Integrating Climate Change in Transportation and Land Use Scenario Planning: *An Inland Example*

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Climate Futures Analysis
for Central New Mexico

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Prepared By: John A Volpe National Transportation Systems Center

CCSP Climate Futures

The Central New Mexico Climate Change Scenario Planning project contextualized regional land use and transportation planning within a framework of uncertain climate futures and expected population and employment growth. A key piece of this work was to use climate projections from global climate models (GCMs) and apply them to the local area around Albuquerque, New Mexico. The project used previous work analyzing possible climate futures for Central New Mexico and the Upper Rio Grande Basin and expanded upon it by developing local downscaled climate projections for specific locations within the planning area of the Mid Region Council of Governments (MRCOG).

Previous Climate Futures Analysis for the Southwest

The CCSP project benefited from a significant amount of previous research that developed GCMs and applied those models to conditions in the Southwestern United States. This research included work conducted by Climate Assessment of the Southwest (CLIMAS) as well as the US Bureau of Reclamation (BoR), US Army Corps of Engineers, and Sandia National Laboratories. The Volpe Center built upon this work by developing and applying a modeling tool to create downscaled climate futures for the Central New Mexico region for MRCOG's Metropolitan Transportation Plan (MTP) planning horizon of 2040.

Most climate change projections of potential temperature and precipitation changes over the next century have been made by analyzing the outputs of GCMs run through a range of greenhouse gas (GHG) emissions scenarios. These models generally agree on the direction of future global change, but the projected size of those changes cannot be precisely predicted. This range of uncertainty is due to three primary sources:[1]

1. **Natural variability**: Natural, year-to-year variability in climate conditions produces a modest level of uncertainty about climate change projections for a particular time period. Natural variability has a greater impact on uncertainty at the local or regional scale than at a global scale. Over a multi-decadal time scale, the effect of natural variability on projection uncertainty is less than over a smaller timeframe.
2. **Emissions uncertainty**: Future GHG emissions rates may follow many possible trajectories, based on global economies, technologies, and policies. Climate projections rely on assumptions about future GHG emissions, which may be higher or lower than the actual emissions path that the world experiences over the next century. The Intergovernmental Panel on Climate Change (IPCC) has developed a range of alternative future emissions scenarios (termed A2, B1, etc. in their 2001 report and RCP2.6, RCP4.5, etc. in their 2014 report) to allow for estimation of future climate change projections under each scenario. These scenarios do not have probabilities assigned to them. Advances in climate science will not reduce the uncertainties associated with emissions paths. Over longer timescales, emissions uncertainty becomes the predominant source of uncertainty in climate projections.
3. **Climate response uncertainty (or model uncertainty)**: GCMs estimate how the global climate will respond to changes in GHG emissions over time. A few dozen GCMs have been developed by scientists around the world, which vary in how they model

[1] Cubasch, et. al., 2013: Introduction. In: Climate Change 2013: The Physical Science Basis.Contribution of Working Group I to the Fifth Assessmnent Report of the Intergovernmental Panel on Climage Change. Stokcker, et. al., Eds. Cambridge University Press, New York, NY.

climate responses based on the approximations they make in modeling complex global processes.

Figure 1 illustrates the relative importance of these three sources of uncertainty over different timescales. The further into the future the projection, the less the models converge. This uncertainty is largely the result of uncertainty about the response of the climate to greater emissions, particularly in the near-term. After 2060, the uncertainty in the projection grows wider as there is less certainty about the amount of emissions that will have been released into the atmosphere. Natural variability remains constant.

