For example, less accessibility or lower transit mode share results in greater congestion, more VMT, and higher GHG emissions all else held equal. Similarly, as accessibility is generally related to density, less accessibility will also drive greater land consumption. Changes in water consumption are also described for phase III, this metric was not available for phases I and II.

3.1 Phase I

MRCOG created three future preliminary land-use scenarios: the allowable uses, emerging lifestyles, and jobs/housing balance scenarios. MRCOG created the preliminary scenarios based on public and stakeholder input collected prior to the first workshop. MRCOG created these scenarios so that participants at the first workshop could evaluate and discuss an initial set of modeling results to provide a baseline for generating ideas for more refined or completely new scenarios. The scenarios are primarily differentiated from each other based on different patterns of zoning. The allowable uses scenario keeps current zoning in place and represents a business as usual scenario.

The emerging lifestyles scenario focused on increasing mixed use density near high frequency transit stops. In other words, it promoted transit oriented development. This was accomplished by zoning areas within a vicinity of existing and future transit stops as either medium-density or high-density mixed use.

The jobs/housing balance scenario mainly focused on addressing the lack of employment on the west side of the Rio Grande. The lack of jobs on the west side is a major cause for the large number of vehicle trips across the region's few river crossings, which results in significant congestion. Zoning was changed to allow higher intensity commercial development in several locations on the west side where commercial development is expected or where it already exists. Zoning was also changed to allow higher density residential development near existing activity centers throughout the region. These changes allow the development of more jobs near existing housing and more housing near existing jobs.

MRCOG used UrbanSim to forecast the type and intensity of development on each parcel in the metropolitan area for each of the three future scenarios. For each scenario, UrbanSim assumed the same 2012 base year transportation network and traffic conditions and the same population and employment growth. MRCOG and the project team also used UrbanSim output to run the regional travel demand model to forecast how changes in land-use, population, and employment patterns predicted by UrbanSim may affect traffic and GHG emissions. MRCOG and the project team ran the travel demand model with the same 2035 transportation network[7] for each of the three land-use scenarios. The only difference between the travel demand modeling runs were the location of different land-uses, population, and employment.

3.1.1 Phase I Modeling Outcomes

There were very few differences between the three future scenarios (Figure 36). Each scenario is expected to consume a large amount of new land, worsen traffic congestion, and increase GHG emissions. While GHG emissions per capita decline in each of the scenarios, this is mostly the result of improvements in vehicle fuel economy over time (only the emerging lifestyles scenario results in less driving). Although only being slightly superior to the other scenarios, the emerging lifestyles scenario performed the best overall. Notably, it was the only scenario where VMT per capita declined from the base year and it performed slightly better on most of the performance metrics, particularly access to transit and transit mode share. The jobs/housing balance scenario did achieve its intended effect of creating a better spatial balance between jobs and housing and as a consequence it also minimized the number of river crossings.

[7] The 2035 network was created for MRCOG's previous long range transportation plan and was used by MRCOG and the project team in the first phase of this project while MRCOG developed an updated 2040 network. The 2040 network is used in phases II and III.

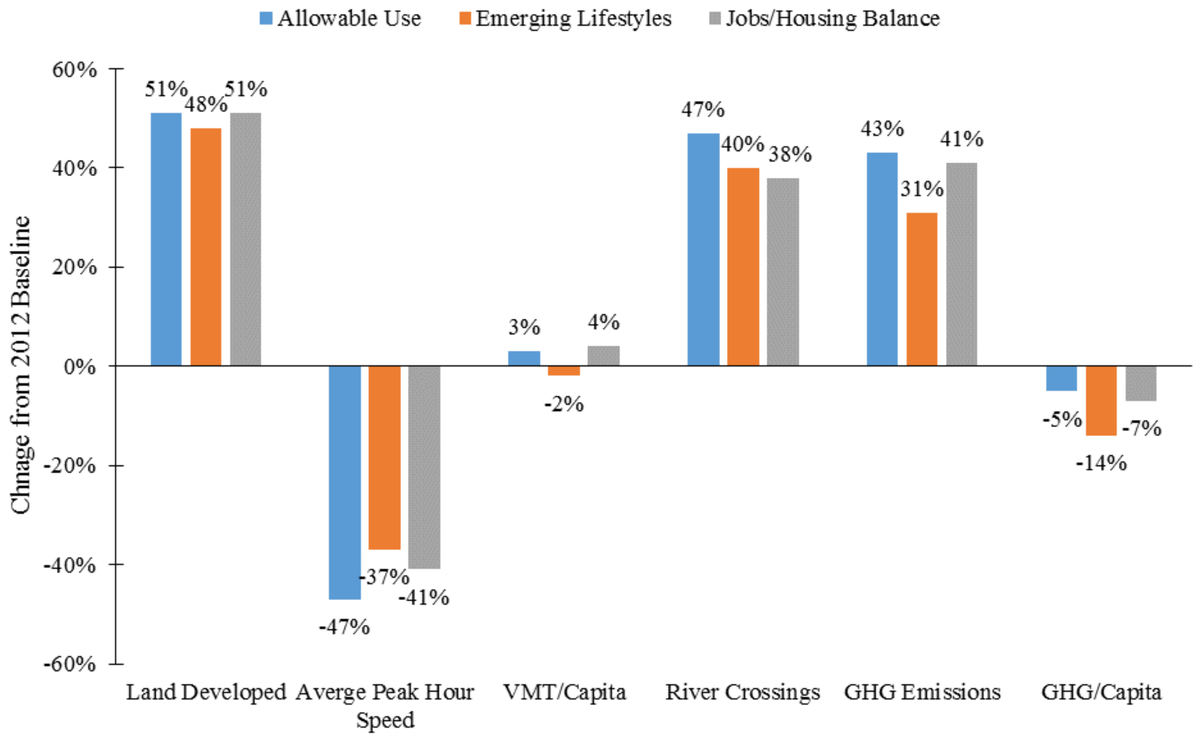

Figure 36. Summary of Phase I Scenario Modeling Outcomes (Key Performance Measures).

Participants at the first workshop pointed out that the differences between scenarios were relatively small. The workshop participants also clearly preferred the emerging lifestyles scenario, but this choice was somewhat reluctant. The general consensus was that the emerging lifestyles scenario made changes in the right direction compared to the trend, but much more needed to be done. Participants wanted to see larger changes from the allowable use scenario. There was also a desire to better address the jobs to housing balance on the west side which was partially addressed in the job/housing balance scenario.

In the context of significant population growth in the region, the small differences between scenarios also led the project team to conclude that none of the scenarios would significantly change the resiliency of the region to climate change. Even though the emerging lifestyles scenario performs better than the trend, increased land and transportation infrastructure development would increase urban heat, further reduce groundwater recharge while consumption increases, and push more development into areas at higher risk of floods, fire, and into crucial wildlife habitat. Overall, under any of the phase 1 scenarios and due the region’s projected significant population growth, the region would continue to contribute to higher GHG levels while also becoming less resilient to climate change.

3.2 Phase II

MRCOG developed two new scenarios in response to comments received from the first workshop, which largely favored the “emerging lifestyles” scenario, but also stressed that much more needed to be done if the region is to grow more sustainably, be more resilient, and reduce GHG emissions. Additionally, MRCOG redefined the business as usual (allowable uses) scenario.

The phase I scenarios used a simplified representation of the region’s zoning allowances. Each municipality has a wide range of zoning types, which MRCOG simplified by collapsing them into a smaller number of categories for the purpose of creating the preliminary scenarios MRCOG then used the actual zoning definitions to create the more refined scenarios in phase II, which is necessary so that each municipality can determine exactly what changes they will need to make to help the region achieve the outcomes forecasted through the scenario modeling. The change in the zoning definitions resulted in the creation of a new business as usual scenario, referred to as the "trend" scenario that replaced the allowable uses scenario from phase I.

MRCOG created two alterative future scenarios: the preferred and the fiscally constrained preferred (constrained) scenarios. These two scenarios have the same land-use zoning and incentives but have different transportation networks. The alterative scenarios were designed to drive larger changes from the trend than either the emerging lifestyles or jobs/housing balance scenarios achieved. To do this, the alternative scenarios change zoning from the trend to allow even more mixed use near transit stops and activity centers; greater multi-family density near activity centers; and greater commercial intensity near west side commercial centers. These changes generally represent a combination of the zoning changes from the emerging lifestyles and job/housing balance scenarios from phase I along with incentives to achieve greater infill, mixed use and transit oriented development. MRCOG incentivized additional infill and transit oriented development by applying shifters in the UrbanSim model to locations near activity centers and transit stops.

The scenarios in phase two also used an updated 2040 transportation network. The 2040 network contains projects that MRCOG expects to include in their next long range transportation plan based on updated project lists provided by each municipality. The trend network includes the full 2040 roadway network and the existing (2012) transit network plus a new bus rapid transit (BRT) line on central. The preferred scenario includes the same 2040 roadway network but added an expanded transit system with much higher service levels (Table 6) The constrained scenario assumes that state and federal transportation funding will decline over time, constraining the funds available to build out the roadway network and transit system. It is assumed that less funding will lead to a slower build out of the transportation infrastructure, and this is represented in the constrained scenario by using the year 2025 roadway and transit networks instead of the 2040 networks. Figure 37 shows the differences in the roadway networks used in each phase of the project.

Table 6. Transit Routes and Level of Service.

Route Type	Route Name	2012		2025		2040	
		Headway (min)	Service Hours	Headway (min)	Service Hours	Headway (min)	Service Hours
Bus Rapid Transit	Central Ave. BRT	15*	16*	5	18	5	18
Bus Rapid Transit	Coors Blvd. BRT	17*	16*	17	16	10	18
Bus Rapid Transit	Paseo del Norte BRT			20	18	15	18
Bus Rapid Transit	UNM-CNM BRT			15	18	15	18
Primary	Bridge-Westgate (54)	45	16	30	18	15	18
Primary	Central Ave. (66)	15	19	15	18	15	18
Primary	Coors Blvd. (155)	33	17	20	18	15	18
Primary	Lomas Blvd. (11)	20	15	15	18	15	18
Primary	Menaul Blvd. (8)	20	16	20	18	15	18
Primary	Montano Blvd.-Uptown-KAFB (157A)	20	17	15	18	15	18
Primary	Montgomery Blvd.-Carlisle Blvd. (5)	20	17	15	18	15	18
Primary	San Mateo Blvd. (140/141)	15	16	15	18	15	18
Rapid Ride	Lomas Blvd. RR					15	18
Rapid Ride	Montgomery Blvd.-Carlisle Blvd. RR					15	18
Rapid Ride	San Mateo RR					15	18
Secondary	Airport-Downtown-Mesa del Sol (50)	30	13	30	13	20	16
Secondary	Eubank Blvd. (2)	30	13	30	16	20	16
Secondary	Isleta Blvd. (53)	45	14	45	14	20	16
Secondary	Juan Tabo Blvd. (1)	25	12	25	16	20	16
Secondary	North 4th St. (10)	25	15	25	15	20	16
Secondary	Rio Bravo Blvd.-Sunport-KAFB (222)	65	12	65	12	20	16
Secondary	Rio Rancho					20	16
Secondary	Wyoming Blvd. (31)	45	15	30	16	20	16
Tertiary	12th St.-Rio Grande Blvd. (36)	60	12	60	12	30	15
Tertiary	ABQ-Rio Rancho-NMRX Connection (251)	30	14	30	14	30	15
Tertiary	Alameda Rd.					30	15
Tertiary	Atrisco Dr.-Rio Bravo Blvd. (51)	60	13	60	13	30	15
Primary	Montano Blvd.-Uptown-KAFB (157B)					30	15
Tertiary	NM 528					30	15
Tertiary	SW-Unser Blvd. (198)	30	16	30	16	30	15
Tertiary	Zuni Rd. (97)	60	13	60	13	30	15

*Currently Rapid Ride Routes

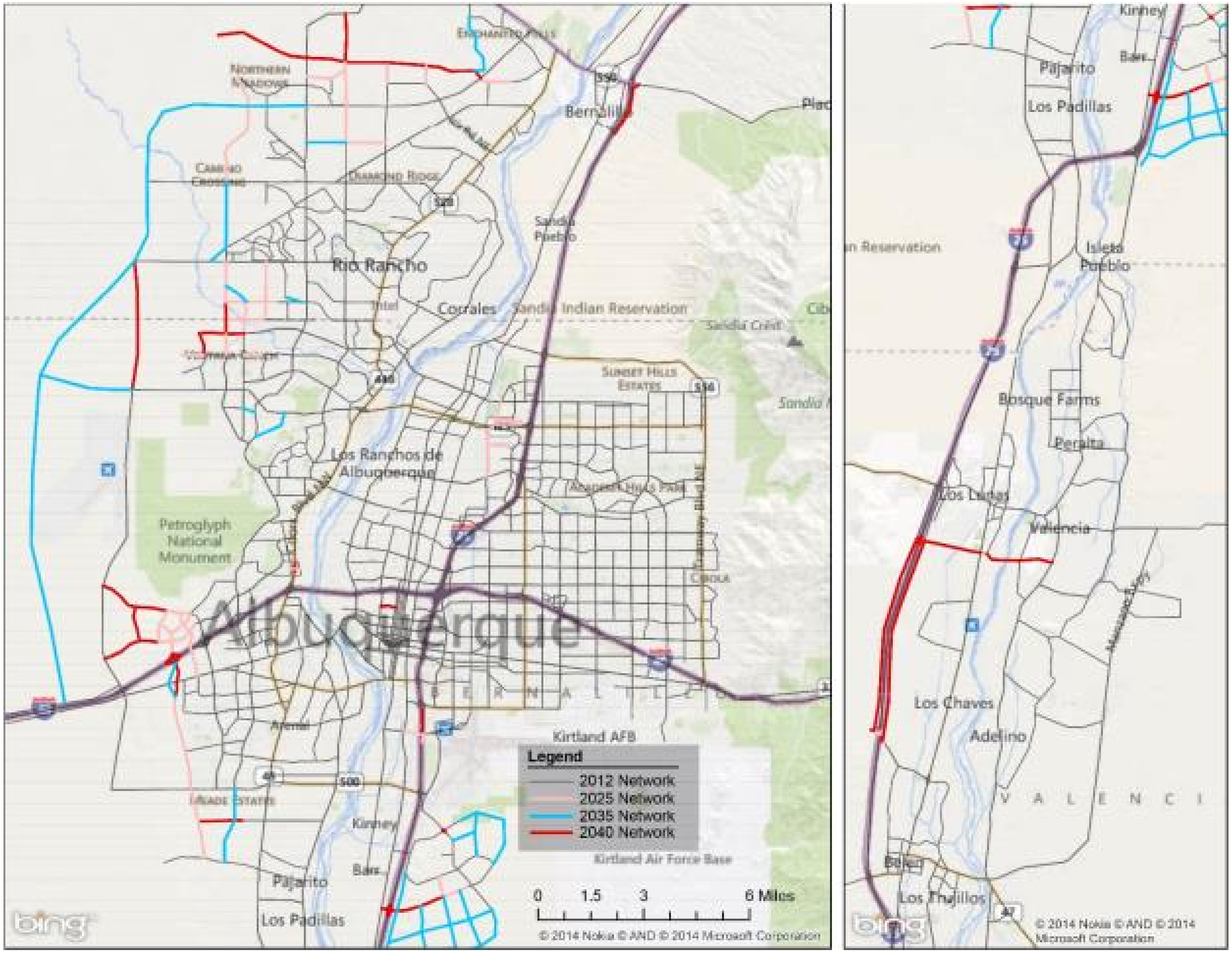

Figure 37. Roadway Networks Used in Each Scenario for Travel Demand Modeling.

3.2.1 Phase II Modeling Outcomes

Similar to phase I, there were relatively small differences between each of the future scenarios but there are some notable differences (Figure 38). The new set of scenarios still consumes a large amount of land and increase regional GHG emissions; however, the alterative scenarios do noticeably better than the trend. Transit accessibility and mode share also increases significantly over current levels in the alternative scenarios: transit mode share increases by 32 percent in the preferred and 14 percent in the constrained. Transit mode share declined in the trend scenario. While these are relatively large increases, overall transit mode share in the preferred scenario is only about one percent. The small transit mode share is why improvements in transit have not resulted in large changes in the key performance measures shown in Figure 38. The trend and the alternatives also result in less driving per capita, which when combined with more efficient vehicles in the future, results in a relatively large decrease in per capita GHG emissions although the differences between scenarios are not large.

