Fresno Council of Governments

Fresno County Regional Transportation Network Vulnerability Assessment

Vulnerability Assessment Summary Memorandum

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Introduction

Project Background

The Fresno Council of Governments (Fresno COG) received grant funding from the California Department of Transportation (Caltrans) under the Senate Bill (SB) 1 Adaptation Planning Grants Program to conduct a Transportation Network Vulnerability Assessment (TNVA) for Fresno County. The TNVA aims to assist Fresno COG and other local agencies in understanding the potential impacts of climate change on the region's transportation infrastructure, identify specific locations that may be affected, and identify strategies to ensure the stability and resiliency of the infrastructure moving into the future. Fresno COG wants to ensure that the region's multimodal transportation network continues to support the area's strong communities and promote positive economic development. Information learned through the TNVA development process will inform not only the next Regional Transportation Plan/Sustainable Communities Strategy (RTP/SCS) update, but will also provide data for local partner jurisdictions to integrate into their respective General Plans.

Objectives of the Fresno County Regional TNVA development process include:

- ✓ Convene regional partners from multiple jurisdictions.
- ✓ Identify climate change impact risks to multi-modal transportation infrastructure in the project area.
- ✓ Identify specific transportation infrastructure vulnerable to climate change impacts.
- ✓ Develop adaptation strategies and specific actions to remedy identified climate related vulnerabilities.

The development process for the TNVA is guided by a diverse Vulnerability Assessment Working Group (VAWG). The VAWG is responsible for providing both policy and technical guidance and shaping how the TNVA can serve the different communities of Fresno County, and adapt to the potential impacts of climate change.

Document Purpose and Structure

The project's Vulnerability Assessment task focuses on identifying climate change impacts to the transportation system in Fresno County. This memorandum documents the Vulnerability Assessment methodology and results.

The Fresno County Extreme Weather and Climate section discusses historical climate and weather impacts in Fresno County. It broadly summarizes projected changes in the county's climate.

The Engagement and Collaboration Findings section reviews information from the VAWG, stakeholder interviews, and public outreach. The separate Public Outreach Synopsis summarizes the community engagement activities and findings from this project. This Vulnerability Assessment memo draws on the engagement findings, but readers should refer to the Public Outreach Synopsis for detail on the project's community engagement and collaboration process.

The Transportation System Analysis Findings section summarizes the analysis of projected climate impacts on the transportation system in Fresno County. A major component of the analysis was a risk indicator scoring process. The process involved gathering relevant data on climate and assets and combining this information into scores representing the relative risks facing different assets. With these results, one can identify individual assets needing facility-level assessments of future climate threats and responses. Aside from the scoring process, the Additional Analysis section presents analyses of the relationship between high temperature events and transit ridership, and of potential areas of future deep-seated landslide risk in the County.

The Summary section synthesizes the findings from the TNVA and concludes with a discussion of next steps in the project how to use the findings.

Fresno County Extreme Weather and Climate

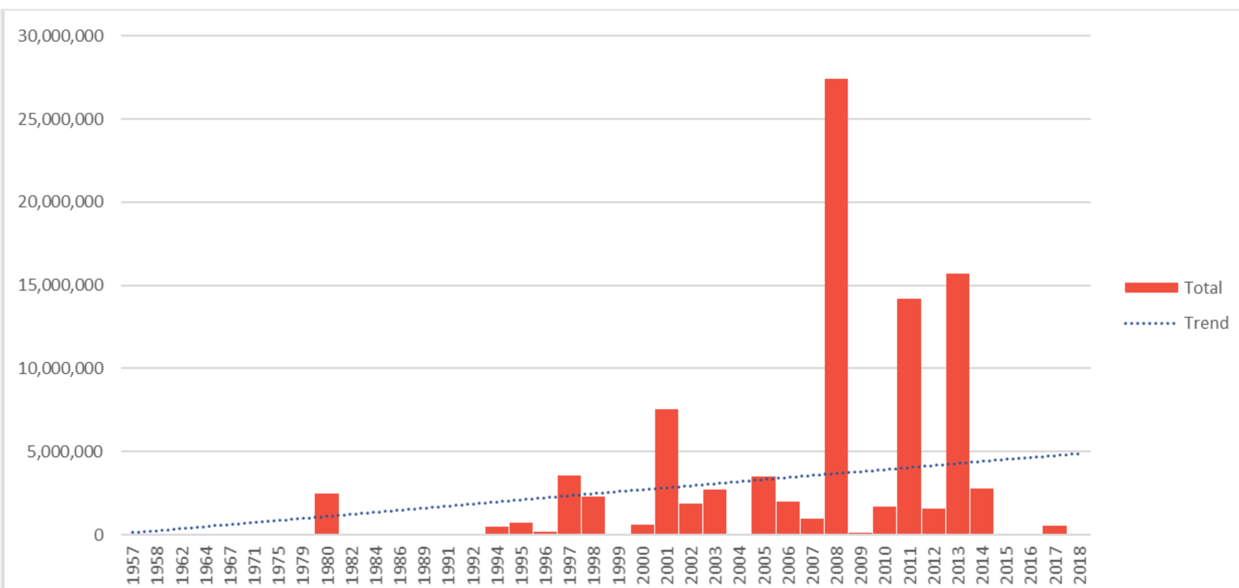
Spanning across the Central Valley and reaching into two major mountain ranges, Fresno County experiences a variety of weather and climate conditions. Extreme heat, riverine flooding, wildfire, drought, dense fog, strong winds and winter storms have affected human activity in different parts of the region in recent years. The impacts of climate change on the planet's natural systems are leading to observable changes in California's environment. Fresno County is likely to experience a future with higher average temperatures and increases in extreme heat events, wildfires, storms, and droughts. The changes in climate are expected to exacerbate related issues, such as air pollution and water supply, and ultimately affect social equity as communities face disproportionate impacts from climate change.

Historical Context

Fresno County's recent Multi-Hazard Mitigation Plan[1] thoroughly summarizes past weather-related events and risks in the region.

For this project, we also reviewed the National Oceanic and Atmospheric Administration (NOAA) Storm Events Database for recent years. Figure 1. Fresno County Property Damage ($) by Year shows storm-related property damage in Fresno County[2] by year, starting in 1957 and ending in 2018. There is a high variation in damages between years. There has also been an upward trend in damages over time. While this study did not review the storm event data collection methodology, it Is possible that there have been changes in methodology over the relatively long period shown on the graph.

Figure 1. Fresno County Property Damage ($) by Year, NOAA Storm Events Database



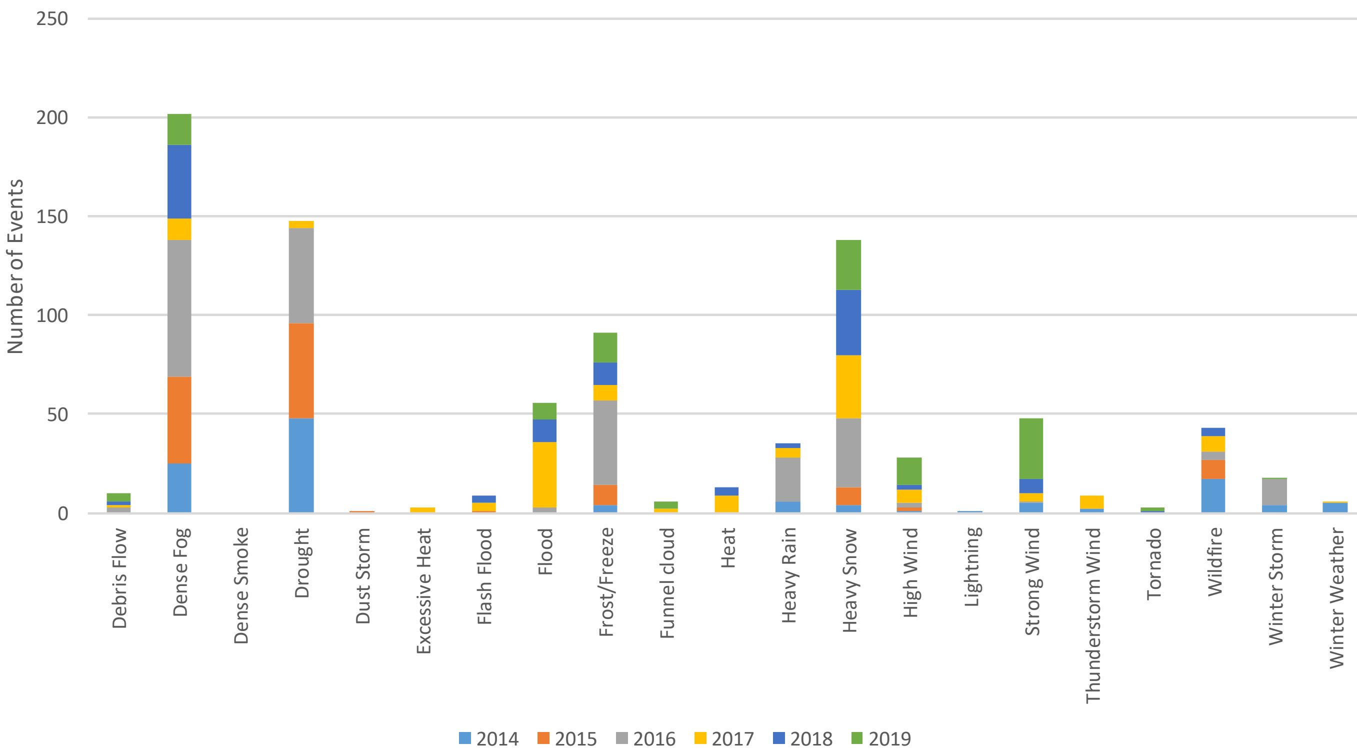
Source: NOAA Storm Events Database

[1] https://www.co.fresno.ca.us/home/showdocument?id=24743

[2] For the NOAA Storm Events Database, Fresno County is defined as: West-Central San Joaquin Valley, East-Central San Joaquin Valley, Mariposa Madera and Fresno County foothills, Sierra Nevada from Yosemite to Kings Canyon, West Side hills, Western San Joaquin Valley, Foggy Bottom, Fresno, Central Sierra Foothills, Central Sierra, North Kings River, and Sequoia Kings.

We analyzed a subset of the most recent NOAA storm event data in greater detail. From January 2014 to April 2019, Fresno County experienced more than 800 storm events that caused a total of 5 deaths, 69 injuries, over $4 million in property damage, and over $50 million in crop damage.[3] These storm events ranged from debris flow to winter weather events (see Figure 2. Number of Events from January 2014 to April 2019 for Fresno County). The county experienced the greatest number of events in 2016 (243 events) and the lowest number of events in 2018 (118 events).

Figure 2. Number of Events from January 2014 to April 2019 for Fresno County, NOAA Storm Events Database



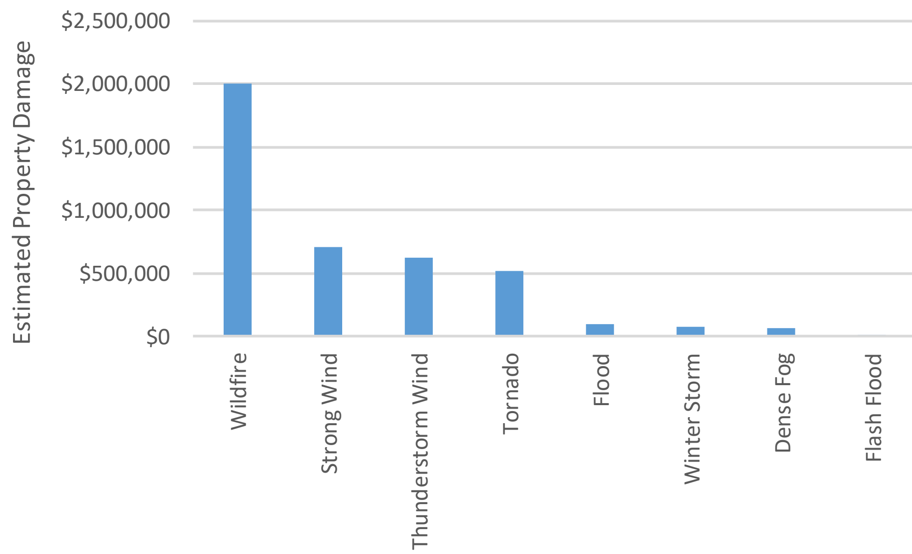
Assuming the events from 2014 to 2018 are a representative sample, the frequency of events occurring in any given year varies on average from 0 to 37 events. The frequencies suggest there is a high probability for occurrences of dense fog, drought, floods, frost/freeze, heavy snow, and wildfire within the county.

Of these storms, a strong wind event on March 5, 2017 was responsible for 1 death, and a wildfire event on July 13, 2018 was responsible for 4 deaths. Injuries were caused by lightning (February 28, 2014) and wildfires (July 13, 2018 and August 8, 2018). Overall, wildfires caused the greatest direct threat in terms of harm to people.

[3] We further reviewed the FEMA disaster declarations and did not identify any major disaster declarations in Fresno County from January 2014 to April 2019. Another type of event – an emergency declaration - can be declared by the President for an emergency for any occasion or instance when the President determines federal assistance is needed. There were 3 such events declared from January 2014 to April 2019.

Wildfires were also responsible for the largest amount of property damage ($2 million), followed by strong winds ($700 thousand) and winds from thunderstorms ($630) (See Figure 3. Property Damage for Fresno County per Storm Event Type from January 2014 through April 2019, NOAA Storm Events Database.

Figure 3. Property Damage for Fresno County per Storm Event Type from January 2014 through April 2019, NOAA Storm Events Database

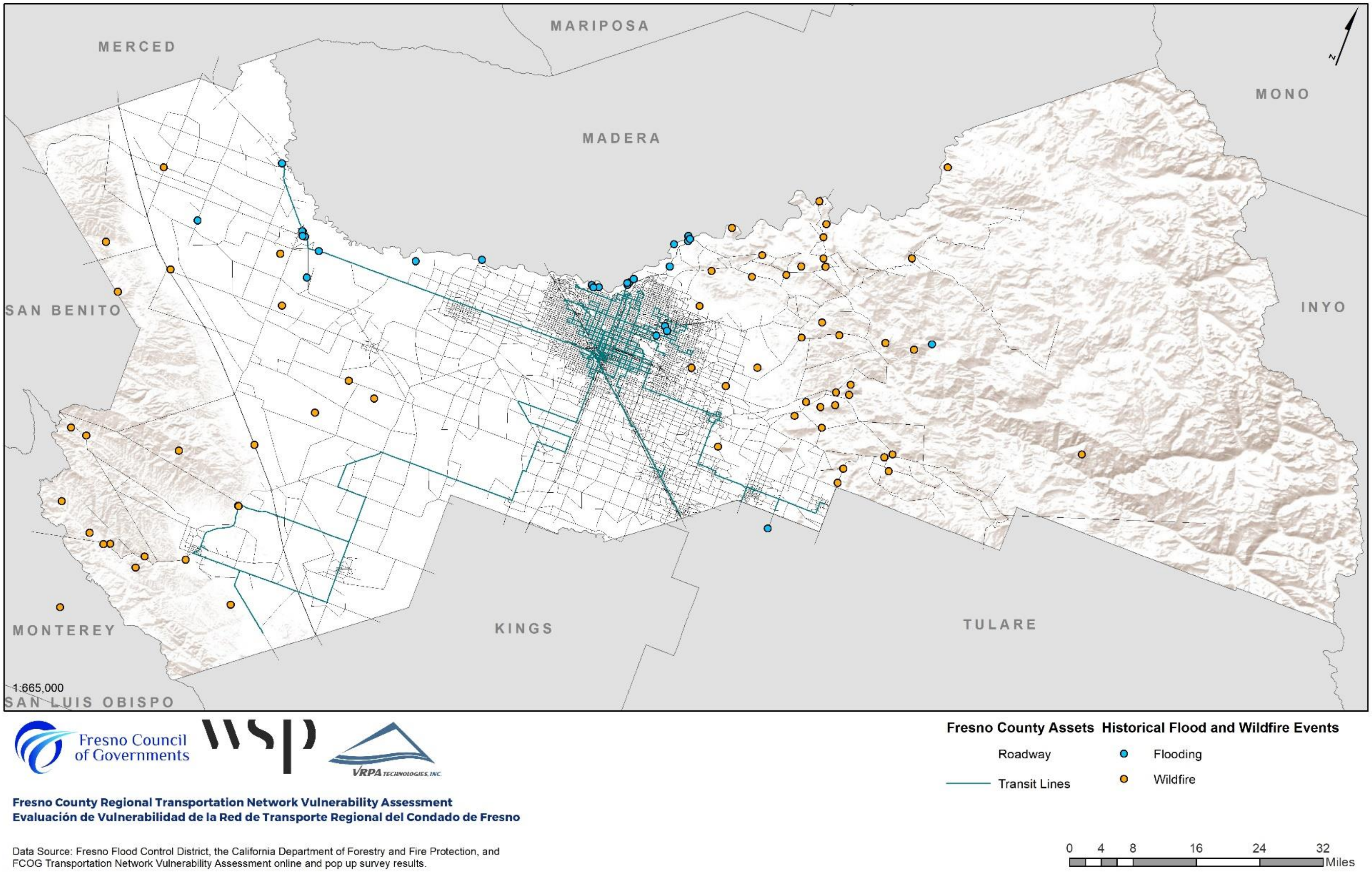


Crops in Fresno County have been damaged by frost/freeze events and strong wind events. A frost/freeze event on February 20, 2018 was responsible for $50M of crop damage, while a strong wind event on December 11, 2014 accounted for $500k of crop damage.

We also reviewed news archives and incident reports for information about the location, type, and year of historical storm events and damages in Fresno County. Historical flood event information was collected by reviewing archived newspapers compiled by the Fresno Metropolitan Flood Control District, which documented the major storms of 1996 to 1998. Past wildfire event information was collected by reviewing California Department of Forestry and Fire Protection (CalFire) incident reports that dated back to 2006. Using these sources, we identified 90 locations impacted by flooding and wildfire (see Figure 4. Fresno County Historical Flood and Wildfire Events).

We later combined this information with input on past events from community members and stakeholders. The Engagement and Collaboration Findings section presents these results.

Figure 4. Fresno County Historical Flood and Wildfire Events



Future Projections

California's Fourth Climate Change Assessment provides a thorough overview of the expected effects of climate change in the state.[4]

As part of this study, we obtained projections from climate models and other sources to better understand how Fresno County's climate is likely to change in the future. Global Climate Models (GCM) simulate climate over time, drawing on physics, climatology, and historical climate observations. They use assumptions about greenhouse gas emissions and other factors to forecast future climate conditions.

Downscaling is the process of enhancing the resolution of these GCMs, which are global in scale, for use at a regional scale. Scripps Institute of Oceanography used a process called Localized Constructed Analogs (LOCA) to downscale thirty-two GCMs for California.[5] In California, ten downscaled GCMs were assessed by state agencies as being most representative of climate change across the state.[6] Data from these models is housed on Cal-Adapt, which is a public web-based platform that provides downscaled GCM projections and other information on climate change in California.[7] We generally used these ten GCMs for this study.

In general, we used two greenhouse gas emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), a major international research institution that provides scientific research on climate change to help policy and decision makers. The scenarios are called Representative Concentration Pathways (RCPs). RCP 4.5 assumes that global annual GHG emissions peak around 2040 and then decline. RCP 8.5 corresponds more closely to the current status quo; it assumes that emissions continue to rise until the end of the century.[8]

We were generally consistent with Caltrans' use of GCMs, RCPs, and timeframes that it uses in its Climate Change Vulnerability Assessment. The Caltrans District 4 Climate Change Vulnerability Report describes the same timeframes used in this study:

> *For this study, analysis periods were defined as the beginning, middle, and end of century, and were represented by the out-years of 2025, 2055, and 2085, respectively. These years are chosen because some statistically-derived climate metrics used in this report (e.g. the 100-year precipitation event) are typically calculated over 30-year time periods centered on the year of interest. Because currently available climate projections are only available through the end of the century, the most distant 30-year window runs from 2070 to 2099. The year 2085 is the center point of this time range, and thus the last year in which statistically derived projections can defensibly be made. The 2025 and 2055 out-years follow from the same logic, but applied to each of the prior 30-year periods (2010 to 2039 and 2040 to 2069, respectively).*[9]

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[4] The Statewide Summary Report is available here: https://www.energy.ca.gov/sites/default/files/2019-07/Statewide%20Reports-%20SUM-CCCA4-2018-013%20Statewide%20Summary%20Report.pdf

[5] http://loca.ucsd.edu/

[6] http://www.water.ca.gov/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf. The models are: ACCESS 1-0, CanESM2, CCSM4, CESM1-BGC, CMCC-CMS, CNRM-CM5, GFDL-CM3, HadGEM2-CC, HadGEM2-ES, and MIROC5.

[7] https://cal-adapt.org

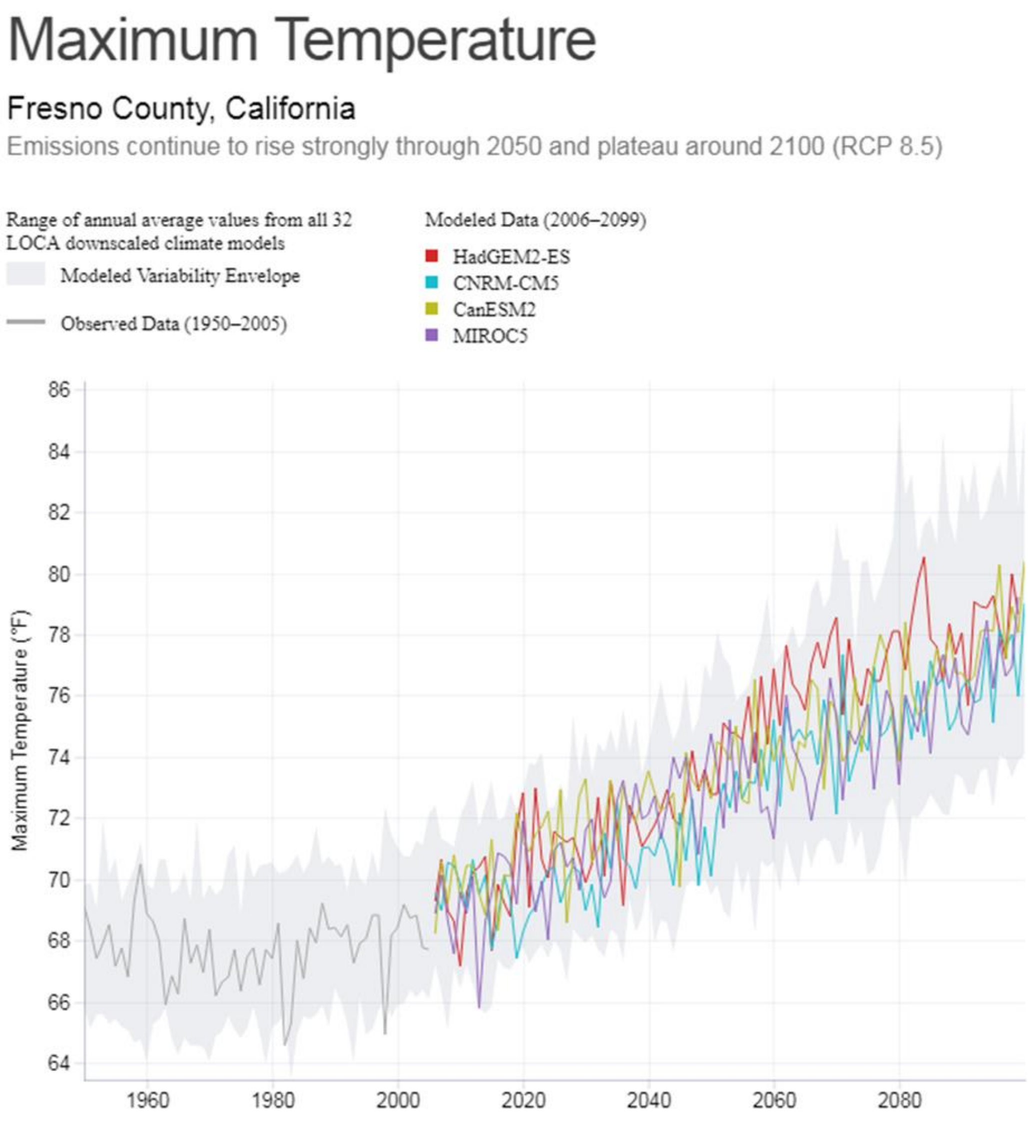
[8] Meinshausen, M.; et al. (November 2011), "The RCP greenhouse gas concentrations and their extensions from 1765 to 2300 (open access)", Climatic Change, 109 (1-2): 213–241.

[9] Caltrans (2017), "*Climate Change Vulnerability Assessments, District 4 Technical Report*".

The following figures show future projections for Fresno County. The Transportation System Analysis Findings section relates the information from the climate projections to the transportation system.

Figure 5. Fresno County Maximum Temperature is from Cal-Adapt and shows the projected average daily maximum temperature in Fresno County under the RCP 8.5 'status quo' emissions scenario for four of the ten GCMs used in this study. There is high agreement between the models that temperatures will rise considerably over the rest of the century.

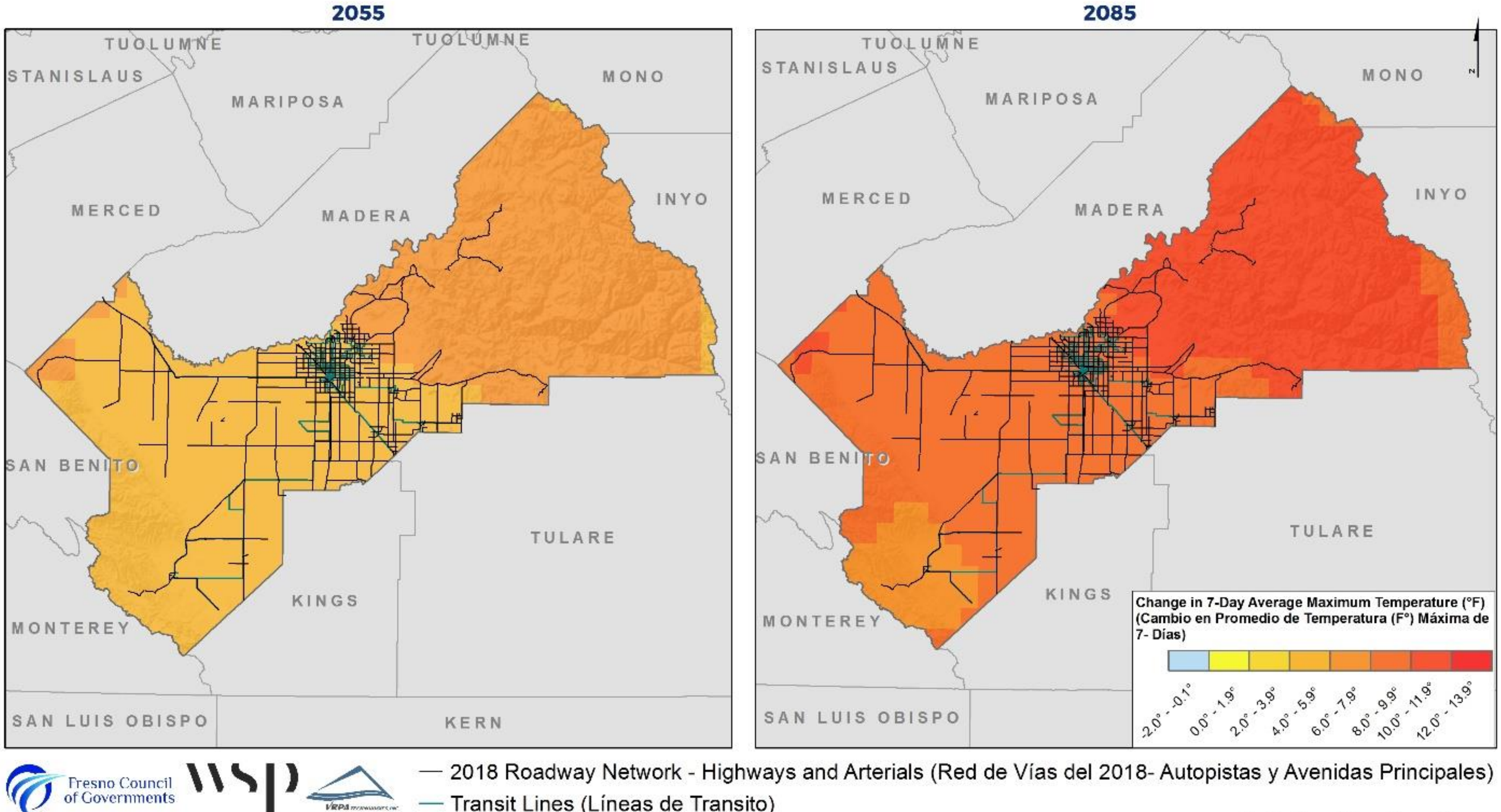
Figure 5. Fresno County Maximum Temperature Projections, RCP 8.5, Cal-Adapt



According to Cal-Adapt, the average daily maximum temperature for Fresno County is expected to increase from 67 °F to approximately 77 °F by end of century (RCP 8.5, model average, 1961-1990 baseline compared to 2070-2099). Also per Cal-Adapt, the average number of extreme heat days (>105.4°F, the 98th percentile daily maximum temperature) per year in the City of Fresno is expected to increase from 7 to approximately 66 by end of century (RCP 8.5, model average, 1961-1990 baseline compared to 2070-2099).

Figure 6. Fresno County Projected Change in 7-Day Average Maximum Temperatures spatially depicts the 7-day average maximum temperature for one of ten GCMs (CMCC-CMS) for two different future timeframes (2055 and 2085). The 7-day average maximum temperature is a parameter often used for pavement binder grades. The spatial pattern shows relatively consistent increases across Fresno County, with the northwestern portion of the county experiencing somewhat higher increases.

Figure 6. Fresno County Projected Change in 7-Day Average Maximum Temperatures, CMCC-CMS, RCP 8.5



Source: CMCC-CMS Global Climate Model, downscaled by the Scripps Institution of Oceanography using the Localized Constructed Analogs technique. RCP 8.5 emissions scenario.

There is much less agreement between the models regarding future precipitation patterns. Figure 7. from Cal-Adapt shows the projected annual precipitation for four of the ten GCMs under RCP 8.5. The model average shows an increase in annual precipitation, but the variability between models and between years within the models is high.