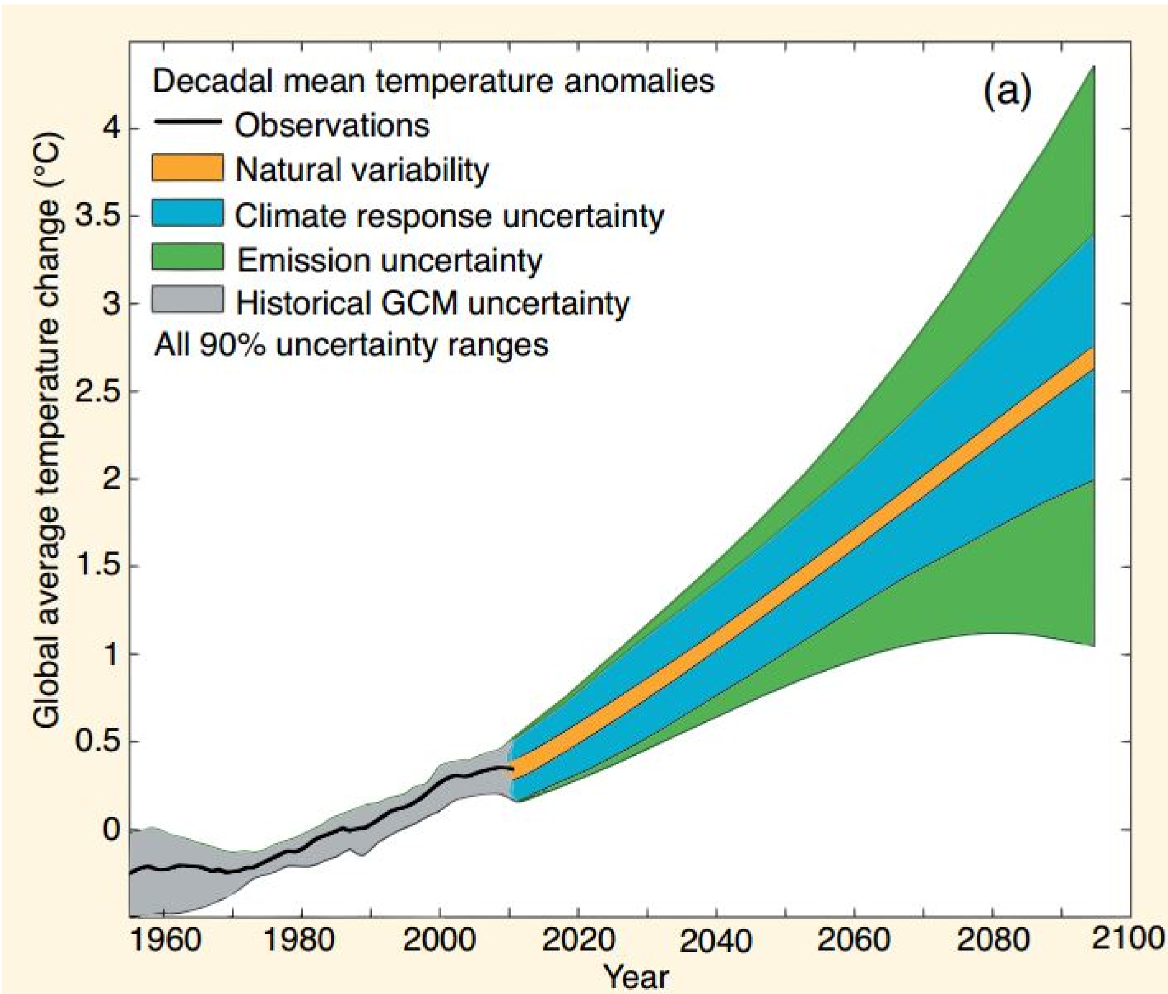

Figure 1: Schematic Diagram Showing the Relative Importance of Different Uncertainties and their Evolution in Time. Source: IPCC Fifth Assessment, Cubasch, et. al.

The work by CLIMAS[2] and the Bureau of Reclamation[3] about the future climate in Central New Mexico and the Upper Rio Grande basin share several general projections in common. There is

[2] Climate Assessment for the Southwest (CLIMAS), 2014, Potential Changes in Future Regional Climate and Related Impacts – A Brief Report for the Central New Mexico Climate Change Scenario Planning Project, prepared for the Central New Mexico Climate Change Scenario Project.

a high confidence that the region will become warmer on average. There is less confidence about whether the region will receive more or less precipitation. The reason for this low confidence level is that Central New Mexico's location on the boundary between the subtropical dry zone and the temperate mid-latitude zone means that if this boundary moves north, then the region will receive less precipitation, while southward movement of this boundary will result in more precipitation for the region. The region's precipitation patterns will thus be influenced by how climate change affects the oceanic and atmospheric processes that influence the location of this boundary and the existence of ocean-driven anomalies such as El Niño, La Niña, and the North American Monsoon. This report states that overall, models project that precipitation in the Upper Rio Grande will remain unchanged or will decline slightly over the 21st century. These analyses project that the frequency of extreme precipitation events is likely to be unchanged, although precipitation may become more concentrated in larger precipitation events in some locations.

CCSP Climate Futures Methodology

The project team built upon these previous studies of regional climate change projections to develop projections that would serve the additional needs of the CCSP by being more local in scale, focusing on the 25-year time horizon of local metropolitan planning, and providing more detailed and quantified scenarios of potential future climate conditions. Accordingly, the CCSP team developed "climate futures" for the plan year 2040, which are multiple scientifically plausible alternative scenarios that provide a quantitative basis to plan for the range of potential changes in future climate in Central New Mexico. These climate futures are not forecasts but rather are alternative model-based visions of how the climate may change in the study area.

In accordance with the NPS Climate Change Response Program guidance for scenario-based planning[4], the project team began their work by following the first three steps of a five-step process to develop the climate futures (Figure 2).[5]

- Step 1 (Orient): stakeholders, including Federal and regional agencies, assembled a Planning Group and two Technical Committees to identify the strategic climate-related challenges of the Central New Mexico region to be explored using scenarios.
- Step 2 (Explore): taking an "outside-in" approach, the project team, MRCOG, the Committees, and partners determined the external forces/climate variables of most impact to the region, namely high temperatures

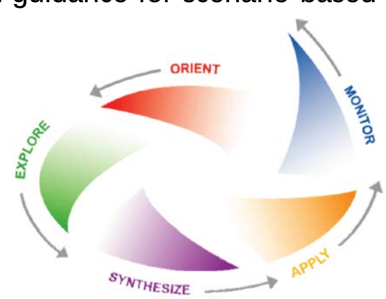

Figure 2: The 5-step NPS Scenario Planning Process Developed by Global Business Network

[3] Llewelyn, et. al., 2013, Appendix B: Literature Review of Observed and Projected Climate Changes, *Upper Rio Grande Impact Assessment*, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and Sandia National Laboratories, **http://www.usbr.gov/WaterSMART/wcra/reports/urgia.html**.

[4]Using Scenarios to Explore Climate Change: A Handbook for Practitioners (July 2013) http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf Developed under the National Park Service Climate Change Response Program, this guide is part of an interdisciplinary, cross-cutting approach to addressing climate change.

[5]Using Scenarios to Explore Climate Change: A Handbook for Practitioners (July 2013) http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf

and precipitation extremes.
- Step 3 (Synthesis): The project team determined the endpoints for critical uncertainties related to temperature and precipitation, defining a continuum of possibilities for these climate variables in the year 2040, consistent with the MRCOG planning horizon. Based on this work, the project team then built plausible, relevant, and divergent climate scenarios, referred to as Climate Futures.