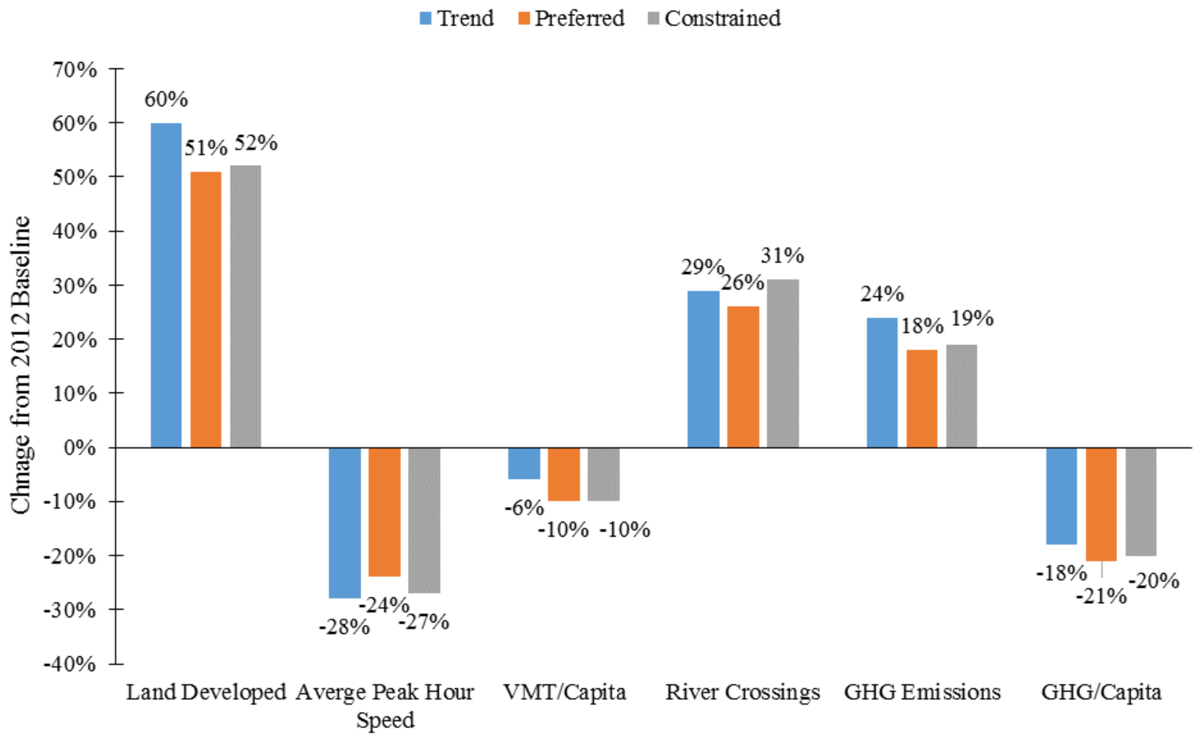

Figure 38. Summary of Phase II Scenario Modeling Outcomes (Key Performance Measures).

Aggregate performance metrics may hide significant local differences between the scenarios. The project team mapped the change in traffic volume to better understand how the alterative scenarios may differ from the trend (Figure 39). While the change in VMT per capita between the trend and preferred scenarios is only four percentage points, Figure 39 indicates large changes in regional traffic patterns. The red colors indicate where traffic volumes increase relative to the trend. The preferred scenario generally results in more trips on Albuquerque's east side and fewer trips in Rio Rancho and Mesa del Sol. These changes make sense since the preferred scenario promoted more residential and commercial development by increasing zoning allowances and incentivizing development near existing activity centers, many of which are on Albuquerque's east side. While this development pattern did not result in a large decrease in VMT per capita from the trend, the concentration of more traffic on the east side also did not result in much change in congestion. Generally, the east side's transportation network has more capacity than the west's and is able to accommodate more growth. The small change in VMT per capita likely results from a persistent imbalance between west side housing and east side jobs, which is indicated by the river crossing metric (Figure 38) and confirmed by the jobs/housing balance metric (see Appendix A. Performance Measure Summary Table) which showed only a two percent difference between the three scenarios.

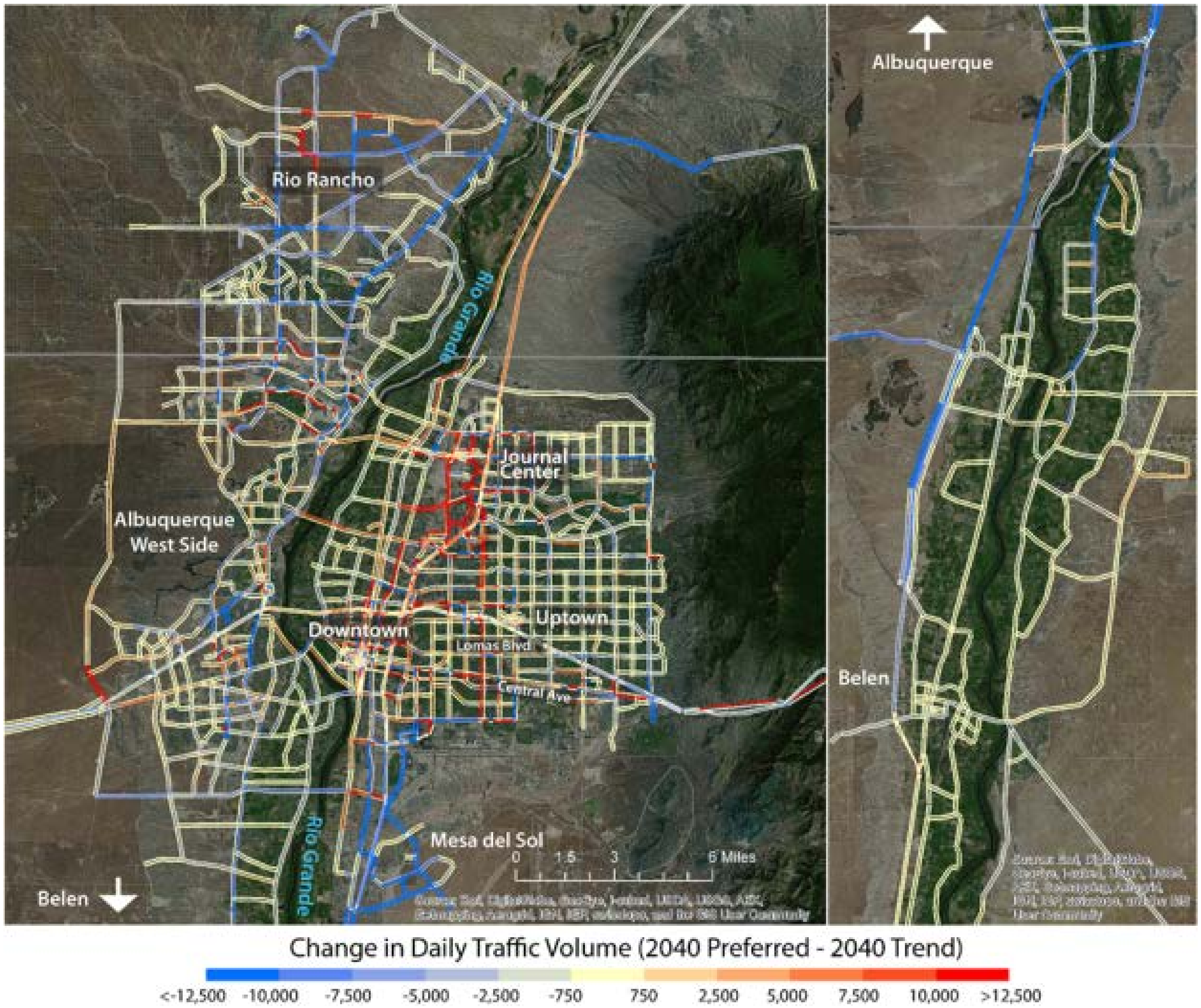

Figure 39. Difference in Traffic Volume between the Preferred and Trend Scenarios.

Overall, the preferred scenario is the highest performing in phase II and when compared to the other scenarios developed for phase I. The greater development in core activity centers and increased transit investments under the preferred scenario result in the least amount of driving and the smallest urban footprint, in-turn leading to less congestion and fewer GHG emissions than other future scenarios. If funding constrains the development of the preferred scenario, the constrained scenario also performs notably better than the trend and the phase I scenarios.

The phase II scenarios were presented at a second workshop, where again participants expressed a desire for larger changes from the trend. The small differences between scenarios also led the project team to conclude once again that none of the scenarios would significantly change the resiliency of the region to climate change in the context of significant population growth. Even if the preferred scenario performs better than the trend, increased land and transportation infrastructure development over the current baseline will increase urban heat, further reduce groundwater recharge while consumption increases, and will push more development into areas at higher risk of floods, fire, and into crucial wildlife habitat. Yet if one scenario is to be selected as the most resilient it would be preferred scenario. The preferred scenario has the smallest development foot print and least amount of vehicle traffic. The project team noted that the preferred scenario could be further improved by controlling the amount of development in high fire and flood risk areas and crucial habitat areas. This could be accomplished with more restrictive zoning or a growth boundary, which MRCOG included in the final set of scenarios described below.

3.3 Phase III

The final set of scenarios developed in phase III are refined versions of the three scenarios developed in phase II. The final scenarios were developed in response to feedback from the second workshop participants that generally included a desire for even greater reductions in travel and emissions and more concentrated infill and mixed use development in high priority centers and corridors. In response, the following changes were made to the scenarios developed for the second workshop to create the final scenarios:

- Decreased parking requirements by increasing allowable floor area ratio for parcels with large amounts of surface parking;
- Increased preservation of agricultural areas by decreasing allowable development for key agricultural areas;
- Increased allowable uses for some activity centers;
- Implemented a tiered infill development incentive shifter in UrbanSim that provides greater incentives to develop in Downtown Albuquerque and Uptown Albuquerque and lesser incentives in two categories of lower priority development centers;
- Implemented development policy shifters in UrbanSim to also direct a greater share of development to certain key corridors (rather than just to centers and transit stops);
- Broke out large undeveloped parcels into smaller parcels to improve the performance of UrbanSim;
- Coded planned developments as committed only if there is something currently being built at the site; and
- Density in flood plains and high fire risk areas reduced by 20 percent.

Other than these changes, the alterative scenarios are defined the same as in phase II. No changes were made to the roadway and transit networks from phase II. Table 7 provides a summary of the scenario definitions from all three phases of the project.

Table 7. Overview of Regional Planning Scenarios.

		Allowable Use	Emerging Lifestyles	Jobs/Housing Balance
Phase I	Land-Use Zoning	Simplified representation of existing zoning	• Mixed use zoning near transit stops. • Higher density near transit stops with more passengers	• High density commercial and residential near activity centers • Some high density mix-used is reduced to low density mixed use.
	Development Incentives	None	None	None
	Highway Network	2035 Network	2035 Network	2035 Network
	Transit Network	Existing	Existing	Existing
		Trend	Preferred	Constrained
Phase II	Land-Use	Current Zoning	• Mixed use near transit stops • Mixed use near activity centers • Increase multi-family density near east side activity centers • Increase commercial density near west side commercial centers	• Mixed use near transit stops • Mixed use near activity centers • Increase multi-family density near east side activity centers • Increase commercial density near west side commercial centers
	Development Incentives	None	• Locations near activity centers • Locations near transit stops	• Locations near activity centers • Locations near transit stops
	Highway Network	2040 Network	2040 Network	2025 Network
	Transit Network	Existing + Central BRT	2040 Network & Service Plan	2025 Network & Service Plan
		Trend	Preferred	Constrained
Phase III	Land-Use	Current Zoning	• 20 % reduction in density for new development in flood plains and high fire risk areas • Increased FAR for parking lots and areas with lots of parking • Plus all changes from Phase II	• 20 % reduction in density for new development in flood plains and high fire risk areas • Increased FAR for parking lots and areas with lots of parking • Plus all changes from Phase II
	Development Incentives	None	• Locations near activity centers • Locations near transit stops • Locations along key corridors • Greatest incentive for Downtown and Uptown Albuquerque, other areas were incentivized less intensively	• Locations near activity centers • Locations near transit stops • Locations along key corridors Greatest incentive for Downtown and Uptown Albuquerque, other areas were incentivized less intensively
	Highway Network	2040 Network	2040 Network	2025 Network
	Transit Network	Existing + Central BRT	2040 Network & Service Plan	2025 Network & Service Plan

3.3.1 Phase III Modeling Outcomes

The final set of scenarios showed larger changes from the trend scenario (or "allowable uses" in phase I) than in the prior phases. While some of the changes are still relatively modest, they drew much clearer distinctions between the trend and the alternatives in the key performance measures (Figure 40). While land consumption continues to increase, the alternatives consume significantly less new land than the trend (30 percent less). The amount of driving, congestion and GHG emissions, including per capita GHG emissions, are also clearly lower than the trend. However, like prior scenarios, addressing river crossings remains a challenge; there were only small differences in the number of river crossings between the scenarios. The alterative scenarios also make significant improvements in access to transit, which results in a 51 percent increase in transit mode share in the preferred scenario. However, given the very small baseline mode share, just 0.8 percent, this large increase does not have a large impact on the key performance measures.

It is also important to note that MRCOG estimated the amount of land development differently in phase III to more accurately represent expected land consumption. Therefore, the absolute differences in land development should not be compared between the three phases of the project. Similarly, the project team changed the way that VMT per capita and GHG emissions were aggregated in phase III. Phases I and II considered VMT and population from the entire modeling domain while only VMT and population occurring within MRCOG's metropolitan planning area was considered in phase III.[8]

[8] The project team made this change after noticing that scenarios resulting in more population being pushed far beyond the urban area's boundary do not necessarily contribute to more VMT. This occurs not because these people are not expected to drive more, but because the travel demand model does not define many rural roads and instead represents them with centroid connectors. Centroid connectors are used to connect TAZs, where people live, to the collector, arterial, and highway network represented in the travel demand model. Essentially, centroid connectors represent local streets that are not explicitly defined in the model. Since centroid connectors are not used in VMT calculations, scenarios with more development far from the urban boundary where the roadway network is not well defined will have VMT estimates that are biased downwards. The project team estimated VMT per capita and GHG emissions in phase III using only VMT and population within the boundary of the metropolitan planning area to avoid this potential bias, and since little development occurs far from the urban boundary.

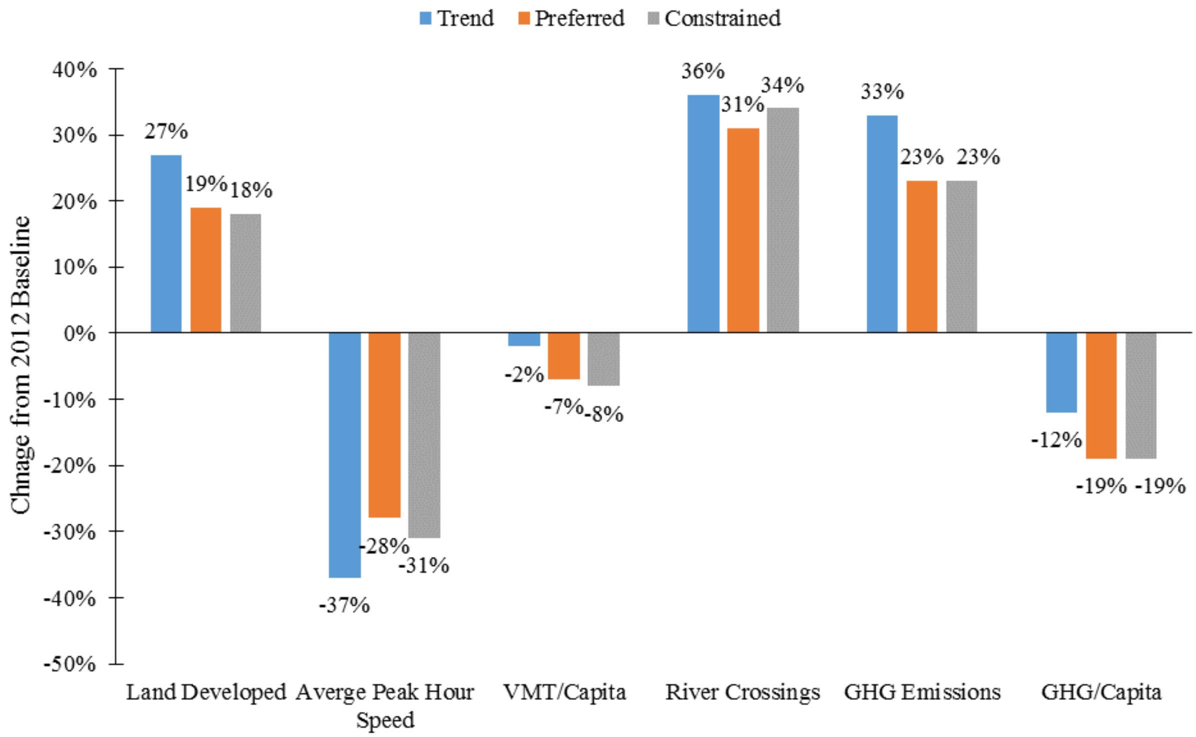

Figure 40. Summary of Phase III Scenario Modeling Outcomes (Key Performance Measures).