Figure 7. Fresno County Annual Precipitation Projections, RCP 8.5, Cal-Adapt

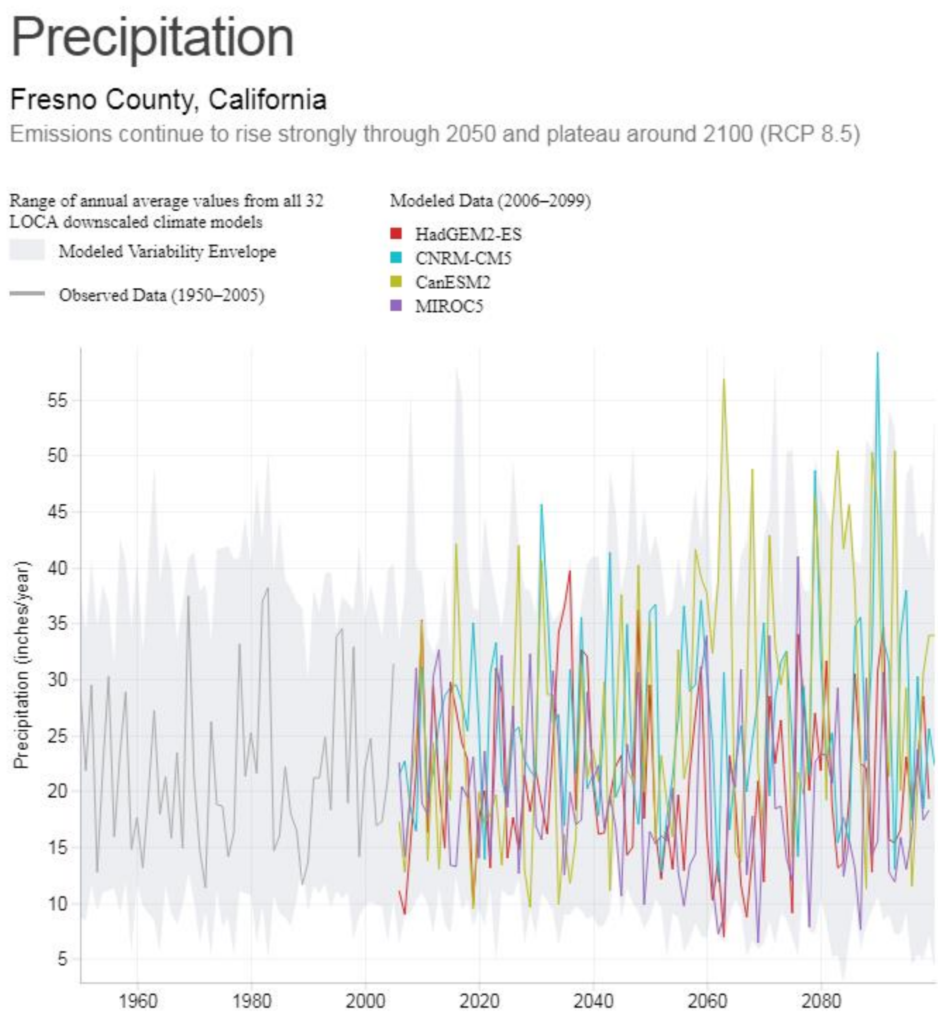


Figure 8. City of Fresno 100-Year/24-Hour Precipitation Event Projections, RCP 8.5, Cal-Adapt shows Cal-Adapt extreme precipitation projections for the City of Fresno under the same four GCMs. It shows the 100-year/24-hour[10] event for the historical timeframe and two future timeframes. The gray lines show the 95% confidence intervals for the projections. Most of the models show increases in the 100-year event, though the confidence intervals are very wide, indicating the uncertainty of future heavy precipitation conditions in the area.

[10] The 100-year event has a 1% chance of occurring in a given year. 24-hour is the duration of the period for which the precipitation event is measured.

Figure 8. City of Fresno 100-Year/24-Hour Precipitation Event Projections, RCP 8.5, Cal-Adapt

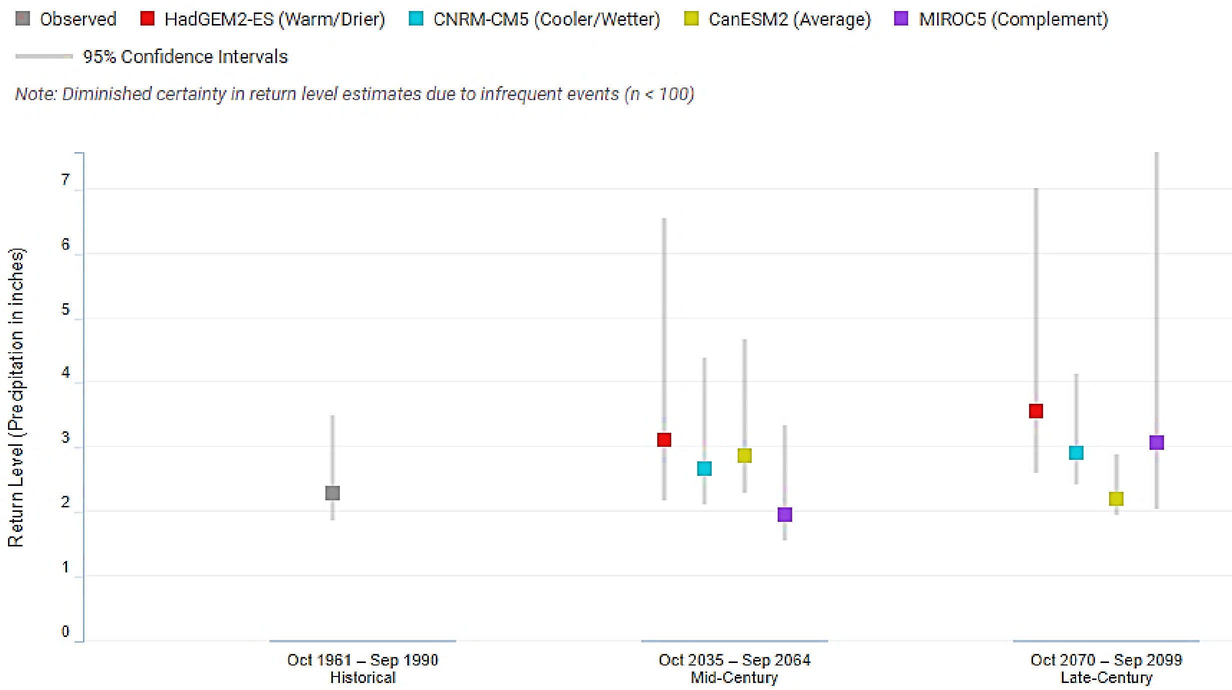
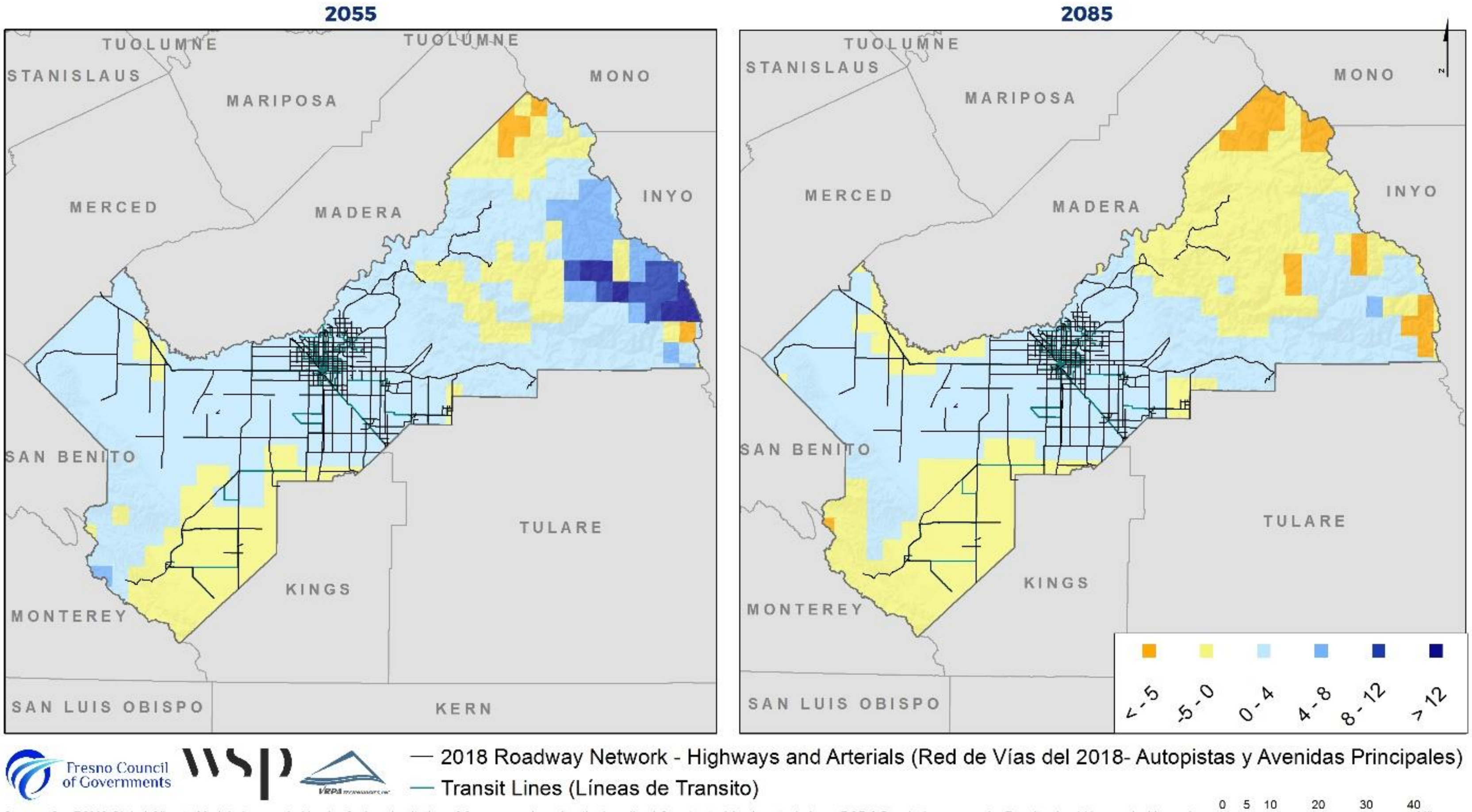


Figure 9. depicts spatially the projected change (in inches) of the 100-year precipitation event for one of the GCMs (CanESM2). For all climate projections, especially for precipitation, it is important to look at multiple models. For the model shown on this map, the largest increases and decreases in heavy precipitation occur in the Sierra Nevada, where precipitation levels are comparatively higher than the rest of the County.

Figure 9. Fresno County Projected Change in 100-Year Precipitation Event, CanESM2, RCP 8.5 (units: inches)



Source: CanESM2 Global Climate Model, downscaled by the Scripps Institution of Oceanography using the Localized Constructed Analogs technique. RCP 8.5 emissions scenario. Results should be used with caution.

Rising temperatures dry out soils and vegetation, which increases wildfire risk in Fresno County. Figure 10. Fresno County Area Burned Projections, RCP 8.5, Cal-Adapt from Cal-Adapt shows projections of area burned in the county from multiple climate models under RCP 8.5. Under that scenario, the historical average annual area burned is expected to increase from about 15,000 hectares historically to approximately 44,000 hectares at the end of century, with high variability between years within the models.

Figure 10. Fresno County Area Burned Projections, RCP 8.5, Cal-Adapt

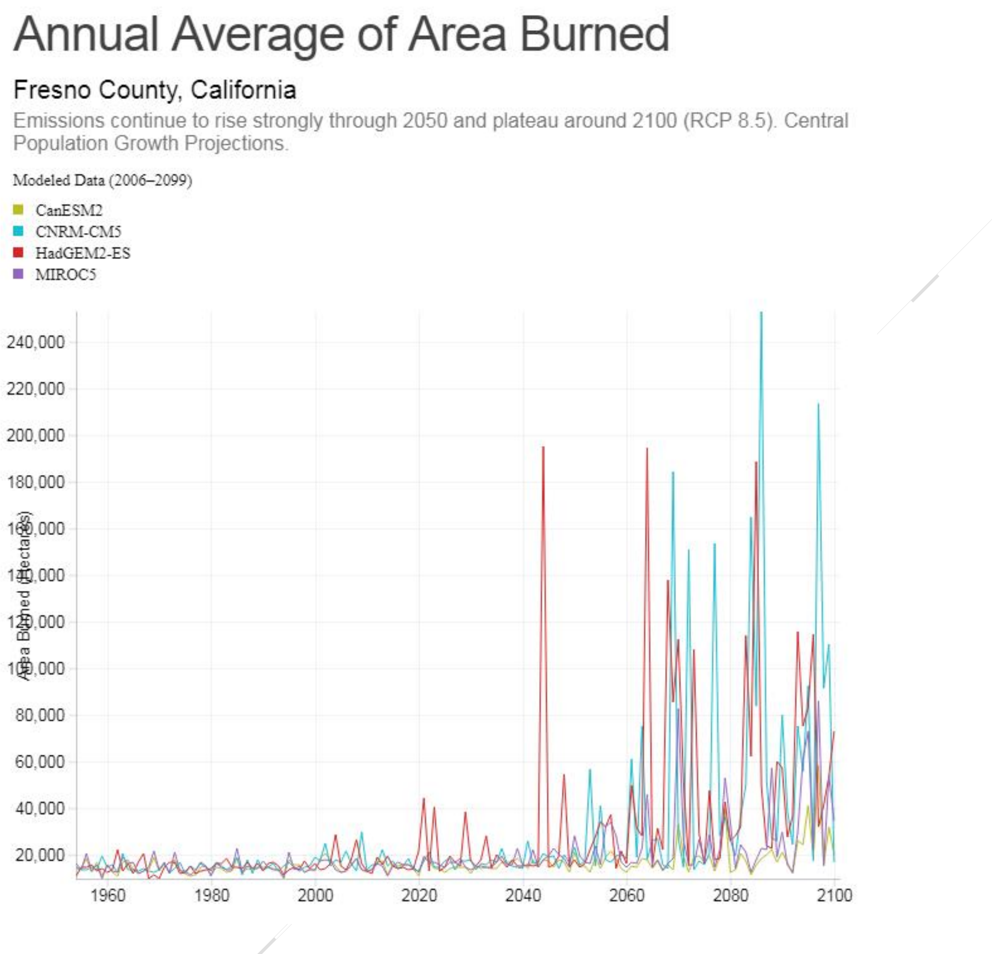
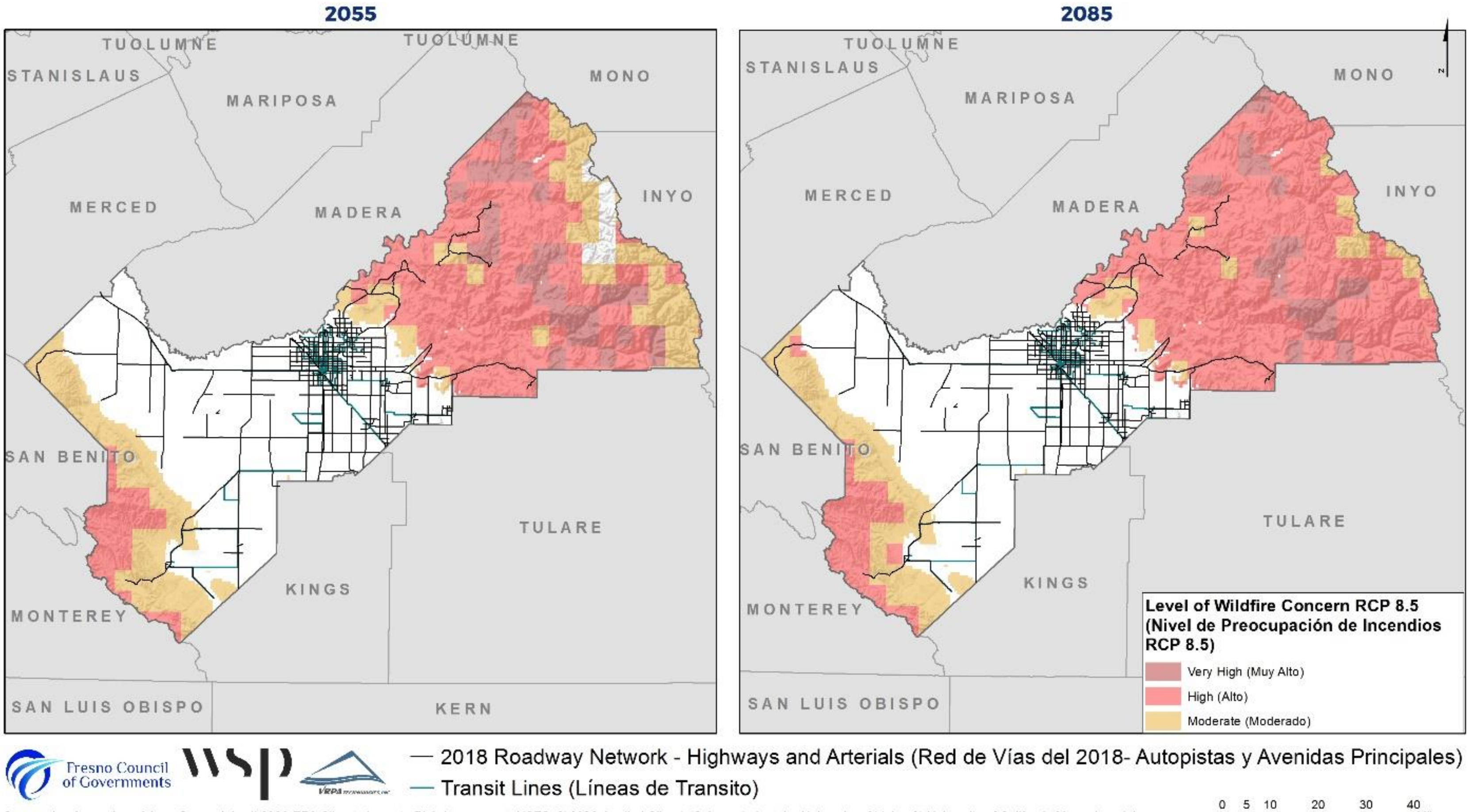


Figure 11. shows the relative level of wildfire concern for a composite of GCMs and wildfire models, with high or very high levels of concern in the Sierra Nevada and foothills and moderate or high levels of concern for the Coastal Range at the western edge of the county.[11]

[11] The fire model composite summaries shown are based on wildfire projections from three models: 1) MC2 – EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; 2) MC2 – Applied Climate Science Lab at the University of Idaho, developed by Dominique Bachelet, University of Idaho; and 3) University of California Merced model, developed by Leroy Westerling, UC Merced. For each of these wildfire models, climate inputs were used from three Global Climate Models: 1) CAN ESM2, 2) Had_GEM2-ES, and 3) MIROC5. Data shows the multi-model maxima for each grid cell across the nine combinations of the three fire models and three GCMs. A classification was developed based on the expected percentage of cell burned. The classification is: 1) Very Low 0-5%, 2) Low 5-15%, 3) Moderate 15-50%, 4) High 50-100%, 5) Very High 100%+. Time periods are averages of 30-

Figure 11. Fresno County Levels of Wildfire Concern, Multi-Model Ensemble, RCP 8.5



Source: Amalgamation of three fire models: 1) MC2-EPA Climate Impacts Risk Assessment, USFS, 2) MC2-Applied Climate Science Lab at the University of Idaho, 3) University of California Merced model.

In addition to the projections analyzed for this study, which focus primarily on Fresno County's transportation system, there are other helpful resources for understanding the broader impacts of climate change on Fresno County, such as drought, groundwater depletion, and subsidence. These sources include:

- **California's Fourth Climate Change Assessment: Climate Change Risk Faced by the California Central Valley Water Resource System.** This paper reviews climate change risks to the integrated California Central Valley System (CCVS) and discusses specific vulnerabilities to this key water system.[12]
- **Central Valley Hydrologic Model.** The US Geological Survey (USGS) developed the Central Valley Hydrologic Model (CVHM) to understand how water use, precipitation, and land use changes will affect surface and groundwater flows in the Central Valley. The model's simulations based on a warmer, drier California show that stream flows may decline by up to 40%, which will increase groundwater demand across the region. The effects of increased groundwater draw-down include increased streamflow infiltration, reduced outflow to the Delta, and increased subsidence rates.[13]
- **Central Valley Flood Protection Plan.** This plan seeks to improve flood risk management in the Central Valley and develop strategies for reducing risk that provide multiple benefits, including transportation system protection. The most recent update was released in 2017 and includes climate change considerations such as more frequent extreme precipitation, changes in flood magnitudes and frequencies, sea level rise, and increased subsidence.[14]
- **California's Fourth Climate Change Assessment: Management of Groundwater and Drought Under Climate Change.** Climate change is projected to alter the natural recharge of groundwater. Decreased inflow from runoff, increased evaporative losses, and warmer and shorter winter seasons are expected to exacerbate existing groundwater overdraft in many basins. The surface water that can be delivered from the Central Valley Project (CVP) and State Water Project (SWP) to areas reliant on this water for groundwater recharge and consumptive use is projected to be less reliable and more expensive.[15]
- **California's Fourth Climate Change Assessment: Assessment of California Crop and Livestock Potential Adaptation to Climate Change.** This report discusses climate change challenges facing California agriculture and how it is likely to adapt to those challenges, focusing on Central Valley crops, the dairy industry, and the beef cattle grazing industry.[16]
- **California's Fourth Climate Change Assessment: Drought Impacts and Drought Vulnerability in Rural Communities of California's San Joaquin Valley.** This report examines the drought vulnerability of farmworkers both in the fields and in their communities by analyzing how changes in water resources and agricultural practices impact socioeconomic drought.[17]
- **California Department of Conservation, Summary and Compilation of Landslide Information for California.** This resource provides background on the history of landslide mapping, the types of landslides that occur in California, and landslide susceptibility mapping. The page also compiles a

12 http://www.climateassessment.ca.gov/techreports/docs/20180827-Water_CCCA4-EXT-2018-001.pdf
13 https://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
14 http://cvfpb.ca.gov/docs/2017CVFPPUpdateFinal/2017CVFPPUpdate-Final-20170828.pdf
15 http://www.climateassessment.ca.gov/techreports/docs/20180827-Water_CCCA4-EXT-2018-006.pdf
16 http://www.climateassessment.ca.gov/techreports/docs/20180827-Agriculture_CCCA4-CNRA-2018-018.pdf
17 http://www.climateassessment.ca.gov/techreports/docs/20180928-PublicHealth_External_Greene.pdf

list of other relevant sources, such as the California Landslide Inventory, a summary of California's Susceptibility to Deep-Seated Landslides, and the USGS National Landslides Hazards Program.[18]

- **California Institute of Technology Jet Propulsion Laboratory, Subsidence in California, March 2015 - September 2016.** This study developed maps of subsidence in the San Joaquin Valley. The two main subsidence bowls in the Central Valley are settling north and south of Fresno. The western portion of the county is subsiding.[19]
- **Joint Center for Political and Economic Studies, Place Matters for Health in the San Joaquin Valley.** This study examines the relationships between place, race and ethnicity, and health in the San Joaquin Valley of California. Some key findings of the study are[20]:
  - The rate of premature deaths in the lowest-income zip codes of the San Joaquin Valley is nearly twice that of those in the highest-income zip codes.
  - Life expectancy varies by as much as 21 years in the San Joaquin Valley depending on zip code.
  - One in six children in the San Joaquin Valley is diagnosed with asthma before the age of 18, an epidemic level.
  - In the San Joaquin Valley, the communities with the highest levels of premature mortality are in San Joaquin County, central Stanislaus, western and central Fresno, north central Tulare, as well as central and eastern portions of Kern County.

[18] https://www.conservation.ca.gov/cgs/geohazards/landslides
[19] https://water.ca.gov/LegacyFiles/waterconditions/docs/2017/JPL%20subsidence%20report%20final%20for%20public%20dec%202016.pdf
[20] http://www.fresnostate.edu/chhs/cvhpi/documents/cvhpi-jointcenter-sanjoaquin.pdf

Engagement and Collaboration Findings

The vulnerability assessment included several community engagement and stakeholder collaboration activities. To engage with the community, the project team conducted several pop-up events, an in-person and online survey, and a 'hot spot' exercise where community members identified locations that have experienced past weather-related issues. To collaborate with stakeholders, the project team established and held meetings with a Vulnerability Assessment Working Group (VAWG) and interviewed key transportation stakeholders about vulnerabilities in the system.

The separate Public Outreach Synopsis summarizes the community engagement activities and findings from this project in detail. The following two subsections highlight key findings from the engagement and collaboration.

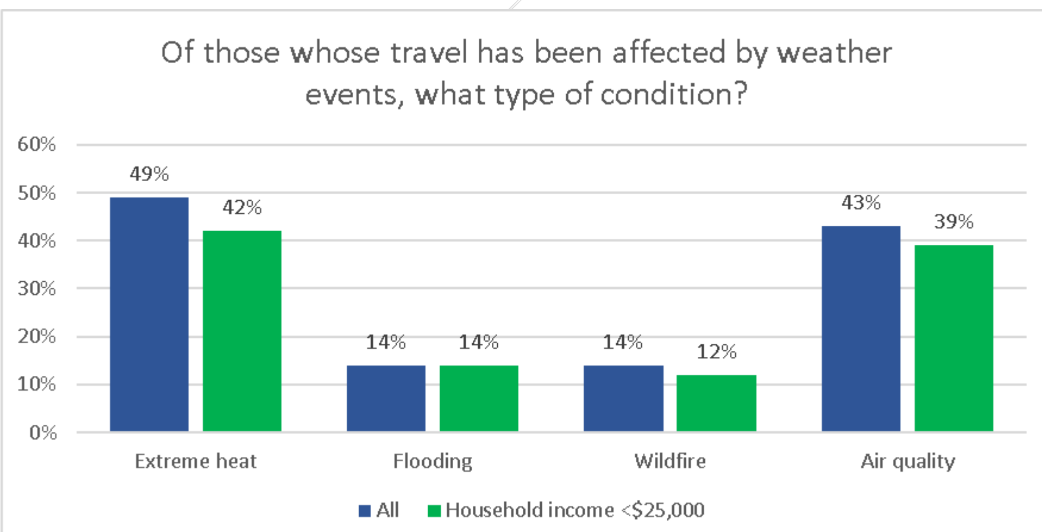
Public Outreach

Between the in-person and online surveys, we gathered 243 responses from the public. 68 of these were from individuals who reported household income of less than $25,000.[21]

Of all survey respondents, 43% reported that weather events or conditions have either affected their travel or required them to evacuate. A higher share, 57%, of those with household incomes under $25,000 reported that weather events or conditions have either affected their travel or required them to evacuate.

Of those whose travel has been affected, extreme heat and air quality were the two most frequently reported hazards. Figure 12. shows the breakdown by event type for both all respondents and for respondents with household incomes below $25,000.

Figure 12. Public Survey Result: Type of Event Affecting Travel



[21] This is slightly below the U.S. Census Bureau's 2018 poverty threshold of $25,465 for a family of four with two children (https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html).

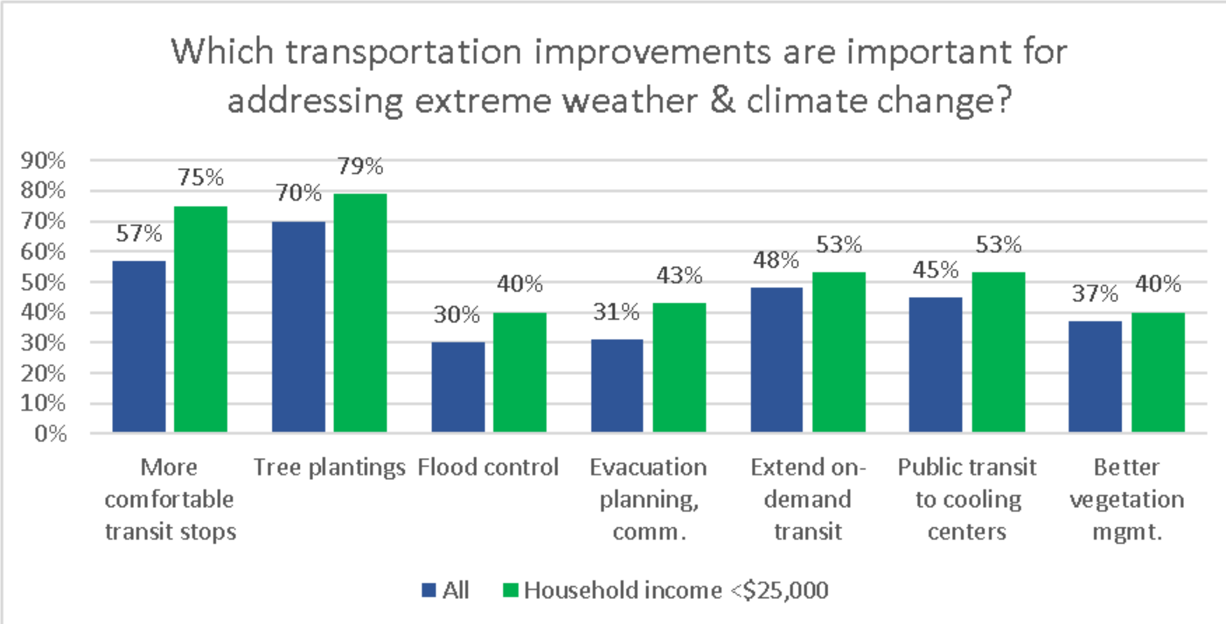
Participants were asked to rank their level of concern about seven types of potential climate change impacts (see Table 1. Public Survey Result: Average Ranking for Level of Concern). One was the highest level of concern, and seven was the lowest level of concern. For all respondents, the highest average ranking was for extreme heat (2.4), followed closely by drought (2.6), and air quality (2.8). The top three average rankings were the same for individuals with household incomes less than $25,000 compared to the overall population (extreme heat followed by drought and air quality). For both groups, wildfire had the fourth highest average ranking, followed by flooding, subsidence, and landslides/erosion. The lower average levels of concern for discrete events like wildfires, flooding, and landslides, are unsurprising because they are experienced in limited portions of the county. Extreme heat, drought, and air quality typically occur more frequently, in a wider geographic portion of the county, and in the most populous portions of the county.

Table 1. Public Survey Result: Average Ranking for Level of Concern

Climate Change Impact	All	Household income <$25,000
Extreme Heat	2.4	2.2
Drought	2.6	2.8
Air Quality	2.8	3.0
Wildfires	4.1	4.1
Flooding	4.6	4.5
Subsidence	5.2	5.4
Landslides/Erosion	5.7	5.7

Participants responded to a question about which transportation improvements are important for addressing extreme weather and climate change. They could select more than one option. Both the all respondent and low-income respondent groups listed “tree plantings along roadways and sidewalks” the most frequently (70% and 79%, respectively). Results were generally consistent across the two groups. However, a substantially higher percentage of low-income answered highlighted “comfortable and shaded transit stops” (75% versus 57%). Other popular options included “expanded service and availability of on-demand transportation (such as vanpool, paratransit, etc.), during high heat or other extreme weather events” and “public transit service to cooling centers on high heat days.”

Figure 13. Public Survey Result: Transportation Improvements to Address Climate Change



The next several pages show maps of some of the information obtained during the public engagement process. Figure 14. Fresno County Pop Up and Survey Results – Number of Responses by Zip Code maps the number of survey respondents by zip code. Pop-up events were held and well attended in Reedley and Kerman, so the respondent numbers from those zip codes are particularly high. Figure 15. Fresno County Pop Up and Survey Results – Percent of Responses that Reported an Income of Less than $15k shows the percentage of respondents within each zip code who reported household incomes of less than $15,000. Figure 16. Fresno County Pop Up and Survey Results – Percent of Responses that Reported a Travel Impact due to Weather shows the percentage of respondents within each zip code who reported a travel impact due to a weather condition or event. Figure 17. Fresno County Pop Up and Survey Results – Percent of Responses Indicating that Public Transit to Cooling Centers is an Important Response to Extreme Weather and Climate Change shows the percentage of respondents within each zip code who indicated that public transit to cooling centers is an important adaptation response to extreme weather and climate change.