The project team developed a Climate Futures Exploration and Synthesis Tool (CFEST) to build on the qualitative NPS framework. This tool enables downscaled climate projections to be quantitatively produced in any future time period through the year 2099 and in any location within the study area, and additionally anywhere in the Western United States. Figure 7 summarizes the results of this tool for the southeast area of the city of Albuquerque.

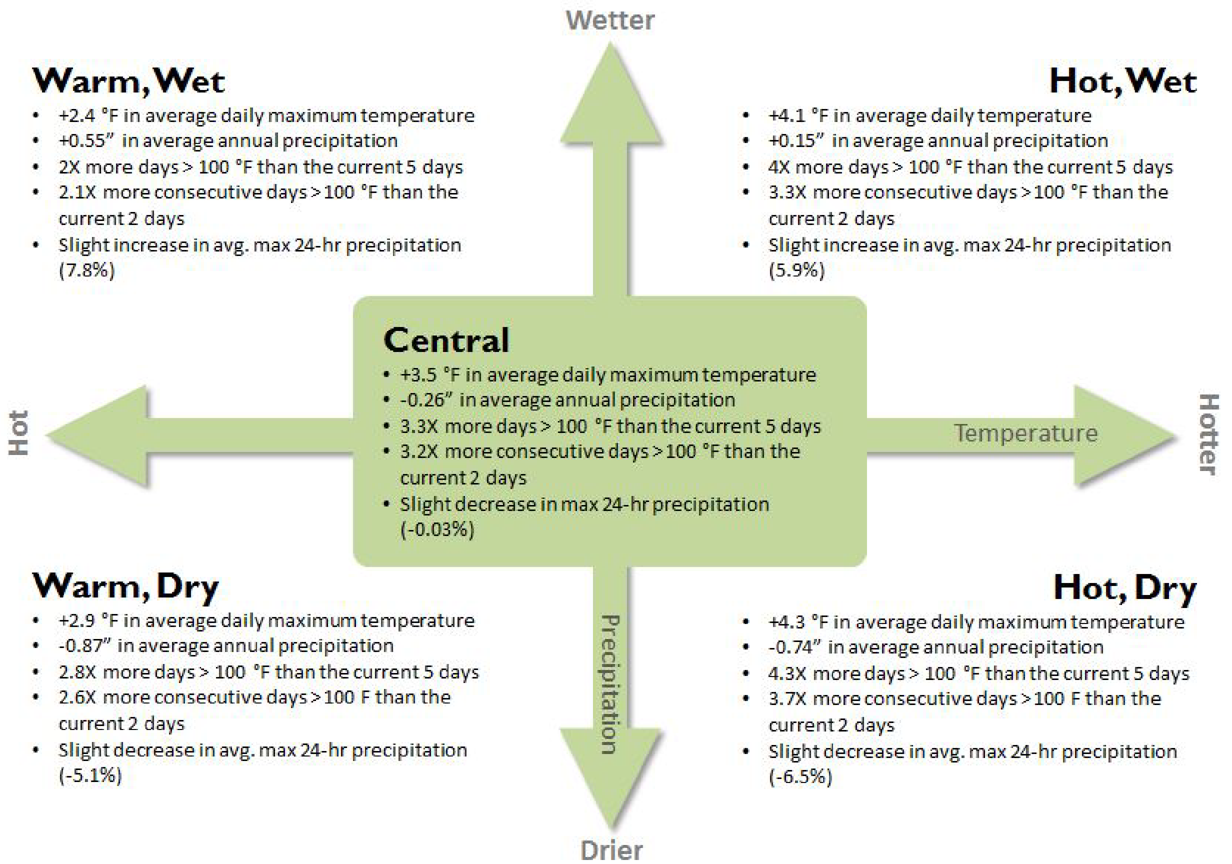

Figure 3. Summary of Climate Change Futures for the Year 2040 for Central New Mexico. Source: Volpe Center.

The CCSP Climate Futures are based on IPCC's Coupled Model Intercomparison Project (CMIP) 3 daily time step climate projections that have been spatially downscaled to 1/8th degree (approximately 7.5 mi^2) resolution by the Bureau of Reclamation.[6] The dataset contains a total

[6] Reclamation, 2011. 'West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections', Technical Memorandum No. 86-68210-2011-01, prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 138pp http://www.usbr.gov/WaterSMART/docs/west-wide-climate-risk-assessments.pdf

of 112 GCM runs, consisting of nine different climate models and three emissions scenarios: A1B (high/current path), A2 (medium), B1 (low).

The project team calculated model outputs for the following time periods:

- Baseline period: 1950-1999
- *Future* period: 2025-2055. This period is centered on 2040, the horizon year of MRCOG's MTP, with 15 years of projections on either side to smooth the data and avoid noise from year-to-year variations.

The project team also performed a calibration of the models' forecasts based on agreement between historic meteorological data and the models' backcasts.

To classify the 112 GCM runs into potential climate futures, the project team divided the model runs into four quadrants based on their changes in a) annual mean **temperature** and b) annual mean **precipitation** (Figure 8). In addition, the project team created a fifth Central Tendency future, which was defined by the 25th and 75th percentile values of the average changes in temperature and precipitation.