3.3.1.1 Traffic Volume

As was done in Phase II, the project team mapped the change in traffic volume to better understand how local travel patterns in the alterative scenario may differ from the trend (Figure 41). While the change in VMT per capita between the trend and preferred scenarios is only five percentage points, Figure 41 indicates large changes in regional traffic patterns. The red colors indicate where traffic volumes increase relative to the trend. The preferred scenario generally results in more trips on Albuquerque's east side and fewer trips on the west side and Mesa del Sol. A notable difference from the Phase II map is that the increase in traffic is more concentrated in the Journal Center area, in a wide area extending east of downtown along the Central Avenue and Lomas corridors, Uptown, and Rio Rancho's town center area. Many of the areas where traffic increases are areas where the preferred scenarios incentivized new development. The land-use zoning and greater incentives seem to have further concentrated growth into fewer areas than in the prior scenarios, resulting in the more defined differences in traffic growth. The constrained alterative results in similar traffic volume changes, but with the removal of some capacity on the far west side, west side traffic volume does increase along some corridors (Figure 42).

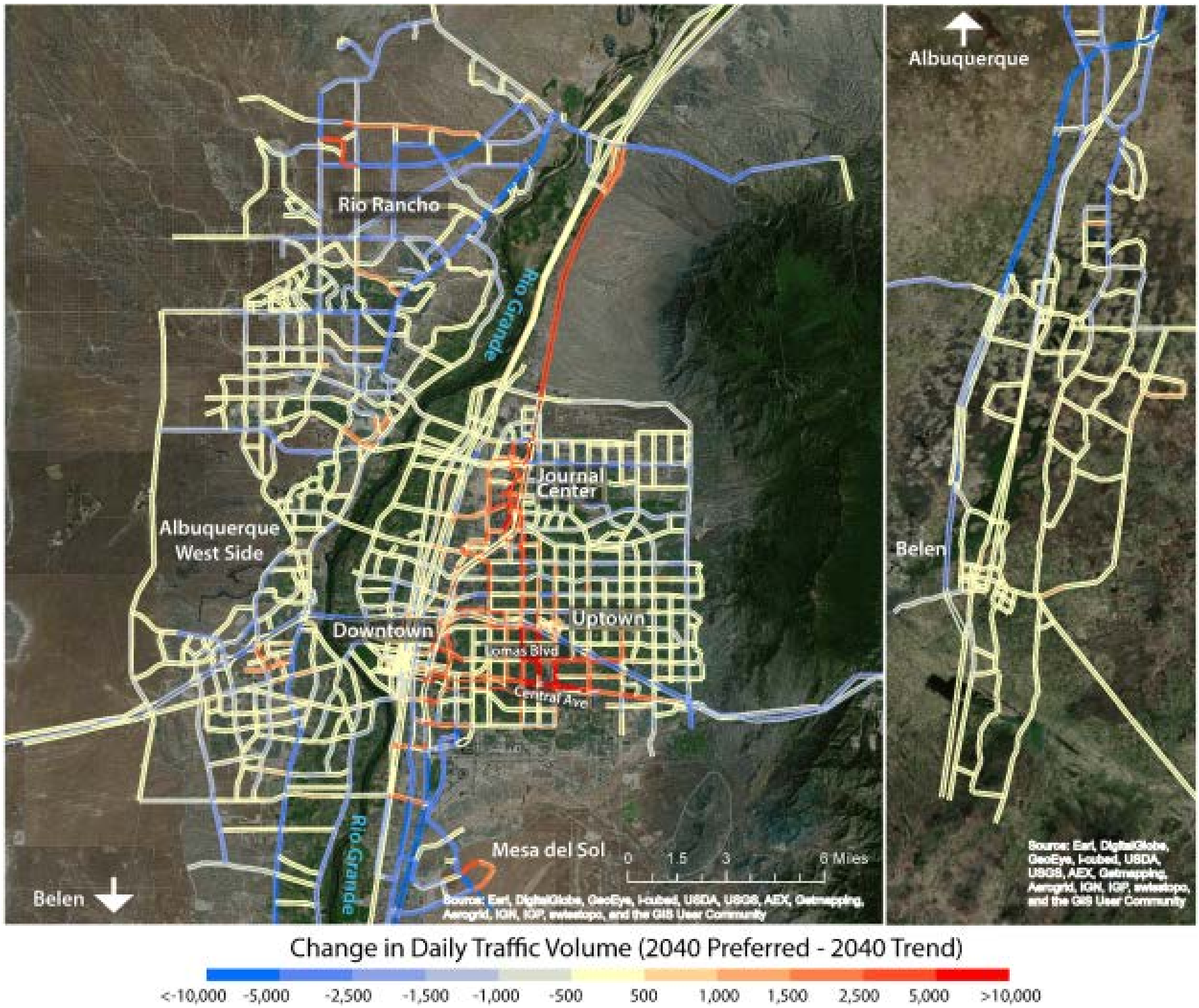

Figure 41. Difference in Traffic Volume between the Phase III Preferred and Trend Scenarios.

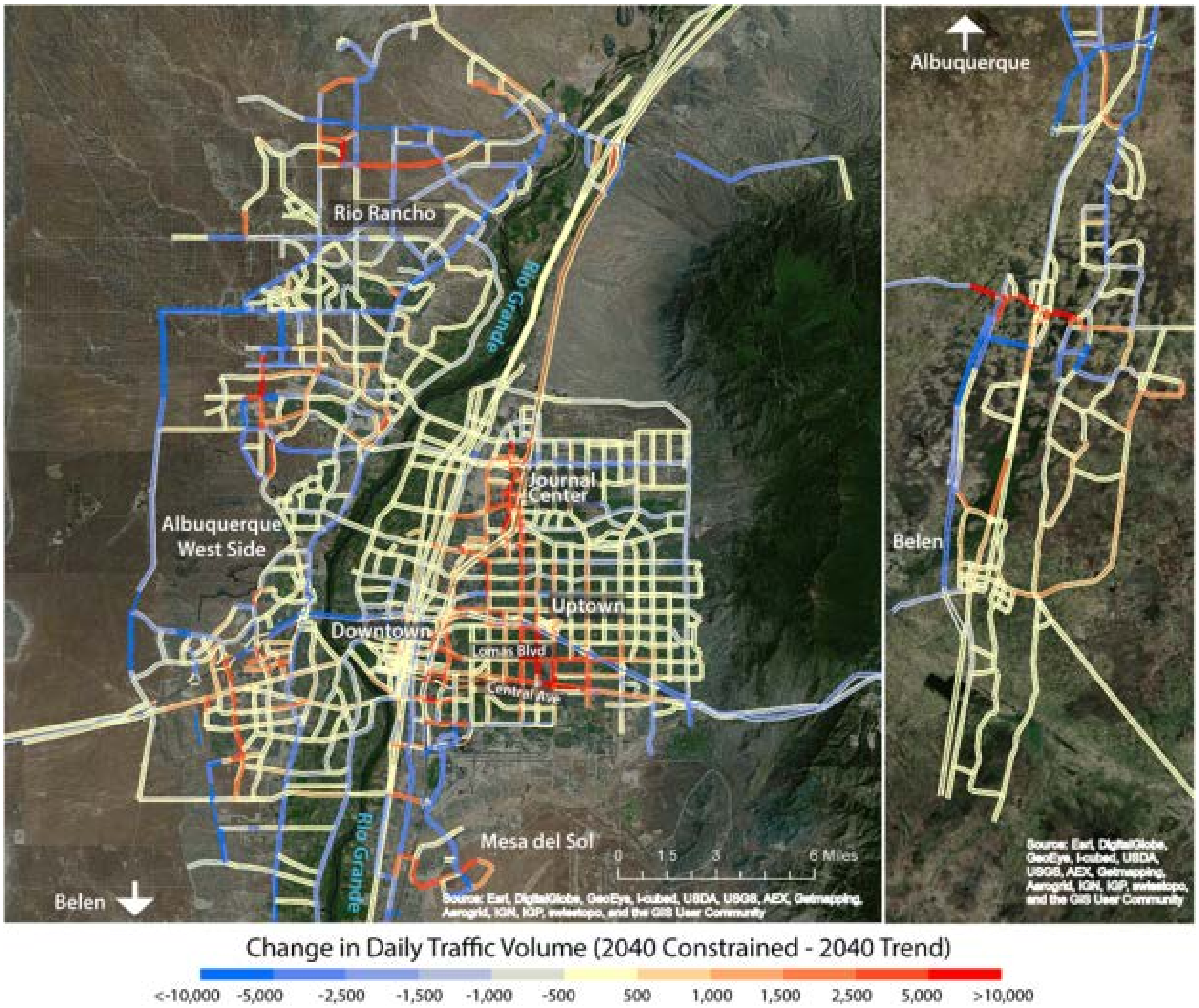

Figure 42. Difference in Traffic Volume between the Phase III Constrained and Trend Scenarios.

3.3.1.2 Water Consumption

For phase III, the project team also evaluated changes in water consumption (Table 8 and Figure 43). Due to the region's projected 52 percent increase in population, water consumption increases significantly from today; however, the alternative scenarios perform notably better than the trend. Most of the change in water consumption between the scenarios is driven by changes in residential development. Denser residential development may be an effective strategy for slowing the region's growing water consumption. Agriculture also consumes a significant amount of water, especially in relation to the amount of land used. There is little expected change in agricultural water consumption between now and 2040 or among the scenarios; however, reducing the amount of land in irrigated agriculture, improving irrigation efficiency, or growing crops that require less water could significantly reduce the region's water consumption.

Table 8. Water Consumption Estimates by Land-Use and Scenario.

Land-Use	Land Development (acres)	Median 2013 Water Consumption Rate (gallons/acre/year)	Annual Water Consumption (millions of gallons) 2012	Trend	Preferred	Preferred Constrained
Agriculture	12,042	2,418,012	29,208	29,090	29,118	29,057
Industrial	13,192	15,987	217	190	211	198
Institutional	14,597	11,117	476	170	162	163
Residential	193,818	421,085	56,607	88,632	81,614	81,425
Commercial	22,287	16,111	205	385	359	362
Total			86,713	118,466	111,464	111,205

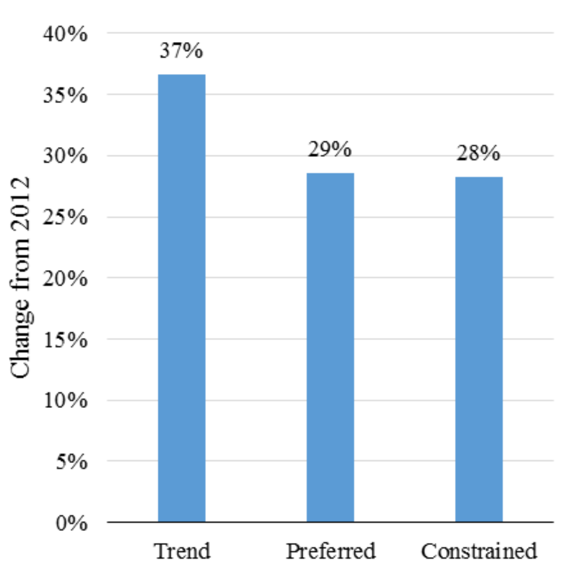

Figure 43. Change in Water Consumption.

3.3.1.3 Flood Risk

In phase III, the project team also evaluated which roadways are currently in existing flood plains (Figure 43). The project team estimates that 172 miles (10 percent) of major roadways (roads included in NMDOT's statewide roadway GIS layer) within the AMPA are in flood plains. As Figure 44 indicates, these include roads within the Rio Grande's flood plain and roads in smaller flood plains scattered across the region. Many of the roads within flood plains are actually up, away from the Rio Grande and located in the higher and more urbanized areas of Albuquerque. While this analysis does not inform which future scenario's transportation infrastructure is more resilient to climate change, these data can be used to evaluate existing infrastructure and local projects that may be at increased risk of flooding. Figures 8 to 13 show the development change in floodplains under the scenarios.

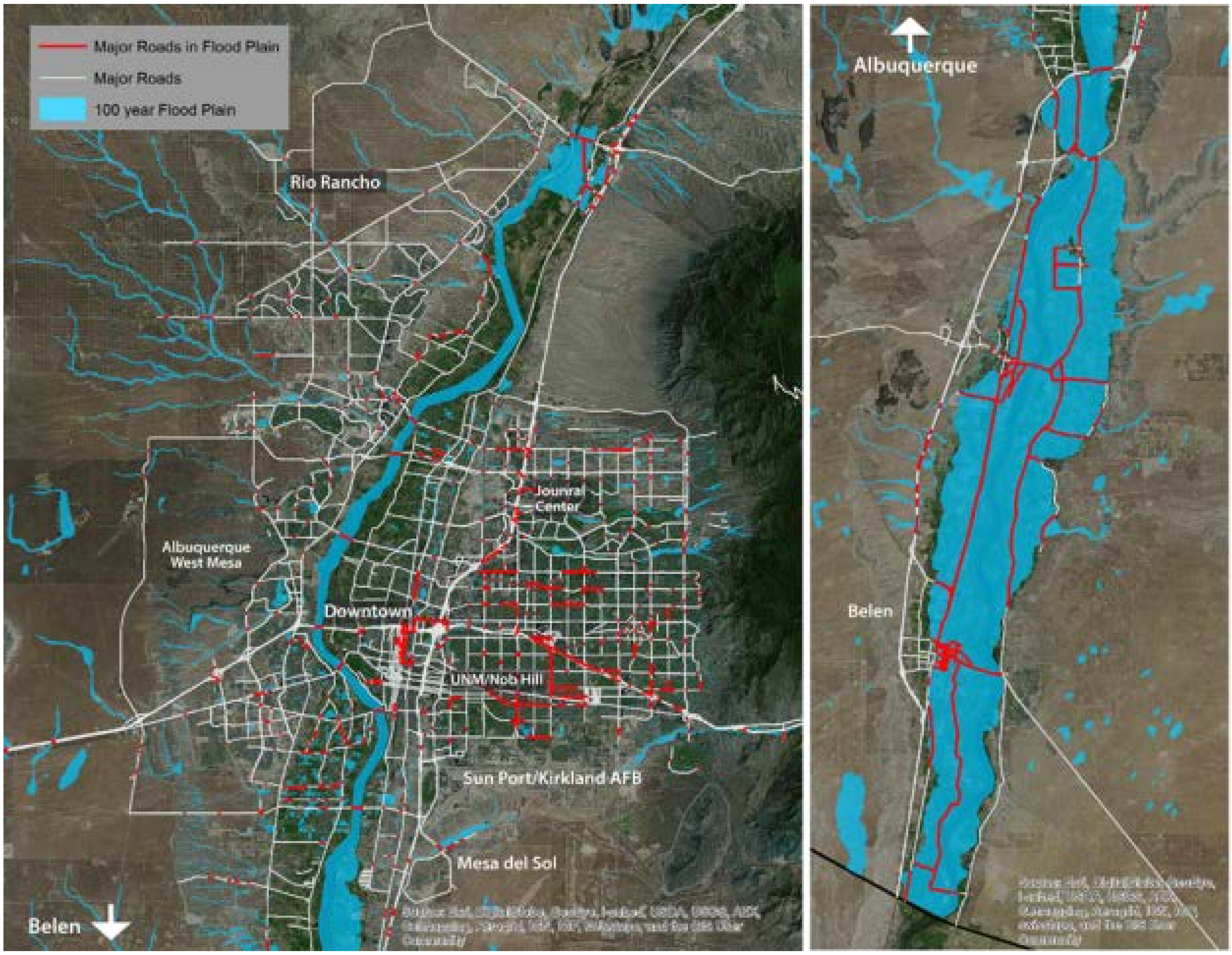

Figure 44. Major roads in 100 year floodplains.

3.3.1.4 Wildfire Risk

Wildfire risk for each scenario is shown in Figures 20 to 25. The most direct land use strategy that will increase wildfire resilience in Central New Mexico involves stopping development in the WUI or slowing its rate by reducing or eliminating housing, commercial, and industrial growth in the WUI. Fewer residents and businesses in the WUI will lead to lower damages from any given event.

Communities at high risk are Algondones, Corrales, Tome, Los Chavez, Bosque Farms, Jarales, Belen, Los Lunas, and Peralta. The preferred scenario will have the least amount of development in all categories whereas the trend scenario will have the most amount of development. Consequently, the preferred scenario will be more resilient to wildfire as less development in the WUI decreases the risk to people and property from wildfire. Areas of greatest risk of wildfire are the bosque along the Rio Grande which flows through the middle of the metropolitan area and the foothills and Sandia Mountains. Interstate 40, Paseo del Norte, Montano, Alameda, Central Avenue SW, and Highway 314 are major roads that cross the Rio Grande and bosque. Interstate 40 passes through the foothills and Sandia Mountains east of Albuquerque. There is no alternative major route through the Sandia Mountains within 60 miles. Wildfire and smoke could lead to traffic closures.