Figure 14. Fresno County Pop Up and Survey Results – Number of Responses by Zip Code

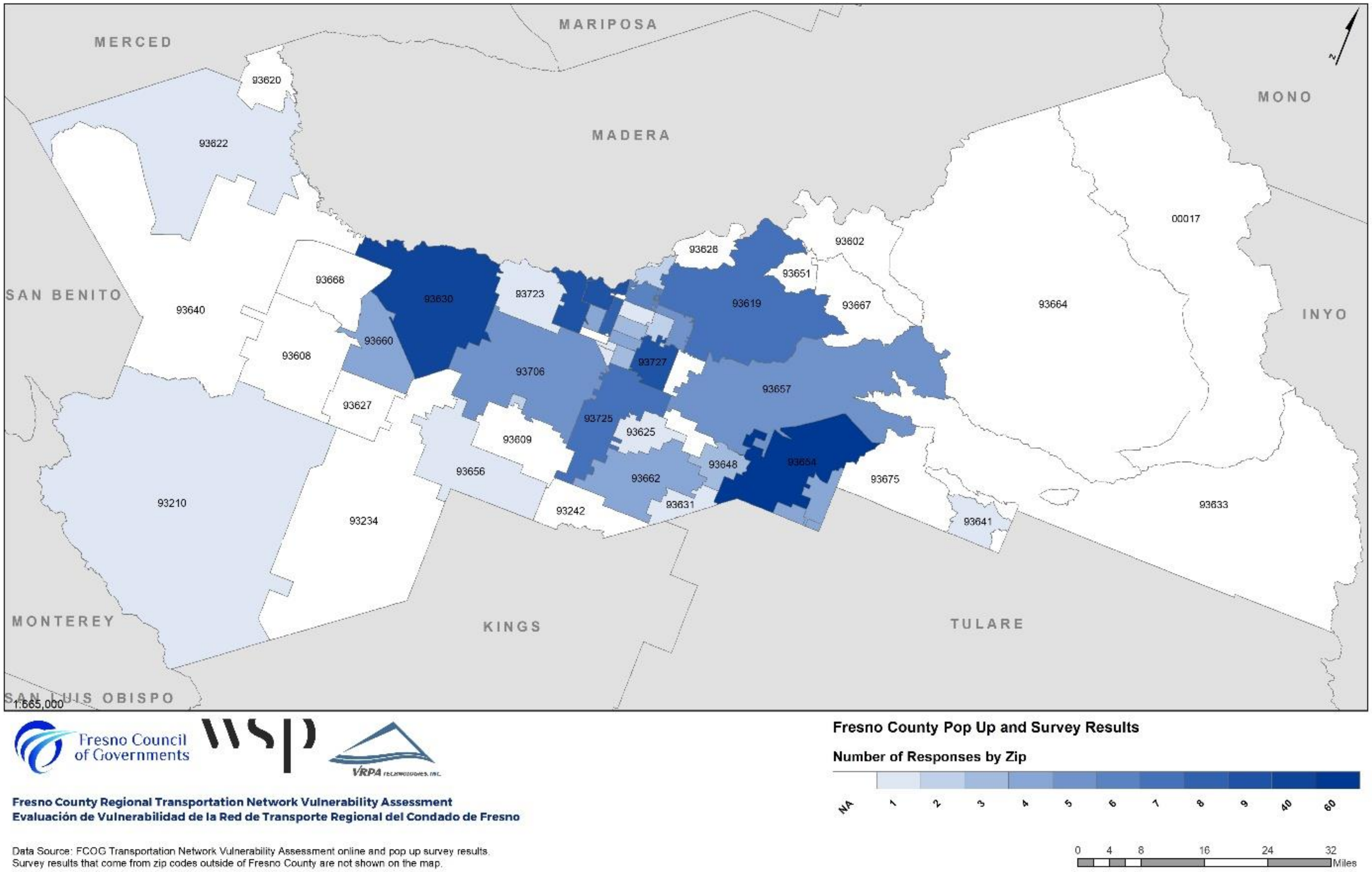


Figure 15. Fresno County Pop Up and Survey Results – Percent of Responses that Reported an Income of Less than $15k

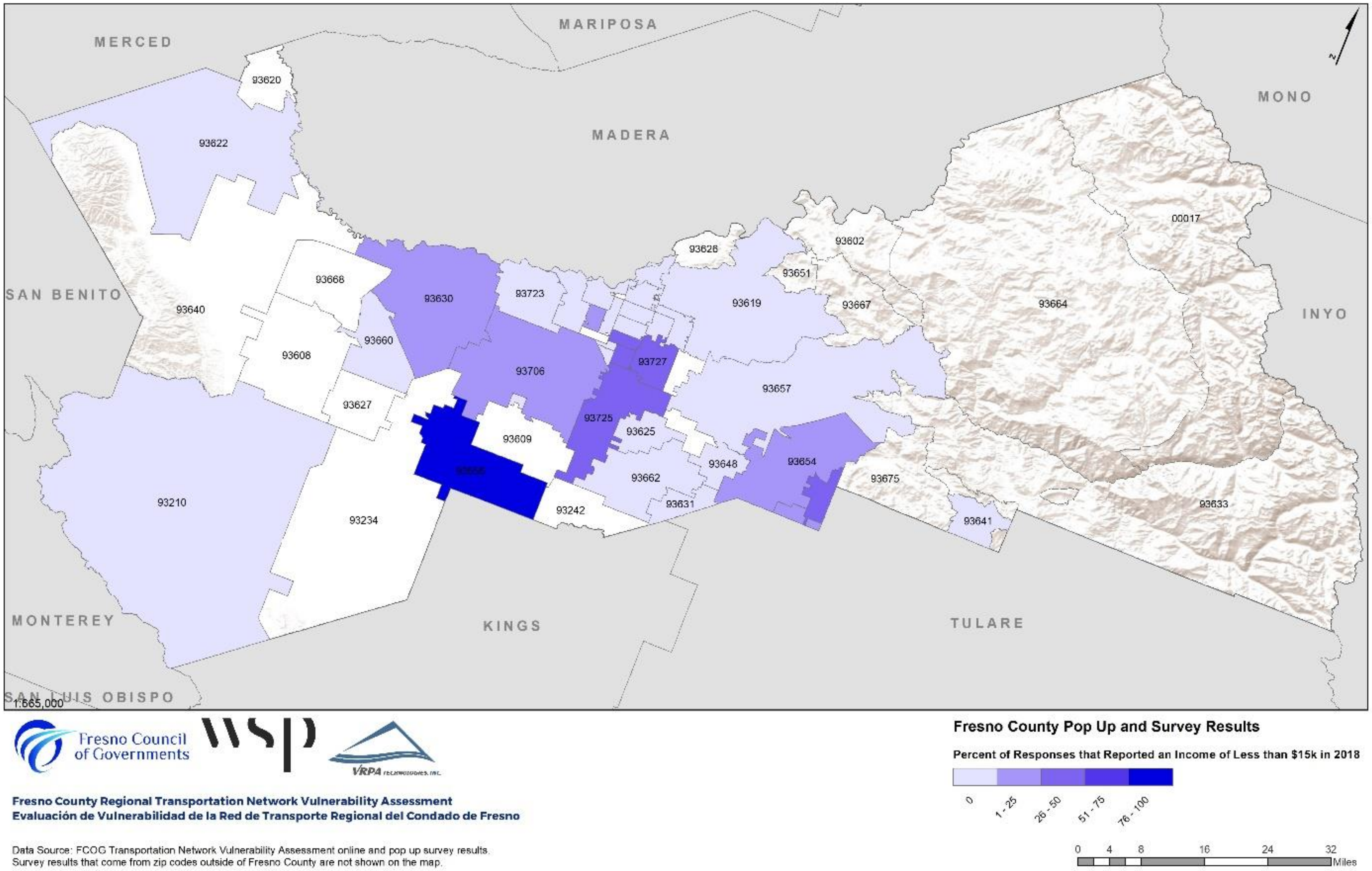


Figure 16. Fresno County Pop Up and Survey Results – Percent of Responses that Reported a Travel Impact due to Weather

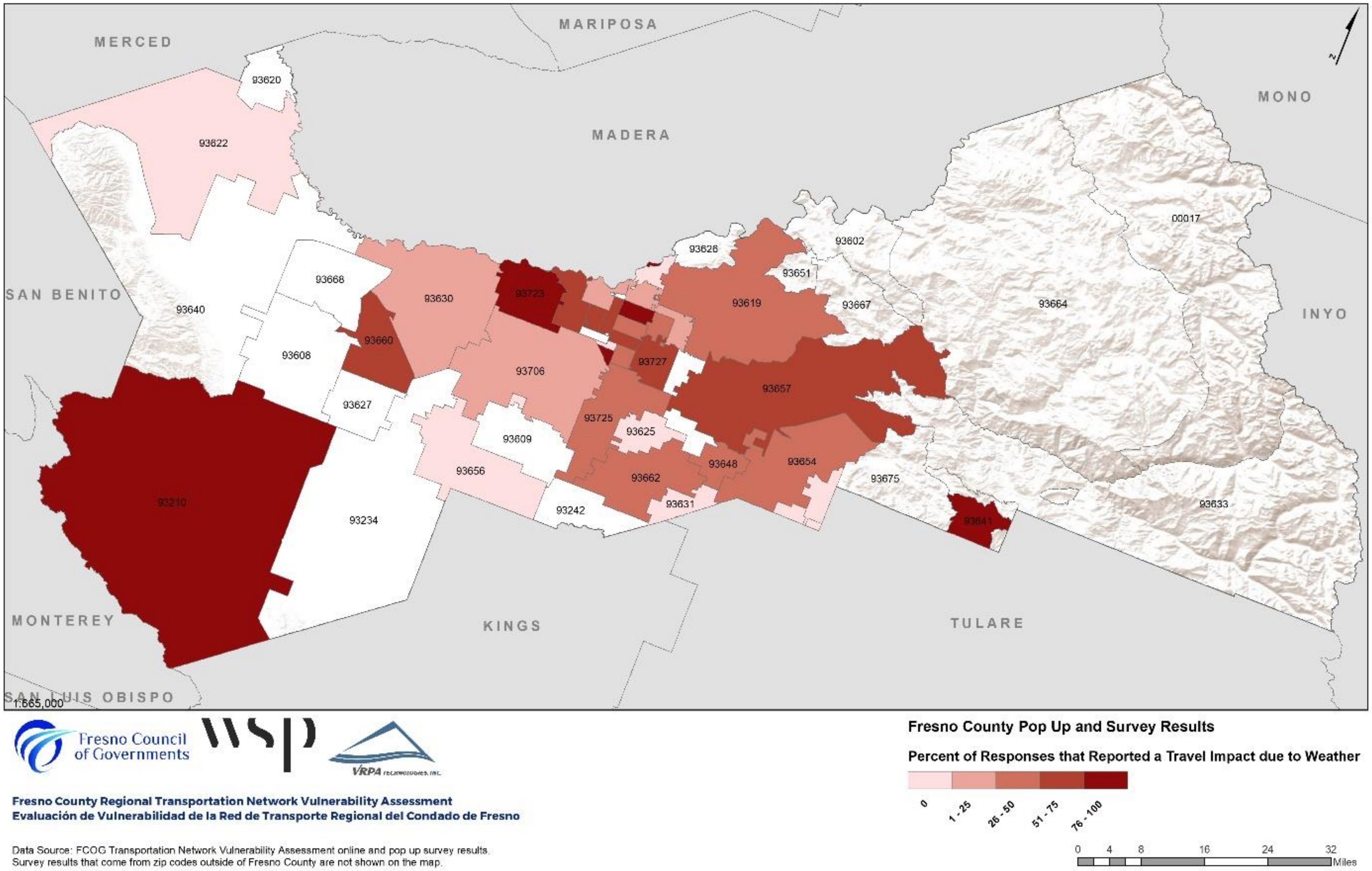
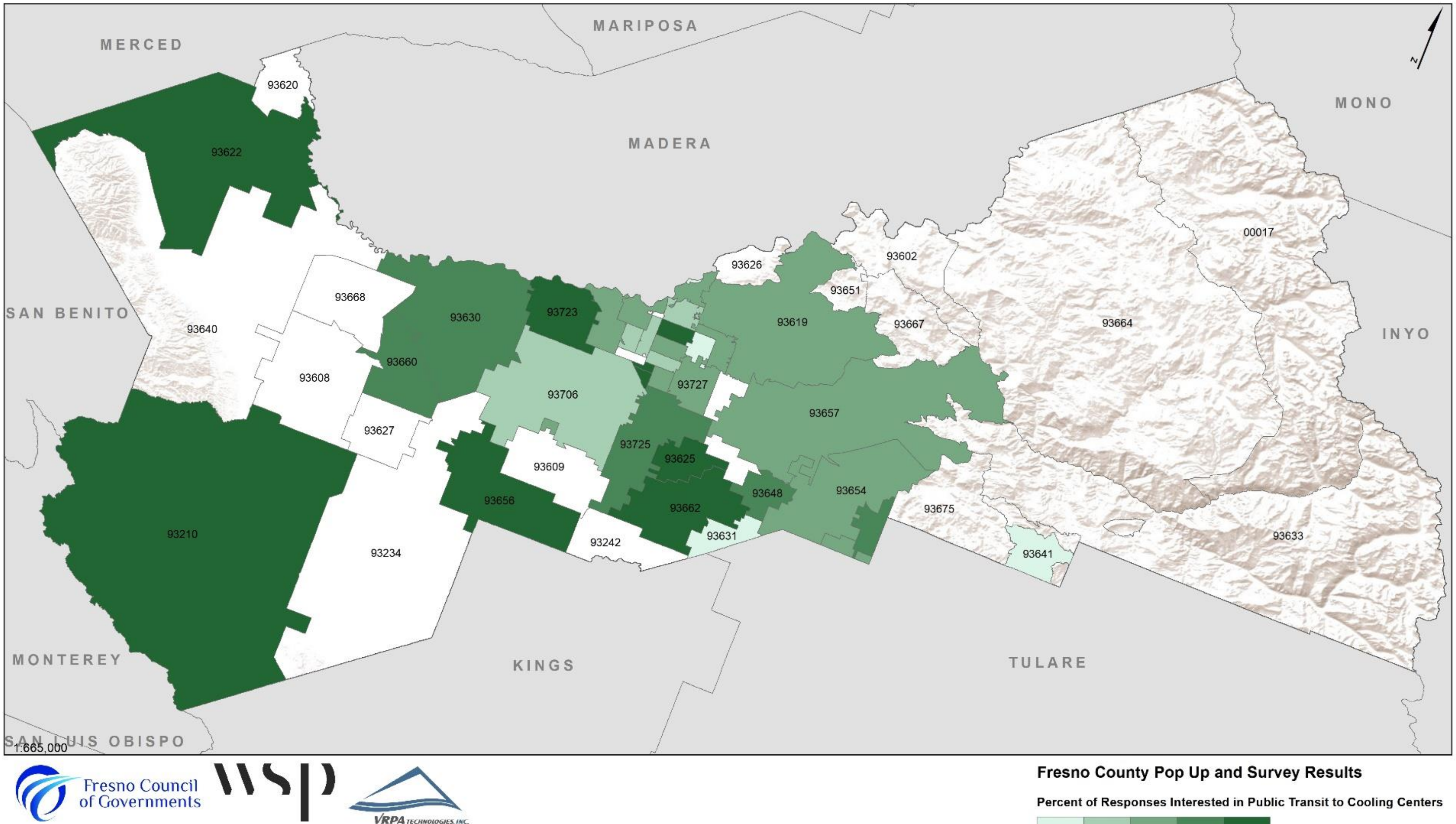


Figure 17. Fresno County Pop Up and Survey Results – Percent of Responses Indicating that Public Transit to Cooling Centers is an Important Response to Extreme Weather and Climate Change



Fresno County Regional Transportation Network Vulnerability Assessment
Evaluación de Vulnerabilidad de la Red de Transporte Regional del Condado de Fresno

Data Source: FCOG Transportation Network Vulnerability Assessment online and pop up survey results.
Survey results that come from zip codes outside of Fresno County are not shown on the map.

Vulnerability Assessment Working Group and Stakeholder Feedback

This section covers important input from the VAWG meetings and transportation stakeholder interviews. This input includes:

- General Information and Vulnerabilities
  - The County Multi-Hazard Mitigation considers what hazards will be most likely to affect the area and how to mitigate those risks.
  - Extreme heat and precipitation will have an impact on the roadways, such as potholes and other roadway degradations. This can ultimately lead to an increase in road maintenance costs. There are potential impacts to signage for transit and other modes as well.
  - Extreme heat can deter active transportation.
  - Rural roads surrounding schools often flood and make it hard to get to campus. Roads often designed to flood along edges.
  - There are potential impacts for maintenance and construction crews working outdoors. Work windows can also be affected by high heat and heavy rain. Also, for agricultural work, many outdoor workers cannot skip a day of work, because if they do not go to work then they cannot get paid.
  - Lots of people in the county do not have or cannot afford air conditioning.
  - Smaller cities often have the same problems as larger cities, but have less funding and fewer staff to address them.
  - The southern part of the county has less shade compared to the northern portion.
  - There is not a central dataset that tracks weather-related damage in the county.
  - Depending upon where an event occurs, the jurisdiction would be the first responders (e.g. City of Fresno). Depending upon how large the event is, and if an evacuation is needed, Fresno OES would be notified and law enforcement would facilitate evacuation. They would do so with partner agencies, such as the American Red Cross, County agencies and schools, to set up shelters and monitor impacts. Fresno County OES would then coordinate with local jurisdictions to provide updates to the state. For situations when there might be a detour, law enforcement is the primary responder. There are wildfire trainings for these types of events. The Sheriff's Office alerts citizens and gives them any specific instructions on road closures. They may use California Highway Patrol, Caltrans, or Fresno County Public Works to close roads. There is also coordination with fire responders or other first responders. There are so many variables that affect an event that instructions are given when the event happens, rather than having detailed evacuation plans laid ahead of time. Schools are often helpful as evacuation destinations.
  - On the roadway network, the low redundancy areas (i.e. limited alternative routes) are the highest concern.
  - Wildfire and flooding event seem to cause the most major and discrete impacts. These events cause roads to get cut off. Good routes enable resources to get in and people to get out. Some small communities built into mountain areas have single roads in, not necessarily a secondary route.
  - Air pollution is getting worse as the climate changes; ozone increases as temperatures rise; smoke from wildfires ends up back to the valley either from the Sierra's, Northern and Southern California; and longer wildfire seasons will cause increase in air pollution. Wildfires are increasing heat and letting off Nitrogen Oxide (NOx). There are attainment plans for air quality but do not consider climate change.

  - Often lower income people work outside and are exposed to air quality issues. Even at home many of these populations are still dealing with these air quality issues.
  - Being able to move around during poor air quality events is important. Active transit is not a viable option during poor air quality events.
  - The county typically will not put in sidewalks in a community that does not have a stormwater drainage plan, but there is limited funding to develop stormwater drainage plans.
  - Socially vulnerable populations are often in small, unincorporated communities with a limited number of English proficient individuals and non-traditional housing. They are hard to reach and often undercounted in the Census, and as a result are often underserved.
  - Flood zone mapping has lots of planning implications, but is based on historical data.
  - Unfunded mandates can create administrative burden for agencies and hinder the climate response.
  - More funding is needed across the board.
- Transit Impacts and Considerations
  - Bus riders are often affected the most by extreme heat and other weather events. There are many low-income, transit dependent riders in the County.
  - FAX is transitioning ahead toward a 100% electric vehicle fleet and is thinking about electricity demands in hotter weather, about resiliency of the grid, and how extreme temperatures affect battery storage
  - FAX and FCRTA both give free rides to cooling centers along their routes on days where temperature exceeds 105°F. The rider needs to know where the cooling center is. There are public service announcements on some of the local television channels for the cooling centers. Cooling centers, such as the mall, are often used for other purposes too. Fresno and Clovis have been the most active in terms of opening cooling centers. The Fresno-Madera Area Agency on Aging (FMAAA) targets the elderly and helps publicize cooling center opportunities.
  - There is some flooding in the rural parts of the county. Sometimes buses need to reroute because of this flooding.
  - Some bus stops in rural areas do not have sidewalks and therefore do not have covered areas.
  - Smaller communities often struggle to maintain sufficient ridership numbers to keep fixed-route services afloat. Therefore, extreme weather that decreases ridership has a potential impact on the long-term sustainability of transit options.
  - Flooding in many communities outside of Fresno metro area can prevent access to transit stops.
- Specific Locations: Flooding
  - Kings River and San Joaquin River are the two major rivers and can cause flooding. These two rivers come together near Mendota. The flows are not necessarily that high, but the confluence can cause flooding.
  - Some mobile home parks in river floodplains have experienced flooding in the past, including Wildwood Mobile Home Park and Woodward Bluffs Mobile Home Park in northern Fresno along the San Joaquin River, and River Bend RV Park in Sanger.
  - Tranquility, Mill Creek, and Hughes Creek flood frequently.
  - Sometimes there are issues in Kerman. Near the 145, there have been issues at the river crossing before. They are no levees in that area.

- Along the Kings River, there can be impacts near Centerville, Reedley and Laton, and as it moves through the west side there can be impacts to Tranquility. If there is a high enough flow it can overtop the banks and create flooding in Mendota/Firebaugh.
- One of the roads that runs into Huron has flooded repeatedly. At times the road has been shut down for months. There are some areas where water can come out of the aqueduct near the Dorris and Lassen intersection.
- In 2017, the rain and snow cut away at a lot of the mountain roads near Dinky Creek and Huntington Lake.
- City of Fresno has relatively good drainage with water basins throughout the city to recharge aquifer and help limit flooding.
- Dam failure at Pine Flat Lake would have catastrophic impacts.

- Specific Locations: Wildfire and Other Hazards
  - Sierra wildfires affect SR-180 and SR-168 (especially near Shaver Lake and Big Creek).
  - Many fires in the County are higher up in the mountains and do not affect people.
  - The Big Creek roadway is an important response and evacuation route during wildfires. It has experienced slides, rockfall, and weather-related impacts before.
  - There are some fires near Coalinga but these are often grass fires that pose less danger.
  - Subsidence has been a major issue on the west side of the county and affects levees.
  - When the drought occurred and the bark beetle took over, many trees were killed in the Sierra. Many of these have been removed to mitigate risk. The work that is needed to remove these trees (impact from trucks) is damaging roadways. There are also erosion/landslide impacts because the trees have been removed.
  - Many areas, such as Humphrey Station, Cold Springs Rancheria, Big Sandy Rancheria, Pine Ridge, have limited routes in and out.
- Adaptation Options[22]
  - Addressing vulnerabilities will cost money, so it is helpful to prioritize where to spend.
  - More shade or other cooling is needed at transit stops.
  - Cool pavements have been considered for parking lots, but not as much for roadways.
  - The County is building more pump stations to pump floodwater into canal system.
  - Advice on pavement - permeable, cool, pavement mixes - would be helpful.
  - Tree planting was mentioned several times.
  - There may be an opportunity to increase the messaging about transit to cooling centers. Also, providing demand responsive transit to these centers is another potential adaptation option.
  - An evacuation plan for a specific area that has been coordinated between all communities and agencies can be very helpful. Trainings and educational outreach helps people learn about their options and prevents panic.
  - Care should be taken when determining where and how development is built. One suggestion was requiring new developments in the mountains to provide multiple routes in/out.
  - Infrastructure should be designed with future climate projections as an input.
  - Some communities would like to have a secondary route but face funding challenges. Many roads are owned and maintained by property owners which can complicate evacuation planning. For some areas, having a shelter in place might be a critical option when evacuation is not feasible.

[22] Adaptation options will be addressed in the project's next task.

- Vulnerable people in rural communities often do not have access to cars. Bus services or other assistance during evacuation events could be beneficial.
- Public notification during poor air quality events is crucial. Working with the Air District, who does have a notification system, but this system is not tailored to the San Joaquin Valley. Last year was the first year this notification was translated into Spanish, but notifications were opt-in.
- There is a need for more education about the impacts of climate change.
- Electric Vehicle (EV) rideshares like those in Cantua Creek and Huron are good examples of options on the climate change mitigation side.
- More rural access to transit would make Fresno County more resilient.

Figure 18. Fresno County Survey and Interview Problem Spots shows past problem spots by hazard type that were identified in both the stakeholder interviews and the public survey. As noted in the previous section, the best-attended pop-up events occurred in Reedley and Kerman, which likely contributed to the disproportionate clusters of problem spots identified in those areas. Figure 19. Fresno County Survey, Interview, and Historical Event Problem Spots combines the problem spots from the survey and interviews with the historical events newspaper review described in the Historical Context subsection.

Figure 18. Fresno County Survey and Interview Problem Spots

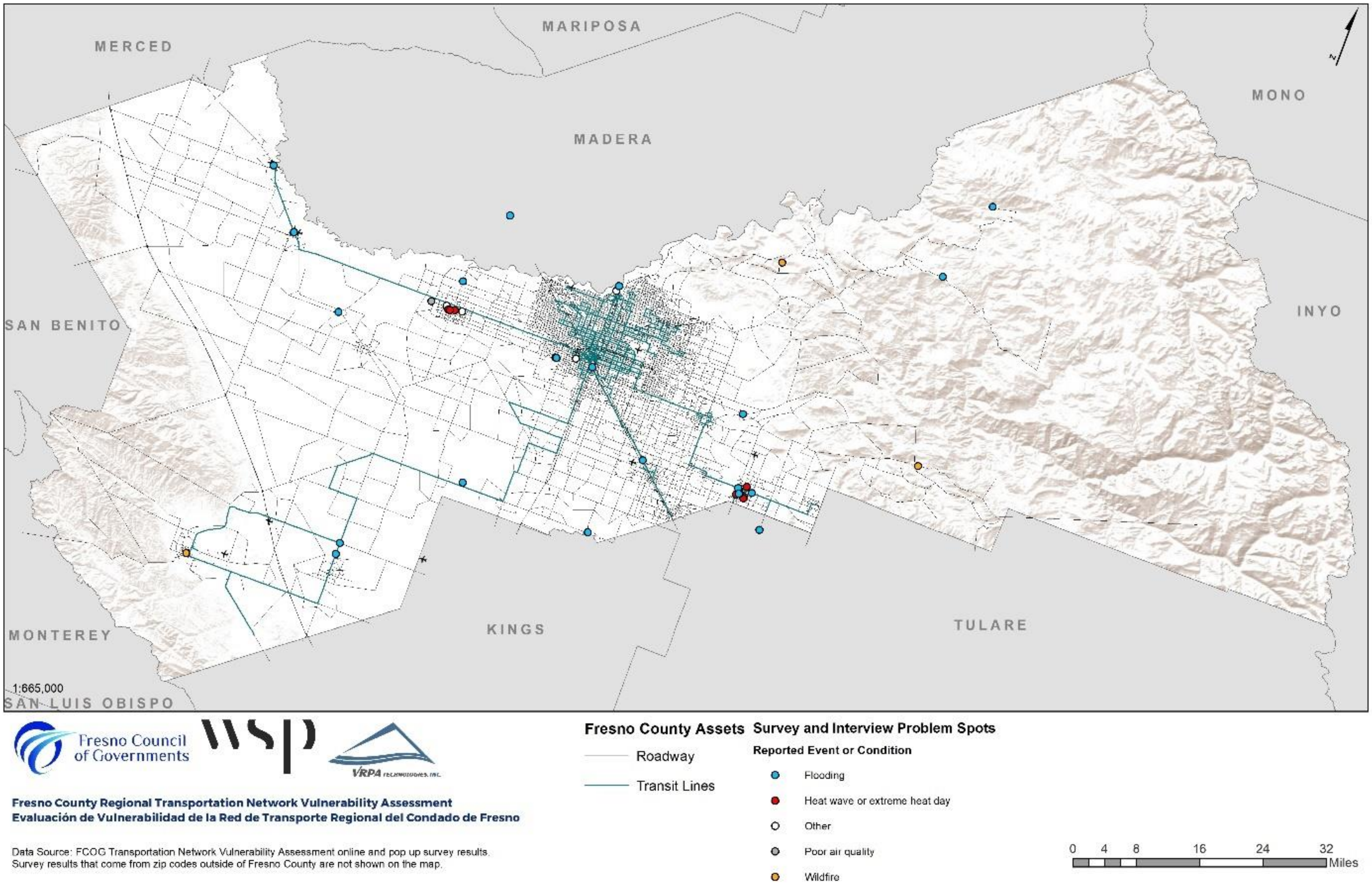
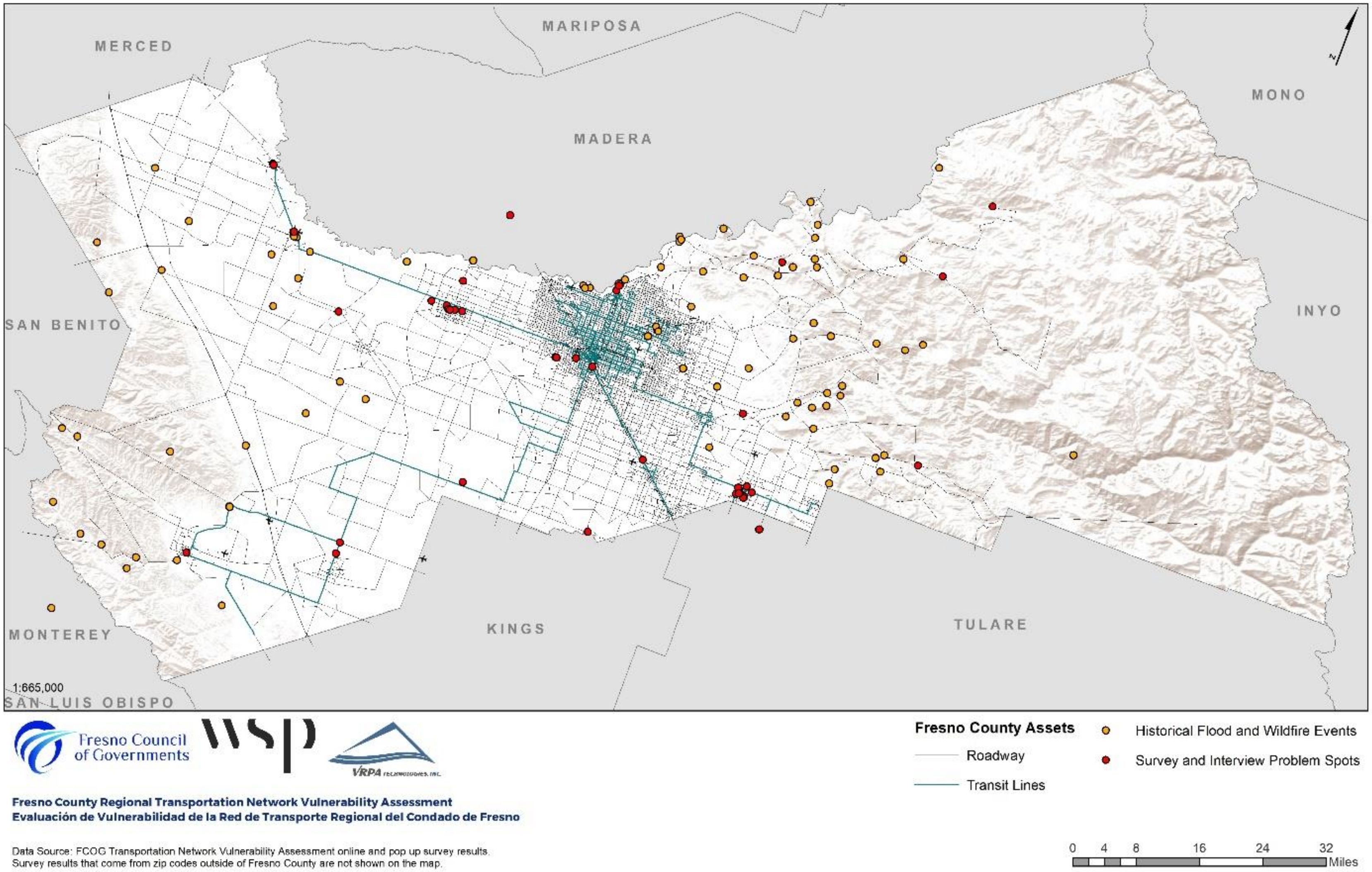


Figure 19. Fresno County Survey, Interview, and Historical Event Problem Spots



Transportation System Analysis Findings

Much of the transportation system, including its infrastructure and users, are expected to be affected by changing climate conditions in the Fresno COG region. The primary transportation and climate-related hazards include flooding, wildfire, extreme temperatures, and precipitation-induced landslides. Higher maximum temperatures can pose health threats for transit passengers and damage pavement and bridges. More frequent wildfires can disrupt the transportation system and hinder or cut off evacuation routes. Heavy rain events and runoff can lead to flooding, washouts, and erosion. Broader effects on the hydrologic and agricultural systems could affect regional travel patterns.