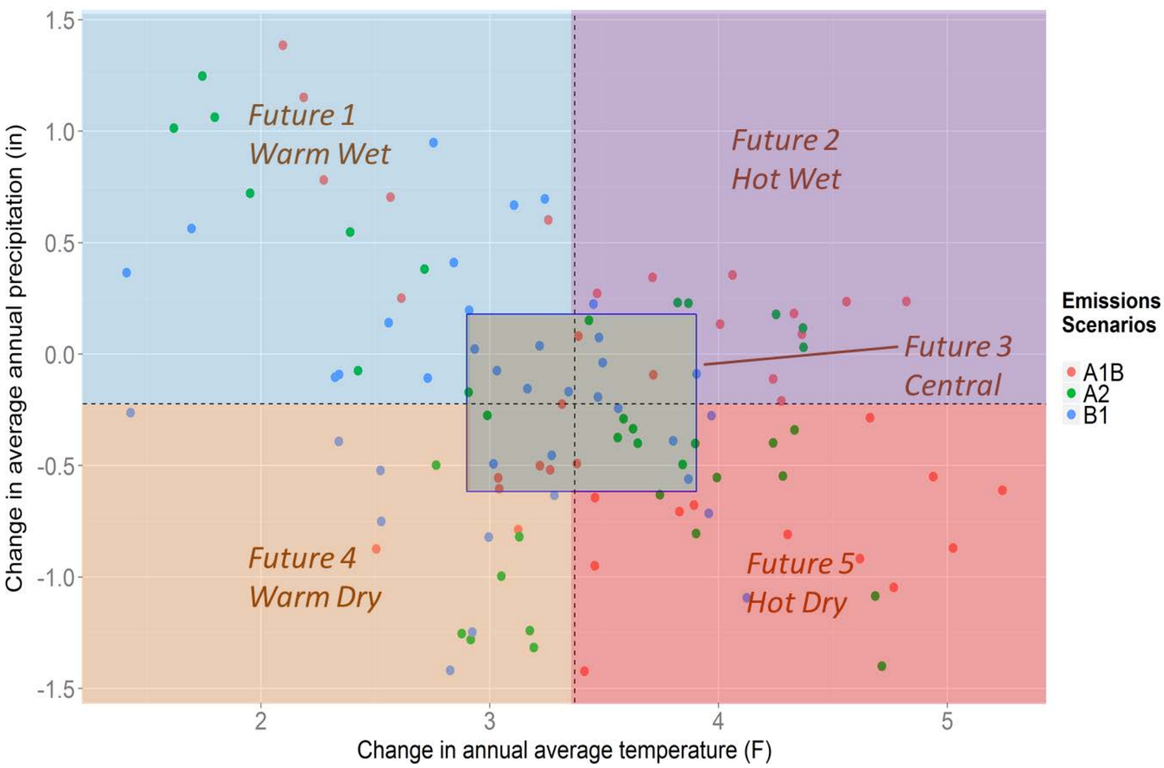

Figure 4: Changes in Annual Climate Averages for all GCMs in Albuquerque in 2040 (averaged over 2025-2055) Versus the Late 20th Century Baseline (1950-1999). Source: Volpe Center.

While the temperatures range along the temperature axis, it is important to note that none of the possibilities for the region indicate a decrease in annual temperature. All of the models agree about the direction of change, but not the magnitude. By contrast, the change in average annual precipitation is less certain and ranges from a small increase in precipitation to a small decrease in precipitation. This is consistent with the findings in the literature cited above, particular the *Upper Rio Grande Impact Assessment*.[7]

In addition to annual mean temperature and precipitation, the project team calculated the following statistics from the 112 GCM runs for six 1/8 degree grid cells in the Albuquerque region:

- Monthly average temperatures
- Extreme hot days (above 100°F)
- Heat waves (defined as the number of consecutive days above 100°F)
- Monthly precipitation change
- Extreme precipitation (maximum 24-hour precipitation amount)
- Drought indicator (consecutive days without precipitation)

While the project team calculated these measures for several grid cells, for the sake of brevity, all of the graphs below are for a grid cell centered on the southeast part of the city of Albuquerque.

Temperature findings

While each climate future has different annual average temperatures, they all have a similar seasonal variation. The plot, shown in Figure 9, illustrates the change in maximum daily temperature for each month in the future time period versus the baseline period. Three conclusions are seen from the plot:

- The temperature change is strongly seasonal, with larger temperature increases expected during the summer months than during the winter months.
- The seasonal dependence is approximately the same under each of the climate futures.
- There is a significant range of 2-3° F between the Warm Wet future and the Hot Dry futures. For example the increase in temperature in June is expected to be between 2.7° F and 5.2° F, respectively.

[7] Llewelyn, et. al., 2013, Appendix B: Literature Review of Observed and Projected Climate Changes, Upper Rio Grande Impact Assessment, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and Sandia National Laboratories, **http://www.usbr.gov/WaterSMART/wcra/reports/urgia.html**.