Bike trails and hiking trails in the Rio Grande Valley State Park are at risk from wildfire. Established by the State Legislature in 1983, this Park is managed cooperatively by the Open Space Division and the

Middle Rio Grande Conservancy District. The 4,300-acre park extends from Sandia Pueblo in the north through Albuquerque and south to Isleta Pueblo. The Albuquerque BioPark, Rio Grande Nature Center, and National Hispanic Cultural Center are important cultural institutions located in close proximity to the bosque. The Sandia, Cibola, and Santa Fe National Forest trails, roads, and camping areas are heavily used by area residents and visitors. The National Forest and bosque trails are likely to be closed more frequently and for longer periods of time due to increased risk of wildfire.

3.3.1.5 Crucial Habitat

Preserving crucial habitat is an important part of ecological resiliency to both urbanization and climate change. Most of the highest ranked crucial habitat is located in the Middle Rio Grande, bosque, the Sandia Mountains and the Jemez Mountains. The Rio Grande is a regulated river and management of water deliveries will be important to increase resilience of the riparian vegetation and river, which provide habitat to species of concern including the southwestern willow flycatcher and the Rio Grande silvery minnow. Figure 28 to Figure 33 show the development change in crucial habitat under the scenarios. Figure 26 shows that there are less households and employment in crucial habitat ranks 1, 2, and 3 under the preferred scenario than the other scenarios.

Overall, less development would occur under the preferred or constrained scenarios than the trend and the development would occur in already developed areas (Figure 28 and Figure 29, Figure 32 and Figure 33). Development would also occur on a small number of parcels rather than a large number of parcels (Figures 28 to 33). This would result in a more compact urban footprint, which would cause the region to be more resilient to climate change than dispersed development. A more compact urban footprint will also allow wildlife corridors and natural areas to be maintained and become less fragmented.

3.3.1.6 Conclusion

The land-use and transportation scenarios developed for phase III result in more significant changes from the trend than scenarios developed in prior phases of the project. Still, a significant amount of new land is consumed by development and traffic congestion and GHG emissions continue to increase significantly over current levels. The results also indicate that each scenario is less resilient than today. The increasing land development increases urban heat, reduces water supply while increasing water demand, and pushes more development into inappropriate places at higher risk for floods and wildfire and where crucial habitat is encroached upon. These results reflect the challenge of accommodating a projected 52 percent increase in the region’s population by 2040.

While the differences between alterative scenarios are small, they perform better than the trend scenario in almost every performance measure and would place the region on a more sustainable and resilient development path. Overall, the preferred and constrained scenarios also perform better than the other scenarios developed for the first two workshops.[9] The greater development in core activity centers, key corridors, and increased transit investments under the preferred and constrained scenarios result in the least amount of driving and the smallest urban footprint, in-turn leading to less congestion, fewer GHG emissions, and less water consumption than other future scenarios. If funding constrains the development of the preferred scenario, the constrained scenario performs equally, and in some cases better (e.g., less water consumption, land development, and VMT per capita), than the preferred scenario.

[9] Note that the results from the final scenario analysis are not directly comparable with the prior scenarios because several performance metrics have been calculated using different methods. Overall, our assessment that the final set of alterative scenarios perform the best is based on them having relatively larger, positive, differences from the trend.

4 ADDITIONAL GHG MITIGATION STRATEGIES

Table 7 provides a list of potential GHG mitigation strategies that were identified by MRCOG in the early phases of the project. The project team evaluated the list and provided an initial ranking on the GHG mitigation potential of each strategy, whether the strategy was a short, medium, or long term measure, and how well the GHG mitigation potential of the strategy could be evaluated with the data and models currently available to MRCOG and the project team.

Four strategies with high GHG mitigation potential were previously evaluated (Table 9A) using MRCOG's integrated land-use, travel demand, and emission factor models in the scenario analysis portion of the project. These strategies changed land-use zoning to allow greater mixed-use, transit oriented, and infill development and also improved transit service by decreasing headways, expanding routes, and adding new bus rapid transit lines. The phase III (final) preferred scenario achieves 5.6 percent fewer vehicle miles traveled (VMT) and 7.3 percent fewer GHG emissions than the trend scenario in the year 2040. However, considering absolute changes from today (2012) and the region's significant project population growth, VMT increased by 41 percent and GHG emissions increased by 23 percent. VMT grew faster than GHG emissions because the region's vehicle fleet is expected to become more energy efficient over time. While the decline in VMT and GHG emissions relative to the trend scenario is significant, to address climate change, GHG emissions will eventually need to fall below current levels. This section considers additional strategies that may help further reduce regional GHG emissions from the transportation sector.

In this section, an additional set of high priority or potentially highly effective GHG mitigation strategies (Table 9B) are considered that could be applied on top of the land-use and transit strategies included in the 2040 preferred scenario developed by MRCOG through the scenario planning process. The strategies in Table 8B were selected by the project team because they have a high GHG mitigation potential or because there was strong regional interest in evaluating the strategy. For example, incident management was rated by the project team, prior to conducting a detailed analysis, as having a relatively low GHG mitigation potential but is considered in this section since there is regional support for considering incident management to reduce traffic congestion. The lower priority set of strategies identified in Table 9C and D are likely to have only a small GHG mitigation potential, are not likely to be implemented in the Albuquerque metropolitan area, or are very difficult to evaluate. While these lower priority strategies may have valuable co-benefits and can contribute to the overall sustainability of the region which combined with other strategies they were not evaluated in this project. The project team determined that focusing on the higher priority and potentially more effective strategies would be the best use of the resources available for this project. The GHG mitigation potential for the strategies evaluated in this section quantified to the extent possible given the available evidence and resources (i.e., time and funding).

Table 9. Potential GHG Mitigation Strategies and their Initial Rankings.

Strategy	GHG Mitigation Potential	Analysis Capability
A. Analysis Completed During the Scenario Planning Phase		
Zoning changes	●●●●● L	●●●●● U
Infill development	●●●●○ L	●●●●○ U
Transit oriented development	●●●●○ L	●●●●○ U,C
Improving public transportation	●●●○○ S	●●●○○ C
B. Higher Priority or Higher Potential GHG Mitigation Effectiveness (evaluated in this report)		
Urban growth boundaries	●●●●● M	●●●●● U
“Wheels” tax (VMT charging) & Gas Tax	●●●●● S	●●●●○ C
Bicycle and pedestrian infrastructure improvements	●●●○○ S	●●○○○ O,P,Q
Incident management	●●○○○ S	●○○○○ Q
Traffic signal enhancement	●●●○○ S	●●●○○ C,P
Establishing roadway connectivity standards	●●●○○ L	●●●●○ C
C. Lower Priority or Lower Potential GHG Mitigation Effectiveness (not evaluated in this report)		
Bike sharing	●○○○○ S	●○○○○ Q
HOV facilities	●○○○○ M	●○○○○ Q,P
Building design standards	●●○○○ L	●○○○○ Q
Establishing a complete streets policy	●●○○○ L	●○○○○ Q
Road pricing (HOT lanes/congestion charging)	●●●○○ S	●●○○○ C,P
Parking management	●●●○○ S	●●●○○ C
Car sharing	●○○○○ S	●○○○○ Q
Ride sharing	●○○○○ S	●●●○○ Q,C
Travel demand management-educational	●○○○○ S	●○○○○ Q
D. Lower Priority or Lower Potential GHG Mitigation Effectiveness (not evaluated in this report)		
Travel demand management-transit incentives	●●●○○ S	●●○○○ Q,P
Intersection improvement	●○○○○ S	●●●●○ P,C
Electric vehicle infrastructure support	●●○○○ M	●○○○○ Q,M
Heavy-duty vehicle retrofit	●○○○○ M	●●●●○ Q,M
Truck-stop electrification technologies	●○○○○ S	●●○○○ M

●○○○○ → ●●●●●
Low High

L = long term
M = medium term
S = short term

U = UrbanSim, C = CUBE,
M = MOVES, O = Off Model,
P = Post Process, Q = Qualitative

The additional GHG mitigation strategies considered here were only evaluated for their ability to reduce GHG emissions. How they may affect other regional goals or transportation system performance metrics was not considered. Most strategies reduce GHG emissions by reducing travel demand or improving traffic flow and are therefore expected to generally improve the region’s traffic conditions. Many of the GHG mitigation strategies also produce benefits in addition to reducing GHG emissions. For example, an urban growth boundary preserves open space and may protect valuable ecosystem services or agricultural land. Multi-use paths not only help mitigate GHG emissions by encouraging bicycle trips but may also increase cyclist’s safety and enjoyment and provide a place for non-motorized recreation and exercise. These types of additional benefits are not considered here. While this following analysis may indicate little or no GHG mitigation potential for a particular strategy that does not necessarily mean the strategy is poor public policy, it only means that the strategy is unlikely to mitigate GHG emissions.

The project team evaluated each strategy for its effectiveness at mitigating regional GHG emissions. Some strategies may be highly effective at reducing per trip GHG emissions but not at reducing regional GHG emissions. For example, riding a bicycle produces no direct GHG emissions (a 100 percent reduction from driving a car) but only a small portion of trips occur using bicycles (about 2 percent) so the regional effect on GHG emissions of a strategy that doubles bicycle model share would still be relatively small. It is also important not to confuse effectiveness with the efficiency of a strategy. If a strategy to increase the share of trips made by bicycle has a very low cost per quantity of GHG reduction then that strategy may be very efficient even though it is not particularly effective on a regional scale. The analysis in this section only considers the effectiveness of GHG mitigation strategies but not their efficiency. Evaluating the efficiency of each strategy requires a cost analysis that is beyond the scope of the present study.

The strategies evaluated below are estimated using data from the phase II preferred scenario and not the phase III scenarios. This was necessary since this portion of the project started before the phase III modeling was complete. Finally, this report uses the terms GHG and carbon dioxide equivalents (CO_2-eq) somewhat interchangeably. CO_2-eq is calculated by transforming the quantity of non-carbon dioxide GHGs such as methane, nitrous oxide, and hydrofluorocarbons into an equivalent quantity of carbon dioxide based on their global warming potentials[10]. These calculations where performed automatically by US EPA's Motor Vehicle Emission Simulator (MOVES) model.

4.1 Evaluation of High Priority Strategies or Strategies with Higher Potential GHG Mitigation Effectiveness

4.1.1 Urban Growth Boundaries

The scenarios developed during this project included changes to existing zoning allowances, and the land-use simulation model also included policy shifters designed as a proxy for the effect of municipal infill and transit oriented development incentives. Both of these strategies, zoning and policy incentives, guided more development away from the region's periphery and into more developed areas. Except for areas where development is currently not allowed, mostly protected open spaces, parks, and national forests, the preferred scenario developed through the scenario planning process did not prohibit the current trend of low to medium density suburban development at the urban fringe (i.e., urban sprawl). Rather, the land-use and transit strategies were designed to provide incentives aimed at reducing or slowing sprawl. Growth boundaries aim to address sprawl more directly by prohibiting development beyond a predetermined boundary defining the urban area. This strategy was selected by the project team for its potential to further constrain suburban development patterns and increase density in areas that are already developed. While there is currently no plan to implement a growth boundary in the metropolitan area, this scenario is evaluated because it could be highly effective.

The effectiveness of an urban growth boundary in the Albuquerque metropolitan area is evaluated by identifying areas beyond the region's existing development footprint and then prohibiting any further development in those areas. The growth boundary is modeled using only MRCOG's travel demand model. The UrbanSim land-use model is not used. Using only the travel demand model simplifies the analysis since any zoning changes that would be required to accommodate more growth in the existing

[10] List of global warming potentials for GHGs: http://unfccc.int/ghg_data/items/3825.php

development footprint do not need to be identified to evaluate the potential VMT and GHG reduction benefits at this point[11].

The existing development footprint is defined as any TAZ with population density greater than 0.5 persons per acre. This criterion was developed based on a visual analysis of aerial photography available through ArcGIS that shows the approximate extent of current development and mapping the current population density of each TAZ. Based on this visual analysis, 0.5 persons per acre appeared to be a reasonable proxy for mostly developed TAZs. A growth boundary was then drawn to create contiguous core urban areas of existing development. Contiguous areas were created by reclassifying as developed, TAZs that did not meet the development criterion defined above if they were surrounded on all sides by TAZs that met the development criterion. A similar process was used to reclassify developed TAZs as undeveloped if they were surrounded by undeveloped TAZs (i.e., leap-frog development). The final growth boundary is shown in Figure 45.

[11] A careful analysis of zoning changes required for accommodating more urban growth should be conducted if a growth boundary will be developed or seriously considered. UrbanSim provides a good platform for conducting a more refined analysis.

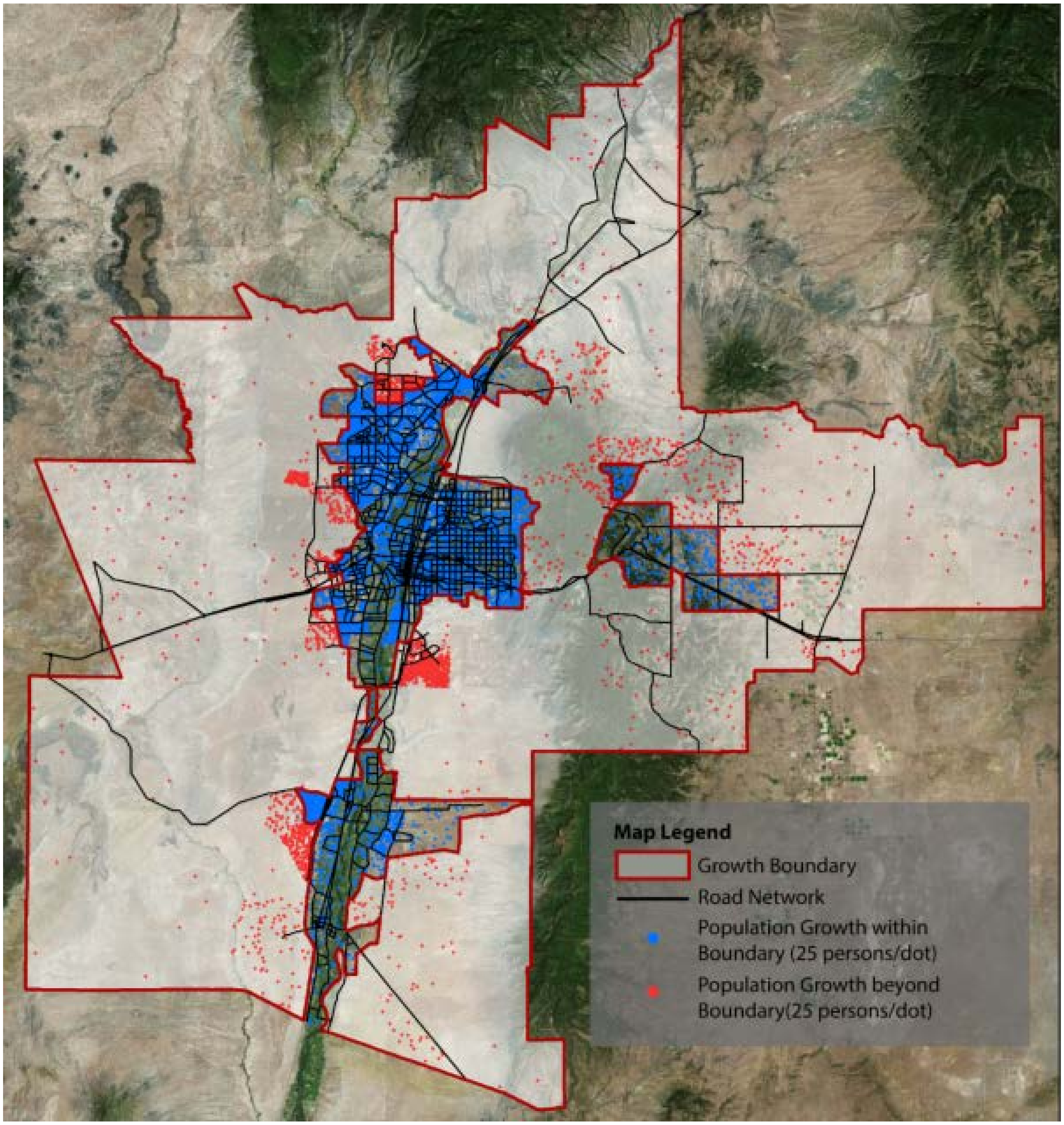

Figure 45. Growth Boundary and Population Growth from 2012 to 2040 for the Preferred Scenario (red and blue points show the location of modeled population growth from 2012 to 2040 under the Preferred Scenario without a growth boundary).