Scoring

Methodology

This section describes the approach for understanding climate-related risks to the transportation network in the Fresno COG region and prioritizing the most vulnerable and critical assets for future action. Specifically, the prioritization approach is intended to identify the relative vulnerability of different transportation assets to climate-related hazards using available information. Higher priority assets can be assessed in further detail to determine how they can be adapted to climate change. The approach incorporates information on hazard likelihood, as well as the asset's criticality and condition. The approach addresses the most important climate-related hazards in the region but could not address the full range of all potential hazards. This does not mean that the risks associated with hazards excluded from the analysis are negligible. This approach is similar to the ones being used for the systemwide climate change vulnerability assessments for the Caltrans Climate Action Report project and for the Sacramento Area Council of Governments (SACOG) Vulnerability and Criticality Assessment project.

Agencies can use a few different methods to prioritize projects. There are at least three different prioritization techniques currently in use. These techniques, ordered from lower to higher level of effort, are the (1) risk matrix/heat map approach, (2) the indicators approach, and (3) the cost-based approach.

1. The risk matrix/heat map approach involves creating a matrix with one axis qualitatively representing the likelihood of an event (low to high probability categories) and the other representing the consequences (low to high consequence categories). Each asset type-hazard combination is assigned to a cell within the matrix by using professional judgment. High risk asset type-hazard combinations are identified for immediate action.
2. The indicators approach involves collecting data on a variety of variables that are deemed relevant to affecting the prioritization. These are then put on a common scale, weighted (if necessary), and used to create a score for each asset. The scores collectively account for all the variables of interest and can be ranked to determine priorities.
3. The most sophisticated approach, the cost-based approach, involves an effort to determine the "do-nothing" cost of climate change if no adaptation is undertaken. This is a very data intensive approach as it requires (1) knowledge of the probability of the event happening, (2) an engineering assessment of what damage/disruptions occur when the asset is exposed to a hazard, and (3) economic analysis to determine the costs to repair damage to the asset along with the socioeconomic costs associated with loss of the asset. Because of its data

intensiveness, the cost-based approach is rarely used for initial assessments. However, an agency can begin with one of the simpler techniques and lay the groundwork for conversion to a cost-based approach later.

Given the resources and timeframe for this project, an indicators approach (the option entailing an intermediate level of effort) was chosen. With the proposed indicators approach, various metrics are used to capture (1) the nature of the asset's exposure to each relevant hazard (timing, severity, and/or extensiveness), (2) the consequences of that exposure (in terms of the sensitivity of the asset to damage and/or impacts to the traveling public, such as through the assessment of traffic volumes on the affected roadway) and (3) programming considerations that affect how rapidly adaptations can be implemented, if necessary. Ultimately, these metrics were compiled mathematically into a score for each individual asset, that can be ranked to show the assets that should be prioritized for detailed study under each hazard. For example, this scoring identifies which bridges are the most vulnerable to riverine flooding hazards out of all the bridges in the region, according to the criteria used in the analysis.

Different metrics were applied to each combination of asset type and hazard. Table 2. Asset Type and Hazards lists the hazards and denotes with an "X" the types of assets that are sensitive to each. Each cell marked with an "X" has its own set of metrics. The metrics used were based on what is relevant to prioritizing amongst assets exposed to the indicated hazard. For example, culvert condition rating is a very relevant metric for prioritizing culverts exposed to riverine flooding, but it is not relevant to prioritizing bridges exposed to the same hazard.

Table 2. Asset Type and Hazards

	Flooding	Wildfire	Extreme Heat
Roadways	X	X	x
Culverts (state-owned)	X	X	x
Bridges	X		x
Airports	X		X
Transit Stops	X	X	X

Indicators

The number of possible metrics for any given asset type-hazard combination is extensive and can be overwhelming. With any prioritization scheme, a limiting factor is data availability, and the effort is restricted to the best available information. Table 3. Asset Type Hazard Combinations lists all the metrics used in the prioritization approach. Also included is a description of each metric, a rationale for inclusion, the data source, other relevant metadata, and the asset type and hazard combinations it is used to assess.

After the metrics were compiled for each asset, each metric was placed on a 0 to 100-point scale where 100 represents that the asset is a priority. With the traffic volume metric, for example, a 0 might be assigned to a minor residential street with extremely low volumes, while a value of 100 would be assigned to the busiest highway in the region. Putting the metrics on a common scale helps reconcile the different units of measurement between metrics.

Table 3. Asset Type Hazard Combinations

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Recurring damage classification	A classification of if the asset has experienced damage and/or been closed or operated at reduced capacity due to extreme weather events in the past couple decades. Values are provided as 1 or 0 for each asset. A 1 represents that the asset has been damaged by extreme weather events in the past and 0 represents no known asset damages from extreme weather.	Assets that have experienced more issues in the past are likely to experience more issues in the future as climate changes and should be prioritized.	Analysis of information from VAWG, stakeholders, public outreach, and news article review	scale_dmg_fld or scale_dmg_fire (field names, depending on hazard type) categorical (field type) scaling: {1(raw value):100 (scaled valued),nan:0} (note: nan indicates null values) unscaled units: binary flag	Flood, Wildfire	Flood, Wildfire	Flood	Flood	Flood, Wildfire
Initial timeframe for elevated level of concern for wildfire	The first timeframe (2010-2039, 2040-2069, 2070-2099, or never), under either representative concentration pathway (RCP) 4.5 or 8.5, during which the asset is exposed to a moderate or higher level of concern for wildfire.	Assets that are more likely to be impacted by wildfire sooner should be prioritized.	Wildfire Model Composite[24]	scale_time_elev_burn categorical scaling: {3:100,2:75,1:50} unscaled units: timeframe priority sequence {2010:3,2040:2,2070:1}	Wildfire	Wildfire			Wildfire

[23] For items marked with "*" in this column: the full citation is included in the Task 1 geodatabase.

[24] The fire model composite summaries shown are based on wildfire projections from three models: 1) MC2 – EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; 2) MC2 – Applied Climate Science Lab at the University of Idaho, developed by Dominique Bachelet, University of Idaho; and 3) University of California Merced model, developed by Leroy Westerling, UC Merced. For each of these wildfire models, climate inputs were used from three Global Climate Models: 1) CAN ESM2, 2) Had_GEM2-ES, and 3) MIROC5. Data shows the multi-model maxima for each grid cell across the nine combinations of the three fire models and three GCMs. As a means of establishing a level of concern for wildfire impacts, a classification was developed based on the expected percentage of cell burned. The classification is as follows: 1) Very Low 0-5%, 2) Low 5-15%, 3) Moderate 15-

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Highest projected wildfire level of concern	The highest level of concern for wildfire (low, moderate, high, or very high) that an asset is exposed to through 2100 under either RCP 4.5 or 8.5.	Assets that have a greater likelihood of experiencing wildfire should be prioritized.	Wildfire Model Composite[25]	scale_cat_burn categorical scaling: {4:100,3:75,2:50,1:25} unscaled units: level of concern (ranging from "very high":4 to "low":1)	Wildfire	Wildfire			Wildfire
Maximum change in 100-year peak flow for the 2010-2039 timeframes	The highest change in 24-hour duration, 100-year peak flow in the 2010-2039 timeframe across Global Climate Models (GCMs) and RCPs.	Assets that have relatively higher peak flow increases in the near-term should be prioritized.	Scaling of past peak flows (USGS StreamStats) using relationship between watershed historical extreme precip. (NOAA Atlas 14) and future extreme precip. (processed from Scripps LOCA downscaled daily GCM outputs).	scale_flow_t1mx continuous scaling: log min-max normalization (natural log of max value: 100,…,natural log of min value: 0) unscaled units: cubic feet per second			Flood		

50%, 4) High 50-100%, 5) Very High 100%+. A classification of greater than 100% means fires are burning portions of each cell more than once in each time period. Time periods are averages of 30-year periods, where 2010 to 2039 is represented by the median year 2025, 2040 to 2069 is represented by the median year 2055, and 2070 to 2099 is represented by the median year 2085. Projected increases in wildfire are compared to a historical backcasted period from 1975 to 2004. Emissions scenarios used are RCP 4.5 or RCP 8.5, representing low and high emissions, respectively.

25 Ibid.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Maximum change in 100-year peak flow across all timeframes	The highest change in 24-hour duration, 100-year peak flow asset across timeframes, GCMs and RCPs.	Assets that have relatively higher peak flow increases over their lifetimes should be prioritized.	Scaling of past peak flows (USGS StreamStats) using relationship between watershed historical extreme precip. (NOAA Atlas 14) and future extreme precip. (processed from Scripps LOCA downscaled daily GCM outputs).	scale_flow_mx continuous scaling: log min-max normalization (natural log of max value: 100,…,natural log of min value: 0) unscaled units: cubic feet per second			Flood		
Maximum Caltrans future riverine flooding exposure score for the 2010-2039 timeframe[26]	The highest Caltrans riverine flooding exposure score for the asset in the 2010-2039 timeframe across all GCMs and RCPs. This score incorporates information on projected future peak flows, projected future wildfire, and capacity.	Assets that have relatively higher riverine flooding exposure in the near-term should be prioritized.	Caltrans Climate Change Action Report project (original data sources include USGS StreamStats, NOAA Atlas 14, Scripps, and Wildfire Model Composite (see above for sources))	scale_ riv_t1mx continuous scaling: not needed unscaled units: 0-100 scale		Flood			

[26] This data source is currently on hold, so results are not included for culverts.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Maximum Caltrans future riverine flooding exposure score across all timeframes[27]	The highest Caltrans riverine flooding exposure score for the asset across all timeframes, GCMs and RCPs. This score incorporates information on projected future peak flows, projected future wildfire, and capacity.	Assets that have relatively higher riverine flooding exposure over their lifetimes should be prioritized.	Caltrans Climate Change Action Report project (original data sources include USGS StreamStats, NOAA Atlas 14, Scripps, and Wildfire Model Composite (see above for sources))	scale_riv_mx continuous scaling: not needed unscaled units: 0-100 scale		Flood			
Maximum change in 100-year precipitation for the 2010-2039 timeframes	The highest change in 24-hour duration, 100-year precipitation in the 2010-2039 timeframe across Global Climate Models (GCMs) and RCPs.	Assets that have relatively higher precipitation increases in the near-term should be prioritized.	Scripps LOCA downscaled daily GCM outputs	scale_pre_t1mx continuous scaling: log min-max normalization (natural log of max value: 100,…,natural log of min value: 0) unscaled units: inches per day	Flood			Flood	Flood
Maximum change in 100-year precipitation across all timeframes	The highest change in 24-hour duration, 100-year precipitation asset across timeframes, GCMs and RCPs.	Assets that have relatively higher precipitation increases over their lifetimes should be prioritized.	Scripps LOCA downscaled daily GCM outputs	scale_pre_mx continuous scaling: log min-max normalization (natural log of max value: 100,…,natural log of min value: 0) unscaled units: inches per day	Flood			Flood	Flood

[27] This data source is currently on hold, so results are not included for culverts.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Maximum change in 7-day maximum temperature	The highest change for extreme temperature across timeframes, GCMs, and RCPs.	Assets that have relatively higher extreme temperature increases over their lifetimes should be prioritized.	Comb. of Scripps LOCA downscaled daily projections and Caltrans Climate Change Vulnerability Assessment	scale_temp7_mx continuous scaling: min-max normalization (max value: 100,…,min value: 0) unscaled units: °F	Extreme Temp.				
Average annual maximum of daily maximum temperature across timeframes	The highest average annual maximum of the daily maximum temperature across timeframes, GCMs, and RCPs.	Extreme high heat can create issues for aircraft and airport operations.	Scripps LOCA downscaled daily projections	scale_temp1_mx continuous scaling: min-max normalization (max value: 100,…,min value: 0) unscaled units: °F				Extreme Temp.	
Maximum change in average annual maximum of daily maximum temperature across timeframes	The highest change in the average annual maximum of the daily maximum temperature across timeframes, GCMs, and RCPs.	Changes in extreme high temperature could cause bridges to expand beyond design threshold	Scripps LOCA downscaled daily projections	scale_tdelt_mx continuous scaling: min-max normalization (max value: 100,…,min value: 0) unscaled units: °F			Extreme Temp.		
Highest Annual Number of Heat Health Events	The projected number of Heat Health Events (heat events that generate public health impacts) across timeframes and GCMs and emissions scenarios.	Assets where users are exposed to heat health events in the asset lifetime should be prioritized.	California Heat Assmt. Tool	scale_max_hh continuous scaling: min-max normalization (max value: 100,…,min value: 0) unscaled units: # events					Extreme Temp.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Lowest floodplain increment that facility lies within or crosses	The lowest floodplain increment that the facility is within or intersects of the following: 100-year floodplain, 500-year floodplain, or none	In general, assets within existing 100-year floodplains should be prioritized most; and assets within existing 500-year floodplain should also be prioritized	FEMA Flood Maps	scale_flood_pln categorical {100:100,500:75,9999:0,nan:0} unscaled units: recategorized into simplified return intervals (100, 500, or none) from FEMA designations[28]	Flood			Flood	Flood
Bridge substructure condition rating	The National Bridge Inventory (NBI) substructure condition rating assigned to the bridge. Possible values range from 9 to 2 with lower values indicating poorer condition. Culverts (code value N, not applicable) are not included nor are bridges closed to traffic (code values 0 and 1).	Poor bridge substructure condition can contribute to failure during extreme weather events. Thus, bridges with poor substructure condition should be prioritized.	National Bridge Inventory (NBI) (Item 60)	scale_Bsubstruct_cond categorical scaling: {'9':0,'8':10,'7':30,'6':50,'5':60,'4':70,'3':80,'2':90,'1':100,'0':100,'N':0,nan:50} unscaled units: see NBI coding guide[29]			Flood		

[28] https://www.arcgis.com/home/item.html?id=e96f674e765b4327bbde92d41a12b087
[29] See NBI coding guide for more information: https://www.fhwa.dot.gov/bridge/mtguide.pdf

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Channel and channel protection condition rating	The NBI channel and channel protection condition rating assigned to the asset. Possible values range from 9 to 2 with lower values indicating poorer condition. Assets with code values N (not applicable because not over water) are not included nor are assets closed to traffic (code values 0 and 1).	Poor channel or channel protection conditions can contribute to failure during extreme weather events. Thus, assets with poor channel or channel protection conditions should be prioritized.	NBI (Item 61)	scale_Bchannel_cond categorical scaling: {'9':0,'8':15,'7':30,'6':45,'5':60,'4':75,'3':90,'2':100,'1':100,'0':100,'N':0,nan:50} unscaled units: see NBI coding guide			Flood		
Culvert condition rating[30]	The Caltrans culvert condition rating (for small culverts) assigned to the culvert. Possible values include Good, Fair, or Critical. Culverts with N/A, NA, or no data coding will be assigned a Fair rating.	Poor culvert condition can contribute to failure during extreme weather events. Thus, culverts in poor condition should be prioritized.	Caltrans conveyances shapefile (Condition field)	scale_Bchannel_cond categorical scaling: {'9':0,'8':15,'7':30,'6':45,'5':60,'4':75,'3':90,'2':100,'1':100,'0':100,'N':0, nan:50} unscaled units: see NBI coding guide		Flood			

[30] This data source is currently on hold, so results are not included for culverts.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Culvert material[31]	The material used to construct the culvert. Possible values include HDPE (high density polyethylene), PVC (polyvinyl chloride), CSP (corrugated steel pipe), Composite, Wood, Masonry, Concrete, -1, N/A, Other, and Unkn.	Culvert material plays a role in determining the sensitivity of assets to wildfire. HDPE, PVC, CSP, Composite, and Wood culvert types should be prioritized. Culverts with values of -1, N/A, Other, and Unkn will be assigned a moderate level of concern.	Caltrans conveyances shapefile (CMaterial field)	scale_CMaterial_fire categorical scaling: {'Concrete':0, 'CSP':0, '-1':50, 'PVC':100, 'HDPE':100,'Composite':100 ,'Wood':100,'Other':50,'Masonry':0} unscaled units: materials categories (see scaling)		Flood			

[31] This data source is currently on hold, so results are not included for culverts.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Scour rating	The NBI scour critical bridge rating assigned to the bridge. Possible values range from 8 to 2 with lower values indicating greater scour concern. Bridges coded N (not over waterway), U (unknown foundation), T (over tidal waters with minimal concern), or 9 (bridge foundations on dry land) will be assigned a value of 6, a moderate value assigned to bridges where no scour analysis has been performed. This reflects the possibility that higher flood levels could cause scour at these facilities which heretofore had not been studied for scour because of a belief that flooding wouldn't affect them.	Excessive scour of bridge foundations makes bridges more prone to failure during extreme weather events. Thus, bridges with a high amount of scour should be prioritized.	NBI (Item 113)	scale_Bscour_crit categorical scaling: {'N':0,'U':50,'T':40,nan:50,'9':0,'8':15,'7':30,'6':50,'5':60,'4':75,'3':90,'2':100,'1':100,'0':100} unscaled units: see NBI coding guide			Flood		
Bridge capacity	NBI Item 71 on Waterway Adequacy to approximate capacity. Values range from 9 to 2 with lower values indicating smaller capacity.	Bridges with lower capacities should be prioritized.	NBI (Item 71)	scale_Bwaterway_adequ categorical scaling: {'N':0,nan:50,'9':0,'8':15,'7':30,'6':45,'5':60,'4':75,'3':90,'2':100,'0':100} unscaled units: see NBI coding guide			Flood		

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Culvert capacity[32]	CDiameter or combination of CWidth and CHeight fields are used to calculate area. Smaller areas are associated with smaller capacities.	Culverts with lower capacities should be prioritized.	Caltrans Conveyances shapefile	scale_Cwaterway_adequ categorical scaling: {'Fair':50, 'Good':0, 'Poor':75, 'Critical':100, '-1':0} unscaled units: Caltrans' categories (see scaling)		Flood			
Facility Level of Service (LOS)	The forecasted LOS from the Fresno COG VMIP 2 travel demand model for 2042. For roadway segments that contain two overlapping model links, the maximum LOS was taken.	Roadways with high congestion and capacity constraints should be prioritized.	Fresno COG VMIP 2, 2042 forecast, LOS_DAILY field	scale_los categorical scaling: min-max normalization (max value: 100,…,min value: 0) unscaled units: numerical scores 1-6 corresponding to AASHTO LOS ratings A-F[33]	Flood, Wildfire, Extreme Temp.				

[32] This data source is currently on hold, so results are not included for culverts.
[33] https://en.wikipedia.org/wiki/Level_of_service

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Average Annual Daily Traffic Volume	For roadways, this is the average daily volume from Fresno COG VMIP 2 travel demand model for 2042. For roadway segments that contain two overlapping model links, the sum of the two volumes was used. For bridges, this is the NBI future ADT and future ADT years used to adjust the future volumes to a common year of 2036 across the assets. For culverts, this is the AADT developed through the Caltrans Climate Action Report project.	The consequences of weather-related failures/disruptions (from either extreme events or more frequent maintenance needs) are greater for assets that convey a higher volume of traffic. Thus, assets associated with higher volumes should be prioritized.	Fresno COG VMIP 2 travel demand model, 2042 forecast, D24_VOL field for roadways. NBI (Items 114 and 115) for bridges. Caltrans Climate Action Report project for culverts.[34]	scale_fac_vol continuous scaling: min-max normalization (max value: 100,…,min value: 0} unscaled units: volume (differs by mode; see Description column for details)	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		

[34] This data source is currently on hold, so results are not included for culverts.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Average Annual Daily Traffic Volume for Trucks	For roadways, this is the average daily truck volume from Fresno COG VMIP 2 travel demand model for 2042. For roadway segments that contain two overlapping model links, the sum of the two volumes was used.	The consequences of weather-related failures/disruptions (from either extreme events or more frequent maintenance needs) are greater for assets that convey a higher volume of freight traffic. Thus, assets associated with higher freight volumes should be prioritized.	Fresno COG VMIP 2 travel demand model, 2042 forecast, D24_TRK_VO field	scale_trk_vol continuous scaling: min-max normalization (max value: 100,…,min value: 0} unscaled units: daily truck volume	Flood, Wildfire, Extreme Temp.				
Airport Type	The airport type associated with the asset. Values include Primary, General, Other, and Reliever.	Airports with more intensive uses (e.g., primary hubs) should be prioritized.	Fresno COG airports layer	scale_aport_class categorical scaling: {'Primary':100,'General':50,'Other':50,'Reliever':0} unscaled units: Airport Type (see above)				Flood, Extreme Temp.	

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
NBI Bypass, Detour Length	The NBI Bypass, Detour Length (XXX kilometers) assigned to the bridge. It represents the total additional travel for a vehicle which would result from a closing of the bridge. Values range from 000 up to a maximum of 199 kilometers.	The greater the detour length around the asset (should it need to be closed due to an extreme weather event) the lower the network redundancy. Assets with low network redundancy should be prioritized.	NBI (Item 19)	scale_Bdetour continuous scaling: min-max normalization (max value: 100,…,min value: 0} unscaled units: kilometers			Flood, Wildfire		
Nodal density (density of network nodes within 0.5 miles)	The density of roadway network intersections (i.e., nodes) within a 0.5-mile buffer of the asset. Units are nodes per square mile. Buffers are clipped to the Fresno COG region.	Nodal density is a proxy for network redundancy. Assets with low network redundancy should be prioritized.	Fresno COG VMIP 2, 2042 forecast network	scale_node_dens continuous scaling: percentile ranking (min value: 100,…,max value: 0} unscaled units: # nodes within .5 miles	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.			Flood, Wildfire, Extreme Temp.
Employment density	Fresno COG employment density within a quarter mile buffer of the asset, aggregated by area weighted mean (AWM).	Assets in areas of higher employment density should be prioritized.	Fresno COG TAZ feature class, EMP field	scale_emp_dens continuous scaling: min-max normalization (max value: 100,…,min value: 0} unscaled units: employment density AWM within 0.25 mile	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		Flood, Wildfire, Extreme Temp.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Household density	Fresno COG household density within a quarter mile buffer of the asset, aggregated by area weighted mean (AWM).	Assets in areas of higher household density should be prioritized.	Fresno COG TAZ feature class, HH field	scale_pop_dens continuous scaling: min-max normalization (max value: 100,…,min value: 0} unscaled units: household density AWM within 0.25 mile	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		Flood, Wildfire, Extreme Temp.
Asset within Fresno COG Environmental Justice (EJ) community	Whether an asset at least partially overlaps a Fresno COG Environmental Justice community.	Disadvantaged communities tend to be more vulnerable to weather-related events, and assets serving these communities should be prioritized.	Fresno COG MIP1_EJ_TAZ feature class, MIP1_EJ_1 field	scale_in_ej categorical scaling: {-1:100,0:0} unscaled units: binary flag	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		Flood, Wildfire, Extreme Temp.
CalEnviroScreen Percentile Score	The percentile CalEnviroScreen score density within a quarter mile buffer of the asset, aggregated by area weighted mean. Values range from 0 to 100, with the most disadvantaged communities receiving larger scores.	Disadvantaged communities tend to be more vulnerable to weather-related events, and assets serving these communities should be prioritized. This is a State indicator of disadvantaged communities.	California OEHHA	scale_ces_den continuous no scaling unscaled units: % AWM within 0.25 miles	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		Flood, Wildfire, Extreme Temp.

Metric	Description	Rationale for Inclusion	Input Data Source[23]	Other Metadata: Field Name, Type, Scaling	Asset Type-Hazard Combinations Applied To				
					Roadways	Culverts (state-owned)	Bridges	Airports	Transit Stops
Percent of Households with No Vehicle	The percent of households with no vehicle within a quarter mile buffer of the asset, aggregated by area weighted mean.	Assets serving communities with high proportion of individuals without vehicle access should be prioritized.	American Community Survey	scale_noveh_den continuous no scaling unscaled units: % AWM within 0.25 miles	Flood, Wildfire, Extreme Temp.	Flood, Wildfire, Extreme Temp.	Flood, Extreme Temp.		Flood, Wildfire, Extreme Temp.

Asset Prioritization Scoring

Once the metrics were placed on a common scale, weights were assigned based on the relative importance of each metric to the overall risk. Table 4. Metric Weights by Asset-Hazard Combination shows the weights for each metric.

After the weights were assigned, they were multiplied by the scaled scores. These products were then summed for each asset type-hazard combination (i.e. each column in the table). Then, a final re-scaling of the results was done to ensure that the final scores were all on a 0-to-100 scale for each asset. Larger numbers on the scale (i.e., closer to 100) represent higher priority (more vulnerable) assets.

After these scaled scores were developed, they were categorized into ten equal intervals, so that categories with scores 90-100 were assigned a 10, scores 80-90 were assigned a 9, and so on. This classification of results helped remove some of the potentially confusing and misleading precision of the numeric scores.

The final product of this approach is a prioritized listing of assets with a separate ranking for each asset type-hazard combination. For example, all culverts are prioritized based on their vulnerability to riverine flooding. Likewise, there are separate prioritized lists for culverts vulnerable to sea level rise and to storm surge.

As described in other portions of this section, the indicator-based prioritization is a helpful tool given the number of different assets, hazard types, and information sources needed to assess relative vulnerability. But it should not be mistaken as a complete understanding of risks facing those assets. It's a tool for system-level analysis that needs to be accompanied with professional judgement and on-the-ground context. It is useful in that it can help identify at-risk assets that should be examined individually at a facility-level.

Table 4. Metric Weights by Asset-Hazard Combination

Metric	Flooding					Wildfire			Extreme Temperature			
	Roads	Bridges	Culverts	Transit Stops	Airports	Roads	Culverts	Transit Stops	Roads	Bridges	Transit Stops	Airports
Initial timeframe for elevated level of concern for wildfire						25%	25%	25%				
Highest projected wildfire level of concern						25%	25%	25%				
Maximum change in 100-year flow for the 2010-2039 timeframe		15%										
Maximum change in 100-year flow across timeframes		15%										
Maximum Caltrans future riverine flooding exposure score for the 2010-2039 timeframe			16%									
Maximum Caltrans future riverine flooding exposure score			16%									
Maximum change in 100-year precipitation for the 2010-2039 timeframe	10%			10%	10%							
Maximum change in 100-year precipitation	10%			10%	10%							
Max change in max 7-day temperature across timeframes									60%			
Avg annual max daily max temperature across timeframes												60%
Max change in avg annual max daily max temperature across all timeframes										55%		
Highest Annual Number of Heat Health Events across timeframes											50%	
Lowest floodplain increment that facility lies within or crosses	30%			30%	30%							
Recurring Damage Classification (flooding)	15%	15%	15%	15%	15%							

Metric	Flooding					Wildfire			Extreme Temperature			
	Roads	Bridges	Culverts	Transit Stops	Airports	Roads	Culverts	Transit Stops	Roads	Bridges	Transit Stops	Airports
Recurring Damage Classification (fire)						10%	10%	10%				
Bridge substructure condition rating		2%										
Channel and channel protection condition rating		2%										
Scour rating		5%										
Bridge capacity		28%										
Culvert condition rating			5%									
Culvert material							4%					
Culvert capacity			30%				4%					
Facility Level of Service (LOS)	5%					5%			5%			
Facility Volume	12.5%	10%	10%			15%	15%		20%	20%		
Facility Truck Volume	2.5%					3%			5%			
Airport class					35%							40%
Detour length		5%								15%		
Density of roadway network nodes within 0.5 miles of facility	10%		4%	5%		10%	10%	10%	5%		5%	
TAZ employment density: AWM within 0.25 miles of facility	1%	0.5%	0.5%	5%		1%	1%	5%	1%	2%	5%	
TAZ household density: AWM within 0.25 miles of facility	1%	0.5%	0.5%	5%		1%	1%	5%	1%	2%	5%	

Metric	Flooding					Wildfire			Extreme Temperature			
	Roads	Bridges	Culverts	Transit Stops	Airports	Roads	Culverts	Transit Stops	Roads	Bridges	Transit Stops	Airports
Facility within or overlaps Fresno COG EJ TAZ	1%	0.5%	1%	5%		2%	2%	5%	1%	2%	15%	
CalEnviroScreen Score: AWM within 0.25 miles of facility	1%	0.5%	1%	5%		1%	1%	5%	1%	2%	5%	
% Households with No Vehicle: AWM within 0.25 miles of facility	1%	1%	1%	10%		2%	2%	10%	1%	2%	15%	
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Analysis Documentation

The scoring approach described in the previous subsections involves many different datasets and analysis processes. This subsection helps document that process and serves as a reference for replicating the analysis.

There are several portions of the analysis. The first is the input data development, which includes the gathering and cleaning of hazard and asset data. The second is the metric development, where this information is combined into the metrics described in the approach section. The final is the scoring, where the metrics are scaled and weighted together to produce scaled scores for each combination of hazard and asset type.