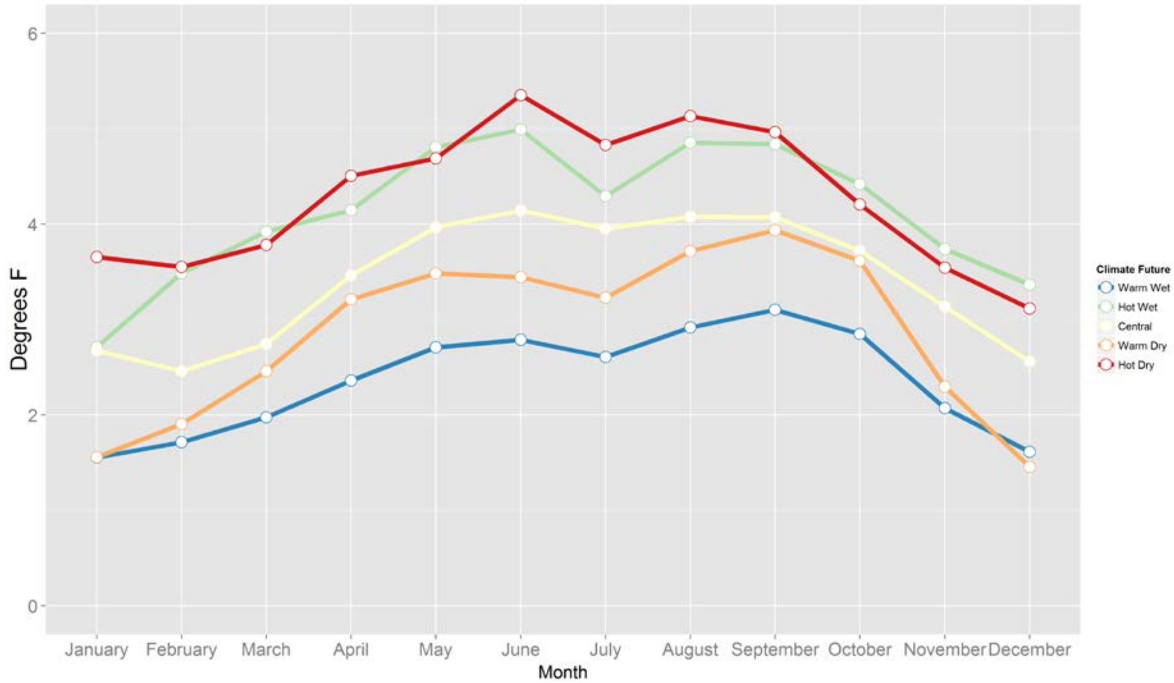

Figure 5. Monthly Temperature Change in 2040 (2025-2055) vs 1950-1999. Source: Volpe Center.

An important potential impact of temperature change is an increased frequency of extremely hot days that require air conditioning. These days, called cooling degree days, may lead to electrical brownouts or blackouts since the increase in electrical load may stress the utility and power system of the region and require upgrades in generation and transmission capacity. The plot in Figure 10 uses boxplots to illustrate the model outputs for the number of annual cooling degree days for each climate future. Each box shows the 25th, 50th, and 75th percentile values based on the models in each climate future; the vertical "whiskers" and dots denote the extent of outlier values. The plot compares the backcast or baseline number of days per year with a maximum temperature exceeding 100° F under each climate future in the baseline period with the forecast number of such days in the future period. Since the models are calibrated to historical data, the backcast frequency of five days per year is the same across all climate futures. The future values, however, vary widely and paint a picture of many more cooling degree days in the year 2040. At the low end under the Wet Warm future, 10 days are expected on average to have a maximum temperature exceeding 100° F (roughly double the baseline value of 5 days/year); on the high end under the Hot Dry future, 22 such days are expected on average. In fact, as shown by the "whisker" extending from the top of the boxplot representing the Hot Dry future, over 30 days per year is plausible and should be considered as the worst-case scenario for future planning.

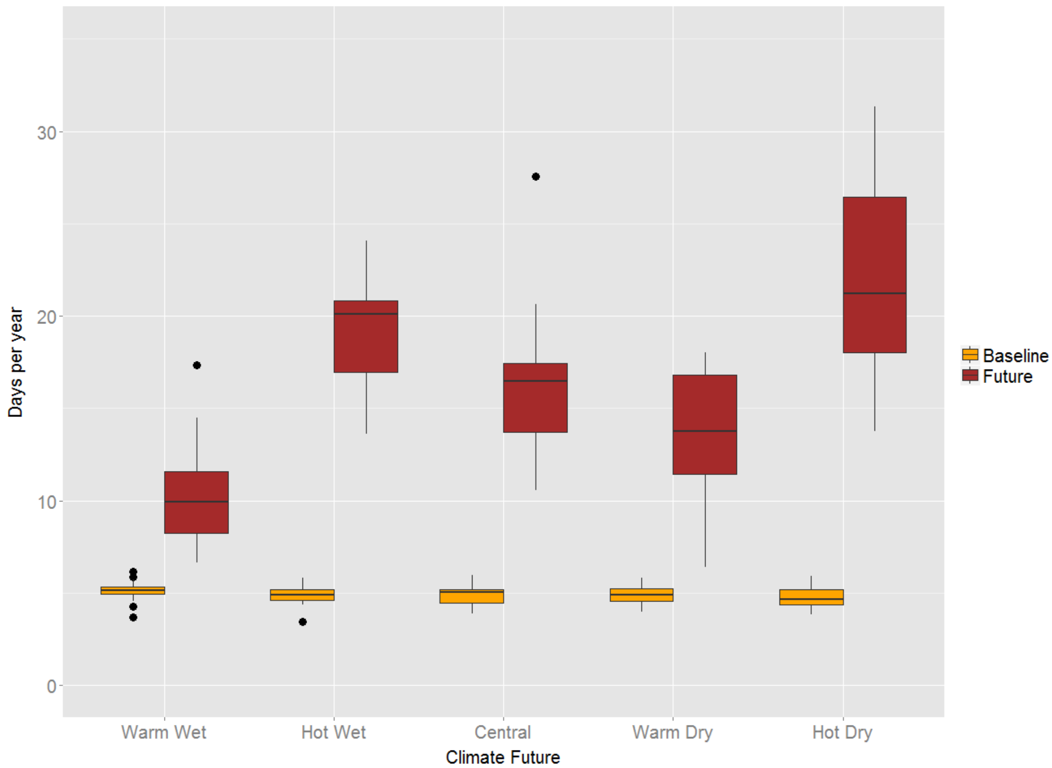

Figure 6. Annual Cooling Degree Days (>100 F) in baseline (1950-1999) and 2040 (2025-2055). Source: Volpe Center.