Population, housing, and employment growth that was forecast to occur beyond the growth boundary in the 2040 preferred scenario is redistributed within the growth boundary. Figure 45 shows the preferred scenario population growth that occurs within and beyond the growth boundary. Growth occurring beyond the boundary is redistributed within the boundary by adding population, households, students, and employment to TAZs in proportion to each TAZ's current share of each of these attributes. This procedure directs more growth to higher density areas and less growth to lower density areas. The intent is to maintain the existing pattern of development and character of neighborhoods within the growth boundary.

The updated TAZ data replaces the TAZ level population and employment data in the preferred scenario travel demand modeling files; all other inputs and parameters are unchanged. MRCOG's travel demand model is run with the updated data and the output is evaluated using the MOVES emission factor model to determine changes in GHG emissions that occur from changes in mode share, traffic speed, and the number and distance of trips. The MOVES GHG analysis follows the same procedure that was used by UNM in the scenario evaluation phase of the project.

The growth boundary reduces regional VMT per capita by 2 percent (19.6 VMT per capita) and GHG emissions by 3.8 percent (511.6 tons per day CO_2-eq). These reductions are on top of the reductions achieved through changes to land-use zoning and transit investments in the preferred scenario. These are significant reductions considering that the 2040 preferred scenario results in a 5 percent reduction in GHG emissions from the 2040 trend scenario. If a growth boundary were given serious consideration, more detailed analysis is required to ensure that existing land-use policies and re-development opportunities could absorb the new growth.

An actual growth boundary could also be drawn more restrictively or more loosely than what was assumed here which would then affect the boundary's GHG mitigation potential. Growth boundaries could also be defined to protect sensitive ecological areas, natural and cultural resources, and prevent development in areas that have a high flood or fire risks, providing additional benefits beyond GHG mitigation. Growth boundaries could also be defined to limit the intensity or type of development outside of the urbanized area; for example, allowing agricultural land-uses but not residential or commercial development which provides some flexibility and economic development opportunity. Additionally, a more detailed growth boundary analysis should consider the potential for leap frog development beyond the boundary in locations that are outside of the control of regional municipalities participating in the growth boundary.

4.1.2 "Wheels" Tax (VMT Charging) and Gasoline Tax

Like all goods and services, demand for travel declines when price increases. A "wheels tax" or "VMT charge" is a per mile tax that could replace or supplement the current gasoline excise tax (gas tax). Any increase in the gasoline tax or adoption of a new VMT tax would have to be made at the state or federal level and is outside of the control of municipal governments and metropolitan planning organizations like MRCOG. Oregon and California have both recently adopted new state legislation setting up VMT tax pilot programs (Oregon Senate Bill 810 and California Senate Bill 1077) and several states have recently increased their gas tax.

A new VMT tax could be set so that the average tax collected equals today's gas tax. Under this scenario, individuals who drive vehicles that are more fuel-efficient than average would end up paying more tax, while those with less fuel-efficient vehicles would pay less tax. A distance-based tax would be more predictable and stable than the current gas tax, which has been eroded over time by the increasing fuel economy of vehicles and the introduction of alternatively fueled vehicles such as natural gas and electric vehicles. A VMT tax would provide a more reliable source of transportation funding than the current gas tax. Raising the VMT tax, rather than the gas tax, would also be a more direct and equitable approach for reducing travel demand since each driver pays the same amount per mile driven regardless of their vehicle's fuel efficiency. There are also benefits to increasing the gas tax. Over time, an equivalent gas tax would affect travel behavior differently than a VMT tax since it would encourage drivers to minimize fuel consumption rather than just travel. Purchasing a more fuel-efficient vehicle or an alternatively fueled vehicle can minimize fuel consumption and the amount of tax paid. A gas tax is a more direct and efficient method for discouraging the production of GHGs since fuel consumption produces GHG emissions and not travel. An optimal approach for controlling GHG emissions and congestion would include a carbon tax to account for the expected future costs caused by GHG emissions and a VMT tax to pay for transportation infrastructure and externalities related to driving such as congestion.

The evaluation in this section considers the adoption of a VMT tax that is on average higher than today's gas tax to achieve greater GHG mitigation. However, the travel demand model used to evaluate how a VMT tax would affect GHG emissions cannot distinguish between a higher gasoline tax and a VMT tax. The model simply considers the average per mile increase in vehicle operating costs. That is, the model does not consider how fuel prices affect vehicle purchase decisions or decisions about where to live. Therefore, this analysis considers both the effectiveness of raising the current gasoline excise tax or introducing a new VMT tax that replaces the gasoline excise tax. In the short run there will be little difference between the GHG mitigation potential of the two tax options but over the long run they will have different effects on consumer and travel behavior which will affect the efficiency of GHG mitigation.

A range of VMT tax rates are considered which are higher than the equivalent per mile rate of the current combined New Mexico ($0.1888 per gallon) and federal ($0.1840 per gallon) gasoline excise tax. Using an average fleet fuel economy of 20.6 miles per gallon (assumption used in the MRCOG travel demand model (Systra Mobility 2010), the VMT tax rate equivalent of the current gas tax is $0.018 per mile. The main purpose of state and federal gas tax is to generate revenue for state and federal highway trust funds that provide funds for roadway construction and maintenance. These taxes are not designed as Pigouvian taxes, designed to internalize external costs that are produced by driving or using gasoline such as traffic congestion, noise, accidents, toxic air pollution, and GHG emissions. From an economic perspective, an optimal tax would include the marginal cost of damages that occur from each of these externalities and the cost of providing and maintaining transportation infrastructure. Additional revenue raised through a new VMT tax or higher gas tax could be used to increase investment in transportation infrastructure, mitigate the harmful effects of externalities (e.g., re-align roadways at risk from flooding due to climate change), or reduce other taxes (e.g., the income tax or gross receipts tax).

A range of VMT tax rates (Table 10) are used in this analysis since estimating the marginal cost of each externality is very challenging, particularly the cost of damages from future global warming caused by today's GHG emissions. The range of VMT tax rates considered brackets Parry and Small's (2005) calculation of the optimal VMT tax rate which they estimate is $0.18 per mile in 2008 dollars. Their optimal tax rate considers roadway infrastructure costs and the full range of externalities and is one of the more comprehensive estimates currently available.

Table 10. Distance Based Tax Effects.

Additional VMT Tax	Equivalent Gas Tax ($/gallon)	Daily VMT per Capita	CO_2-eq (tonne/day)	% Change in CO_2-eq from 2012
$0.00	$0.00	20.0	13,352	0%
$0.03	$0.62	19.4	12,572	-6%
$0.06	$1.24	18.5	11,959	-10%
$0.12	$2.47	17.1	10,968	-18%
$0.25	$5.15	15.0	9,616	-28%
$0.50	$10.30	12.3	7,955	-40%

MRCOG's travel demand model is used to evaluate the VMT taxes by adjusting the model's per mile vehicle operating cost parameter setting. Currently, the model uses a vehicle operating cost of $0.164 per mile in 2008 dollars (Systra Mobility 2010) which includes $0.018 in state and federal gas tax. The current vehicle operating cost assumes that the region's vehicle fleet achieves an average fuel economy of 20.6 miles per gallon and that a gallon of gasoline costs $3.38 per gallon. The VMT tax rates in Table 10 are added to the current operating costs. The travel demand model is used to evaluate the 2040 preferred scenario at each of the higher per mile operating costs. GHG emissions are estimated from the model output with MOVES using the same methods that were used in the scenario evaluation phase of the project.

The modeling results shown in Table 10 indicate that a VMT tax set at a rate higher than the equivalent average per mile cost of the current gasoline excise tax can reduce GHG emissions. The effectiveness of a VMT tax or higher gasoline tax depends on the ability to raise fuel or VMT taxes. The reductions in GHG emissions in Table 10 occur with tax rates that are much higher than today's and would likely face significant political and popular opposition. The effect of a smaller (or larger) VMT tax on GHG emissions can be evaluated by using elasticities derived from the modeling results. The price elasticity of CO_2-eq ranges from -0.26 to -0.32. Using the median elasticity (-0.29) and a more modest 25 percent increase in the current gasoline tax (approximately a half cent per mile VMT tax, a 2.7 percent increase in the cost of driving) GHG emissions would decrease by only 0.8 percent. Using the same elasticity, maintaining CO_2-eq emissions at 2012 levels (11,358 tonne/day) would require a VMT tax of $0.084 per mile in additional to today's gas tax, or equivalently, increasing the gas tax by $1.74 per gallon.

The travel demand model has several limitations that may bias the results in Table 10 downwards. The location of trip destinations (trip length) and mode choice are sensitive to changes in vehicle operating costs imposed by the VMT tax or gasoline tax. These sensitivities are what drive the modeled GHG emission reductions. However, changing travel costs do not affect the number of trips made by each household or the location of households, businesses, and other travel productions and attractions in the model. Iterating the travel demand model with the land-use model would overcome these limitations.[12] Despite these limitations the elasticities calculated from the results fall within the range found in prior studies which range from -0.02 in the short run to -0.3 in the long run, with most long run results falling between -0.2 and -0.3 (Litman 2013). A more recent study evaluating the change in VMT as gas prices rose over the past decade in California estimates an elasticity of -0.22 (Gillingham 2014), similar to the range found in prior studies and the modeling results in Table 10.

4.1.3 Bicycle and Pedestrian Infrastructure Improvements

The land-use and transportation plans developed during the scenario planning phase of this project did not evaluate changes to bicycle and pedestrian infrastructure. This infrastructure is not defined in either the land-use or travel demand models. While the travel demand model does estimate the number of non-motorized trips (walking and cycling), the estimate is mostly influenced by household characteristics (income and vehicle availability), transportation costs, and trip distance. The presence of bicycle and pedestrian infrastructure such as bicycle lanes and wide sidewalks are not a factor in the travel demand model estimates, a common limitation of most regions' travel demand models.

The logic embedded in the current travel demand model for predicting bicycle and pedestrian trips is based on a 1992 household travel survey conducted in the Albuquerque metropolitan area. In that survey respondents indicated how they traveled during the survey period. Some respondents indicated that they make some trips by walking or riding a bicycle. Equations developed from the survey data estimate the probability of choosing to make a trip by walking or riding a bicycle. The equations associate household and trip characteristics from survey respondents with their travel mode choices. The availability and quality of pedestrian and bicycle infrastructure in 1992 likely influenced the survey respondents travel choices. The availability and quality of bicycle and pedestrian infrastructure has since changed, and because the availability and quality of pedestrian and bicycle infrastructure are not factors in the mode choice equations within the travel demand model, current and future changes in this infrastructure are not accounted for in any way. This limitation is addressed by using the results of previous studies reported in the peer reviewed literature to estimate how the extent of new bicycle lanes and paths may affect VMT and GHG emissions.

4.1.3.1 <u>Bicycle Infrastructure</u>

---

[12] The land-use model was not available for this portion of the analysis.

The GHG mitigation potential of building additional bicycle facilities is evaluated by estimating the effect of building out the City of Albuquerque's 2014 draft bicycle plan (City of Albuquerque 2014). Comprehensive plans for building bicycle facilities in other parts of the region were either unavailable or not up to date. The City of Albuquerque's bicycle plan at full build out increases the length of bicycle lanes by 99 percent and multi-use paths by 75 percent (Table 11).

Table 11. Bicycle Mode Share and GHG Reduction Calculations.

	Bike Lanes	Multi-Use Paths
Mode Share Calculation		
Current Miles (2014)	197	154
Additional Miles	196	115
Current Bike Mode Share	2.0%	2.0%
Elasticity (mode share, facility miles)	0.25	.091
% Increase in Bike Mode Share	24.9%	6.8%
New Bike Mode Share	2.5%	2.1%
Emission Reduction Calculation		
Regional Trips (trips/day)	3,699,195	3,699,195
New Bicycle Trips (trips/day)	9,201	2,514
Average Trip Length (miles)	5.7	5.7
VMT Reduction (miles/day)	52,446	14,330
Average CO_2-eq Emission Factor (g/mi)	429.9	429.9
CO_2-eq Reduction (tons/day)	22.5	6.2

Elasticities that relate the extent of bicycle lanes and multi-use paths to bicycle mode share are obtained from a recent study by Buehler and Pucher (2012). Their study of the relationship between cycling rates and bicycle infrastructure in 90 U.S. cities is the most comprehensive study currently available. Their elasticities are derived from a regression analysis that relates bicycle commute mode share in each city to a number of explanatory variables including the extent of bicycle lanes and bicycle paths. The elasticity for bicycle lanes is 0.25 and is 0.091 for multi-use paths. These elasticities indicate that bicycle mode share increases less than proportionally with an increase in bicycle infrastructure. For example, the bicycle lane elasticity of 0.25 indicates that a 10 percent increase in the miles of bicycle lanes results in a 2.5 percent increase in bicycle mode share. These elasticities are used to estimate the change in bicycle mode share in Albuquerque from building new bicycle lanes and multi-use paths, which can then be used to estimate the change in the number of vehicle trips, VMT, and GHG emissions.

While the elasticities from Buehler and Pucher (2012) represent the best available information at this time, there are a number of limitations. The elasticities are for bicycle commute mode share, there is no comparable information for other trip purposes. In this analysis, these elasticities are applied to all trip purposes. The elasticities are also estimated at the mean level of each explanatory variable in their regression analysis. The elasticities therefore represent the relationship between providing more bicycle infrastructure and bicycle mode share under average conditions. It is unclear how conditions in Albuquerque compare to the average conditions of the cities in Buehler and Pucher's study. For example, a higher than average traffic fatality rate or greater amount of sprawl would result in a lower elasticity while more temperate weather than average would increase the elasticity. While it is possible to compute elasticities using Buehler and Pucher's results that are more tailored to Albuquerque's characteristics, the current analysis uses the average values given the time constraints for completing this analysis. Finally, Buehler and Pucher's study is a cross sectional design, it does not evaluate how bicycle mode share changes after the construction of bicycle facilities. Instead, their analysis considers how mode share varies with the amount of bicycle infrastructure (and other characteristics) across the cities in their sample. This type of analysis can find a correlation but cannot prove causation. It is possible that demand for cycling in some cities has caused those municipalities to provide more bicycle infrastructure. It is also possible that individuals who prefer to ride a bike have preferentially relocated to cities with good bicycle infrastructure (i.e., residential self-selection bias). If either of these situations is occurring then the elasticities are biased upwards and the effect of providing more bicycle infrastructure is overstated.

Based on MRCOG's most recent 2013 household travel survey, approximately two percent of trips are made by bicycle in the region. The travel demand modeling results for the 2040 preferred scenario indicates that 6.1 percent of trips are non-motorized. For this analysis, we assume that two percent of the modeled trips are bicycle trips and the remaining 4.1 percent are walking trips. Considering the percentage change in the miles of bicycle lanes and multi-use bicycle paths from completing Albuquerque's bicycle plan and using Buehler and Pucher's elasticities, bicycle mode share is estimated to increase from 2 percent to 2.6 percent in 2040 (Table 11).

The project team estimated the reduction in vehicle trips by multiplying the change in bicycle mode share (0.6 percent) by 50 percent of the total number of trips estimated by the travel demand model. Fifty percent of the trips are used to account for the new bicycle facilities only being added to the City of Albuquerque, which is where 56 percent of the region's VMT occurs. The project team also assumed that all new bicycle trips substitute for vehicle trips and not for walking or transit trips. The project team then estimated the change in VMT by multiplying the average bicycle trip distance of 5.7 miles (estimated from MRCOG's 2013 household travel survey) by the change in the number of vehicle trips. The project team then used MOVES with the average system-wide vehicle speed, derived from the travel demand model to calculate an average CO_2-eq emission rate. Finally, the project team calculated the change in CO_2-eq emissions by multiplying the change in VMT by the average CO-eq emission rate (Table 11).

The results indicate that building out Albuquerque's bicycle plan, approximately doubling the amount of bicycle facilities in the city, would result in a 0.2 percent decrease in VMT and GHG emissions from the 2040 preferred scenario (total VMT is 27 million and CO_2-eq is 13,352 tons per day). There is a lot of uncertainty in these estimates; however, the results indicate that bicycle infrastructure can be effective. Even though the effect is small, the relatively low cost of creating most bicycle facilities, particularly bicycle lanes, may make this a relatively efficient GHG mitigation strategy.

4.1.3.2 Additional Bicycle Facility Evidence

There are few studies that provide strong evidence on the ability of bicycle facilities to reduce vehicle trips. The study by Buehler and Pucher (2012) is only suggestive due to its reliance on a cross sectional design and national commute mode share data. The UNM research team has recently completed a study in cooperation with MRCOG and the City of Albuquerque on the effectiveness of past investments in bicycle lanes and multi-use paths in the region (the study is currently under peer review for publication in Transportation Research Part A: Policy and Practice). The study asked cyclists if they used a bicycle lane or multi-use path on a regular utilitarian trip and what they would do if the bicycle lane or path did not exist.

The study found that most Albuquerque area cyclists use multi-use paths (74 percent) and bike lanes (92 percent). It was also found that 30 percent of multi-use path users would not continue to bike if the path they regularly use did not exist. Most would choose to drive instead. Similarly, 25 percent of bike lane users would not continue to bike if bike lanes were not available. The results indicate that bicycle facilities are effective at reducing vehicle trips, though most cyclists would continue to cycle regardless of bike lane or path availability. Like most prior studies, safety was overwhelmingly the main concern of cyclists. The study also suggests the bicycle lanes and multi-use paths play a role in attracting new cyclists by providing a safer environment to ride. While this study does not indicate how much VMT could be reduced if more bike lanes or multi-use paths were built, it does provide the most recent and direct evidence of how bicycle facilities affect vehicle trips.

4.1.3.3 Pedestrian Facilities

Improving the quality of pedestrian facilities and adding facilities where none currently exist was not evaluated. There is little information available about the current extent and quality of the region's existing pedestrian facilities or plans to improve facilities. There is also little evidence available to estimate the effect of higher quality pedestrian infrastructure. Based on these factors the project team did not evaluate the potential GHG mitigation potential of improved pedestrian facilities.

4.1.4 Incident Management

The project team is not aware of any studies that have quantified the GHG mitigation potential of highway incident management programs. This is the same conclusion recently reached by a research team at the University of California Davis and Irvine preparing a policy brief on incident management systems for the California Air Resources Board (Boarnet, Weinreich, and Handy 2013). Several studies have estimated the potential criteria air pollutant emission reduction benefits of specific incident management programs (Guin et al. 2007; Chang et al. 2002; Skabardonis et al. 1998; Skabardonis et al. 1995), but GHG emission reductions are not estimated. Furthermore, the prior studies have not provided results that are generalizable; they report the specific quantity of emission reduction rather than relative reductions attributable to specific program features or highway conditions.

The existing evidence suggests that incident management programs can reduce GHG emissions if they reduce delays and increase speed. As Figure 46 shows, the average CO_2 emission rate of the vehicle fleet declines rapidly as speeds increase from slow, congested speeds towards typical free flow highway speeds. The magnitude of potential GHG reduction depends on traffic volume, congestion, and the frequency of incidents. Very congested corridors with high traffic volume that experience frequent incidents would benefit the most from an incident management program; these corridors have the most potential for increasing average speed. Estimating the GHG mitigation potential of an incident management program would require estimating the change in delay or traffic speed with and without the program. At a minimum, information describing the current average incident duration, incident frequency, and resulting traffic impacts are required to understand baseline conditions. From the baseline conditions, hypothetical incident management systems that reduce the duration of incidents could be evaluated for their GHG mitigation potential.

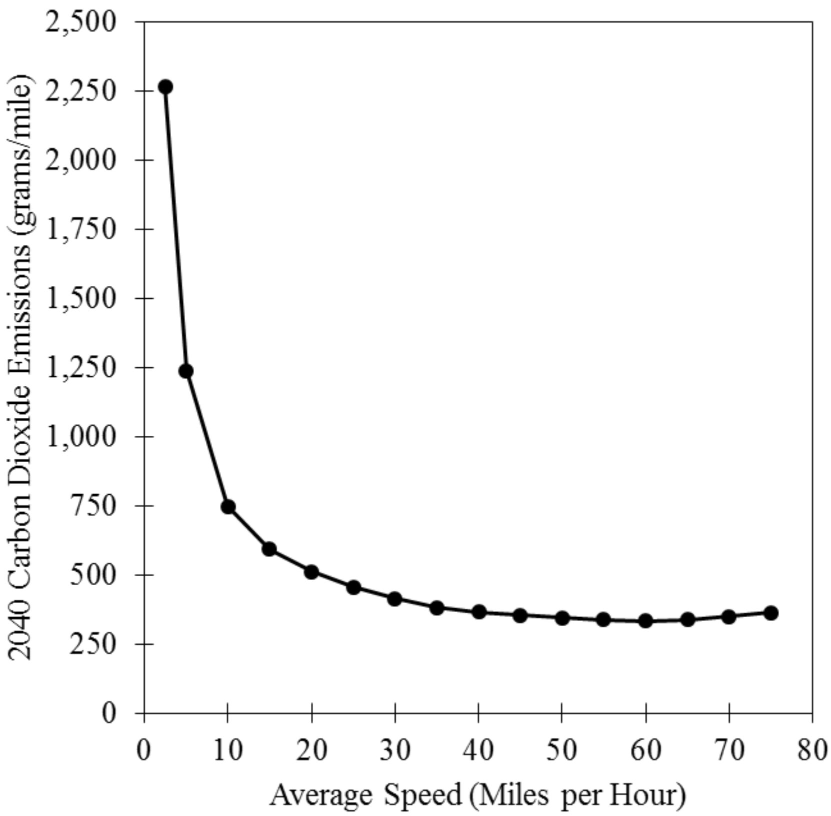

Figure 46. Fleet Average CO2 Emission Rate vs. Average Speed from US EPA's MOVES Emission Factor Model.

One caveat noted by Boarnet, Weinreich, and Handy (2013) is that since an incident management program decreases average travel time, it will also tend to induce new travel demand in much the same way as adding highway capacity (Duranton and Turner 2011). Induced demand would be strongest where programs are most effective; corridors that are highly congested with frequent incidents. The frequency of incidents on these corridors, and the delays they cause, also reduce travel time reliability which in many cases has been found to be valued more than travel time (Carrion and Levinson 2012). Over time, induced demand driven by improvements in average speed and travel time reliability may partially, if not completely, erode the traffic flow and GHG mitigation benefits of an incident management program. Based on the existing evidence and the caveat noted above, an incident management program may have a small short run potential to mitigate GHG emissions which will likely erode over time due to induced demand. With the information that is currently available to the UNM research team it is not possible to quantify a range of potential GHG mitigation.

4.1.5 Traffic Signal Enhancement

There are many strategies and systems for improving traffic signal control to improve traffic flow. One strategy that is being adopted in the Albuquerque metropolitan region is adaptive signal control. Adaptive signal control continuously collects and evaluates traffic data from sensors along the roadway to optimize the timing of traffic signals to minimize signal delay. Prior research, as reviewed by Rodier et al. (2014) for the California Air Resources Board, finds that signal coordination can reduce GHG emissions by 1 to 10 percent. An additional study by De Coensel et al. (2012) estimates GHG reductions from 10 percent up to 40 percent under ideal conditions (that are unlikely in practice) using a simulation model. None of the studies consider the potential for induced demand, which in the long run could offset some or all of the control system's traffic flow and GHG mitigation benefits.

Recently, Bernalillo County installed an adaptive traffic control system on a portion of Alameda Boulevard in the Albuquerque metropolitan area. Traffic data was collected before and after the adaptive control system was installed. The control system has reduced morning peak travel time by 21 percent, evening peak travel time by 11 percent and increased off peak travel time by 1 percent (Sussman 2013). The UNM research team used the travel time reductions along with reported traffic speeds and flow rates to estimate the reduction in GHG emissions attributable to the new control system. MOVES was used to produce CO_2-eq emission factors based on average speeds before and after the control system was installed. The Alameda adaptive control system reduced GHG emissions by 5.9 percent along the improved section of roadway (Table 12).

Table 12. Potential Changes in GHG Emissions from Implementing an Adaptive Traffic Control System.

	Distance	CO_2-eq (tons/day)				
Road	**(miles)**	**Before**	**After**	**Change**	**% Change**	**% of 2040 Total**
Alameda*	2.3	60.8	57.2	-3.6	-5.9%	-0.03%
Montgomery/Montano	12.8	288	276	-12.0	-4.2%	-0.09%
Coors	24.7	442	426	-15.6	-3.5%	-0.12%

* Only the portion of Alameda where adaptive traffic signals were installed was studied.

To further investigate the GHG mitigation potential of adaptive traffic control systems, the reported percentage change in travel times from the Alameda study were applied to traffic traveling the entire Montgomery/Montano corridor and Coors Boulevard. These two heavily used roadways carry significant traffic volume, are much longer than the section of Alameda that was studied, have many signalized intersections, and do not currently have adaptive traffic control systems. These roads were selected to gauge if upgrading the signal systems on these relatively long and heavily used corridors would produce regionally significant GHG reductions.

Traffic flow and speed data for each roadway segment were obtained from the MRCOG travel demand model for the 2040 preferred scenario. Emission factors were obtained from MOVES for the average speed on each link before and after the speeds were adjusted to account for the expected improvements of an adaptive signal control system. The results indicate that applying adaptive traffic control systems to these two roads would result in a three percent to four percent reduction in GHG emissions from each road. Regionally, the effect is a 0.2 percent reduction in GHG emissions. The actual Alameda results and the results of applying a similar travel time reduction to the Coors and Montgomery/Montano fall around the median of GHG reductions reported in prior studies.

The estimated GHG mitigation potential of installing an adaptive traffic control system on Coors or Montgomery/Montano should be considered an order of magnitude estimated. There are many factors that affect these estimates, the largest being how effective an adaptive traffic control system would be on these longer and more complex corridors. The estimates in do not account for broader network effects on improvements made to these specific roadways. For example, reduced travel times along improved corridors could cause bottlenecks in other parts of the network. Furthermore, like most prior studies, induced demand is not evaluated. A traffic simulation study that investigated an improvement to a signalized intersection by Stathopoulos and Noland (2003) find that induced demand is likely to eliminate initial emission reduction benefits. There have not been any empirical studies to support simulation findings but the results agree with travel demand theory and empirical evidence on induced demand from highway capacity projects (Duranton and Turner 2011). Adaptive traffic control systems increase a roadway's capacity and reduce travel time just as expanding highway capacity does. The decrease in travel time increases the attractiveness of the roadway and reduces the cost of making trips. The reduction in congestion is likely to result in additional travel demand combined with a return to congested conditions which may increase GHG emissions overtime, potentially reducing or eliminating the initial benefits of this strategy.

4.1.6 Roadway Connectivity

Regular street grids generally provide the shortest path from any one point to any other point in a street network while irregular street patterns, particularly those with cul-de-sacs and dead ends, increase the distance required to travel through the network. Street networks with regular grids are also more redundant, there are many alterative paths through the network which can reduce congestion and provide alternatives when there is an incident on a particular network link. Achieving shorter network distances between various origins and destinations can reduce VMT by reducing trip length and also increase walking, bicycle, and transit mode share since these modes are most sensitive to distance. Regular grids or other street designs with a high level of redundancy that reduce traffic congestion could also mitigate GHG emissions by increasing traffic speeds (see Figure 45 for CO_2-eq – speed relationship).

Several prior studies have evaluated the effect of greater street network connectivity and travel demand (see Handy et al. (2014) for a comprehensive review). Prior studies generally indicate that better connectivity leads to less VMT and more bicycle, walking, and transit trips (Handy et al. 2014; Ewing and Cervero 2010). However, results vary across studies, which have been conducted at different times, in different places, and have used various definitions of street connectivity. Ewing and Cervero (2010) completed a comprehensive review and meta-analysis of the existing evidence and report an average VMT elasticity of street connectivity using two common street connectivity definitions: percent of four-way intersections and intersection density. Both definitions have the same elasticity of -0.12.

A VMT elasticity of -0.12 for intersection density is used to evaluate four typical street network patterns in Albuquerque to illustrate the GHG reduction potential of greater street connectivity. Intersection density is used rather than the percentage of four way intersections because intersection density appears more robust to different street patterns. For example, in Figure 47, the NE Albuquerque and Downtown Albuquerque neighborhoods both have 100 percent four way intersections; however, the NE Albuquerque neighborhood has much lower intersection density because it has much longer block lengths. Longer block lengths increase average network distances between points. Intersection density metrics control for differences in block size.

The project team selected four different Albuquerque neighborhoods that represent typical street network designs in the area (Figure 47). The project team then calculated neighborhood intersection density was by including intersections on the boundary of each neighborhood but excluding intersections that only contained cul-de-sacs or dead ends since these provide no connectivity. Finally, the project team calculated the percentage change in intersection density between the SW Albuquerque neighborhood, which had the lowest interstation density, and each of the other neighborhoods. The results shown in Table 13 indicate that increasing the density of street intersections from a typical suburban subdivision layout, which can be accomplished with different street patterns, may significantly reduce VMT and therefore GHG emissions. Additional GHG mitigation benefits may occur if the street pattern also reduces congestion, increasing average speed.

Figure 47. Examples of Different Albuquerque Area Street Network Designs and Intersection Density (intersections per km^2).

Table 13. Intersection Density and VMT Calculation.

Neighborhood	Area (km^2)	Intersections	Intersection Density (intersections/km^2)	% Change in VMT from SW Albuquerque [a]
SW Albuquerque	0.78	51	65.6	0.0%
NW Albuquerque	0.71	50	70.6	-0.9%
University Area	0.67	56	83.9	-3.3%
Downtown Albuquerque	0.45	52	116.8	-9.4%

[a] VMT elasticity of intersection density used in calculation equals -0.12 (Ewing and Cervero 2010)

The regional effectiveness of adopting a street connectivity standard is difficult to quantify. The potential GHG mitigation beyond what is forecast for the 2040 preferred scenario is unclear since the travel demand model does not contain local streets. Local streets are represented by "centroid connectors" in the travel demand model that represent the average distance from households in a TAZ to a roadway link in the model (collectors, arterials, and highways). For TAZs in the metropolitan area that have not yet been developed and where no roadway network exists, it is unclear what assumptions were used to create the centroid connectors. For example, what street pattern was assumed in calculating the average distance and travel time from each TAZ to the nearest network link? Since the preferred scenario focuses more growth into already developed areas, new street connectivity standards, which would only affect new development, may only have a small regional GHG mitigation potential. However, changing the street pattern of yet to be built roadway networks should be a very low cost mitigation strategy and therefore may be a very efficient GHG mitigation strategy even if it is not regionally significant over the forecast horizon.

The estimates in Table 13 are also subject to many uncertainties. While there have been many studies of street network design and changes in travel behavior, it is difficult to generalize these results including the meta-analysis by Ewing and Cervero (2010). The effect of intersection density likely depends on population and employment density, land-use mix, bicycle and pedestrian infrastructure, quality of transit service, and the extent of the network patterns (only a few blocks or is the whole city designed in a similar pattern?). There are also many unique street designs that do not match up well with designs considered in prior studies. For example, some neighborhood designs have greater pedestrian and bicycle connectivity than vehicle connectivity due to bicycle paths and features that block vehicle access. Figure 48 shows a typical network design in Davis, California. Most neighborhoods in Davis, excluding the downtown area, have irregular street network designs with many cul-de-sacs and dead ends; however, many of these neighborhoods also have a multi-use path network interlaced with the street network as shown in Figure 48. The multi-use path network adds connectivity to cul-de-sacs and dead ends for non-motorized modes, and in many places has grade separated railroad, street and highway crossings. Some neighborhoods in Albuquerque contain similar features, though on a much smaller and less frequent scale. For example, Albuquerque's multi-use path network adds some connectivity to dead end streets and cul-de-sacs, but only a very small percentage of them. Some neighborhoods also have pedestrian access through sound and privacy walls that surround many of the region's subdivisions.

Figure 48. Example of Network Design for Greater Pedestrian and Cyclist Connectivity (Red Lines are Bicycle and Pedestrian Paths, GIS Data from the City of Davis, California[13]).

4.1.7 Summary of Additional GHG Mitigation Potential

The strategies where GHG mitigation potential could be quantified are summarized in Table 14. Growth boundaries and VMT or gasoline taxes have the greatest potential for achieving significant additional GHG reductions. Bicycle infrastructure and traffic signal enhancement, while having a smaller effect, would face much less opposition in being implemented and provide popular co-benefits (recreation and less congestion, respectively). The mitigation potential of improved street connectivity and incident management programs could not be quantified but each strategy is expected to have a small GHG mitigation potential. Greater street connectivity for new developments comes at little to no cost (although less land for real estate development is a cost for developers) and could therefore be a very efficient policy even if only having a small mitigation potential. Improving street connectively of existing neighborhoods could be very expensive if additional right of way is required.

[13] City of Davis GIS Data Library: http://maps.cityofdavis.org/library/

Table 14. Summary of GHG Mitigation Potential.

	CO2-eq	Reduction
Growth Boundary	512	3.8%
VMT Tax 0.005 per mile[a]	107	0.8%
VMT Tax 0.03 per mile	780	5.8%
VMT Tax 0.12 per mile	2384	17.9%
Bicycle Infrastructure[b]	28.7	0.2%
Traffic Signal Enhancement[c]	27.6	0.2%

[a] Equal to a 25 percent increase in the current state and federal gasoline excise tax
[b] Building out the City of Albuquerque's 2014 Draft Bicycle Plan
[c] Implementing adaptive signal control on Montgomery, Montano, and Coors, and ignoring induced demand

The results in Table 14 also illustrate that by only adopting the relatively popular and low cost GHG mitigation strategies, GHG emissions in the region will still grow higher than today's level. Achieving GHG mitigation that reduces emissions from the 13,352 tons/day expected under the preferred scenario in 2040 to today's level of 11,358 tons/day requires adopting a VMT tax between 6 and 8.4 cents per mile. The lower VMT tax rate corresponds to a scenario where all other strategies are also adopted while the higher tax corresponds to scenario where only a VMT tax is adopted. A growth boundary would significantly reduce GHG emissions but would still not be enough to hold GHG emission at today's level.

Finally, the analysis in this section and most other studies fail to account for induced demand. Induced demand should be expected to occur for any strategy that reduces travel time or improve travel time reliability without also charging a fee or tax to pay for the improvement. Improved traffic signaling and incident management programs suffer from this limitation, which has the potential to significantly reduce or completely eliminate their GHG mitigation potential over the long term. Interim GHG emission reductions from these strategies may still be valuable compared to a baseline of not implementing them as long as they do not lock the region into greater vehicle dependency or come at the expense of more effective strategies. The most durable strategies for reducing GHG emissions include reducing vehicle travel demand, improving vehicle fuel efficiency, and promoting the adoption of alternatively fueled vehicles. This project focuses on reducing travel demand, which can be accomplished through two general strategies: reducing the need for vehicle trips, which in this project is accomplished by changing land-use patterns and improving transit options, and increasing the cost of travel through taxes, fees, and tolls.

4.2 Conclusions

Table 15 is an updated version of Table 9 and reflects the project team's final assessment of the GHG mitigation potential of each strategy considered in the project. The revised assessment is based on the outcome of the modeling completed in Phase III and for the additional GHG mitigation strategies considered in section 4.

Table 15. High Priority and High Potential GHG Mitigation Strategies with Updated Rankings.

Strategy	GHG Mitigation Potential	Analysis Capability
Analysis Completed During the Scenario Planning Phase		
Zoning changes	●●●●○ L	●●●●● U
Infill development	●●●●○ L	●●●●● U
Transit oriented development	●●●●○ L	●●●●● U,C
Improving public transportation	●●●○○ M	●●●○○ C
Higher Priority or Higher Potential GHG Mitigation Effectiveness		
Urban growth boundaries	●●●○○ M	●●●●● U,C
"Wheels" tax (VMT charging) & Gas Tax	●●●●● S	●●●●○ C
Bicycle and pedestrian infrastructure improvements	●●●○○ S	●●○○○ O,P
Incident management	●○○○○ S	●○○○○ Q
Traffic signal enhancement	●●○○○ S	●●○○○ P
Establishing roadway connectivity standards	●●○○○ L	●●●○○ O,C

●○○○○ → ●●●●●
Low → High

L = long term
M = medium term
S = short term

U = UrbanSim, C = CUBE,
M = MOVES, O = Off Model,
P = Post Process, Q = Qualitative

The project team concluded that the land-use strategies incorporated in the final alternative scenarios have a high GHG mitigation potential and that transit improvements have a moderate mitigation potential given the very low mode share starting point. The benefits of the land use strategies will also continue to reduce GHG emission well beyond the planning horizon as land use patterns are difficult to undo and because greater densities and mix of land uses will enhance other strategies. For example, the project team expects that the mitigation potential of transit investments will grow over time as the region becomes denser with more defined activity centers. The project team's assessment of the additional GHG mitigation strategies concluded that they could achieve significant additional GHG mitigation. Adopting each of the strategies, with the exception of raising taxes, would produce an estimated four to five percent reduction in GHG emissions. This is a relatively large reduction but not enough to keep GHG emissions from growing. The only strategy considered that would be able to stop the growth in GHG emissions is a relatively large $0.06 to $0.08 per mile tax or its gas tax equivalent. Adopting such a tax would be politically challenging and is something that would have to happen at the state or federal level. Other strategies that could achieve significant additional GHG mitigation are accelerated adoption of alternative lower carbon transportation fuels, more efficient vehicles, and alternatively fueled vehicles.

5 CONCLUSIONS

Within the context of adding nearly 500,000 people to the region over the next 25 years, the scenario planning project identified two alterative scenarios that if adopted would put the region on a more sustainable development path than business as usual (the "trend" scenario). Compared to the trend scenario, the alterative scenarios developed by MRCOG reduce GHG emissions and increase resilience to climate change by incentivizing growth in more favorable locations, rather than restricting growth in unfavorable locations. While the alterative scenarios would decrease the growth in GHG emissions, they would not keep them from growing beyond today's level. The region's growth will therefore continue to contribute to global climate change. The changes in regional development patterns and water consumption under the alterative scenarios will also make the region more resilient to climate change than business as usual; however, generally the region will become less resilient than it is today. The region's development footprint will continue to grow, increasing urban heat, putting additional pressure on crucial wildlife habitat, and pushing new development into areas at higher flood and fire risk. Water consumption will also continue to grow as new development also decreases the ability of rain to recharge ground water resources.

The project team evaluated the GHG mitigation potential of additional strategies, including restrictions on where future growth could take place that could be adopted in addition to the strategies incorporated in each of the scenarios. A very large increase in gasoline excise taxes or a new and relatively high VMT tax were the only strategies identified by the project team that the region or state could take that would hold GHG emissions at today's levels. Other strategies such as adding additional bicycle infrastructure and increasing street connectivity could also help reduce GHG emissions at a relatively low cost. The project team did not evaluate strategies that would likely require federal action such as increasing vehicle fuel economy or strategies where there was not enough available information to quantify potential regional GHG emission reductions.

These conclusions highlight the regional benefits of adopting one of the alterative scenarios but they also highlight the challenge of accommodating a projected 52 percent increase in population by 2040. In the face of this population growth, more needs to be done to mitigate GHG emissions and increase resiliency.

6 REFERENCES

Boarnet, Marlon, David Weinreich, and Susan Handy. 2013. *Policy Brief on the Impacts of Traffic Incident Clearance Programs (Freeway Service Patrols) Based on a Review of the Empirical Literature*. Prepared for the California Air Resources Board. http://www.arb.ca.gov/cc/sb375/policies/tic/traffic_incident_clearance_brief120313.pdf.

Breshears, D.D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyer. 2005. Regional vegetation die-off in response to global change type drought. Proceedings of the National Academy of Sciences 102:15144–15148.

Brooks, D.R. and E.P. Hoberg. 2007. How will global climate change affect parasite-host assemblages? Trends in Parasitology 23:571–574.

Brown, J. H., T.J. Valone, C.G. Curtin. 1997. Reorganization of an arid ecosystem in response to recent climate change. Proceedings of the National Academy of Sciences 94:9729–9733.

Brown, H. E., A. C. Comrie, D. M. Drechsler, C. M. Barker, R. Basu, T. Brown, A. Gershunov, A. M. Kilpatrick, W. K. Reisen, and D. M. Ruddell. 2013. "Human Health." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 312–339. A report by the Southwest Climate Alliance. Washington, DC: Island Press

Buehler, Ralph, and John Pucher. 2012. "Cycling to Work in 90 Large American Cities: New Evidence on the Role of Bike Paths and Lanes." *Transportation* 39 (2): 409–32.

Camp, J. M. Abkowitz, G. Hornberger, L. Benneyworth, J.C. Banks. 2013. Climate Change and Freight-Transportation Infrastructure: Current Challenges for Adaptation. Journal of Infrastructure Systems. American Society of Civil Engineers 19:363–370.

Carrion, Carlos, and David Levinson. 2012. "Value of Travel Time Reliability: A Review of Current Evidence." *Transportation Research Part A: Policy and Practice* 46 (4): 720–41. doi:10.1016/j.tra.2012.01.003.

Chang, G., A. Petrov, P. Lin, N. Zou, and J. Y. Point-Du-Jour. 2002. "Performance Evaluation of CHART–The Real-Time Incident Management System-Year 2000." *Dept. of Civil and Environmental Engineering, University of Maryland, College Park*.

City of Albuquerque. 2014. *Draft Bikeways & Trail Facility Plan*. http://www.cabq.gov/planning/residents/sector-development-plan-updates/bikeways-trails-facility-plan/.

De Coensel, B., A. Can, B. Degraeuwe, I. De Vlieger, and D. Botteldooren. 2012. "Effects of Traffic Signal Coordination on Noise and Air Pollutant Emissions." *Environmental Modelling & Software* 35 (July): 74–83. doi:10.1016/j.envsoft.2012.02.009

DeGomez, T. 2011. Wildfire Hazard Severity Rating Checklist for Arizona Homes and Communities. The University of Arizona College of Agriculture and Life Sciences Cooperative Extension.

Department of Energy/Los Alamos National Laboratory. 2013. Wildfires may contribute more to global warming than previously predicted. Science Daily. Available from www.sciencedaily.com/releases/2013/07/130709124153.htm.

Duranton, Gilles, and Matthew Turner. 2011. "The Fundamental Law of Road Congestion: Evidence from US Cities." *The American Economic Review* 101 (6): 2616–52.

Ewing, R., and R. Cervero. 2010. "Travel and the Built Environment: A Meta-Analysis." *Journal of the American Planning Association* 76 (3): 265–94. doi:DOI 10.1080/01944361003766766.

Federal Register. 2013. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Jemez Mountains Salamander. Vol. 78, No. 224.

Finch, Deborah M., ed. 2012. Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment. General Technical Report RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 139 p.

Friggens, M. M.; D.M. Finch, K.E. Bagne, Coe, S.J. Coe, D.L. Hawksworth. 2013. Vulnerability of species to climate change in the Southwest: terrestrial species of the Middle Rio Grande**.** General Technical Report RMRS-GTR-306. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 191 p.

Funk, J., S. Saunders, T. Sanford, T. Easley, A. Markham. 2014. Rocky Mountain Forests at Risk: Confronting Climate-driven Impacts from Insects, Wildfires, Heat, and Drought. Union of Concerned Scientists and the Rocky Mountain Climate Organization, Cambridge, MA.

Gillingham, Kenneth. 2014. "Identifying the Elasticity of Driving: Evidence from a Gasoline Price Shock in California." *Regional Science and Urban Economics*, SI: Tribute to John Quigley, 47 (July): 13–24. doi:10.1016/j.regsciurbeco.2013.08.004.

Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Guin, Angshuman, Christopher Porter, Bayne Smith, and Carla Holmes. 2007. "Benefits Analysis for Incident Management Program Integrated with Intelligent Transportation Systems Operations: Case Study." *Transportation Research Record: Journal of the Transportation Research Board* 2000 (1): 78–87.

Handy, Susan, Gil Tal, Giovanni Circella, and Marlon Boarnet. 2014. *Policy Brief: Impacts of Network Connectivity on Passenger Vehicle Use and Greenhouse Gas Emissions*. Prepared for the

California Air Resources Board. http://www.arb.ca.gov/cc/sb375/policies/connectivity/network_connectivity_brief.pdf.

Indian Country. October 25, 2013. Second FEMA Disaster Declaration for Flooded Santa Clara Pueblo in a Month.

Koetse, M.J. and P. Rietveld. 2009. The impact of climate change and weather on transport: An overview of empirical findings. Transportation Research Part D 14:205–221.

Litman, Todd. 2013. "Changing North American Vehicle-Travel Price Sensitivities: Implications for Transport and Energy Policy." *Transport Policy*, Special Issue on Transportation Pricing Policies Special Issue on Transport Security - Policies and Empirical Perspectives, 28 (July): 2–10. doi:10.1016/j.tranpol.2012.06.010.

Llewellyn, D. and S. Vaddey. 2013. West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment. U.S. Department of Interior, Bureau of Reclamation, Upper Colorado Region, Albuquerque Area Office.

National Energy Fire Center. 2014. http://www.nifc.gov/

National Research Council, 2008. Potential Impacts of Climate Change on US Transportation. Transportation Research Board Special Report 290. 280 pp.

Parmenter, B. 2009. Jemez Mountains Climate Adaptation Workshop. Presentation on Ecological Trends and Consequences of Climate Change in the Jemez Mountains.

Parry, Ian W. H., and Kenneth A. Small. 2005. "Does Britain or the United States Have the Right Gasoline Tax?" *The American Economic Review* 95 (4): 1276–89. doi:10.1257/0002828054825510.

Pounds, J.A., M. R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P. L. Fogden, P.N. Foster, E.L. Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S. R. Ron, G. Arturo Sanchez-Azofeifa, C.S. Still, and B.E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature 439:161–167.

Radeloff, V.C., R.B. Hammer, S.I. Stewart, J.S. Fried, S.S. Holcomb, and J.F. McKeefery. 2005. The wildland-urban interface in the United States. Ecological Applications 15:799–805.

Robles, M. D. and C. Enquist. 2010. Managing changing landscapes in the Southwestern United States. The Nature Conservancy. Tucson, Arizona. 26 pp.

Rodier, Caroline, Susan Handy, and Marlon Boarnet. 2014. *Policy Brief: Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions*. Prepared for the California Air Resources Board. http://www.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf.

Romps, David M., et al. 2014. Projected increase in lightning strikes in the United States due to global warming." *Science* 346.6211:851–854.

Root, T.L., D.P. MacMynowski, M.D. Mastrandrea, and S.H. Schneider. 2005. Human-modified temperatures induce species changes: joint attribution. Proceedings of the National Academy of Sciences 102:7465–7469.

Schoener, Gerhard, n.d. Flood Risk Analysis: Potential Impacts of Climate Change on the Upper Calabacillas Arroyo. Memo prepared by Southern Sandoval County Arroyo and Flood Control Authority.

Skabardonis, Alexander, Hisham Noeimi, Karl Petty, Dan Rydzewski, Pravin Varaiya, and Haitham Al-Deek. 1995. “Freeway Service Patrol Evaluation.” *California Partners for Advanced Transit and Highways (PATH)*. https://escholarship.org/uc/item/36r1t2m2.pdf.

Skabardonis, Alexander, Karl Petty, Pravin Varaiya, and Robert Bertini. 1998. “Evaluation of the Freeway Service Patrol (FSP) in Los Angeles.” *California Partners for Advanced Transit and Highways (PATH)*. http://escholarship.org/uc/item/3920p806.pdf.

Stathopoulos, Fotis, and Robert Noland. 2003. “Induced Travel and Emissions from Traffic Flow Improvement Projects.” *Transportation Research Record* 1842 (1): 57–63. doi:10.3141/1842-07.

Stromberg, J.C., M.K. Chew, P.L. Nagler, and E.P. Glenn. 2000. Changing Perceptions of Change: The Role of Scientists in *Tamarix* and River Management. Restoration Ecology 17:177–186.

Sussman, Aaron. 2013. *Memorandum: Summary Results – Alameda Blvd Side Street Control Dela*. Mid Region Council of Governments.

SWCA Environmental Consultants. 2007. Middle Rio Grande Bosque Community Wildland Protection Plan.

Systra Mobility. 2010. *Middle Rio Grande Regional Travel Model Recalibration and Validation Report*. Prepared by Systra Mobility for the Mid Region Council of Governments.

Tidwell, V.C., L. Dale, G. Franco, K. Avery, M. Wei, D. M. Kammen, and J. H. Nelson. 2013. “Energy Supply, Demand, and Impacts.” In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 240-266. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

The Nature Conservancy of New Mexico. 2009. The wildfire risk model. Available on line from http://nmconservation.org/downloads/data/wildfire_risk/.

U.S. Department of Interior, 2013. Appendix B: Literature Review of Observed and Projected Climate Changes. Bureau of Reclamation, Upper Colorado Region, Albuquerque Area Office. December 2013.

U.S. Fish and Wildlife Service. 2002. Southwestern Willow Flycatcher Recovery Plan. Albuquerque, NM, 210 pp. Appendices A-Oxiii.

Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389–395.

U.S. Forest Service. 2010. Silvis WUI layer accessed online from http://silvis.forest.wisc.edu/projects/WUI_Main.asp.

Water Assembly and Mid-Region Council of Governments. 2004. Summary of the Middle Rio Grande Regional Water Plan 2000–2050. Volume 1. Albuquerque, NM.

APPENDIX A. PERFORMANCE MEASURE SUMMARY TABLE

Preliminary Scenarios

			Absolute Value				Percent Change from 2012			Percent Change from AU	
Performance Measure Category	Performance Measure	Unit of Analysis	Base Year 2012	Allowable Use	Emerging Lifestyles	Jobs/Housing Balance	Allowable Use	Emerging Lifestyles	Jobs/Housing Balance	Emerging Lifestyles	Jobs/Housing Balance
Accessibility	Proximity to Recreation Sites	Households within 5 miles		48,600	47,756	47,215					
	Proximity to Activity Centers	Households within 1 mile of Activity Center	50,616	89,053	87,679	90,338	76%	73%	78%	-1.5%	1.4%
	Proximity to Transit	Households within 1/4 mile of premium transit	1,358	10,800	12,876	9,579	695%	848%	605%	19.2%	-11.3%
	Proximity to Bicycle Facilities	Households within 1/4 miles of a bicycle path	110,421	151,309	153,955	155,286	37%	39%	41%	1.7%	2.6%
	Proximity to Schools	Households within 1/2 miles of a school	129,487	168,253	164,939	163,565	30%	27%	26%	-2.0%	-2.8%
	Non-motorized Mode Share	% Trips bike or walk	5.6%	5.9%	6.2%	5.7%	6%	11%	3%	4.7%	-2.9%
	Jobs/Housing Mix in Activity Centers	Average jobs to housing ratio within 1 mile of activity centers	2.76	2.49	2.46	2.21	-10%	-11%	-20%	-1.0%	-11.4%
Land Use	Proximity to Key Corridors	Employment within 500 feet of key corridors	46,705	54,520	56,699	60,377	17%	21%	29%	4.0%	10.7%
	Lane Miles	Roadway Lane Miles	4,169	4,713	4,713	4,713	13%	13%	13%	0.0%	0.0%
	Land Developed	Acres Land Developed	162,788	245,378	241,224	245,321	51%	48%	51%	-1.7%	0.0%
	Population Density	Persons per Acre of Developed Land	5.5	5.5	5.6	5.5	0.5%	2.3%	0.6%	1.7%	0.0%
	Population Density of New Development	New Persons per Acres of New Development		5.6	5.9	5.6	1.6%	7.0%	1.6%	5.3%	0.1%
Mobility: Highway	System wide Speed	PM peak hour speed (MPH)	36.4	19.2	23.1	21.4	-47%	-37%	-41%	20.3%	11.6%
	Vehicle Hours of Delay (VHD)	PM peak hour: congested travel time - free flow travel time (hours)	12,927	88,264	59,664	72,450	583%	362%	460%	-32.4%	-17.9%

	Vehicle Hours Traveled (VHT)	PM peak hour: total travel time (hours)	50,778	149,555	118,007	133,254	195%	132%	162%	-21.1%	-10.9%
	Vehicle Miles Traveled (VMT)	Total vehicle miles traveled per day	20,335,265	31,807,335	30,295,936	31,984,758	56%	49%	57%	-4.8%	0.6%
	VMT per Capita	Average vehicle miles traveled per person	22.8	23.6	22.4	23.7	3%	-2%	4%	-4.8%	0.6%
	Percentage of Network in Congested Conditions	PM peak hour: % of network exceeding capacity (v/c > 1)	2.1%	9.1%	7.9%	8.5%	344%	286%	312%	-13.0%	-7.1%
	Congested Conditions along Freight Corridors	PM peak hour: % of freight network exceeding capacity (v/c > 1)	0.6%	16.2%	15.6%	15.3%	2439%	2335%	2302%	-4.1%	-5.4%
Mobility: Transit	Transit Ridership	Daily boardings	56,291	73,871	76,658	72,369	31%	36%	29%	3.8%	-2.0%
	Transit Passenger Miles Traveled	Daily passenger miles traveled	194,679	370,908	374,590	360,819	91%	92%	85%	1.0%	-2.7%
	Transit Mode Share	% Trips by Transit	1.1%	0.8%	0.9%	0.8%	-28%	-19%	-32%	12.5%	-6.5%
Mobility: River Crossings	River Crossing - Congested Conditions	PM peak hour: average volume to capacity ratio (v/c ratio)	0.76	1.20	1.15	1.12	58%	51%	47%	-4.1%	-6.8%
	River Crossings	Daily number of vehicle trips	592,609	873,122	831,338	817,189	47%	40%	38%	-4.8%	-6.4%
Economic Competitiveness	Proximity to Employment Sites	Households within 1 mile of employment	33,729	46,998	53,711	47,870	39%	59%	42%	14.3%	1.9%
	Average Commute Time	Minutes	17.43	35.32	25.03	28.38	103%	44%	63%	-29.1%	-19.6%
	Economic Value of Network Efficiency	Gross Regional Product (billion dollars*)	$38.4	$73.0	$73.1	$73.0	90%	90%	90%	0.1%	-0.1%
	Economic Value of Network Efficiency	GRP per Capita	$43,123	$54,115	$54,167	$54,078	25%	26%	25%	0.1%	-0.1%
Safety	Safety - High Crash Risk Locations Crash Rate	Crashes per 100 million VMT	550	1,023	1,031	1,026	86%	88%	87%	0.7%	0.2%
Sustainability & Resiliency	GHG Emissions	Daily CO2-eq (tonnes/day)	11,313	16,226	14,774	15,930	43%	31%	41%	-8.9%	-1.8%
	GHG Emissions per Capita	Daily CO2-eq per Capita (kg/day)	12.7	12.0	10.9	11.8	-5%	-14%	-7%	-8.9%	-1.8%
	Residential Water Consumption	Million gallons per year	30,027	44,450	44,615	44,275	48%	49%	47%	0.4%	-0.4%
	Development in High Flood-Risk Areas	Employment + Dwelling Units in 100 year Flood Plains	34,190	66,924	69,770	53,321	96%	104%	56%	4.3%	-20.3%
	Development in	Weighted value based on	3.11	4.47	4.55	4.68	44%	46%	50%	1.9%	4.7%

	Forest Fire Risk Areas	emp + housing in wildland-urban interface areas									
	Development in Crucial Habitat Areas	Weighted value based on emp + housing in priority ranking areas	5.73	7.46	7.57	7.30	30%	32%	27%	1.4%	-2.1%

Refined Scenarios

Performance Measure Category	Performance Measure	Unit of Analysis	Absolute Value				Percent Change from 2012			Percent Change from Trend	
			Base Year 2012	Trend	Preferred	Constrained	Trend	Preferred	Constrained	Preferred	Constrained
Accessibility	Proximity to Activity Centers	Households within 1 mile of Activity Center	50,616	88,555	91,694	91,032	75	81	80	3.5	2.8
	Proximity to Transit	Households within 1/4 mile of premium transit	1,358	14,380	17,460	16,586	959	1186	1121	21.4	15.3
	Proximity to Bicycle Facilities	Households within 1/4 miles of a bicycle path	110,421	151,360	157,070	156,037	37	42	41	3.8	3.1
	Proximity to Schools	Households within 1/2 miles of a school	129,690	168,659	166,444	165,742	30	28	28	-1.3	-1.7
	Non-motorized Mode Share	% Trips bike or walk	5.8%	5.8%	6.1%	6.1%	1	5	6	4.1	4.6
Land Use	Jobs/Housing Mix in Activity Centers	Average jobs to housing ratio within 1 mile of activity centers	2.76	2.30	2.24	2.25	-17	-19	-18	-2.6	-2.2
	Proximity to Key Corridors	Employment within 1000 feet of key corridors	92,613	133,409	130,139	127,854	44	41	38	-2.5	-4.2
	Lane Miles	Roadway Lane Miles	8,113	8,502	8,502	8,279	5	5	2	0.0	-2.6
	Land Developed	Acres Land Developed	162,788	259,934	245,584	247,201	60	51	52	-5.5	-4.9
	Population Density	Persons per Acre of Developed Land	5.5	5.2	5.5	5.5	-5.1	0.4	-0.2	5.8	5.2
	Population Density of New Development	New Persons per Acres of New Development		4.7	5.5	5.4	-13.6	1.3	-0.6	17.3	15.1

Mobility: Highway	Systemwide Speed	PM peak hour speed (MPH)	35.8	25.6	27.1	26.0	-28	-24	-27	5.7	1.5
	VHD - Vehicle Hours of Delay	PM peak hour: congested travel time - free flow travel time (hours)	9,648	47,450	21,337	22,525	392	121	133	-55.0	-52.5
	VHT - Vehicle Hours Traveled	PM peak hour: total travel time (hours)	51,876	104,470	94,492	98,677	101	82	90	-9.6	-5.5
	Vehicle Miles Traveled (VMT)	Total vehicle miles traveled per day	19,722,826	28,055,982	27,006,046	27,043,141	42	37	37	-3.7	-3.6
	VMT per Capita	Average vehicle miles traveled per person	22.1	20.8	20.0	20.0	-6	-10	-10	-3.7	-3.6
	Percentage of Network in Congested Conditions	PM peak hour: % of network exceeding capacity (v/c > 1)	2.0%	6.9%	6.1%	6.8%	251	211	243	-11.3	-2.1
	Congested Conditions along Freight Corridors	PM peak hour: % of freight network exceeding capacity (v/c > 1)	5.0%	17.4%	15.0%	15.5%	252	203	212	-14.0	-11.3
Mobility: Transit	Transit Ridership	Daily number of transit trips	41,033	52,153	83,589	67,507	27	104	65	60.3	29.4
	Transit Passenger Miles Traveled	Daily passenger miles traveled	147,369	187,772	262,171	221,037	27	78	50	39.6	17.7
	Transit Mode Share	% Trips by Transit	0.8%	0.7%	1.0%	0.9%	-9	32	14	44.4	25.0
Mobility: River Crossings	River Crossing - Congested Conditions	PM peak hour: average volume to capacity ratio (v/c ratio)	0.77	0.99	0.97	1.00	29	26	30	-2.3	0.6
	River Crossing Trips	Daily number of vehicle trips	598,018	770,235	754,444	781,283	29	26	31	-2.1	1.4
Economic Competitiveness	Proximity to Employment Sites	Households within 1 mile of employment	33,729	49,573	59,886	60,608	47	78	80	20.8	22.3
	Average Commute Time	Minutes	17.48	20.94	19.42	19.77	20	11	13	-7.3	-5.6
Safety	Crash Rate	Crashes per 100 million VMT	369	373.7	376.4	374.3	1	2	1	0.7	0.2
Sustainability & Resiliency	GHG Emissions	Daily CO2-eq (tonnes/day)	11,358	14,058	13,352	13,519	24	18	19	-5.0	-3.8
	GHG Emissions per Capita	Daily CO2-eq per Capita (kg/day)	12.7	10.4	10.1	10.2	-18	-21	-20	-3.0	-1.7
	Residential Water Consumption	Million gallons per year	25,107	37,224	36,420	36,444	48	45	45	-2.2	-2.1
	Development in High Flood-Risk Areas	Employment + Dwelling Units in 100 year Flood Plains	34,470	52,755	50,782	51,853	53	47	50	-3.7	-1.7
	Development in Forest Fire Risk Areas	Weighted value based on emp + housing in wildland-urban interface areas	3.14	4.85	4.53	4.57	54	44	46	-6.6	-5.8
	Development in Crucial Habitat Areas	Weighted value based on emp + housing in priority ranking areas	5.73	7.65	7.71	7.70	34	35	34	0.8	0.7

Final Scenarios

Performance Measure	Performance Measure		Absolute Value	Percent Change from 2012	Percent Change from Trend

Category		Unit of Analysis	Base Year 2012	Trend	Preferred	Constrained	Trend	Preferred	Constrained	Preferred	Constrained
Accessibility	Proximity to Activity Centers	Households within 1 mile of Activity Center	64,842	98,029	128,973	129,519	51	99	100	31.6	32.1
	Proximity to Transit	Households within 1/4 mile of premium transit	25,530	40,608	53,206	53,258	59	108	109	31.0	31.2
	Proximity to Bicycle Facilities	Households within 1/4 miles of a bicycle path	113,645	150,434	157,877	159,063	32	39	40	4.9	5.7
	Proximity to Schools	Households within 1/2 miles of a school	171,986	224,138	222,467	225,276	30	29	31	-0.7	0.5
	Non-motorized Mode Share	% Trips bike or walk	5.8%	5.6%	6.0%	6.0%	-2	5	5	7.3	7.3
Land Use	Jobs/Housing Mix in Activity Centers	Average jobs to housing ratio within 1 mile of activity centers	2.72	2.34	2.23	2.21	-14	-18	-19	-4.4	-5.5
	Proximity to Key Corridors	Employment within 1000 feet of key corridors	60,151	84,000	117,692	117,547	40	96	95	40.1	39.9
	Lane Miles	Roadway Lane Miles	4,353	4,676	4,676	4,528	7	7	4	0.0	-3.2
	Land Developed	Acres Land Developed	215,660	273,495	255,936	254,859	27	19	18	-6.4	-6.8
	Population Density	Persons per Acre of Developed Land	4.1	4.9	5.3	5.3	20	28	28	6.9	7.3
	Population Density of New Development	New Persons per Acres of New Development		7.9	11.4	11.7	92.4	176.3	183.9	43.6	47.5
	Taxable Land Value	Dollars	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mobility: Highway	System wide Speed	PM peak hour speed (MPH)	35.8	22.7	25.3	24.8	-37	-29	-31	11.4	9.1
	VHD - Vehicle Hours of Delay	PM peak hour: congested travel time - free flow travel time (hours)	9,648	60,922	45,534	47,221	531	372	389	-25.3	-22.5
	VHT - Vehicle Hours Traveled	PM peak hour: total travel time (hours)	51,876	120,310	101,836	103,300	132	96	99	-15.4	-14.1
	Vehicle Miles Traveled (VMT)	Total vehicle miles traveled per day	19,102,969	28,363,093	26,955,101	26,786,538	48	41	40	-5.0	-5.6
	VMT per Capita	Average vehicle miles traveled per person	22.3	21.9	20.7	20.6	-2	-7	-8	-5.6	-6.2
	Percentage of Network in Congested Conditions	PM peak hour: % of network exceeding capacity (v/c > 1)	5.7%	20.3%	16.7%	17.8%	254	192	211	-17.5	-12.1
	Congested Conditions along Freight Corridors	PM peak hour: % of freight network exceeding capacity (v/c > 1)	1.0%	25.6%	26.1%	21.4%	2535	2593	2107	2.2	-16.2
Mobility: Transit	Transit Ridership	Daily number of transit trips	41,033	57,258	99,446	79,545	40	142	94	73.7	38.9
	Transit Passenger Miles Traveled	Daily passenger miles traveled	147,369	198,645	308,132	249,310	35	109	69	55.1	25.5
	Transit Mode Share	% Trips by Transit	0.8%	0.8%	1.2%	1.0%	-4	51	28	56.6	32.9
Mobility: River	River Crossing - Congested Conditions	PM peak hour: average volume to capacity ratio (v/c ratio)	0.76	1.05	1.00	1.03	38	31	34	-4.7	-2.6

Performance Measure Category	Performance Measure	Unit of Analysis	Absolute Value				Percent Change from 2012			Percent Change from Trend	
			Base Year 2012	Trend	Preferred	Constrained	Trend	Preferred	Constrained	Preferred	Constrained
Crossings	River Crossing Trips	Daily number of vehicle trips	592,609	808,089	776,628	794,791	36	31	34	-3.9	-1.6
Economic Competitive-ness	Proximity to Employment Sites	Households within 1 mile of employment	35,069	48,970	61,440	60,779	40	75	73	25.5	24.1
	Average Commute Time	Minutes	17.48	23.77	19.62	19.53	36	12	12	-17.5	-17.8
Safety	Crash Rate	Crashes per 100 million VMT	292.5	293.38	311.348	303.41	0	6	4	6.1	3.4
Sustainability & Resiliency	GHG Emissions	Daily CO2-eq (tons/day)	10,952	14,542	13,479	13,483	33	23	23	-7.3	-7.3
	GHG Emissions per Capita	Daily CO2-eq per Capita (kg/day)	12.8	11.2	10.4	10.4	-12	-19	-19	-7.9	-7.9
	Water Consumption	Million gallons per year	86,713	118,466	111,464	111,205	37	29	28	-5.9	-6.1
	Development in High Flood-Risk Areas	Employment + Dwelling Units in 100 year Flood Plains	34,470	52,755	50,782	51,853	53	47	50	-3.7	-1.7
	Development in Wildfire Risk Areas	Weighted value based on emp + housing in wildland-urban interface areas	3.14	4.85	4.53	4.57	54	44	46	-6.6	-5.8
	Development in Crucial Habitat Areas	Weighted value based on emp + housing in priority ranking areas	5.73	7.65	7.71	7.70	34	35	34	0.8	0.7

[a] n/a = data not available from MRCOG