There are several files and folders that were used to conduct the analysis and contain the results:

- The previous subsections of this Methodology section document the raw datasets used and includes important metadata, such as original data sources, scaling methodology, and field names of scaled values.
- The results geodatabase ("fcog_tnva_20190918.gdb") contains the asset feature classes with the results. The fields include:
    - The final tiered scores, which are provided in 10 equal interval tiers, with 10 corresponding with more vulnerable assets and 1 corresponding with less vulnerable assets. These fields are named "final_score_", followed by a hazard type abbreviation, followed by an asset type abbreviation.[35] For example, "final_score_flood_brid" in the bridge feature class contains the final scores for flooding threats to bridges.
    - The scaled overall scores for each asset type-hazard combination, which range from 0 to 100, with 100 corresponding with more vulnerable assets and 0 corresponding with less vulnerable assets. These fields are named "scalescore_", followed by a hazard type abbreviation, followed by an asset type abbreviation.
    - The scaled metrics scores that are weighted together into the scaled overall scores. The Indicators subsection of this memorandum documents all of these field names and definitions.
    - Unscaled metrics values. The Metric Weights Template file (see below) contains a list of all the unscaled metric field names and their corresponding scaled metric field names. The Asset Prioritization Scoring subsection in this memorandum also documents these weights.
    - Other fields that were included in the original asset files, such as asset name, location, and description. There are also a few other intermediary fields created during the metric development.
- Summary sheets and scores spreadsheets: "fcog_scores_tables_20190918" folder. This includes

[35] In these fields and others in this geodatabase, hazard abbreviations are {Wildfire: "fire", Extreme Temperature: "temp", Flooding: "flood"}. The asset abbreviations are {Roadways: "road", Transit stops: "trans", Culverts: "culv", Bridges: "brid", Airports: "air}.

.csv versions of the results by asset type in the results geodatabase. It also includes summary .csv files with results broken out by asset type-hazard combination.

- Metric Development Python script for ArcGIS: "fresno_arcpy_processing_v02.py". Most of the metric development occurred with this Python script, which relies heavily on ArcPy, the Python package for running ArcGIS geoprocesses. The script can be viewed in Notepad++ or other source code editor. It is commented with instructions on how to rerun the metric development geoprocesses.
- Scoring Development Jupyter Notebook for Python: "fresnocog_asset_scaling_weighting_scoring.ipynb". This Jupyter Notebook runs blocks of Python code.[36] This notebook was used for the metric scaling, weighting, and final scoring and classification. While ArcGIS is offers rich geoprocessing functionality, traditional Python packages such as pandas and numpy are better suited for systematic tabular data manipulation. This notebook is commented and can be rerun in the future. It reads .xls (or other tabular) files exported from ArcGIS. It also reads the Metric Weights Template (see below) for the weighting process.
- Metric Weights Template: "Fresno_COG_TNVA_weights_20190918.csv". This is an input file into the Scoring development Jupyter Notebook. It is a table with rows corresponding to metric names, columns corresponding to asset type-hazard combinations, and values corresponding to the weights used to combine the scaled metrics together for each asset type-hazard score. The weights in that table are the same as those that appear in the Asset Prioritization Scoring subsection of this document. The weights in the Metric Weights Template can be modified if the user wants to rerun the scoring with a different weighting. However, the formatting of the Template should not be modified, as the Notebook may not be able to process the weights properly.
- The supplemental geodatabase ("fcog_tnva_20190918_supplemental.gdb") contains additional feature classes used in this memorandum, including those used for the climate projection maps in the Future Projections subsection and for the landslide maps used in the Future Deep-Seated Landslides subsection.

Note regarding bridge analysis: We analyzed bridges from two data sources: the Fresno County Department of Public Works and Planning's bridge inventory and the National Bridge Inventory (NBI). We combined the two datasets into one feature class of 1,336 bridge features. Of these, 761 appeared in the NBI alone, 136 appeared in both the NBI and the Fresno County inventory, and 439 appeared in the Fresno County inventory alone. We wanted to include in the scoring the rich information on conditions and consequences in the NBI. But we also did not want to 'penalize' bridges for not being in the NBI. For bridges not appearing in the NBI, we composed their scores from using all of the non-NBI variables and scaled them accordingly. While we show results for all bridges on the same map, the scores for the non-NBI bridges were compiled with fewer inputs. The NBI scores are therefore somewhat more robust than the non-NBI scores.

[36] Jupyter Notebook is free and open source and can be downloaded here: https://jupyter.org/.

Note regarding roadway analysis: We analyzed roadways using the Fresno COG VMIP 2 travel demand mode network for 2042. This network contains forecasts of numerous metrics related to travel volumes and congestion. The network is more spatially accurate in the heavily trafficked urban areas and less spatially accurate in the sparser mountainous regions of the County. We pre-processed the network by combining directly overlapping links (those that shared endpoints A and B) into single links. For each combined link, we added volume across its two composite links and took the maximum of the LOS ratings between the two composite links. Many links in the network did not span all the way from intersection to intersection but rather started or ended between intersections. For the vulnerability assessment, we sought units of analysis that were true intersection-to-intersection segments. But we also wanted to preserve the volume information in the segments. Therefore, we slightly rounded volume and then dissolved by volume to combine segments with very similar volumes. We then used the network nodes (which represented the true intersections) to split the dissolved network into intersection-to-intersection segments with volume information.

Results

This section covers the full results of the vulnerability scoring exercise. It is organized by hazard-asset combinations. Each combination includes a map of results, table of top scoring assets, and brief narrative of the results. The accompanying files contain the results in geodatabase feature class (GIS) and comma-separated value (CSV) format. The Summary section synthesizes the results from the scoring and from other Vulnerability Assessment analyses.

Bridges and Future Flooding

Riverine peak flows are expected to increase under at least some of the future climate scenarios. Many bridges were identified as vulnerable to future riverine flooding. Most of these are lightly traveled roads in low-density areas, though network redundancy is limited in many of these areas, so detour routes are often long.

Several of the most vulnerable bridges span the Kings River South Fork on the SR-180 or nearby roads in far eastern Fresno County. These roads are characterized by low travel volumes but significant detour lengths. Some of these bridges already experience flooding issues and have below average conditions ratings. A couple other bridges along SR-180 were flagged as highly vulnerable; one across Mill Creek farther west in the Sierras, and one across Fresno Slough near Mendota.

There were three bridges with vulnerability scores over 80 along the I-5 over the Panoche Creek and Little Panoche Creek. These have higher travel volumes than the other highly vulnerable bridges and each received at least one weak condition score (substructure condition rating, channel condition rating, scour critical rating, or waterway adequacy rating).

One of the most vulnerable bridges to future flooding was the North Fork Road bridge over the San Joaquin River in Friant. It has experienced flooding in the past, rates poorly for scour, and will likely experience high increases in flows under many of the climate scenarios.

There were a few other highly vulnerable bridges north of Reedley across Cameron Slough and Wahtoke Creek, one farther west over the Cole Slough on SR-43, and one in the county's southwestern corner on SR-198 over Warthan Creek. There are also a couple in the county's northwestern corner on N Russell Ave over Outside Canal and Delta-Mendota Canal.

Non-NBI bridges (i.e. those in the Fresno County bridge inventory that are not in the NBI) were also scored, though there is less confidence in these results given the lack of condition and consequence information that is available for the NBI bridges. Of the non-NBI bridges, many of the most vulnerable are several bridges in the Kings River watershed that have high expected increases in flows. Some of these assets are on the Murphy Slough, a side channel of the Kings River. It appears that USGS Streamstats, the data source for the watershed geometries, assigns Murphy Slough a large portion of the overall Kings River watershed area, which could overstate the flow in Murphy Slough and understate the flow in the parallel portion of the Kings River. Therefore, these flows should be assessed in more detail as part of facility-level assessments.

Figure 20. Vulnerability Scoring: Bridges & Future Flooding

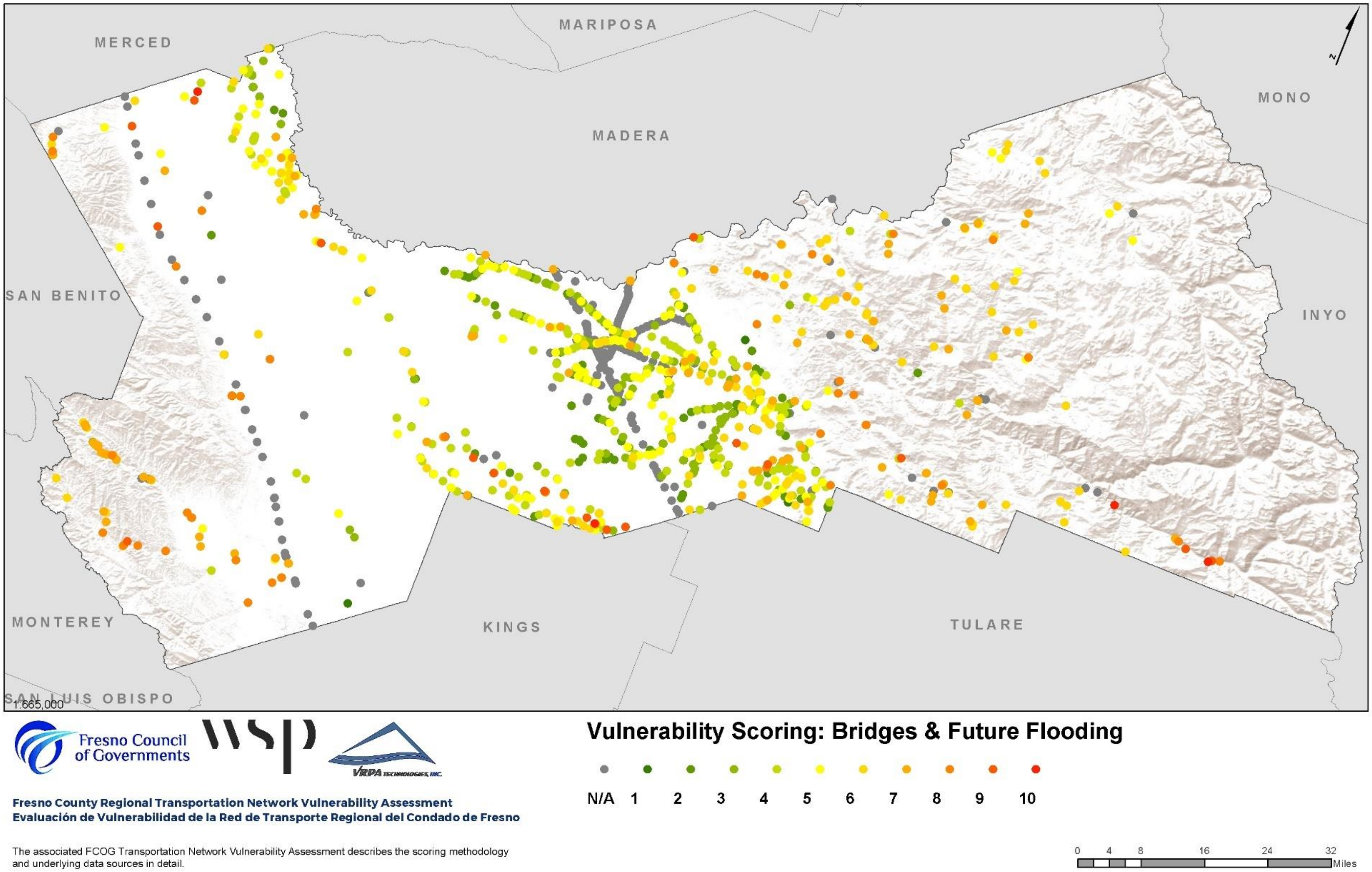


Table 5. Highest Flooding Vulnerability Scores for Bridges

OID_num	FCBN	NBI_STRUCTURE_NUMBER_008_trim	ROUTE_NUMBER_005D	FEATURES_DESC_006A	FACILITY_CARRIED_007	LOCATION_009	final_score_flood_brid	scalescore_flood_brid	scale_flow_t1mx	scale_flow_mx	scale_dmg_fld	scale_Bsubstruct_cond	scale_Bchannel_cond	scale_Bscour_crit	scale_Bwaterway_adequ	scale_fac_vol	scale_Bdetour	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
34	05-064						10	90	95	94	0					0		4	15	100	14	2
154	01-017	42C0047	0	OUTSIDE CANAL '	'N RUSSELL AVE '	'3.9 MI NORTH OF NEES AVE '	10	95	65	62	0	60	60	60	100	1	19	3	3	0	15	6
578		8580003P0000000	11	ROARING RIVER'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY. MP 31.9'	10	92	81	76	0	30	45	15	75	0	100	0	0	0	6	2
583		42 0024	180	'SOUTH FORK KINGS RIVER '	'STATE ROUTE 180 '	06-FRE-180-130.13'	10	100	87	83	0	30	60	60	75	0	100	1	2	0	6	2
33	05-058						9	87	95	94	0					0		7	17	0	14	2
110	05-039						9	87	95	94	0					0		6	10	0	15	3
118	05-049						9	88	95	94	0					0		3	7	0	31	5
157	01-021	42C0142	0	'DELTA-MENDOTA CANAL '	'N RUSSELL AVE '	AT ALTHEA AVE '	9	85	59	53	0	60	15	15	100	1	10	3	3	0	15	6
221	07-001	42C0001	0	'SAN JOAQUIN RIVER '	'NORTH FORK ROAD '	'0.1 MI W/O FRIANT RD '	9	83	36	37	100	60	30	90	45	2	26	0	11	0	58	6
372	05-069						9	87	95	94	0					0		3	14	0	14	2
406	10-040						9	87	95	94	0					0		2	4	0	15	0
420	10-053	42C0237	0	WAHTOKE CREEK '	'E JEFFERSON AVE '	'0.31 MI W BUTTONWILLOW AV'	9	83	77	71	0	30	30	50	75	0	1	4	7	0	15	0
504	05-054						9	87	95	94	0					0		3	4	0	15	3
577		8580005P0000000	11	' SOUTH FORK KINGS RIVER'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY. MP 32.3'	9	86	85	82	0	50	30	90	45	0	100	0	0	0	6	2
579		8580006P0000000	205	' SOUTH FORK KINGS RIVER'	' WEST SIDE ROAD'	'KINGS CANYON HWY. MP 28.8'	9	81	85	82	0	30	15	50	60	0	5	0	0	0	6	2
622		42 0080	180	MILL CREEK '	'STATE ROUTE 180 '	06-FRE-180-92.18 '	9	86	84	80	0	30	30	60	60	3	45	6	33	0	6	2
711		42C0007	0	CAMERON SLOUGH '	'E GOODFELLOW AVE '	'0.14 MI E/O RIVERBEND AVE'	9	81	95	94	0	30	30	60	45	2	7	2	4	0	15	0
789		42 0081	43	COLE SLOUGH '	'STATE ROUTE 43 '	06-FRE-043-0.78 '	9	83	95	94	0	30	45	60	45	7	9	3	3	0	14	2
1243		42 0041	180	KINGS SLOUGH '	'STATE ROUTE 180 '	06-FRE-180-26.95 '	9	86	95	94	0	30	60	60	45	4	19	5	2	100	74	26
1278		42 0012	198	WARTHAN CREEK '	'STATE ROUTE 198 '	06-FRE-198-13.60 '	9	80	82	82	0	60	45	15	45	2	100	2	3	0	11	3
1322		42 0249R	5	PANOCHE CREEK '	'INTERSTATE 5 NB '	06-FRE-005-49.99 '	9	80	79	87	0	30	60	60	45	8	20	7	1	100	18	13
1323		42 0249L	5	PANOCHE CREEK '	'INTERSTATE 5 SB '	06-FRE-005-49.99 '	9	81	79	87	0	60	60	60	45	8	17	7	1	100	18	13
1331		42 0374	5	'LITTLE PANOCHE CREEK '	'INTERSTATE 5 '	06-FRE-005-62.21 '	9	88	81	80	0	0	90	15	75	16	1	1	1	0	15	6

Bridges and Future Temperature Change

Bridges expected to experience large increases in temperature could be at risk of thermal expansion that exceeds design thresholds. Generally, the highest absolute daily maximum temperature *increases* (not to be confused with temperatures themselves) are expected in the eastern regions of Fresno County, with lower increases toward the western and southwestern regions. Therefore, bridges farther east and north tend to receive higher temperature vulnerability scores. For NBI bridges, the travel volume and detour length of the bridges also contributes considerably to their vulnerability scores.

Given their low redundancy and high exposure, several bridges on the SR-168 and SR-180 in the Sierras receive most of the highest vulnerability scores. The highest volume bridge in the dataset which is on the short stretch of SR-180 between SR-168 and SR-41 near downtown Fresno, also receives a very high vulnerability score.

Figure 21. Fresno County Bridges & Future Temperature

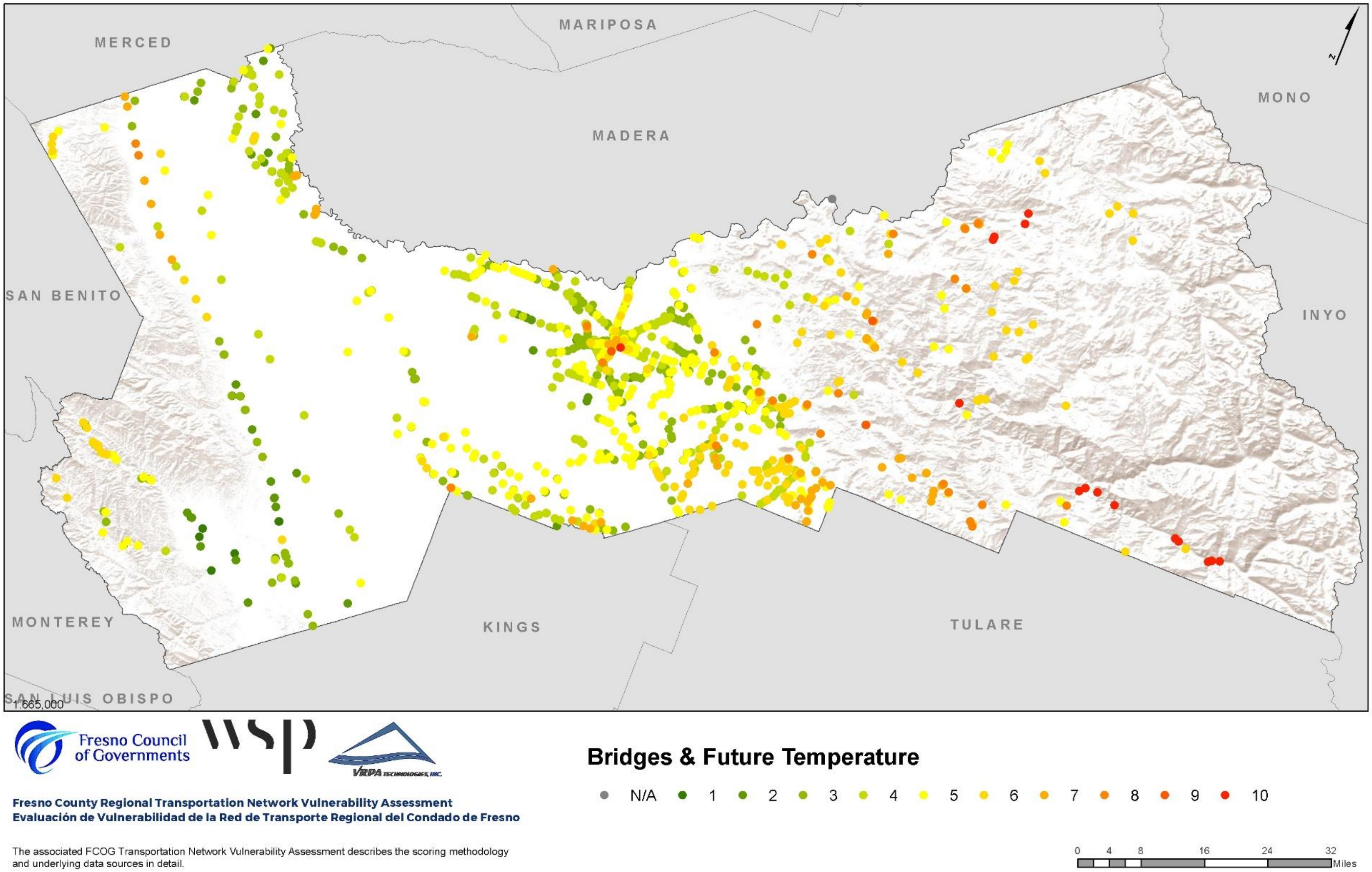


Table 6. Highest Temperature Vulnerability Scores for Bridges

OID_num	FCBN	STRUCTURE_NUMBER_008_trim	ROUTE_NUMBER_005D	FEATURES_DESC_006A	FACILITY_CARRIED_007	LOCATION_009	final_score_temp_brid	scalescore_temp_brid	scale_tdelt_mx	scale_fac_vol	scale_Bdetour	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
249	09-006	42C0591	0	'KINGS RIVER '	'TRIMMERS SPRING RD'	'14 MI E OF MAXSON RD '	10	93	95	0	100	3	16	0	9	4
576		8580002P0000000	11	' GRANITE CREEK'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY MP 33.1 '	10	96	97	0	100	0	0	0	6	2
577		8580005P0000000	11	' SOUTH FORK KINGS RIVER'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY. MP 32.3'	10	96	97	0	100	0	0	0	6	2
578		8580003P0000000	11	' ROARING RIVER'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY. MP 31.9'	10	96	97	0	100	0	0	0	6	2
580		8580004P0000000	11	' SOUTH FORK KINGS RIVER'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY MP 32.1 '	10	97	98	0	100	0	0	0	6	2
581		8580001P0000000	11	' LEWIS CREEK'	'CEDAR GROVE ROAD ('	'KINGS CANYON HWY. MP 27.2'	10	99	99	0	100	1	2	0	6	2
583		42 0024	180	'SOUTH FORK KINGS RIVER '	'STATE ROUTE 180 '	'06-FRE-180-130.13 '	10	100	100	0	100	1	2	0	6	2
584		42 0411	180	'HILLSIDE '	'SR 180 '	'06-FRE-180-126.14 '	10	100	100	0	100	1	2	0	6	2
585		42 0432	180	'SIDEHILL VIADUCT '	'ROUTE 180 '	'06-FRE-180-124.40 '	10	98	99	0	100	1	2	0	6	2
586		42 0020	180	'TEN MILE CREEK '	'STATE ROUTE 180 '	'06-FRE-180-123.56 '	10	98	99	0	100	1	2	0	6	2
615		42 0121	168	'BIG CREEK '	'STATE ROUTE 168 '	'06-FRE-168-64.12 '	10	97	98	1	100	2	1	0	3	5
616		42 0122	168	'RANCHERIA CREEK '	'STATE ROUTE 168 '	'06-FRE-168-65.74 '	10	99	99	1	100	2	1	0	3	5
619		42 0111	168	'TAMARACK CREEK '	'STATE ROUTE 168 '	'06-FRE-168-58.67 '	10	96	97	1	100	3	11	0	3	5
620		42 0057	168	'S FK TAMARACK CREEK '	'SR 168 '	'06-FRE-168-58.23 '	10	95	96	1	100	3	11	0	3	5
946		42 0443G	180	'SR 41-E180 CONNECT '	'E180-E168 CONNECT '	'06-FRE-180-R58.60 '	10	92	77	100	2	5	65	100	38	36
636		42C0573	0	'MILL CREEK '	'LUPINE DRIVE '	'0.2 MI NORTH OF ELWOOD RD'	9	81	87	0	100	3	16	0	6	2
648		42C0624	0	'LITTLE DRY CREEK '	'SYCAMORE ROAD '	'0.17 MI E OF WATTS VALLEY'	9	85	89	0	100	4	24	0	6	6
976		42 0283	0F347	'STATE ROUTE 41 '	'TULARE ST '	'06-FRE-041-R23.74-FRE '	9	85	75	24	100	50	53	0	39	42

Roadways and Future Flooding

According to the scoring, many of the roads vulnerable to flooding occur in the western portion of the county in the rural portions of the San Joaquin Valley. There are several vulnerable mountain roads in the foothills of both the Diablo Range and the Sierra Nevada. There are also some pockets of vulnerable roads in the Fresno metropolitan area where the street network overlaps riverine floodplains.

The roadway segment with the highest vulnerability scores was the SR-180 over the Fresno Slough near Mendota. This stretch was identified as a location experiencing recurring issues. It lies within the 100-year floodplain and is projected to experience relatively high increases in precipitation. It is also relatively high volume and low redundancy and is in a Fresno COG designated EJ community. Belmont Avenue in Mendota near its intersection with SR-180 was also highlighted by the scoring.

The SR-269 north of Huron was another high vulnerability stretch of roadway, identified because of its past issues, exposure, low redundancy, and being located within an EJ community.

A few short stretches of SR-99 were also rated highly vulnerable. These include a portion just south of the interchange with SR-41 and a portion just south of the S Cedar Avenue overpass in Fresno.

Other segments identified as highly vulnerable include Manning Avenue over Kings River in Reedley and North Fork Road over the San Joaquin River in Friant.

Portions of SR-41 just north of downtown Fresno were flagged for vulnerability, though this may have been in part due the resolution and accuracy of the floodplain and or the roadway data; it appears to be elevated above the surface in some places where it intersects the 100-year floodplain.

Figure 22. Vulnerability Scoring: Roadways & Future Flooding

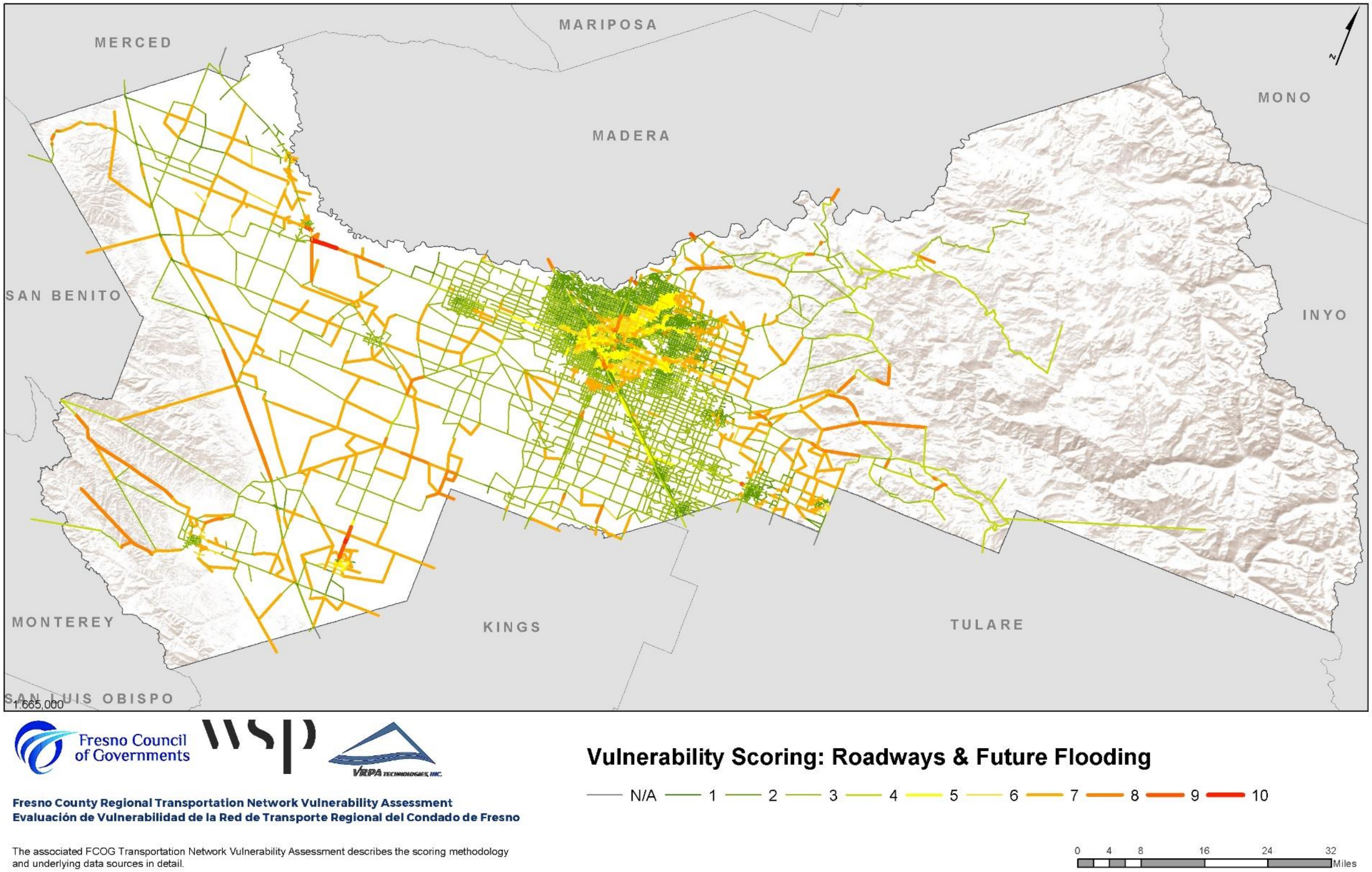


Table 7. Highest Flooding Vulnerability Scores for Roadways

OID_num	NAME	ROUTE	JURISDICTI	AB_code	FACTYP	final_score_flood_road	scalescore_flood_road	scale_pre_t1mx	scale_pre_mx	scale_flood_pln	scale_dmg_fld	scale_los	scale_fac_vol	scale_trk_vol	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
20273	SR 180	0	CALTRANS	28445_28446	2	10	100	55	79	100	100	33	19	6	98	3	1	100	30	16
20277	SR 180	0	CALTRANS	28448_43135	2	10	99	55	79	100	100	33	19	6	98	1	0	100	4	2
20274	SR 180	0	CALTRANS	28446_28447	2	10	99	55	79	100	100	33	19	6	98	3	1	0	32	17
20275	SR 180	0	CALTRANS	28447_43135	2	10	99	55	79	100	100	33	19	6	98	3	1	0	31	16
20271	SR 180	0	CALTRANS	28444_28445	2	10	99	55	79	100	100	33	19	6	90	2	1	100	19	10
20691	SR 180	0	Fresno County	6767_30994	2	10	98	55	79	100	100	50	20	6	79	0	0	100	17	13
20272	SR 180	0	CALTRANS	28444_53875	2	10	97	55	79	100	100	33	19	6	82	0	0	100	14	11
20309	SR 180	0	CALTRANS	30995_53875	2	10	97	55	79	100	100	33	19	6	81	0	0	100	11	9
20666	SR 180	0	Fresno County	30994_30995	2	10	97	55	79	100	100	33	18	5	80	0	0	100	14	11
20665	SR 180	0	Fresno County	30993_30994	2	10	93	55	79	100	100	17	1	1	79	0	0	100	19	15
20351	SR 180	0	CALTRANS	6768_30995	2	10	93	55	79	100	100	17	1	0	80	0	0	100	15	12
7187	Belmont	0	Mendota	28349_30173	4	10	91	56	63	100	100	17	7	2	76	1	8	100	16	11
7188	Belmont	0	Mendota	28349_42639	4	10	91	56	63	100	100	17	7	2	76	1	8	100	16	11
20990	SR 269	0	Fresno County	6621_28224	2	10	91		30	100	100	17	9	2	94	2	0	100	3	8
20965	SR 269	0	Fresno County	28224_39466	2	9	90		24	100	100	17	9	2	95	1	0	100	2	6
22823	Upper Brdg	0	Reedley	6961_28994	2	9	90	53	34	100	100	17	23	5	76	4	7	100	20	12
22821	Upper Brdg	0	Reedley	6960_28993	2	9	90	53	34	100	100	17	22	5	76	4	7	100	20	12
20964	SR 269	0	Fresno County	28223_39466	2	9	88		24	100	100	17	9	2	85	2	3	100	3	6
20968	SR 269	0	Fresno County	28404_52033	2	9	88	41	40	100	100	17	9	2	95	2	0	100	3	6
21005	SR 269	0	Huron	28223_42222	2	9	88		24	100	100	17	9	2	82	3	7	100	8	17
20991	SR 269	0	Fresno County	6621_6622	2	9	88	41	40	100	100	17	9	2	92	3	0	100	4	10
21004	SR 269	0	Huron	28222_42223	2	9	88		24	100	100	17	9	2	81	2	7	100	7	16
21007	SR 269	0	Huron	42222_42223	2	9	88		24	100	100	17	9	2	81	3	7	100	8	17
20966	SR 269	0	Fresno County	28225_52033	2	9	88	41	40	100	100	17	9	2	90	6	1	100	9	20
20992	SR 269	0	Fresno County	6622_28225	2	9	88	41	40	100	100	17	9	2	90	6	1	100	8	18
20709	SR 180	0	Mendota	30175_38552	2	9	86	56	63	75	100	50	21	7	79	1	8	100	16	11
20708	SR 180	0	Mendota	28350_30175	2	9	86	56	63	75	100	50	21	7	78	2	9	100	19	13
21389	SR 41	0	CALTRANS	18572_51555	1	9	85	76	47	100	0	100	96	9	10	7	55	100	32	36

Roadways and Future Wildfire

The Central Valley is home to most of Fresno County's population, where wildfire risk is lower. But the rural roadway networks in of both the Sierra Nevada and Diablo Range are highly exposed to wildfire.