Heat waves occur when extremely hot days occur consecutively. The impacts of heat waves include public health emergencies, especially affecting vulnerable populations, as well as damage to roads, railroads, and certain other infrastructure. The boxplot in Figure 11 compares the baseline and future maximum consecutive days of 100° F or more. As for the previous output for the total number of cooling degree days, this threshold temperature can be set to any value by the user. Compared to a maximum two-day event in the baseline period, the climate futures indicate maximum annual heat wave durations between an average of four and seven days, with outlier values exceeding 11 days.

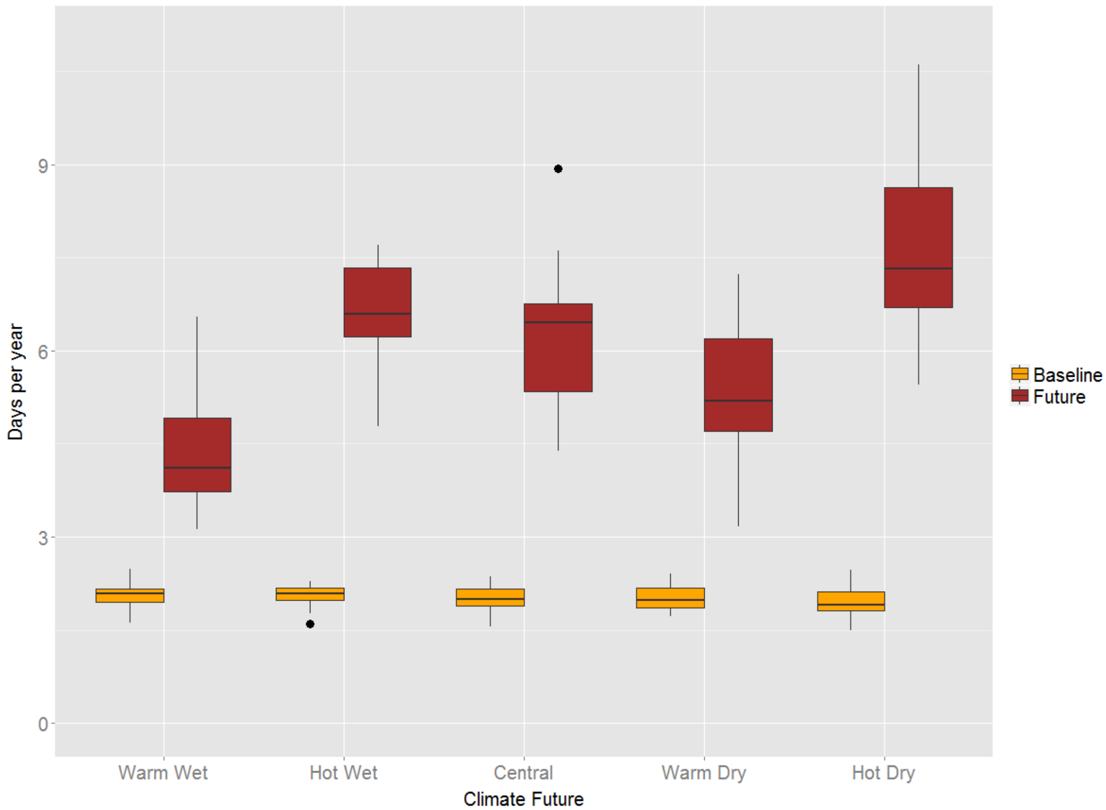

Figure 7. Maximum Consecutive Days Over 100° F in baseline (1950-1999) and 2040 (2025-2055). Source: Volpe Center.

Precipitation findings

Precipitation is a critical uncertainty for this region for two reasons. One reason for uncertainty in projections of annual average precipitation is the region's location near the boundary of the tropical and temperate climate zones and the resulting lack of convergence of the models about the future of the North American Monsoon. Projections for short-term, extreme precipitation events also have high uncertainty because downscaled global climate models do not provide sufficient detail to project when and how intensely that rain falls in the region. These details are important because arid regions like Central New Mexico can experience either drought or heavy rainfall that is not easily absorbed by the drought-stressed soil.

Although based on GCMs, which are less certain about future precipitation trends in the region, the CFEST tool does show variation among the four climate futures in the pattern of seasonal precipitation change. The changes in average monthly precipitation in the future period versus the baseline period under each of the five climate futures are shown in Figure 12 as colored bars. At least three conclusions and their potential impacts can be seen:

- The climate futures consistently project reduced precipitation in the spring months of March, April, and May. With these months being drier, changes in snowpack may be expected.
- The models diverge during the winter, summer, and fall seasons, indicating that those months are highly uncertain and that planning should account for either increases or decreases in precipitation.
- The magnitudes of the projected changes are small, not exceeding 1/6th inch per month.

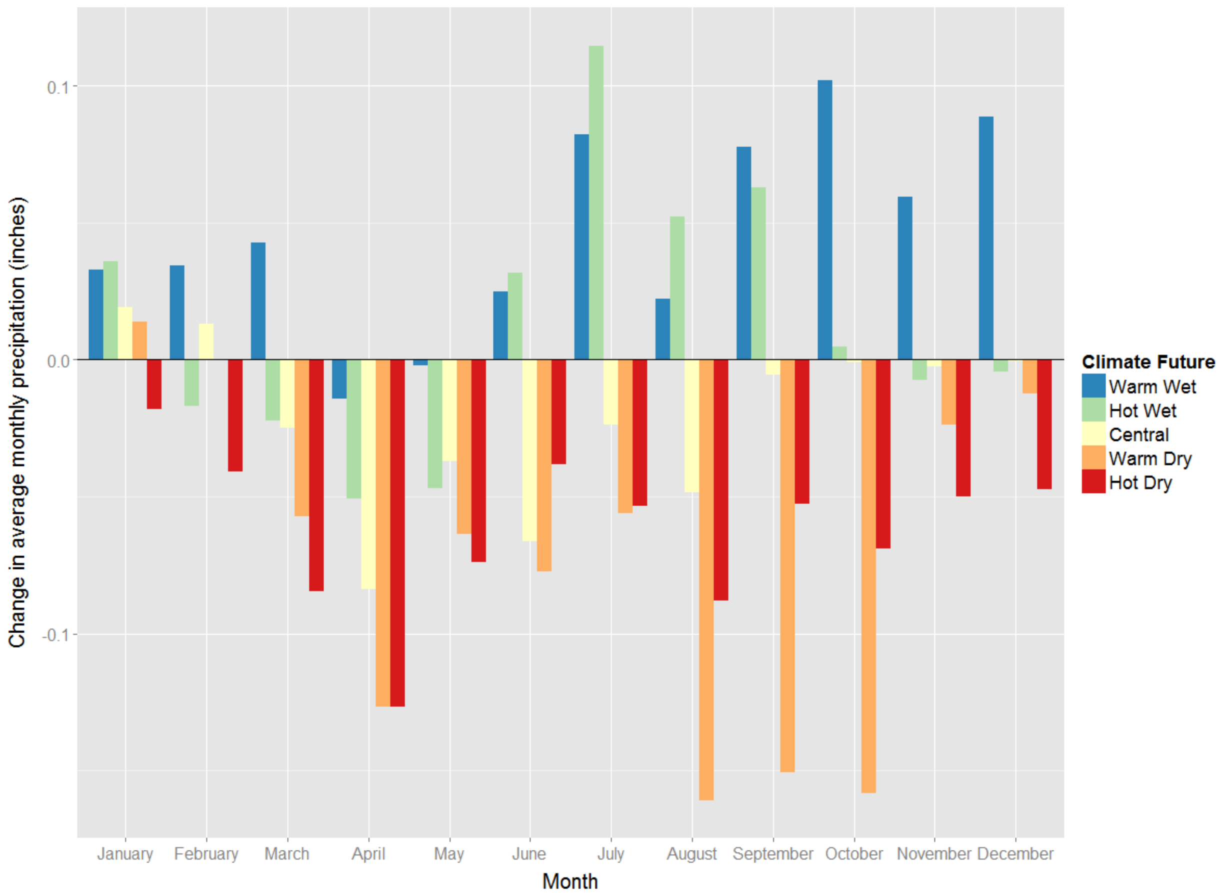

Figure 8. Monthly Average Precipitation Change in 2040 (2025-2055) vs 1950-1999. Source: Volpe Center.

While some climate change-associated impacts, such as heat waves, are due mostly to changes in the projected trend of increased temperatures, others, such as flash flooding, are attributable to specific extreme events such as heavy short periods of precipitation, which is more difficult to project with certainty. Figure 13 compares the maximum 24-hour precipitation event during an "average" year in the late 20th century versus forecasted future periods. With relatively modest increases and decreases shown in this figure, the climate futures do not provide clear projections of major precipitation events. This result, however, may be the result of a limitation of the downscaling process used by the Bureau of Reclamation and may not indicate that there will be little effect on flash flood risk in the region.[8]

[8] According to a BoR Technical Services Center Technical Memorandum, a byproduct of the downscaling process used to produce the 1/8th degree dataset is the removal of extreme precipitation value outliers. Possible future approaches to better analyze potential extreme events include projecting them by correlating the curve of the distribution of known events in the recent past with the model's version of the present and extrapolating this correlation to the future projections; or downscaling the coarse GCMs using a different methodology.

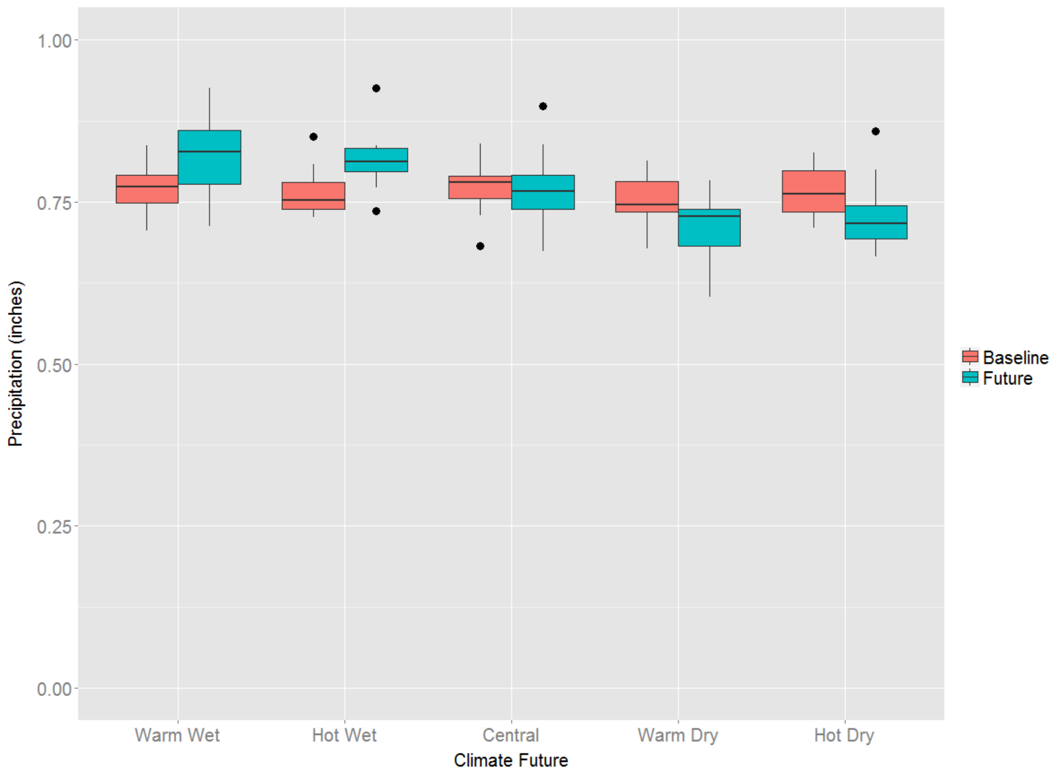

Figure 9. Maximum 24-hour Precipitation Amount in Baseline (1950-1999 average) and 2040 (2025-2055 average). Note: climate futures do not provide clear projections of major precipitation events because high precipitation outliers were removed from the dataset. Source: Volpe Center.

Temperature and precipitation trends together affect water resources in the region. Drought is caused by a combination of a lack of rainfall and heat-driven evapotranspiration of water stored in the soil and in plants. The expected higher temperatures in the region will likely dry the soil out more quickly through the year, thereby reducing the soil's infiltration capacity and limiting its ability to absorb and store stormwater during events. Furthermore, the higher temperatures expected in the future will increase the temperature of the ground and lead to higher rates of evapotranspiration of rainfall.

At the request of MRCOG, the project team analyzed five additional locations to produce a regional picture of the climate futures (Figure 14). Using the same time intervals as for the original locations, the effects of elevation and location in the region became apparent in outputs such as the heat wave analysis, which showed that mountainous areas that historically saw zero days per year exceeding 100° F are projected to see none in 2040 in all but the Hot Dry future. In contrast, low-elevation locations such as Los Lunas are projected to see increases in heat wave duration as large or even larger than downtown Albuquerque.

This analysis of several locations that will experience varying impacts from climate change demonstrates the value of using downscaled projections to differentiate the plausible climate change impacts in different parts of the study area and to test growth scenarios accordingly. As discussed further in the next section, the Climate Futures informed the identification of where existing development is at risk, where future development should be minimal, the energy consumption increase for cooling, and impacts for natural and cultural resources.

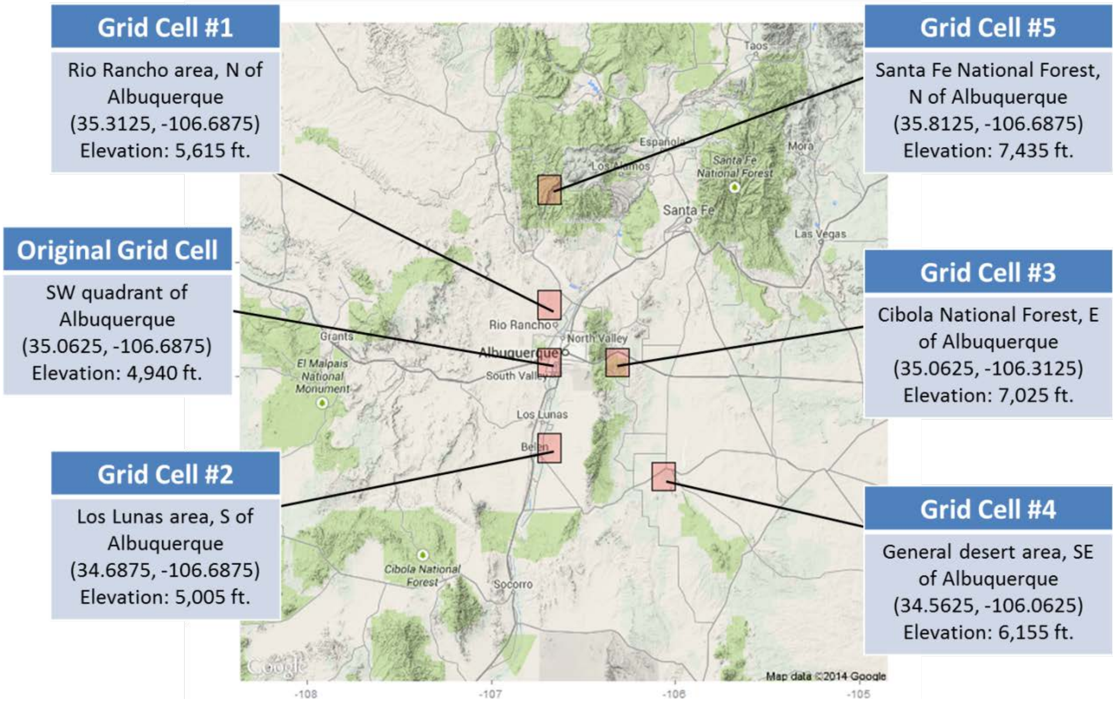

Figure 10: Five Additional MRCOG-Identified Grid Cells of Different Elevations and Areas of the 5-County Study Area. Source: Volpe Center