The longest stretches of highly vulnerable roadway are the SR-180, Auberry Road, and the SR-168 in the Sierras. These have very low redundancy and relatively high volume (especially portions of Auberry Road and SR-168 lower in the mountains) compared to other rural roads in the county's exposed areas. Other highly vulnerable Sierra roadways include Lodge, Powerhouse, SR-63, Trimmer Springs, and Watts Valley.

On the Diablo Range side, the most vulnerable roadways were the SR-198 west of Coalinga and Los Gatos Creek Road. Little Panoche Road was also flagged as highly vulnerable, though the portion of the roadway in Fresno County appears to be mostly in grassland (rather than woodland or scrub) and therefore likely poses less of a threat to the transportation network.

Figure 23. Vulnerability Scoring: Roadways and Future Wildfire

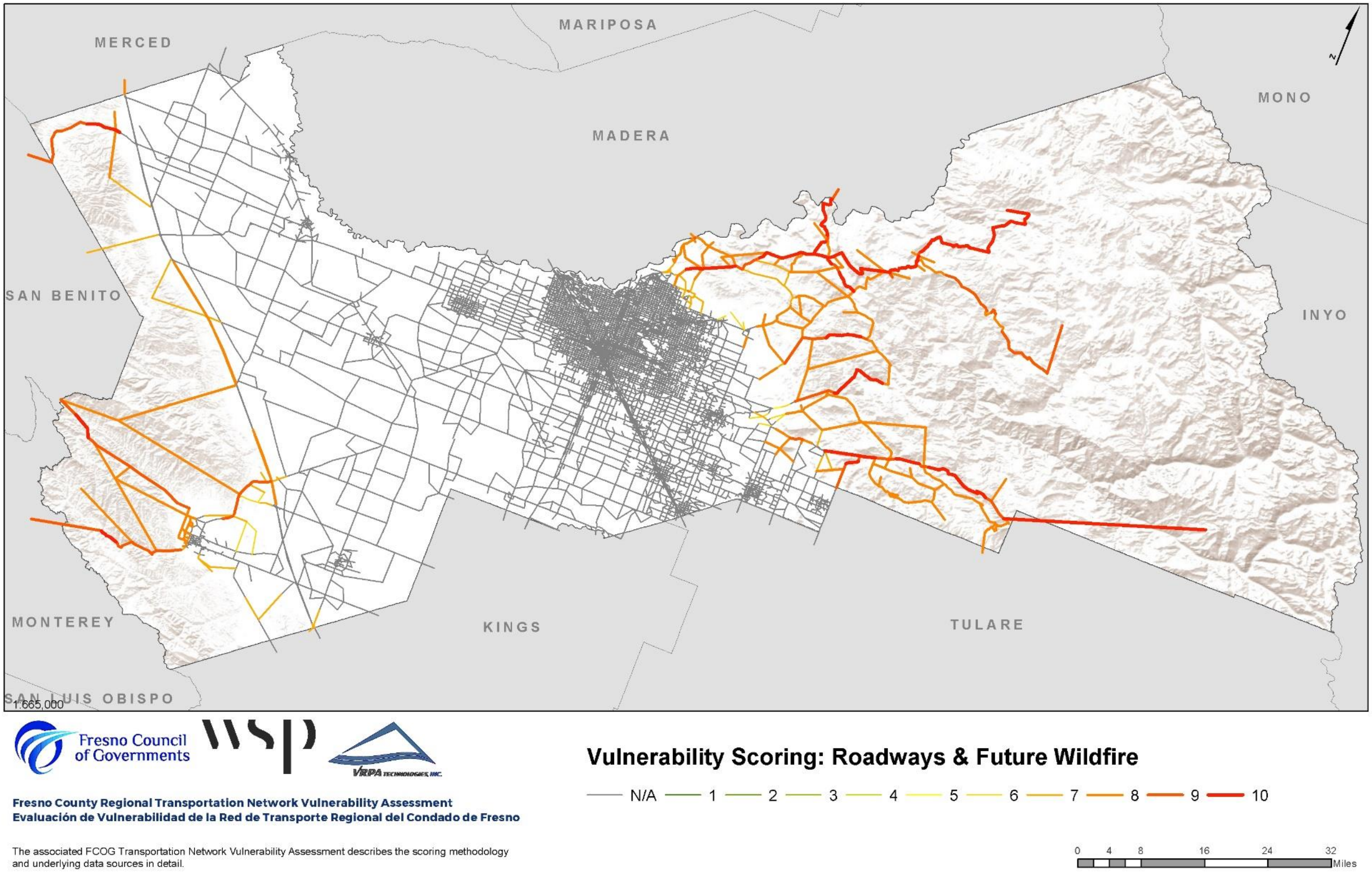


Table 8. Highest Wildfire Vulnerability Scores for Roadways

OID_num	NAME	JURISDICTI	AB_code	FACTYP	final_score_fire_road	scalescore_fire_road	scale_time_elev_burn	scale_cat_burn	scale_dmg_fire	scale_los	scale_fac_vol	scale_trk_vol	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
6505	Auberry	Fresno County	7620_45095	4	10	100	100	75	100	100	18	3	98	0	1	0	1	1
20175	SR 168	Fresno County	41850_47404	2	10	100	100	100	100	17	2	0	98	2	8	0	2	4
20224	SR 168	Fresno County	7134_7135	2	10	100	100	100	100	17	2	0	98	2	7	0	2	4
20156	SR 168	Fresno County	36658_47353	2	10	100	100	100	100	17	2	0	98	2	6	0	2	3
20155	SR 168	Fresno County	36623_53909	2	10	100	100	100	100	17	2	0	98	2	6	0	2	3
20154	SR 168	Fresno County	36622_36623	2	10	100	100	100	100	17	2	0	98	2	6	0	2	3
20157	SR 168	Fresno County	36658_47404	2	10	100	100	100	100	17	2	0	98	1	5	0	1	2
20169	SR 168	Fresno County	38917_47984	2	10	100	100	100	100	17	2	0	98	1	1	0	2	4
20221	SR 168	Fresno County	7105_36622	2	10	100	100	100	100	17	2	0	98	1	1	0	2	4
20159	SR 168	Fresno County	36663_36664	2	10	100	100	100	100	17	2	0	98	1	1	0	2	4
20173	SR 168	Fresno County	41849_41850	2	10	100	100	100	100	17	2	0	98	1	4	0	1	2
20164	SR 168	Fresno County	36667_53903	2	10	100	100	100	100	17	2	0	98	1	0	0	2	3
20163	SR 168	Fresno County	36667_47984	2	10	100	100	100	100	17	2	0	98	1	0	0	2	3
20166	SR 168	Fresno County	36668_47991	2	10	100	100	100	100	17	2	0	98	1	0	0	2	3
20168	SR 168	Fresno County	36686_38845	2	10	100	100	100	100	17	2	0	98	1	0	0	2	3
20174	SR 168	Fresno County	41849_47351	2	10	100	100	100	100	17	2	0	98	1	3	0	1	2
20167	SR 168	Fresno County	36686_38844	2	10	100	100	100	100	17	2	0	98	1	0	0	1	2
20165	SR 168	Fresno County	36668_38844	2	10	100	100	100	100	17	2	0	98	1	0	0	1	2
20223	SR 168	Fresno County	7134_47351	2	10	100	100	100	100	17	2	0	98	1	3	0	1	1
20160	SR 168	Fresno County	36664_47971	2	10	100	100	100	100	17	2	0	98	1	0	0	1	2
20225	SR 168	Fresno County	7135_36659	2	10	99	100	100	100	17	2	0	98	1	3	0	1	1
20161	SR 168	Fresno County	36665_47572	2	10	99	100	100	100	17	2	0	98	1	0	0	1	2
20170	SR 168	Fresno County	38917_47991	2	10	99	100	100	100	17	2	0	98	1	0	0	1	2
20162	SR 168	Fresno County	36665_47971	2	10	99	100	100	100	17	2	0	98	1	0	0	1	1
20177	SR 168	Fresno County	47572_53903	2	10	99	100	100	100	17	2	0	98	1	0	0	1	1
20176	SR 168	Fresno County	47353_53909	2	10	99	100	100	100	17	2	0	98	0	2	0	0	1
20222	SR 168	Fresno County	7105_50049	2	10	99	100	100	100	17	2	0	98	0	0	0	1	1
20158	SR 168	Fresno County	36659_36663	2	10	99	100	100	100	17	2	0	98	0	0	0	1	1
6506	Auberry	Fresno County	7620_7621	4	10	99	100	75	100	100	18	3	91	0	2	0	2	1
6507	Auberry	Fresno County	7621_51354	4	10	99	100	75	100	100	18	2	88	0	3	0	3	2
4561		Fresno County	2852_38845	10	10	98	100	100	100	0	2	0	98	0	0	0	0	1
4564		Fresno County	2855_7166	10	10	98	100	100	100	0	0	0	97	0	0	0	0	0
14635	Ll Panoche	Fresno County	28249_38449	4	10	95	100	75	100	17	9	0	98	3	1	100	17	13
14636	Ll Panoche	Fresno County	28250_38448	4	10	95	100	75	100	17	9	0	98	3	0	100	15	11
6480	Auberry	Fresno County	43652_51354	4	10	95	100	75	100	50	18	2	90	0	1	0	1	0
14639	Ll Panoche	Fresno County	28251_38448	4	10	95	100	75	100	17	9	0	98	3	0	100	13	10
14633	Ll Panoche	Fresno County	28248_28249	4	10	95	100	75	100	17	9	0	98	2	0	100	10	8
14637	Ll Panoche	Fresno County	28250_38449	4	10	95	100	75	100	17	9	0	98	1	0	100	8	6
14634	Ll Panoche	Fresno County	28248_39548	4	10	95	100	75	100	17	9	0	98	1	0	100	5	4
6452	Auberry	Fresno County	27829_43652	4	10	95	100	75	100	50	17	2	86	3	7	0	1	0

Roadways and Future Temperature Change

Changes in prolonged periods of high temperatures can exceed the design thresholds of the pavement binder grades used on the roadways. To measure exposure, we analyzed the maximum change in 7-day moving average maximum temperature across different climate scenarios and timeframes. Generally, the eastern and northern portions of Fresno County are projected larger increases in this metric compared to portions of the County farther to the west and south. Because exposure was combined with consequence information and travel volumes were weighted highly in the scoring, most of the high-volume roadways in Fresno County were flagged as most vulnerable to future temperature increases. This includes most of SR-99 within Fresno County, the SR-41 north of its interchange with SR-99, and a small portion of SR-180 between its interchanges with SR-41 and SR-168 near downtown Fresno.

Figure 24 Vulnerability Scoring: Roadways & Future Temperature

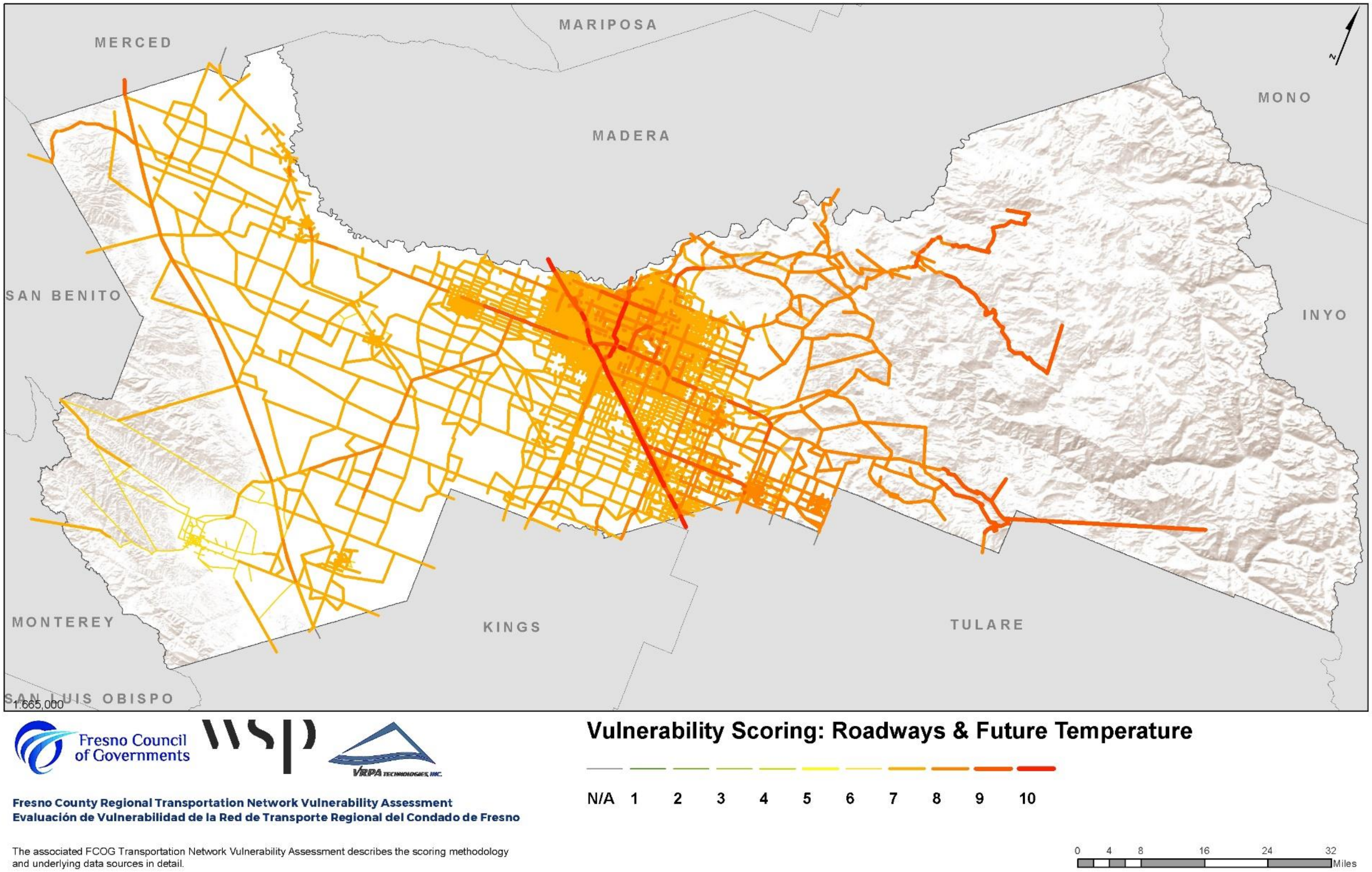


Table 9. Highest Temperature Vulnerability Scores for Roadways

OID_num	NAME	JURISDICTI	AB_code	FACTYP	final_score_temp_road	scalescore_temp_road	scale_temp7_mx	scale_los	scale_fac_vol	scale_trk_vol	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
21408	SR 41	CALTRANS	19677_19680	1	10	100	78	100	99	8	14	27	30	100	21	21
21400	SR 41	CALTRANS	18825_40109	1	10	100	78	100	99	8	19	6	31	100	17	19
21409	SR 41	CALTRANS	19677_55277	1	10	100	78	100	99	8	16	21	24	100	17	10
21396	SR 41	CALTRANS	18746_18747	1	10	100	78	100	98	7	11	9	41	100	27	29
21952	SR 99	Fresno County	24202_52216	1	10	100	78	100	91	37	47	1	8	0	9	2
21404	SR 41	CALTRANS	18841_18843	1	10	100	78	100	98	7	19	6	33	100	25	20
21484	SR 41	CALTRANS	18585_50368	1	10	100	76	100	100	9	9	5	59	100	37	41
21406	SR 41	CALTRANS	18842_55277	1	10	100	78	100	99	8	14	8	28	100	19	16
21483	SR 41	CALTRANS	18583_50368	1	10	100	76	100	100	9	8	5	59	100	37	41
21937	SR 99	Fresno County	10959_10961	1	10	99	77	100	88	35	63	6	1	0	16	7
21913	SR 99	Fowler	24271_24522	1	10	99	78	100	88	37	59	1	2	0	5	2
21951	SR 99	Fresno County	24200_52217	1	10	99	78	100	91	37	43	1	6	0	11	2
21973	SR 99	Fresno County	52216_52217	1	10	99	78	100	91	37	43	1	6	0	11	2
21243	SR 41	CALTRANS	19678_55258	1	10	99	78	100	98	7	16	21	24	100	18	10
21912	SR 99	Fowler	24271_24275	1	10	99	78	100	88	37	54	2	12	0	7	2
21979	SR 99	Fresno County	7445_24202	1	10	99	78	100	91	37	40	2	9	0	8	2
21395	SR 41	CALTRANS	18745_55281	1	10	99	78	100	99	8	13	6	27	100	6	9
21922	SR 99	Fowler	24522_24531	1	10	99	78	100	88	37	51	1	1	0	18	5
21407	SR 41	CALTRANS	18843_55258	1	10	99	78	100	98	7	13	8	28	100	19	16
21481	SR 41	CALTRANS	18577_18583	1	10	99	76	100	100	9	4	4	52	100	36	43
21915	SR 99	Fowler	24274_24275	1	10	99	78	100	88	37	50	2	15	0	9	2
21881	SR 99	CALTRANS	11133_50221	1	10	99	76	100	97	38	12	6	14	100	10	8
21889	SR 99	CALTRANS	50221_50356	1	10	99	76	100	97	38	11	6	15	100	10	9
21908	SR 99	Fowler	24209_24210	1	10	99	78	100	91	37	35	1	13	0	10	2
21397	SR 41	CALTRANS	18747_55254	1	10	99	78	100	98	7	12	6	27	100	6	9
21926	SR 99	Fowler	7445_24209	1	10	99	78	100	91	37	35	1	13	0	8	2
21947	SR 99	Fresno County	11011_52360	1	10	99	77	100	85	34	66	5	1	0	21	9
21975	SR 99	Fresno County	52224_52360	1	10	99	77	100	85	34	66	5	1	0	21	9
21883	SR 99	CALTRANS	11191_11193	1	10	99	76	100	97	38	8	9	2	100	16	12
21888	SR 99	CALTRANS	50220_50356	1	10	99	76	100	97	38	9	6	11	100	8	7
21938	SR 99	Fresno County	10959_11011	1	10	99	77	100	85	34	66	4	1	0	16	7
21884	SR 99	CALTRANS	11191_50220	1	10	99	76	100	97	38	8	5	2	100	8	7

Transit Stops and Future Flooding

In Fresno County, the most vulnerable transit stops to future flooding lie in the Fresno metro area, though there are a few pockets elsewhere. Large swaths of the metro area are located within the current 500-year floodplain, rendering many of the transit stops in the area vulnerable.

The largest concentrations of highly vulnerable stops are in the portions of the Roosevelt neighborhood of Fresno and downtown Fresno that overlap the 500-year floodplain. The cluster of Roosevelt stops is in an EJ community with a high population density and high 'no vehicle access' rates. The downtown stops are in an EJ community with a high employment density, high 'no vehicle access' rates, and high CalEnviroScreen scores. Several transit stops along Dry Creek to the North of downtown Fresno are within the 100-year floodplain and thus are considered high vulnerable. Closer to downtown, there are several stops in the 100-year floodplain near the channel that runs on north of and parallel to SR-180 as well as along the SR-99.

Outside of the Fresno metro area, several stops along the SR-180 across the Fresno Slough floodplain near Mendota are highly vulnerable due to their high exposure, sparsity of the roadway network, and location within a designated EJ community. There are a few highly vulnerable stops in the 100-year floodplain between Five Points and Lanare on W Mount Whitney Avenue. These are also in an EJ community on roadways with low redundancy.

Figure 25 Fresno County Vulnerability Scoring: Transit Stops & Future Flooding

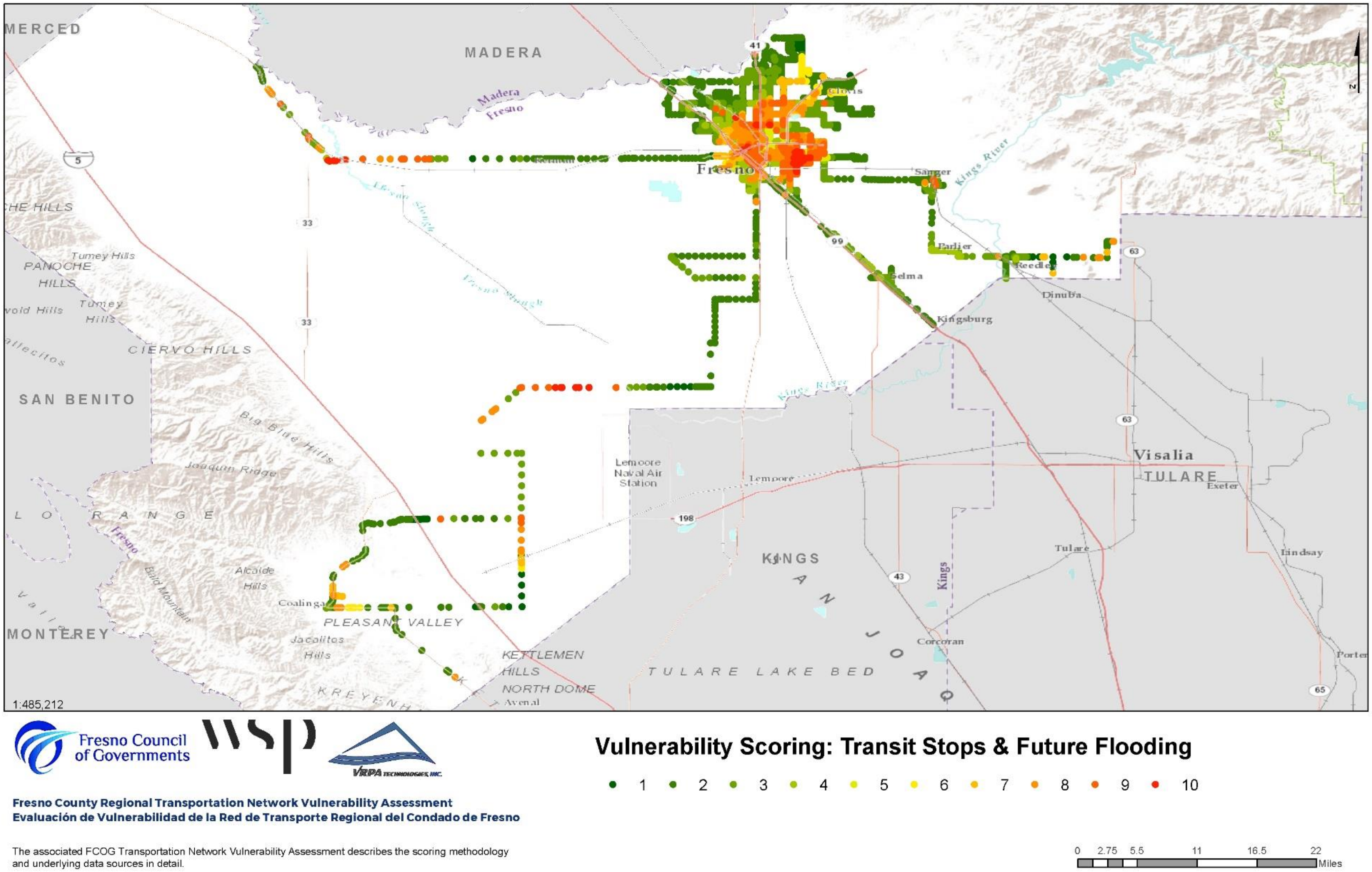


Table 10. Highest Flooding Vulnerability Scores for Transit Stops

OID_num	OBJECTID	LINEID	SEQNO	NODES	final_score_flood_trans	scalescore_flood_trans	scale_pre_t1mx	scale_pre_mx	scale_flood_pln	scale_dmg_fld	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
7172	7172	37	61	28445	10	100	66	100	100	0	99	4	2	100	71	19
7491	7491	38	163	28445	10	100	66	100	100	0	99	4	2	100	71	19
2589	2589	13	73	27907	10	99	96	59	100	0	24	9	45	100	67	37
8114	8114	42	95	27907	10	99	96	59	100	0	24	9	45	100	67	37
4629	4629	22	164	16535	10	98	96	59	100	0	28	9	37	100	67	37
2587	2587	13	71	16535	10	98	96	59	100	0	28	9	37	100	67	37
3984	3984	19	73	16535	10	98	96	59	100	0	27	9	37	100	67	37
8112	8112	42	93	16535	10	98	96	59	100	0	27	9	37	100	67	37
2434	2434	12	97	16535	10	98	96	59	100	0	27	9	37	100	67	37
2061	2061	10	110	16535	10	98	96	59	100	0	27	9	37	100	67	37
8089	8089	42	70	16535	10	98	96	59	100	0	27	9	37	100	67	37
9826	9826	55	165	16535	10	98	96	59	100	0	27	9	37	100	67	37
4115	4115	20	55	16535	10	98	96	59	100	0	27	9	37	100	67	37
6409	6409	32	61	13132	10	98	100	66	75	0	57	15	100	100	75	48
9614	9614	54	210	13132	10	98	100	66	75	0	56	15	100	100	75	48
10734	10734	66	27	13130	10	98	100	66	75	0	68	41	67	100	53	55
1473	1473	8	49	13130	10	98	100	66	75	0	68	41	67	100	53	55
10683	10683	65	12	13130	10	98	100	66	75	0	68	41	67	100	53	55
1373	1373	7	202	13130	10	98	100	66	75	0	67	41	67	100	53	55
10745	10745	66	38	13058	10	97	100	66	75	0	70	8	67	100	74	57
8213	8213	42	194	13058	10	97	100	66	75	0	70	8	67	100	74	57
10744	10744	66	37	13061	10	97	100	66	75	0	62	8	67	100	74	57
8212	8212	42	193	13061	10	97	100	66	75	0	62	8	67	100	74	57
8211	8211	42	192	13064	10	97	100	66	75	0	62	8	67	100	74	57
7580	7580	39	28	10591	10	97	96	59	100	0	12	8	44	100	55	39
7747	7747	40	83	10591	10	97	96	59	100	0	12	8	44	100	55	39
10743	10743	66	36	13064	10	97	100	66	75	0	61	8	67	100	74	57

Transit Stops and Future Wildfire

Very few transit stops in Fresno County are flagged as vulnerable to wildfire. The only exposed stops were a few north of Coalinga along the SR-198, which has limited redundancy. However, this area appears to be mostly grassland, which poses less of a threat to the transportation system than an exposed woodland or scrubland.

Figure 26. Fresno County Vulnerability Scoring: Transit Stops & Future Wildfire

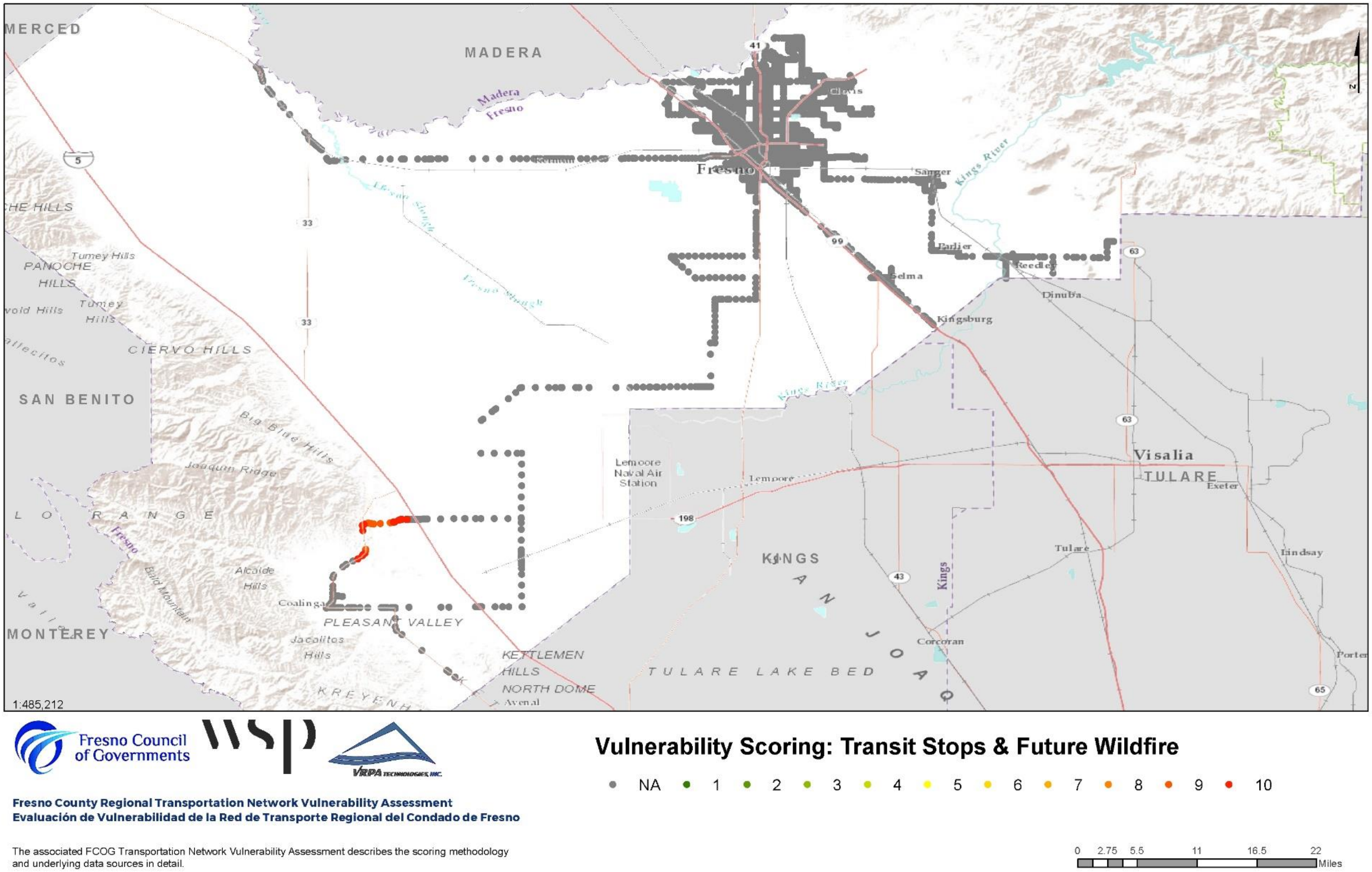


Table 11. Highest Wildfire Vulnerability Scores for Transit Stops

OID_num	OBJECTID	LINEID	SEQNO	NODES	final_score_fire_trans	scalescore_fire_trans	scale_time_elev_burn	scale_cat_burn	scale_dmg_fire	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
8846	8846	49	159	42244	10	100	100	50	0	99	3	1	0	11	2
5854	5854	29	30	42244	10	100	100	50	0	99	3	1	0	11	2
6011	6011	30	79	42244	10	100	100	50	0	99	3	1	0	11	2
8925	8925	50	40	42244	10	100	100	50	0	99	3	1	0	11	2
5981	5981	30	49	38236	10	100	100	50	0	99	2	1	0	11	2
5885	5885	29	61	29660	10	100	100	50	0	99	2	1	0	11	2
8953	8953	50	68	38235	10	100	100	50	0	99	2	1	0	11	2
8954	8954	50	69	46461	10	100	100	50	0	99	2	1	0	11	2
5982	5982	30	50	46461	10	100	100	50	0	99	2	1	0	11	2
5983	5983	30	51	38235	10	100	100	50	0	99	2	1	0	11	2
8955	8955	50	70	38236	10	100	100	50	0	99	2	1	0	11	2
8951	8951	50	66	29659	10	100	100	50	0	99	2	1	0	11	2
8956	8956	50	71	29660	10	100	100	50	0	99	2	1	0	11	2
8819	8819	49	132	39397	10	100	100	50	0	99	2	1	0	11	2
5980	5980	30	48	29660	10	100	100	50	0	99	2	1	0	11	2
5984	5984	30	52	39397	10	100	100	50	0	99	2	1	0	11	2
5985	5985	30	53	29659	10	100	100	50	0	99	2	1	0	11	2
8816	8816	49	129	38236	10	100	100	50	0	99	2	1	0	11	2
8820	8820	49	133	29659	10	100	100	50	0	99	2	1	0	11	2
5882	5882	29	58	38235	10	100	100	50	0	99	2	1	0	11	2
5880	5880	29	56	29659	10	100	100	50	0	99	2	1	0	11	2
5881	5881	29	57	39397	10	100	100	50	0	99	2	1	0	11	2
5883	5883	29	59	46461	10	100	100	50	0	99	2	1	0	11	2
5884	5884	29	60	38236	10	100	100	50	0	99	2	1	0	11	2
8815	8815	49	128	29660	10	100	100	50	0	99	2	1	0	11	2
8817	8817	49	130	46461	10	100	100	50	0	99	2	1	0	11	2
8818	8818	49	131	38235	10	100	100	50	0	99	2	1	0	11	2
8952	8952	50	67	39397	10	100	100	50	0	99	2	1	0	11	2
5986	5986	30	54	28190	10	100	100	50	0	98	2	1	0	11	2
5987	5987	30	55	28189	10	100	100	50	0	98	2	1	0	11	2
5988	5988	30	56	29658	10	100	100	50	0	98	2	1	0	11	2
5989	5989	30	57	28188	10	100	100	50	0	98	2	1	0	11	2
8948	8948	50	63	29658	10	100	100	50	0	98	2	1	0	11	2
8934	8934	50	49	28180	10	100	100	50	0	97	3	1	0	11	2

Transit Stops and Future Extreme Heat

Extreme temperature and associated poor air quality pose threats to transit users. The projected future high temperatures are relatively uniform in the Central Valley portion of Fresno County, where virtually all the transit stops are located. The variation in high heat vulnerability scores are therefore driven primarily by social factors.

The most vulnerable stops are in the Fresno metro area. There are two major clusters of highest vulnerability stops. One is in downtown Fresno area, roughly bounded by E Divisadero Street, E Street, Ventura Avenue, and P Street. This area is a County-designated EJ community, has very high CalEnviroScreen scores, 'no vehicle access' rates, and density (particularly employment density). The other cluster is in the Roosevelt neighborhood, particularly on S Chestnut Avenue between E Huntington Avenue and E Florence Avenue, and on the blocks of E Kings Canyon Road and E Butler Avenue near there. Most of this area is an EJ community and characterized by high CalEnviroScreen scores, relatively high 'no vehicle access' rates, and high population density.

There are many other highly vulnerable transit stops surrounding both these clusters too. Most of central Fresno and the broader Roosevelt neighborhood are considered highly vulnerable. Other highly vulnerable clusters of transit stops outside of the Fresno metro area include several along SR-180 between Mendota and Kerman, and along and near S Golden State Boulevard in and just outside of Selma.

The scoring results are not meant to be interpreted in an overly precise or a binary manner. In general, extreme heat poses risks to transit users, particularly those in Fresno County's disadvantaged communities and those with few transportation alternatives. Warming temperatures are expected to amplify this risk.

Figure 27 Vulnerability Scoring: Transit Stops & Future Temperature

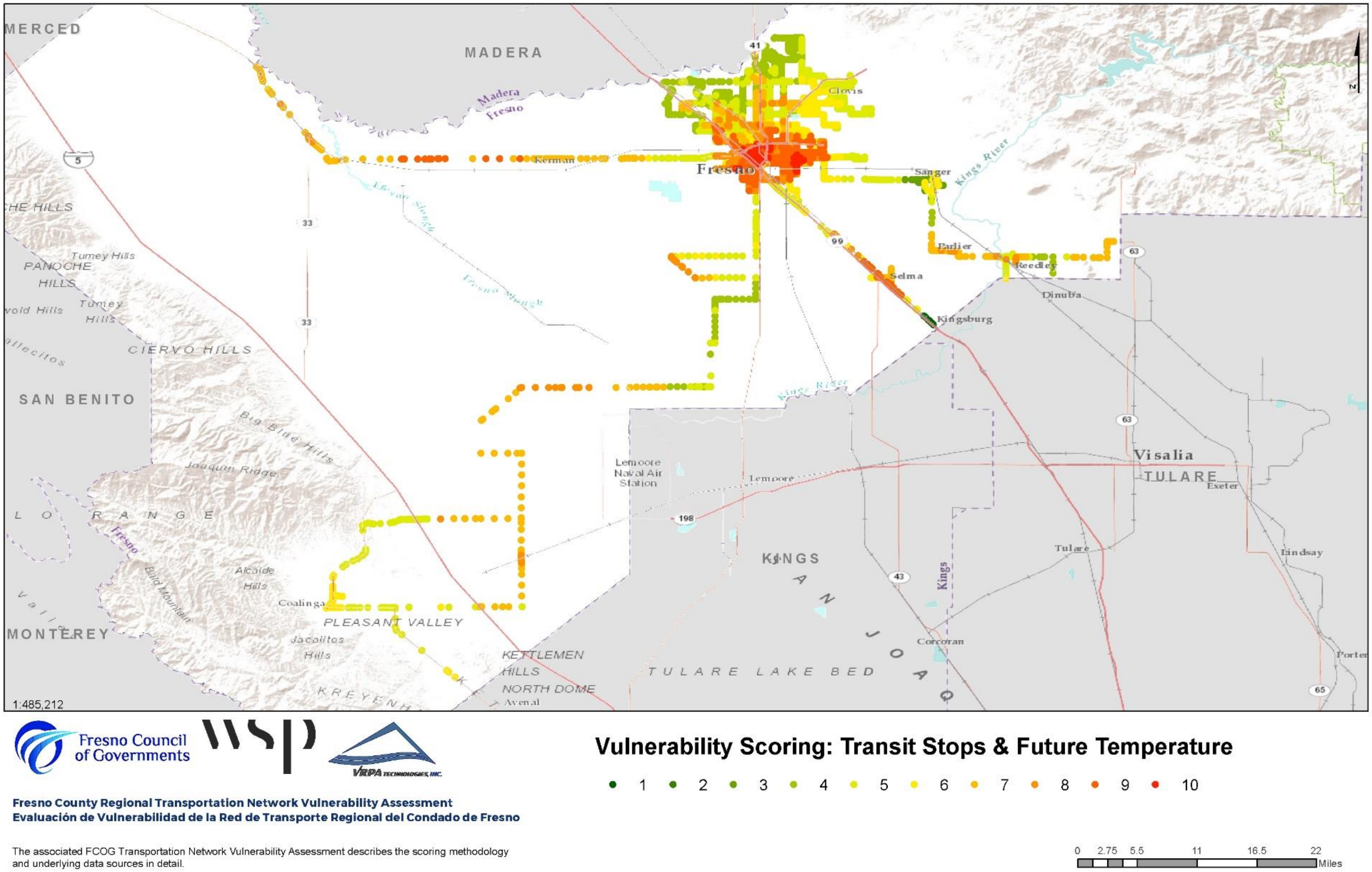


Table 12. Highest Temperature Vulnerability Scores for Transit Stops

OID_num	OBJECTID	LINEID	SEQNO	NODES	final_score_temp_trans	scalescore_temp_trans	scale_max_hh	scale_node_dens	scale_emp_dens	scale_pop_dens	scale_in_ej	scale_ces_den	scale_noveh_den
9783	9783	55	122	11734	10	100	86	8	89	41	100	58	78
5538	5538	28	95	11576	10	100	86	1	21	8	100	98	100
6337	6337	31	297	11576	10	100	86	1	21	8	100	98	100
6361	6361	32	13	11576	10	100	86	1	21	8	100	98	100
1999	1999	10	48	11576	10	100	86	1	21	8	100	98	100
3077	3077	15	138	11576	10	100	86	1	21	8	100	98	100
3199	3199	16	57	11576	10	100	86	1	21	8	100	98	100
9566	9566	54	162	11576	10	100	86	1	21	8	100	98	100
5350	5350	27	285	11576	10	100	86	1	21	8	100	98	100
9754	9754	55	93	11576	10	100	86	1	21	8	100	98	100
1863	1863	9	172	11576	10	100	86	1	21	8	100	98	100
10581	10581	62	21	11732	10	100	86	7	89	41	100	58	78
2390	2390	12	53	11732	10	100	86	7	89	41	100	58	78
560	560	4	7	11732	10	100	86	7	89	41	100	58	78
9538	9538	54	134	11732	10	100	86	7	89	41	100	58	78
10579	10579	62	19	11732	10	100	86	7	89	41	100	58	78
6972	6972	36	3	10467	10	100	86	4	79	11	100	79	84
7285	7285	37	174	10467	10	100	86	4	79	11	100	79	84
6346	6346	31	306	10467	10	100	86	4	79	11	100	79	84
6351	6351	32	3	10467	10	100	86	4	79	11	100	79	84
7375	7375	38	47	10467	10	100	86	4	79	11	100	79	84
6967	6967	35	135	10467	10	100	86	4	79	11	100	79	84
2010	2010	10	59	10483	10	100	86	2	80	12	100	79	84
3634	3634	18	3	10483	10	100	86	2	80	12	100	79	84
6976	6976	36	7	10483	10	100	86	2	80	12	100	79	84
3088	3088	15	149	10483	10	100	86	2	80	12	100	79	84
2663	2663	13	147	10483	10	100	86	2	80	12	100	79	84
1315	1315	7	144	10483	10	100	86	2	80	12	100	79	84
1530	1530	8	106	10483	10	100	86	2	80	12	100	79	84
10633	10633	64	11	10483	10	100	86	2	80	12	100	79	84
1850	1850	9	159	10483	10	100	86	2	80	12	100	79	84
811	811	5	133	10483	10	100	86	2	80	12	100	79	84
9543	9543	54	139	10483	10	100	86	2	80	12	100	79	84
2273	2273	11	138	10483	10	100	86	2	80	12	100	79	84
1002	1002	6	92	10483	10	100	86	2	80	12	100	79	84
1314	1314	7	143	10479	10	100	86	3	67	23	100	79	84
10634	10634	64	12	10479	10	100	86	3	67	23	100	79	84
1003	1003	6	93	10479	10	100	86	3	67	23	100	79	84
1849	1849	9	158	10479	10	100	86	3	67	23	100	79	84
810	810	5	132	10479	10	100	86	3	67	23	100	79	84

Airports and Future Extreme Heat

Extreme high temperatures can affect aircraft operations and assets. High temperature projections are relatively uniform across the Central Valley portion of Fresno County, where the region’s airports are located. Thus, the scores are driven primarily by the airport type, which is an indicator of consequence in the event of disruption. Fresno Yosemite International Airport is the County’s sole Primary airport, so it received the highest heat vulnerability score.

Figure 28. Fresno County Vulnerability Score: Airport and Future Temperature

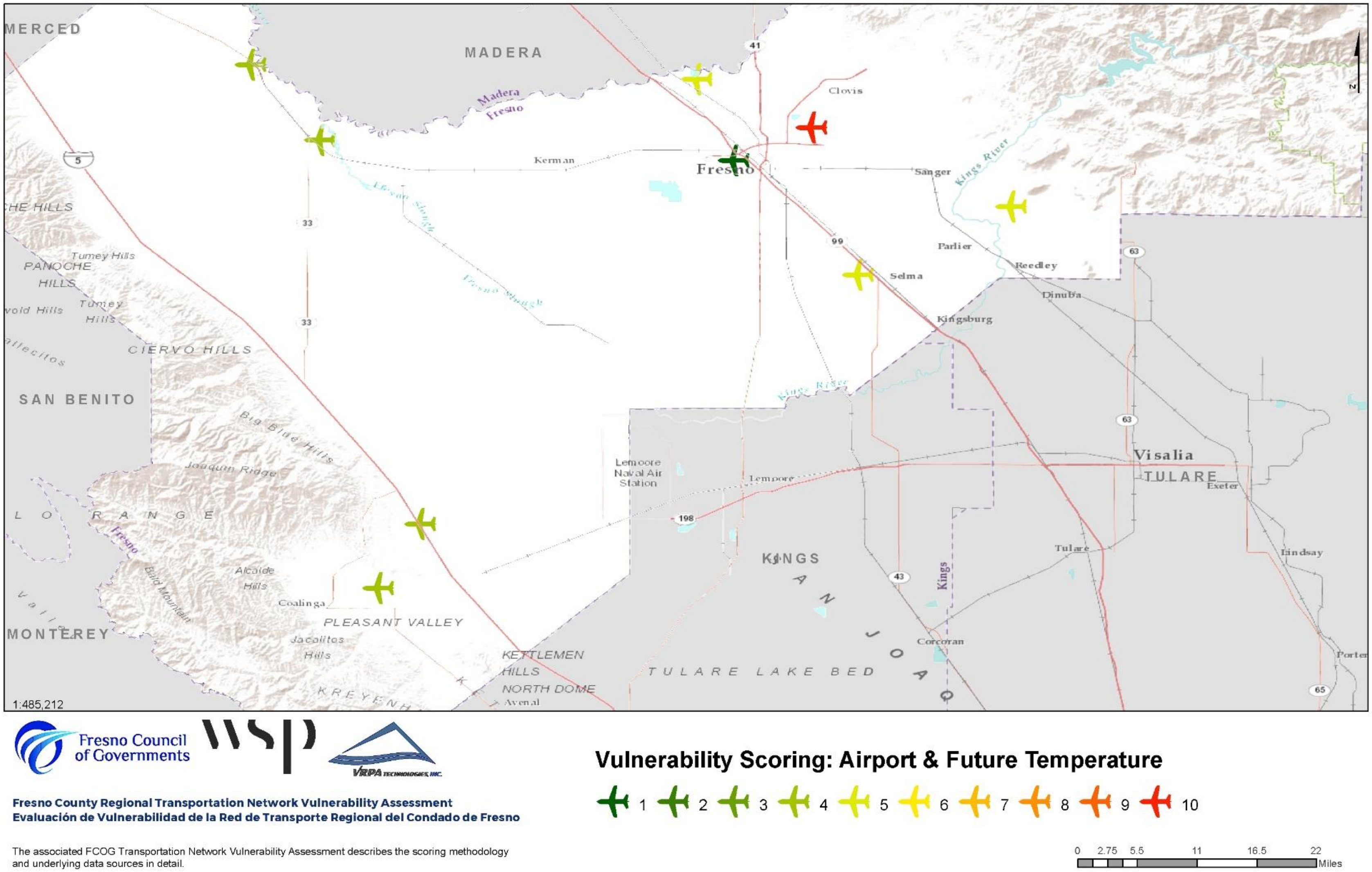


Table 13. Temperature Vulnerability Scores for Airport

OID_num	OBJECTID	AIRPORT_NAME	final_score_temp_air	scalescore_temp_air	scale_temp1_mx	scale_aport_class
9	9	Fresno Yosemite International	10	100	100	100
5	5	Selma Aerodome	5	42	94	50
6	6	Reedley Municipal Airport	5	47	97	50
8	8	Sierra Sky Park	5	48	98	50
1	1	Firebaugh Municipal Airport	4	32	87	50
2	2	Mendota Municipal Airport	4	32	87	50
3	3	Coalinga Municipal Airport	4	40	92	50
4	4	Harris Ranch Airport	4	36	90	50
7	7	Chandler Downtown Airport	1	0	99	0
10	10	Lemoore NAS			88	50

Airports and Future Flooding

Selma Airport is considered the most vulnerable to future flooding, as it overlaps the current 100-year floodplain and is projected to experience increases in heavy precipitation under some of the future climate scenarios. Fresno Yosemite International was also flagged as vulnerable given its designation as the county's sole Primary airport and high heavy precipitation projections under some of the climate scenarios. Chandler Downtown Airport is located in the current 500-year floodplain but did not receive a high vulnerability score since it is classified as a Reliever facility.

Figure 29. Fresno County Vulnerability Scoring: Airport & Future Flooding

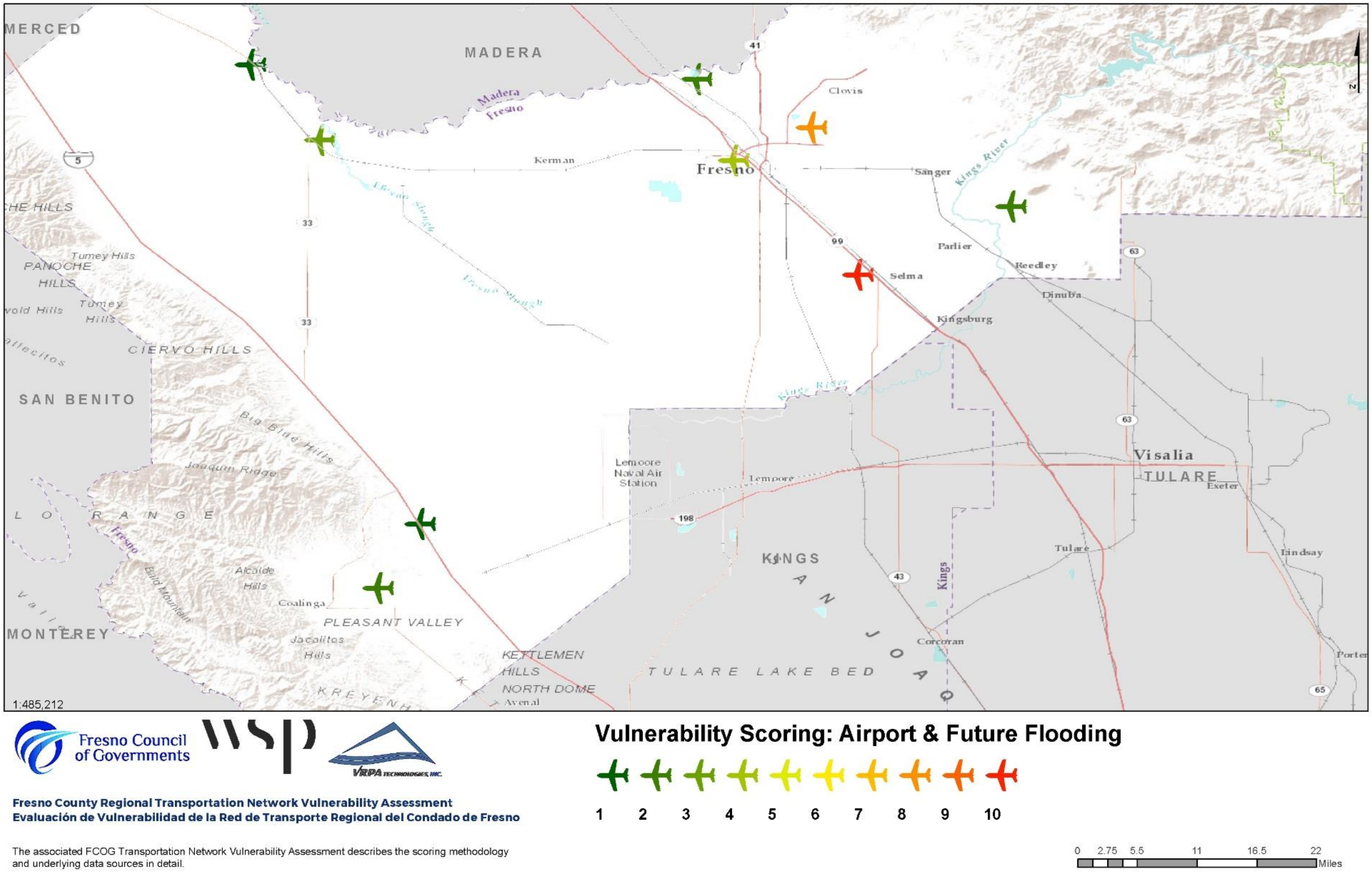


Table 14. Flooding Vulnerability Scores for Airport

OID_num	OBJECTID	AIRPORT_NAME	final_score_flood_air	scalescore_flood_air	scale_pre_t1mx	scale_pre_mx	scale_flood_pln	scale_dmg_fld	scale_aport_class
5	5	Selma Aerodome	10	100	79	100	100	0	50
9	9	Fresno Yosemite International	8	73	100	81	0	0	100
7	7	Chandler Downtown Airport	4	34	80	50	75	0	0
2	2	Mendota Municipal Airport	3	22	42	85	0	0	50
3	3	Coalinga Municipal Airport	2	15	54	42	0	0	50
6	6	Reedley Municipal Airport	2	10	42	31	0	0	50
8	8	Sierra Sky Park	2	14	76	16	0	0	50
1	1	Firebaugh Municipal Airport	1	0	27	0	0	0	50
4	4	Harris Ranch Airport	1	6	36	20	0	0	50
10	10	Lemoore NAS			0	34	0	0	50

Additional Analysis

Transit Ridership and High Heat

The project team analyzed transit ridership data from the Fresno Area Express (FAX) to explore the relationship between ridership and high heat events.[37] We paired systemwide daily ridership estimates with historical maximum temperature observations on the same days in the summers of 2017 and 2018. The ridership data were from Tuesdays, Wednesdays, and Thursdays during the summer break for school occurring in June, July, and August. Limiting the ridership to this window helped control for ridership variability due to school-related rides or day-of week-fluctuations.

The

[37] Ridership data were provided by the City of Fresno Department of Transportation.

Figure 30. FAX Summer Ridership and Maximum Temperature (2017, 2018) scatterplots show daily ridership on the vertical axes and degrees Fahrenheit daily maximum temperatures on the horizontal axes. The left scatterplot shows all of the data points included in the analysis. The right scatterplot shows the same data points minus the Fourth of July records. The right plot also includes a linear trendline, which indicates a negative correlation between daily maximum temperature and summer ridership.

We also conducted a brief regression analysis to evaluate the effect of daily maximum temperature (an explanatory variable) on ridership (the dependent variable). An Ordinary Least Squared (OLS) regression was used. The control variables were (1) a binary outlier flag indicating whether a day was the Fourth of July and (2) the date, which helped control for changes in service over time, particularly in between years.

According to the regression, daily maximum temperature is a significant predictor of daily ridership in the summer months. Controlling for the data and for holidays, higher maximum temperatures are associated with lower ridership. A 1°F increase in summer daily maximum temperature is associated with a roughly 130-person ridership decrease (90% confidence interval of 65-196 person decrease). Figure 31. FAX Summer Ridership and Maximum Temperature Regression Results shows the regression results and diagnostics.

The analysis implies that fewer people ride transit on very hot days in Fresno County. This could be for a variety of reasons, such as concerns about heat-related or poor air quality-related health issues for transit-dependent riders, discomfort, and the use of other modes, such as personal vehicles on these days.

Figure 30. FAX Summer Ridership and Maximum Temperature (2017, 2018)

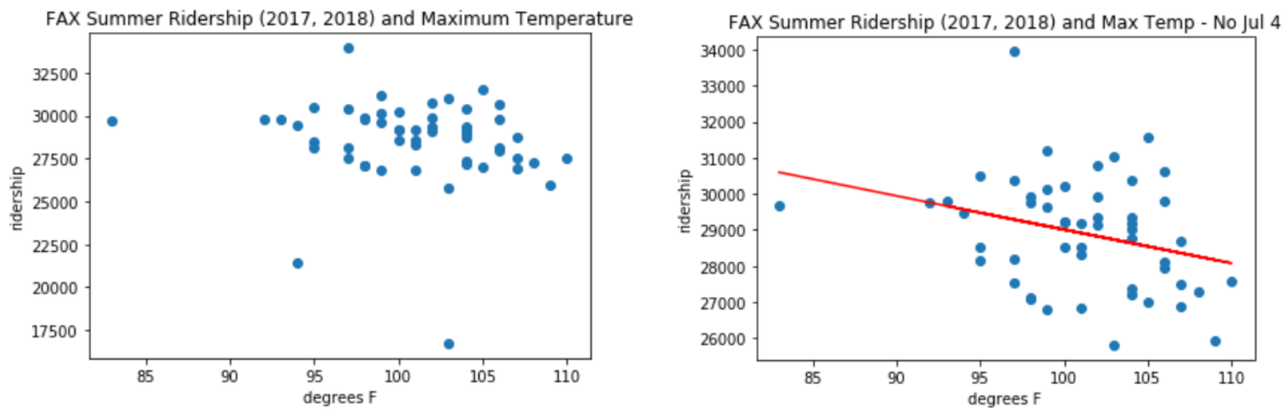


Figure 31. FAX Summer Ridership and Maximum Temperature Regression Results

Dep. Variable:	ridership	**R-squared:**	0.701
Model:	OLS	**Adj. R-squared:**	0.683
Method:	Least Squares	**F-statistic:**	39.13
Date:	Fri, 06 Sep 2019	**Prob (F-statistic):**	3.68e-13
Time:	16:40:53	**Log-Likelihood:**	-465.29
No. Observations:	54	**AIC:**	938.6
Df Residuals:	50	**BIC:**	946.5
Df Model:	3		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	-2.702e+06	7.72e+05	-3.500	0.001	-4.25e+06	-1.15e+06
tempmax	-130.7304	39.167	-3.338	0.002	-209.399	-52.062
holiday_outlier	-1.016e+04	1005.109	-10.104	0.000	-1.22e+04	-8137.058
date	3.7248	1.049	3.551	0.001	1.618	5.832

Omnibus:	3.194	**Durbin-Watson:**	1.202
Prob(Omnibus):	0.202	**Jarque-Bera (JB):**	2.496
Skew:	0.520	**Prob(JB):**	0.287
Kurtosis:	3.160	**Cond. No.**	3.01e+09

Battery Electric Buses and Heat-Related Operating Costs

Battery Electric Buses (BEBs) are being more readily deployed across California, due to the state's mandate to adopt such infrastructure to meet greenhouse gas reduction goals. In high-heat environments – such as Fresno County – and with the risk of increased high-heat days and heatwave events due to climate change, transit providers have a few key factors to consider when opting to procure BEB fleets. This subsection provides descriptions of potential risks of procuring BEBs in these geographies, including the risk of increased energy usage which underlie energy costs, risk of increased electricity costs during high-demand, and reliability concerns for batteries in these environments.

Risks of Increased Energy Usage & Risks of Increased Electricity Costs:

Material from Arcadia Power indicates that Los Angeles, CA residents saw a 42% increase in usage when comparing June 2016 average usage to June 2017 average usage—a result of above average temperatures.[38] Additionally, research conducted by the US Environmental Protection Agency (EPA) states that if the U.S.'s climate warms by 1.8 degrees Fahrenheit, the demand for energy used for air conditioning is expected to increase by 5% to 20%. These trends have implications for energy costs and for the sustainability of energy infrastructure, such as transmission lines and power stations, which may be pushed to capacity to meet energy demands.

Energy costs increase during high demand, which is exacerbated by increased temperatures and sustained increased temperatures when residents are relying heavily on air conditioning to keep cool. These are often referred to as "cooling degree days." Material from Arcadia Power indicates that Los Angeles, CA residents saw a 7% increase in the price per Kilowatt hour (kWh) when comparing June 2016 and June 2017 energy prices due to the heat waves in 2017.[39] The percent increase in price per kWh and average monthly usage for LA, Phoenix, Reno, and Tucson are listed in Table 15 below.

[38] Arcadia Power, 2018. <https://blog.arcadiapower.com/why-a-heatwave-costs-more-than-you-might-think/>

Table 15: Energy Usage and Costs for Cities in the Western US

City/State	Month/Year	Avg. Energy Usage/Month (kWh/month)	Avg. Rate ($/kWh)	Avg. Cost/Month ($/month)	% Increase in price per kWh	% Increase in Usage
Los Angeles, CA	June 2016	264 kWh/month	18.11 cents/kWh	$48/month		
	June 2017	374 kWh/month	19.39 cents/kWh	$73/month	7%	42%
Phoenix, AZ	June 2016	963 kWh/month	12.54 cents/kWh	$121/month		
	June 2017	1377 kWh/month	12.65 cents/kWh	$174/month	1%	43%
Reno, NV	June 2016	512 kWh/month	11.40 cents/kWh	$58/month		
	June 2017	643 kWh/month	11.64 cents/kWh	$75/month	2%	28%
Tucson, AZ	June 2016	932 kWh/month	12.54 cents/kWh	$117/month		
	June 2017	1078 kWh/month	12.65 cents/kWh	$136/month	1%	17%

While the 7% increase in cost per kWh cannot be used as a standard increase for all high-heat events, it provides a California-based example of the potential spike in energy costs, which will have implications for the operating costs of BEB infrastructure. The remaining examples help to bolster the argument that utility users should be cognizant of rate spikes and the strain of high demand on the system during high-heat events. Further, it is worth noting that these costs are indicative of residential power usage.

Reliability Concerns due to Increased Temperature & Increased Use of A/C:
External temperatures have implications on the performance of the battery. Research from the National Renewable Energy Laboratory indicates that the desired operating temperature to maximize efficiency for a BEB ranges between 15 degrees Celsius and 35 degrees Celsius.[40] The same research indicates that lithium ion batteries experience higher rates of power loss over a fifteen-year lifecycle of the asset in high temperature environments when compared to moderate and lower temperature environments. Operating at temperatures that exceed the desired range results in discharge degradation. The power loss through HVAC/air conditioning used to keep the bus operator and passengers cool influences the overall state of charge, resulting in a reduced range for the bus.[41] Further, high temperatures can also lead to non-uniform aging of batteries due to the experienced thermal gradients, which has implications for the full lifecycle cost of the asset or fleet. For example, battery electric bus pilot trials in Phoenix and Minnesota saw increased operating costs due to the demands for running cooling and heating systems.[42]

[40] National Renewable Energy Laboratory, 2011. <https://www.nrel.gov/docs/fy13osti/52818.pdf>
[41] Jewels Carter, WSP Bus/Public Works Facilities expert at WSP's Fleet & Facilities Division.
[42] Levy, Alon. 2019. <https://www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/>

Electric heat will be the primary factor to impact battery range impact, with electric cooling as the secondary factor and the individual driver performance (how the operator starts / stops / brakes) the tertiary factor. These three factors are not directly impacted by ambient air temperature, but managing the heat and cool of the ambient air creates the decrease in battery range. Good operator training can potentially reduce the negative impact of efficiency and range.

It is worth noting, that when procuring buses, agencies can define the bus vehicle specifications to be suitable for the climate and elevation range of the geography. The current American Public Transit Association (APTA) bus procurement standard range before being confirmed tweaked by each agency is 10 degrees Fahrenheit to 115 degrees Fahrenheit at a relative humidity between 5% and 100% and at an altitude from 3000 ft. above sea level down to sea level.[43]

Future Deep-Seated Landslides

The project team also identified and assessed locations of deep-seated landslide risk around Fresno County.[44] This assessment did not fit into the indicator scoring approach explained in the earlier section and transportation network impacts were analyzed separately. The assessment paired existing, landslide susceptible locations with future precipitation projections to identify areas where there is an existing risk of landslides that may be exacerbated or triggered by heavier precipitation events in the future.

Deep-seated landslides are slow-moving slides where the majority of the moving earth is deep under the ground, by anywhere from ten to several hundred feet. Once moving, these slides can continue on for years.[45] While shallow landslides are much more sudden and intense, deep-seated landslides can cause dangerous slope failure and can even trigger additional shallow slides. The deadliest landslide in the US, the 2014 Oso slide, which killed 45 and led to over $50 million in damages, was caused by the reactivation of an ancient, deep-seated landslide.[46] These types of slides can be triggered by geological and hydrological changes such as earthquakes and soil saturation from precipitation, respectively.

For this assessment, existing deep-seated landslide risk was based upon the California Geological Survey's (CGS) deep-seated landslide susceptibility dataset.[47] Future precipitation projections were included by calculating the change in the 60-day duration, 100-year depth precipitation values between historical observations and future projections for 2085.[48] The 60-day precipitation totals were used as an indicator

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[43] Jewels Carter, WSP Bus/Public Works Facilities expert at WSP's Fleet & Facilities Division.

[44] Due to data availability, the assessment did not analyze shallow landslides like debris flows and rock falls.

[45] http://www.wfpa.org/news-resources/blog/deep-seated-landslides-shallow-landslides-washington/

[46] http://www.geerassociation.org/administrator/components/com_geer_reports/geerfiles/GEER_Oso_Landslide_Report_low-res.pdf

[47] See metadata for more information: https://atlas.resources.ca.gov/arcgis/rest/services/Ocean/CSMW_Landslide_Susceptibility_in_California/MapServer/0

[48] These projections were calculated by finding the percentage change between the 100-year, 60-day precipitation ensemble median, RCP 8.5 projections in 2085 (2070 to 2099) and the backcasted projections. This percentage

for heavy soil saturation conditions that can trigger deep-seated landslides.[49] These layers were overlaid with one another to identify locations with *both* high deep-seated landslide susceptibility and high percentage increase in 60-day precipitation totals.

A scale was created to distinguish between low and high concern areas based upon existing susceptibility combined with considerations of future precipitation. This scale is as follows:

- **Very low** = These areas *do not* show any existing deep-seated landslide susceptibility **and** show *low* changes in 60-day precipitation totals.
- **Low** = These areas show *low* existing susceptibility ratings **and/or** *low* changes in 60-day precipitation totals.
- **Medium** = These areas fall in-between low and high levels of concern.
- **High** = These areas show *high* existing deep-seated landslide susceptibility **and/or** *high* percentage changes in 60-day precipitation totals.
- **Very High** = These areas demonstrate a high landslide susceptibility rating **and** high percentage change in 60-day precipitation totals.

The figures on the following pages show a selection of the of the results of combining the two datasets.[50] The transportation assets intersecting the areas of high to very high concern areas are shown on the maps in red. However, assets directly above or below the areas of concern may also be exposed. Nearly all of the high/very high concern areas appear in the Sierra Nevada and Diablo Range. Note that in the mountain regions, the roadway GIS layer used in the analysis is fairly sparse and has some spatial inaccuracies. Thus, some roads may not be shown here or be shown in incorrect locations.

Figure 32 on the following page provides an overview of the landslide concern areas across Fresno County. This map does not highlight individual assets that are in high to very high concern areas, but instead shows the general geography of deep-seated landslide risk areas.

Figure 33 shows landslide concern areas near Piedra and North Pine Flat Lake. This map demonstrates how landslide concern is consistent across Wildcat, Red, and Hog mountains. Watts Valley Rd (to the north) and East Trimmer Springs (to the south, near Piedra) both cross this terrain. This map also provides an example of how the roadway GIS layer has spatial inaccuracies. The center road that crosses right across the range from Stony Point eastward represents a rural and winding road through the mountains, but it is represented as a straight line in the network file.

Figure 34 follows SR-180 east of Hume, which travels along the South Fork of the Kings River. SR-180 lies in high landslide concern areas until it approaches Stag Dome, where the concern increases to very high. This map was chosen to include here as it shows a very high concern area in the Sierra Nevada.

change was then applied to the NOAA Atlas 14 100-year, 60-day values, which are derived from historical observations.

[49] Kenneth Johnson, WSP Geotechnical Engineer.

[50] Nine zoomed-in maps were generated for high/very high concern areas around the county, four of which are shown in this memorandum.

Figure 35 follows SR-168 from Prather all the way northeast to Lake Shore, by Huntington Lake. The map shows how risk exists in select locations throughout the corridor. It also shows how some assets outside of the corridor are also exposed to landslide concern, but the roadway network is so sparse in this area that it does not full represent the network. For example, two bridges lie north of Sugarloaf Hill (one is labeled as exposed), but they do not lie on the roadway network file. This means that there could be many more exposed roadways in this area that are not represented on the map.

Finally, Figure 36 shows landslide exposure along I-5, Los Gatos Creek Road, and SR-198 near Coalinga. This map demonstrates that landslide concern exists close to the valley floor, and not just in the Sierra Nevada.

Figure 32: Future Landslide Concern across Fresno County

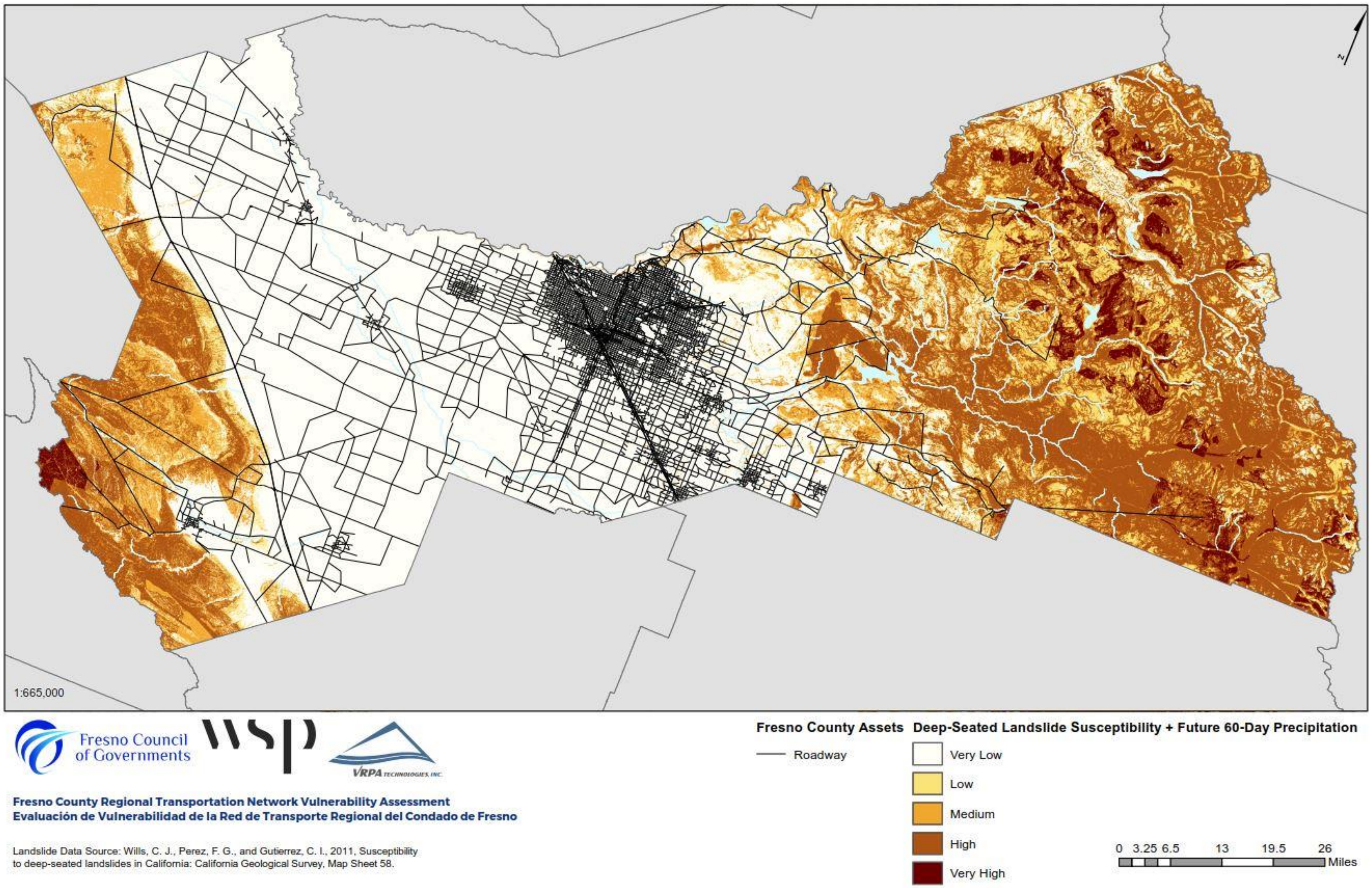


Figure 33: Future Landslide Concern North of Piedra and Pine Flat Lake (Map 1)

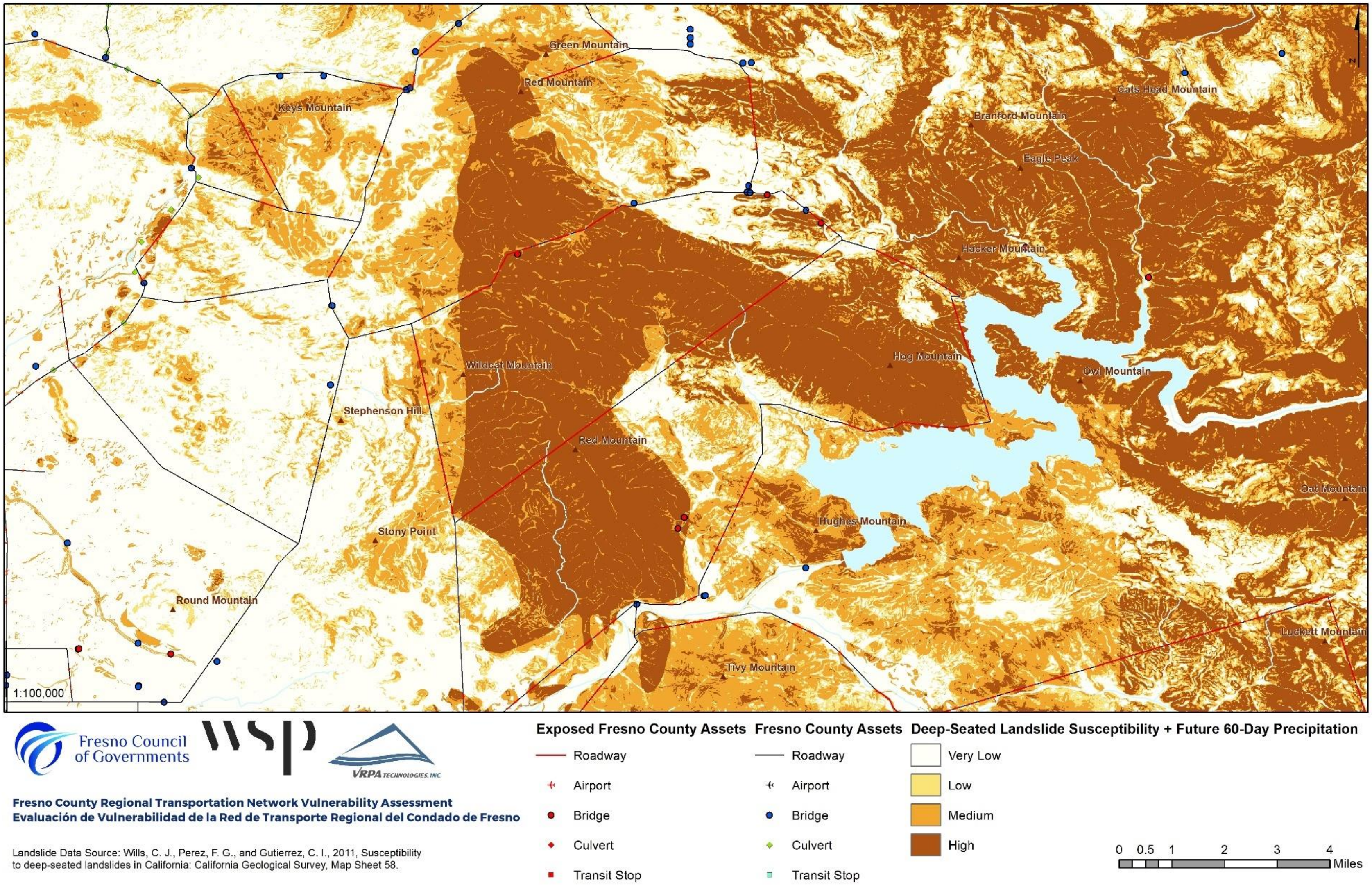
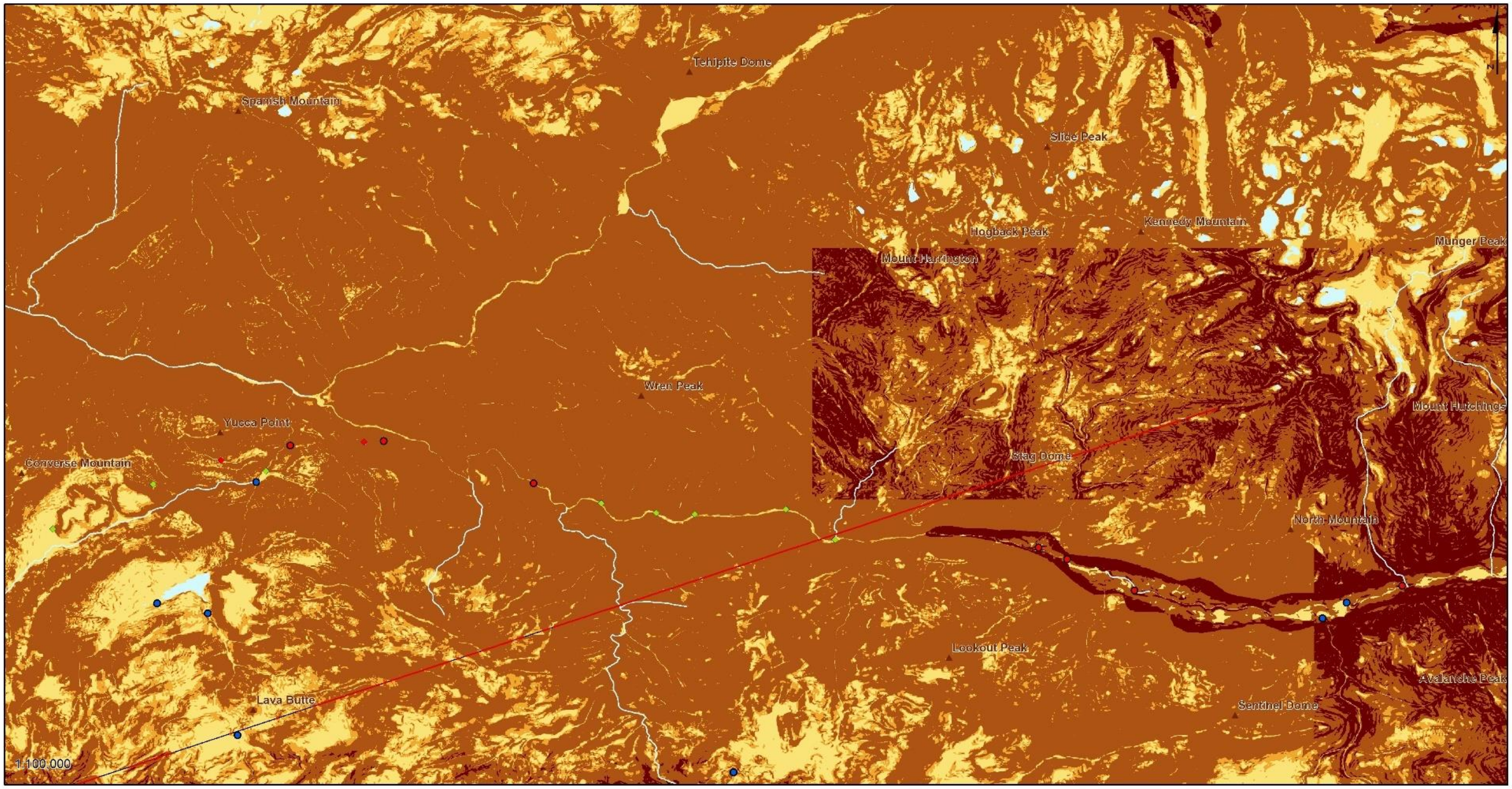


Figure 34: Future Landslide Concern along SR-180 East of Hume (Map 3)



Fresno Council of Governments

Fresno County Regional Transportation Network Vulnerability Assessment
Evaluación de Vulnerabilidad de la Red de Transporte Regional del Condado de Fresno

Landslide Data Source: Wills, C. J., Perez, F. G., and Gutierrez, C. I., 2011, Susceptibility to deep-seated landslides in California: California Geological Survey, Map Sheet 58.

Exposed Fresno County Assets	Fresno County Assets	Deep-Seated Landslide Susceptibility + Future 60-Day Precipitation
Roadway	Roadway	Low
Airport	Airport	Medium
Bridge	Bridge	High
Culvert	Culvert	Very High
Transit Stop	Transit Stop	

0 0.5 1 2 3 4 Miles

Figure 35: Future Landslide Concern along SR-168 and Dinky Creek Rd (Map 4)

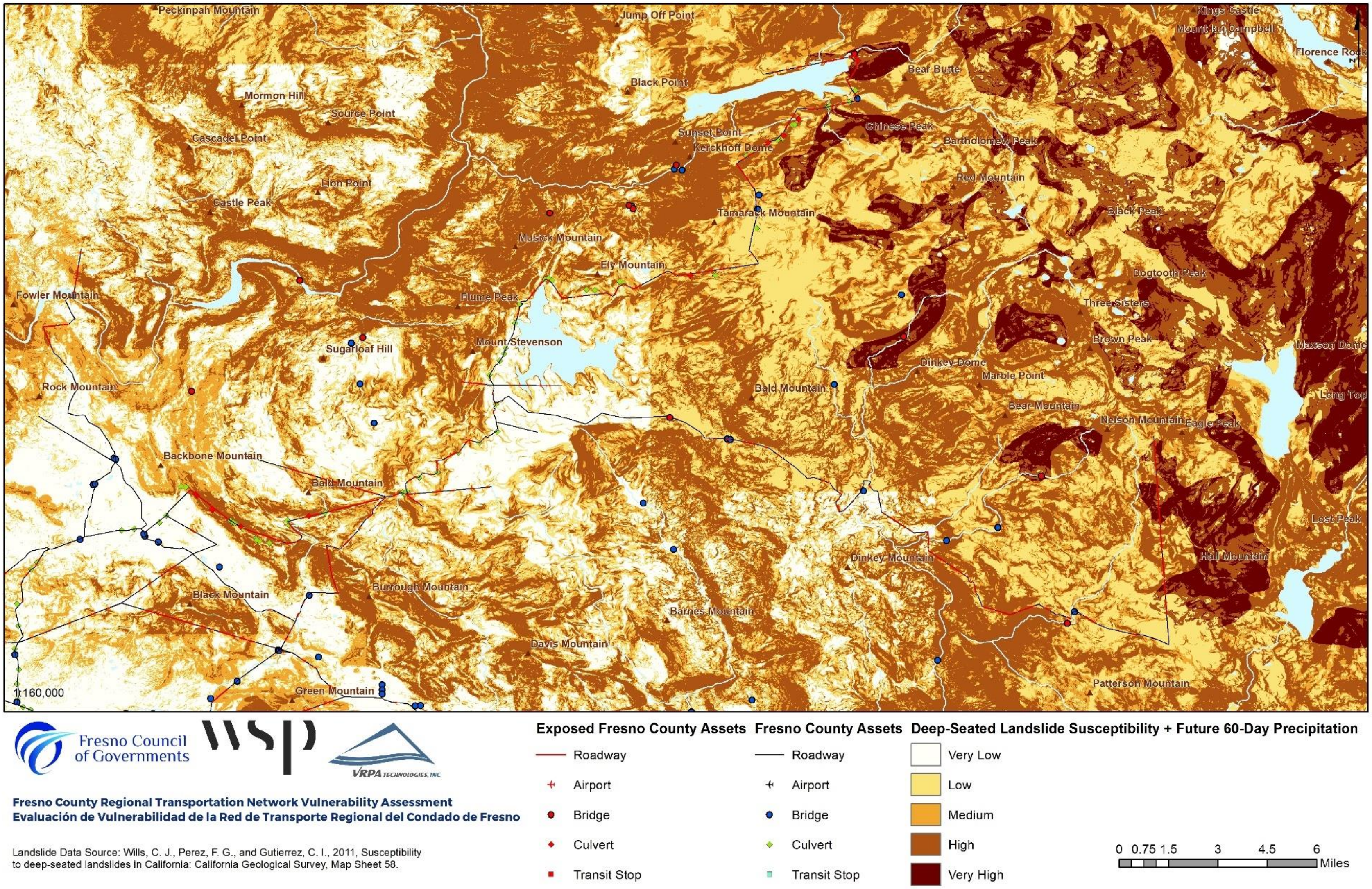
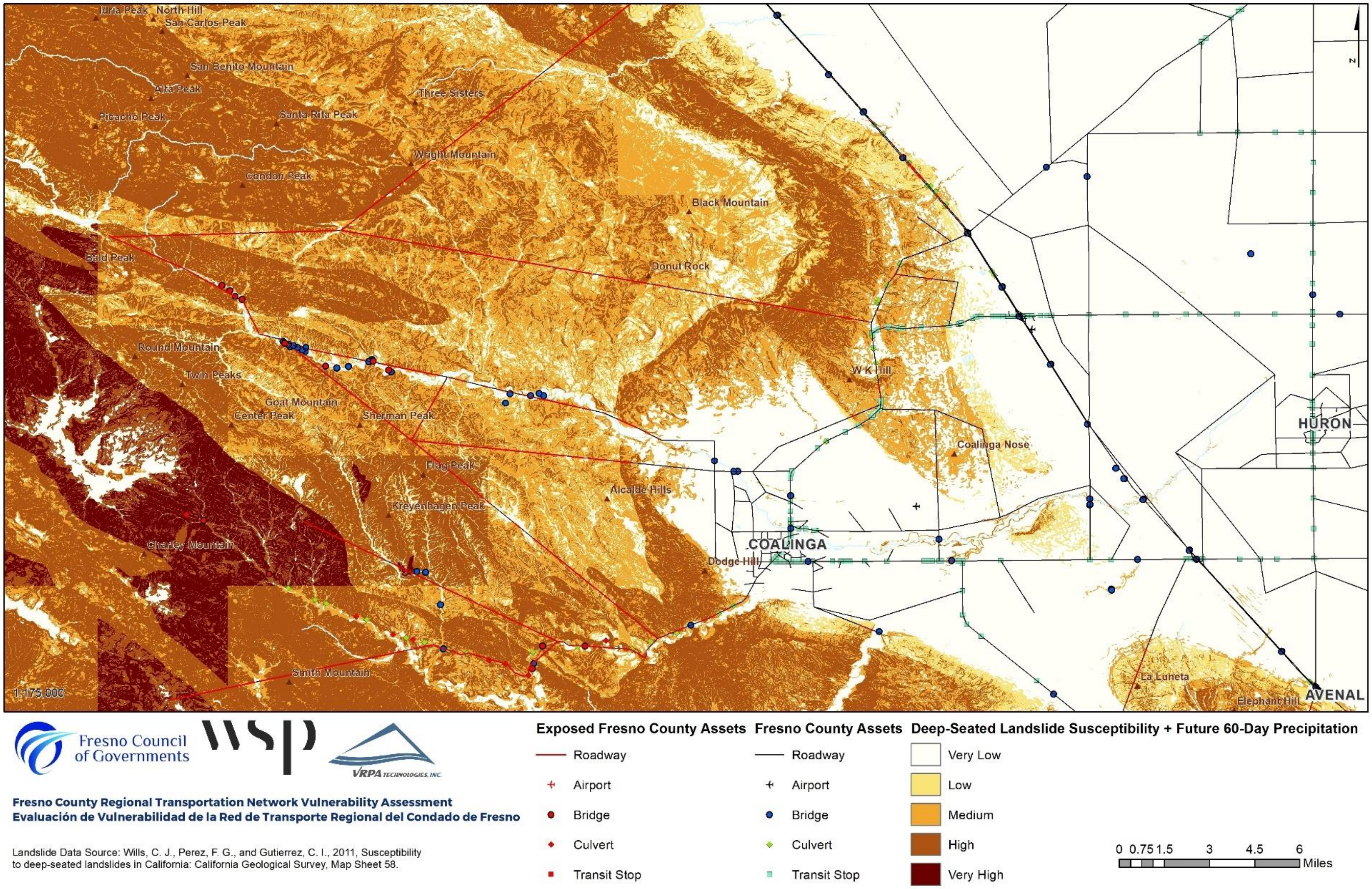


Figure 36: Landslide Concern along Los Gatos Creek Rd and SR-198 West of Coalinga (Map 5)



Summary

Results Synthesis

Extreme heat, riverine flooding, wildfire, and other weather-related conditions events have affected Fresno County's transportation system in the past. Going forward, the county is likely to experience a future that holds substantially more high heat events and associated air quality issues; more frequent wildfires; more uncertain precipitation patterns with the potential for heavier high precipitation events; and strains on water supply.

Roughly half of residents surveyed reported that weather events or conditions have affected their travel or required them to evacuate. Extreme heat and poor air quality were the most frequently cited reasons. With climate change, respondents are most concerned about extreme heat, drought, and air quality issues.

Socially vulnerable residents, such as those with low incomes, without English fluency, or with asthma or other respiratory issues, are disproportionately at risk. Many of these individuals are transit dependent and more exposed to high heat and poor air quality.

The projected future high temperatures are relatively uniform in the Central Valley portion of Fresno County, where virtually all the transit stops are located. In the FAX system, bus ridership tends to be lower on hotter summer days. Transit agencies also face operational challenges due to increased energy demand in higher temperatures.

While wildfire and riverine flooding affect a smaller portion of the population, they pose substantial risks, especially to rural parts of the County with limited redundancy in the transportation network.

Riverine peak flows are expected to increase under at least some of the future climate scenarios. The Kings River and San Joaquin River both pose threats to communities and associated transportation infrastructure. Failure of Friant Dam or Pine Flat Dam would be potentially catastrophic.

Many bridges and roadways were identified as vulnerable to future riverine flooding. Most of these are lightly traveled roads in low-density areas, though network redundancy is limited in many of these areas, so detour routes are often long. Specific areas of flood vulnerability include:

- Several of the most vulnerable bridges span the Kings River South Fork on the SR-180 or nearby roads in far eastern Fresno County. These roads are characterized by low travel volumes but significant detour lengths.
- There are a few vulnerable bridges the I-5 over the Panoche Creek and Little Panoche Creek.
- One of the most vulnerable bridges to future flooding was the North Fork Road bridge over the San Joaquin River in Friant. It has experienced flooding in the past, rates poorly for scour, and will likely experience high increases in flows many of the climate scenarios.
- The SR-180 over the Fresno Slough near Mendota.
- The SR-269 north of Huron.
- Selma Airport ranked as the most vulnerable airport to future flooding

- Some mobile home parks in river floodplains have experienced flooding in the past, including Wildwood Mobile Home Park and Woodward Bluffs Mobile Home Park in northern Fresno along the San Joaquin River and River Bend RV Park in Sanger.

For wildfire, there are many small communities in the Sierra Nevada and foothills with limited routes for access and egress. The longest stretches of highly vulnerable roadway are the SR-180, Auberry Road, and the SR-168 in the Sierras. These have very low redundancy and relatively high volume compared to other rural roads in the county's exposed areas. Other highly vulnerable Sierra roadways include Lodge, Powerhouse, SR-63, Trimmer Springs, and Watts Valley. On the Diablo Range side, the most vulnerable roadways were the SR-198 west of Coalinga and Los Gatos Creek Road.

Extreme heat and precipitation will have an impact the maintenance of roadways, causing potholes and other roadway degradations. This can ultimately lead to an increase in road maintenance costs.

Landslide susceptibility already exists around Fresno County and this susceptibility is expected to increase over time as more precipitation falls during heavy events. Some areas are higher concern than others, but this risk exists throughout the Diablo Range and Sierra Nevada.

From an organizational resiliency perspective, smaller cities often face the same hazards as larger cities but have less funding and fewer staff to address them. Funding constraints were mentioned repeatedly and make addressing vulnerabilities to climate change particularly challenging.

Application and Next Steps

Fresno COG's member agencies and other stakeholders can use this memorandum's findings in several ways. The memorandum material can be used to help members meet the California Senate Bill 379 requirements for accounting for climate change in local hazards mitigation plans and the safety elements of general plans.[51] Those requirements include conducting a vulnerability assessment. Members can draw on information in this document on Fresno County's projected future climate conditions and transportation network vulnerabilities for their vulnerability assessments. Members can also use the data and maps underlying this memorandum for their vulnerability assessments or other planning activities. Also, the indicator scoring approach is designed specifically to help agencies, such as Fresno COG and its members, prioritize which assets warrant more detailed facility-level assessments. These facility-level assessments help agencies select cost-effective, resilient courses of action for their assets and systems.

The next phase of the TNVA focuses on adaptation options. It will cover how agencies can conduct facility-level assessments, introduce transportation adaptation options for Fresno County, and provide further policy guidance to Fresno COG and its members.

[51] SB 379 will be discussed in greater detail in the next task of this study. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB379