Fresno Council of Governments

Fresno County Regional Transportation Network Vulnerability Assessment

Adaptation Strategies Summary Memorandum

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Introduction

The Fresno Council of Governments (Fresno COG) conducted a Transportation Network Vulnerability Assessment (TNVA) for Fresno County to understand the potential impacts of climate change on the region's transportation infrastructure. The results of this TNVA are summarized in a Technical Memorandum that covers the assessment methodology and results. As part of the TNVA development process, the project team directly engaged with the community and Fresno COG stakeholders to understand the public's perspective on the threats of climate change. Findings and details on the community engagement process are summarized in a Public Outreach Synopsis.

The findings of the TNVA are also intended to help Fresno County jurisdictions with responding to Senate Bill 379, which requires that all cities and counties address climate adaptation and resiliency strategies in the next revision of the Safety Element of their General Plans. See the Senate Bill 379 section below for policy guidance.

The overarching objectives of the Fresno County Regional TNVA development process are to:

- Convene regional partners from multiple jurisdictions.
- Identify climate change impacts 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 change-related vulnerabilities.

This memorandum addresses the final objective of the TNVA by summarizing adaptation strategies that can be implemented around the county to prepare for climate change impacts. This list of strategies is intended to act as a toolkit or menu of various response options, which Fresno COG and their stakeholders can pull from as needed. It is not intended to provide prescriptive recommendations for the county and its infrastructure. There are a wide range of responses for Fresno County to consider and they are based around changes to planning, policy, design, operations, and maintenance. Some strategies are more focused on natural or "green" infrastructure as opposed to engineered responses. There is no one response that is considered the "best' response to climate change-related vulnerabilities, they should all be considered and weighed individually depending upon the stressor of concern, project location, project budget and timeline, and other considerations. See the General Principles and Strategies section below for more information on how to generally evaluate and implement adaptation strategies.

The different adaptation options are summarized at a high-level by each climate stressor. The climate stressors assessed for the Fresno County Regional TNVA are:

- Temperature Rise
- Precipitation and Flooding
- Wildfire
- Landslides

Each section summarizes the main impacts to the transportation network that stem from these climate stressors and the variety of responses that mitigate those impacts. Each response includes descriptions of the strategy, the transportation network components it applies to, the co-benefits associated with the response, and resources to consult for more information.

To provide some examples of how these adaptation strategies can be incorporated into typical transportation projects, the final section of this memorandum highlights several Fresno County projects from the Regional Transportation Plan (RTP). These examples were chosen to demonstrate how climate change can be considered in transportation planning and identify some project types where adaptation strategies can be incorporated.

Senate Bill 379

Overview

California SB 379 requires that all cities and counties address climate adaptation and resiliency strategies in the next revision of the Safety Element of their General Plans by January 1, 2022. If cities and counties had a hazard mitigation plan when the bill was signed in October 2015, they can meet the requirements of the bill by instead updating their local hazard mitigation plan beginning January 1, 2017. SB 379 requires that the update include three core elements:

- **Vulnerability assessment** – Jurisdictions are expected to conduct and document a vulnerability assessment using data from sources including Cal-Adapt, California Adaptation Planning Guide, and relevant local, state and federal agencies, and considering historical materials and existing and planned development.
- **Set of adaptation and resilience goals, policies, and objectives –** These goals, policies, and objectives should be informed by the vulnerability assessment.
- **Set of feasible implementation measures** – The implementation measures should be designed to carry out the set of adaptation and resilience goals, policies, and objectives.

Additional information on the bill and the three primary requirements can be gleaned from reading the SB 379 bill text (California Legislature, 2015) and the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA) guidance (ARCCA, 2016).

Fresno Transportation Network Vulnerability Assessment & SB 379

The Fresno Transportation Network Vulnerability Assessment (TNVA) can be utilized to help jurisdictions fulfill SB 379 requirements. The Vulnerability Assessment Summary Memo, completed earlier in the project, has information, maps, and data that can be used to help meet the first core obligation of SB 379. This document, the Adaptation Strategies Summary Memo, is a compendium of strategies that can be used to help meet the second core obligation of the policy. Jurisdictions can draw on the portions of these TNVA analyses that are most applicable to their local settings.

As the TNVA focuses primarily on transportation, climate impacts and adaptations pertaining to other sectors would also need to be considered. Jurisdictions also need to develop their own implementation measures. The implementation measures convey the “who does what” details of how the adaptation strategies are applied.

The Fresno County Multi-Hazard Mitigation Plan is another excellent resource for understanding the county’s climate-related hazards, strategies for mitigating these hazards, and how these mitigation strategies are implemented. While the plan focuses more on current rather than future climate conditions, it does include discussions about the impacts associated with climate change.

Strategies & Language for Addressing SB 379

We conducted research to understand how cities and counties across the state have addressed SB 379 to-date, by summarizing strategies for fulfilling the requirements and language used in the local hazard mitigation plans or general plans. In reviewing updates to these plans, it appears that many counties and cities are opting to incorporate by reference updates to their local hazard mitigation plans into their general plans to fulfill the requirements of SB 379. Also, given that general plan updates are not required to be completed until January 1, 2022, most of the updates identified in the research have been to hazard mitigation plans. Several examples are included below:

- **City of Los Angeles, Local Hazard Mitigation Plan (2018)** – Los Angeles has opted to update their local hazard mitigation plan to fulfill the requirements of SB 379, which is explicitly addressed in the update. Additionally, LA has integrated by reference the "Sustainable City Plan" into their local hazard mitigation plan. LA adopted a specific chapter on climate change, titled "Climate Change and Sea Level Rise," which provides an overview of what climate change is and also discusses in more detail how climate change will impact the identified hazards of concern. Climate resilience and adaptation strategies are then incorporated into the mitigation strategies for each identified hazard of concern, rather than as standalone mitigation alternatives (City of Los Angeles Emergency Management Department, Tetra Tech, 2018).
- **Humboldt County Operational Area Hazard Mitigation Plan (2019)** – Humboldt County updated the Action Plan Implementation Section of the hazard mitigation plan to address SB 379. The plan has a chapter dedicated to climate change, including overviews of vulnerability assessments conducted in relation to hazards identified in the report (dam failure, drought, earthquake, flood, landslide, sever weather, tsunami, wildfire, and sea level rise). Climate change impacts are discussed in other sections of the report as well. Much like Los Angeles—the reports were prepared by the same consulting firm—the plan's mitigation strategies incorporate climate change into strategies for identified hazards rather than having a standalone section (Humboldt County Office of Emergency Services, Tetra Tech, 2019).
- **Inyo County Multi-Jurisdictional Hazard Mitigation Plan – City of Bishop (2017)** – Inyo County formally has incorporated by reference the multi-jurisdictional hazard mitigation plan into the Public Safety Element of the county's general plan (Inyo County Planning, 2018). Inyo County's approach to addressing climate change was to not develop a separate section on climate hazards, but to discuss the projected effects climate change has had/will have on each type of hazard. The plan states, "Climate change is not profiled as a distinct hazard, but rather a phenomenon that could exacerbate hazards. Climate change will be considered as a factor for relevant identified hazards" (Inyo County, City of Bishop, 2017)
- **San Diego County Multi-Jurisdictional Hazard Mitigation Plan (2018) & the City of San Diego General Plan, Public Facilities, Services, and Safety Element (2018)** – The City of San Diego's General Plan references working with the County of San Diego to make updates to the hazard mitigation plan to address climate adaptation and resiliency in fulfillment of SB 379. The County's hazard mitigation plan approached climate change as an impact that exacerbates other hazards, stating, "Climate change was not included as a hazard. However, the impact of climate change on the identified hazards was included in the evaluation of hazards and their impacts." As a result, strategies to address climate change are incorporated into goals to address identified hazards, not as a standalone section (City of San Diego, 2018).

General Principles and Strategies

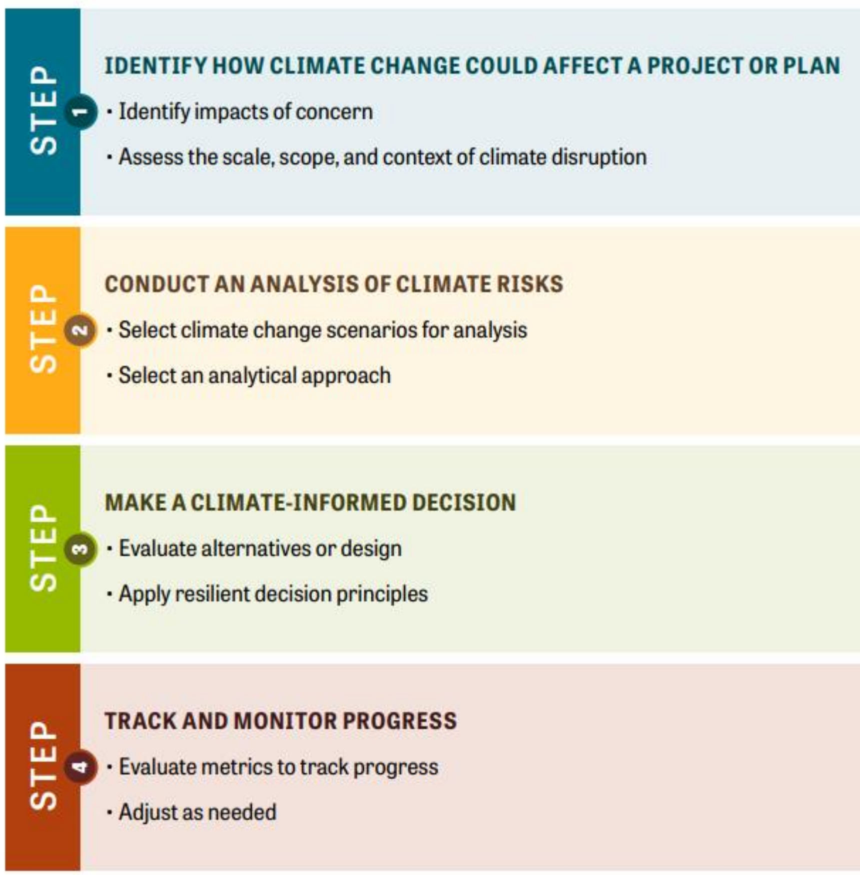
The term adaptation refers to an action taken to address a risk related to climate change. Transportation infrastructure has always interacted with the natural environment and its potential hazards, including flooding, high temperature, wildfire, and landslides. Infrastructure managers, operators, planners, and designers already have an arsenal of strategies for addressing these hazards. Thus, an adaptation is often simply an application of one of these traditional strategies. But the principles behind adaptations and adaptation decision making are different. Most current practice in Fresno County, the State of

California, and the U.S. assumes that the properties of the climate and its associated hazards will remain constant over time. As research and experience show that this assumption is unwarranted, different principles and methods are needed to address the risks associated with climate change and enable the transportation system to fulfill its objectives related to mobility, economic activity, public health, social equity, and the environment.

Processes and Resources

There are numerous resources and guidance documents on adaptation strategy approaches and evaluations, and this document will highlight a few of these rather than exhaustively catalogue them. The California Governor's Office of Planning and Research (OPR) guidebook entitled *Planning and Investing for a Resilient California* aims to "inform planning and investment processes to address the two primary elements of resilience – planning for future conditions and doing planning itself differently" (Governor's Office of Planning and Research, 2018). Figure 1 shows the OPR guidebook's high-level process for adaptation planning.

Figure 1: OPR's Process for State Agencies to Integrate Climate Change into Decisions



The Federal Highway Administration (FHWA) Adaptation Decision-Making Assessment Process (ADAP) is facility-level framework that helps transportation practitioners analyze climate hazards and evaluate adaptation options (see Figure 2) (FHWA, 2019). ADAP addresses some of the key challenges associated with climate change and transportation systems:

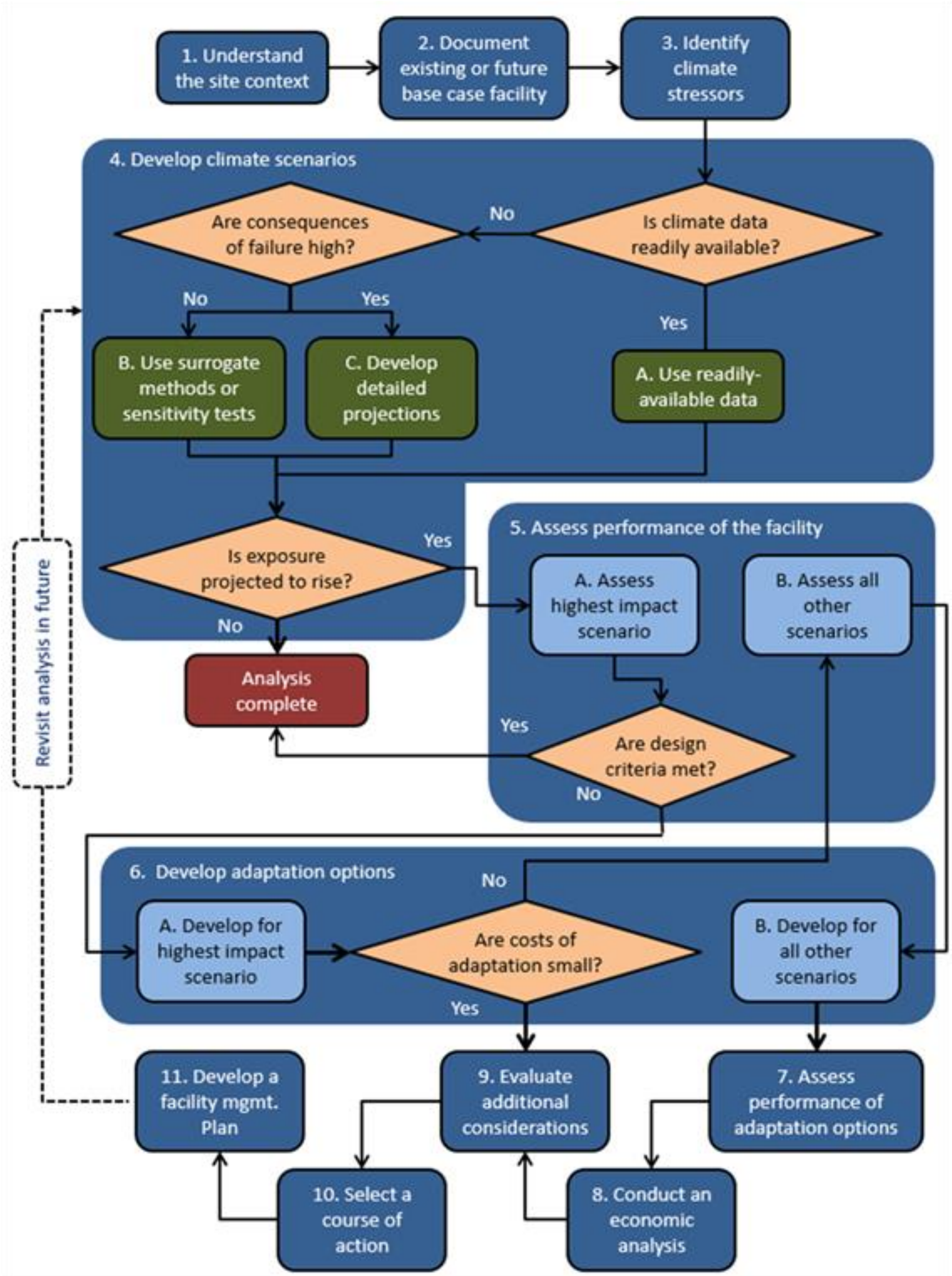
- The status quo assumption that historical climate conditions will remain the same in the future. This is often referred to as stationarity.
- The status quo assumption that we have certainty about climate conditions and other inputs into the design process. However, there is imperfect information about climate hazards and other factors attributing to risk. There is much uncertainty about the climate, whether it be historical, current, or future.
- The lack of accounting for the full consequences of infrastructure failure. The traditional planning and design process does not consider the costs of failure, including both damage and disruption, and how these affect the wider system and its users.

The ADAP process is a risk-based approach that addresses these challenges through several features:

- It uses climate scenario analysis to understand how an asset would perform under different future conditions. This helps address uncertainty and incorporate the best available information about future conditions.
- It assesses benefits and costs of different action alternatives across the lifecycle of the facility, accounting for how climate conditions could change over time. It includes measures of cost effectiveness (e.g., Net Present Value), which are helpful for decision making and making a case for support and funding for an alternative.
- It includes a consideration of socioeconomic benefits and costs in addition to damage repair and lost revenue estimates. ADAP includes ways to incorporate monetizable socioeconomic values (i.e., cost that can be estimated in dollar terms) and non-monetizable socioeconomic values.

The FHWA website describes the ADAP process and rationale behind in detail. ADAP was developed as part of FHWA's Transportation Engineering Approaches to Climate Resiliency (TEACR) project, and the TEACR website provides example applications of the ADAP framework that practitioners can reference (FHWA, 2019).

Figure 2: FHWA's Adaptation Decision-Making Assessment Process



At the local level, the Vulnerability Assessment memo for this study (the Fresno COG Transportation Network Vulnerability Assessment) references other tools and resources that can be used for adaptation planning. These include the Fresno County Multi-Hazard Mitigation Plan.

Policy and Funding

Aside from SB 379, there are other policies and programs that are relevant for adaptation planning in the Fresno region.

California Executive Order (EO) B-30-15, signed in 2015, requires that state agencies (and, therefore, the infrastructure they fund) "take climate change into account in their planning and investment decisions" (Office of Governor Edmund G. Brown Jr., 2015). It requires them to use "full life-cycle cost accounting to evaluate and compare infrastructure investments and alternatives." Assembly Bill 2800, approved in 2016, codifies EO B-30-15. It requires state agencies to account for "current and future impacts of climate change when planning, designing, building, operating, maintaining and investing in state infrastructure (California Legislature, 2016)."

The implication of these policies is that local agencies that understand their climate-related risks and seek to make their systems more resilient will be better positioned to obtain state funding for these projects and activities. They may also be better positioned for federal funding. The Federal Emergency Management Agency (FEMA) will soon increase its pre-disaster funding, which aims to protect infrastructure and communities from hazards before they occur. Its new pre-disaster program is called Building Resilient Infrastructure and Communities (BRIC). BRIC authorizes a "National Public Infrastructure Pre-Disaster Mitigation fund, which will be funded through the Disaster Relief Fund as a six-percent set aside from estimated disaster grant expenditures" (FEMA, 2019). This six-percent set aside will likely represent a larger, more reliable source of funding (Holdeman, 2019). In addition to public programs, private lenders, insurers and credit rating agencies have demonstrated more concern about climate-related risks embedded in financial instruments and insurance policies.

Figure 3: Yolo Bypass: Central Feature of the Sacramento River Flood Control Project

Source: California Department of Water Resources

Co-Benefits

Co-benefits are other key considerations of adaptation planning. These are the additional benefits that may stem from a single adaptation strategy, which positively influence the surrounding community and social equity, natural resources, greenhouse gas mitigation, and/or the local economy. Natural infrastructure solutions can provide a variety of different co-benefits.

For example, project landscaping can be

designed so that it is an adaptation strategy that reduces risks from temperature rise, flooding, and wildfire, and it also provides co-benefits by reducing greenhouse gas emissions, providing habitat and green space, and even recreational activities.

The benefits that are generated by an adaptation strategy depend on the factors such as the local geography, environment, and community. What is most beneficial depends upon location. For example, planting shade trees to reduce Urban Heat Island (UHI) would be more beneficial along a roadway in a low-income neighborhood then along a highway with no pedestrian access.

Where applicable, the adaptation strategies summarized in this memo will outline relevant co-benefits associated with that response.

Understanding Consequences of Design Criteria Exceedance

Transportation assets are often engineered to withstand certain design events or similar standards. For instance, a critical roadway might be designed to remain in service during a 50- or 100-year storm (i.e., a storm that has a 2% or 1% chance of occurring each year). A design event is selected based on the risk tolerance for the facility. An agency with a relatively low risk tolerance for an asset would typically use a relatively low probability (and therefore higher magnitude) design event. But issues can occur when a design event is at some point over its service life. This can occur due to statistical chance, uncertainties in the underlying nature of the climate event, uncertainties in the infrastructure design, maintenance practices, changing land use patterns, changing climate factors (i.e., non-stationarity) and other factors.

Practitioners can make the system more resilient by understanding the consequences of exceeding an asset's design event. This includes information about what magnitudes of hazards could substantially affect an asset (e.g., flood elevation, discharge rate, temperature threshold). It also includes information about how the asset itself could be affected, including damage and disruption costs associated with those magnitudes (West Riverside Council of Governments, 2019). Consequence information can be used during the design process and later in an asset's lifecycle to improve performance from an operations and maintenance perspective.

A simple way to examine consequences is to require that designers assess and document the consequences a check event, which refers to an event whose magnitude exceeds the design event.[1] For example, an asset with a design storm recurrence interval of 100 years could have a check storm recurrence interval of 500 years. For higher risk facilities, a more comprehensive analysis may be warranted, particularly given the expected changes in climate conditions.

Other Principles

Decision making timing is another important factor in climate adaptation. Adaptation can require increased capital spending depending on the facility and applicable strategies. In these cases, there can be opportunities for agencies to incorporate adaptation into their other projects and planning activities. For instance, whereas modifying a bridge to withstand higher magnitude floods might be a costly effort in and of itself, if the asset is to be replaced or repaired anyway, it could be a cost-effective opportunity to adapt it to those higher floods. Furthermore, because climate change is a relatively long term trend,

1 For example, see https://flh.fhwa.dot.gov/resources/design/pddm/Chapter_07.pdf

there is a temptation to delay response and take a reactive approach. This may be sufficient in some cases, but in others it might be cost effective to be more proactive. By assessing the lifecycle costs and benefits of adaptation and no action options (see "Processes and Resources" above), practitioners can better understand how best to time their adaptation-related activities.

Community engagement is another crucial component to adaptation planning. With knowledge of the challenges facing the communities they represent, agencies can better cater adaptation responses. This is particularly important in disadvantaged communities, where members may not have access to resources necessary to respond to extreme events or changing climate conditions. The resources can include funding to address damaged property or infrastructure or equipment such as vehicles that can be used for evacuation or for avoiding extreme weather conditions. There is also a need for stakeholder and public education regarding climate change risks and adaptation options. Increased awareness can enhance the capacity of communities to respond to hazards. This could include knowledge of evacuation best practices or who to contact when extreme events do occur.

Temperature Rise

Climate change-related temperature rise and the UHI effect can result in impacts to 1) health and community and 2) the operations of transportation assets. This section discusses these two categories of impacts and the possible responses Fresno COG and members can adopt to respond to and mitigate these impacts.

Health and Community Impacts

Increased temperatures can impact human health and put additional stress on communities, resulting in 1) heat stress, 2) reduced access to transit, and 3) increased localized air pollution.

The body can regulate its temperature on a hot day, but more stress is put on the body if there are multiple high heat days in a row and/or if temperatures do not cool off at night. These events can lead to risk of heat-related illnesses, especially if those affected cannot escape the heat and rest in a cool area. Vulnerability to heat impacts varies geographically and with certain population characteristics. Key vulnerability factors include age, socio-economic status, pre-existing health, pregnancy, occupation, as well as geographic variables such as local surface temperature, tree cover, and distance from the coast.

High heat days can also have secondary health and community impacts, including the degradation of localized air quality. Customer energy demand rises during warm months due to the need for air conditioning. Increased energy demand and consumption will also lead to higher emissions of greenhouse gases and unhealthy air pollutants.

Responses

Shaded Bus Stops

Brief Description: Providing shade at bus stops can address the health and transit accessibility implications of climate change-related high heat days by keeping riders cooler while waiting for transit services. Many survey results noted that bus stops lack shelters around Fresno County. Shade protection can be provided by building shade canopies or by planting trees near transit stops, which relates to the section on vegetation cover below. More advanced options to provide shade and cooling for riders at transit stops include installing misters, water fountains, and benches. Additionally, bus shelters can be installed with green roofs, solar panels, or even enclosed shelters with air conditioning.

Figure 4: Shaded Bus Stop

Source: City of Santa Monica

Relevant Transportation System Components: Transit stops & passengers

Co-Benefits: Increased urban shade/decreased UHI, benefit to public health and safety

Resources:

- Calscape's California Native Plant Gardening Guide provides information on what types of plants thrive where.
- Climate Change Response Framework provides resources on different tree species and their vulnerability to climate change.
- The U.S. Forest Service has resources about how tree species distribution will change due to climate change.
- The Caltrans' Complete Streets Elements Toolbox provides information on roadway elements that can be adopted to provide multi-modal mobility and access, including transit stops.
- Sacramento Metropolitan Utility District's (SMUD) initiative "Shading Sacramento" can be an exemplary model for urban forestry in Fresno.
- Tree Fresno could be a potential partner for a Fresno-based initiative.

Vegetation Cover (Urban Forestry)

Brief description: Increasing vegetation cover by planting more trees, also known as urban forestry, can be used as a strategy to combat the temperature rise and the UHI. Increased tree cover increases the amount of shade and can help to reduce exposure to high heat and as a result reduce the risk of health and community impacts for transit riders and the general public. Trees should be planted in strategic areas, such as along roadways and sidewalks. This strategy was a recommendation from the FCOG TNVA community survey.

Figure 5: Tree Shaded Transit Stop, Escondido, CA

Relevant Transportation System Components: Transit stops, roadways & passengers

Co-Benefits: Improved air quality, greenhouse gas mitigation

Resources:

- Sacramento Metropolitan Utility District's (SMUD) initiative "Shading Sacramento" can be an exemplary model for urban forestry in Fresno.
- Tree Fresno could be a potential partner for a Fresno-based initiative.
- Calscape's California Native Plant Gardening Guide provides information on what types of plants thrive where.
- Climate Change Response Framework provides resources on different tree species and their vulnerability to climate change.
- The U.S. Forest Service has resources about how tree species distribution will change due to climate change.

- The Caltrans' Complete Streets Elements Toolbox provides information on roadway elements that can be adopted to provide multi-modal mobility and access, including transit stops.

Cooling Centers

Figure 6: Fresno Cooling Centers

Source: Fox 26 News

Brief Description: Establishing cooling centers is a strategy to address human health hazards associated with high-heat conditions and the UHI effect (West Riverside Council of Governments, 2019). Cooling centers are air-conditioned public locations where individuals can keep cool during high-heat and extreme heat days. Fresno County's local jurisdictions already offer cooling centers on high-heat days and local transit agencies provide free transit to those cooling centers. The county may consider conducting a small study to better understand who utilizes cooling centers, when, and how people access the center. This information is currently unavailable and the results of this study could inform strategies local jurisdictions take to enhance the effectiveness of cooling centers. Depending on the results from the study, enhancements could include offering expanded hours, more locations, increased messaging and advertising about cooling centers and free transit opportunities, and on-demand transit to cooling centers.

Relevance to Transportation System: Passengers

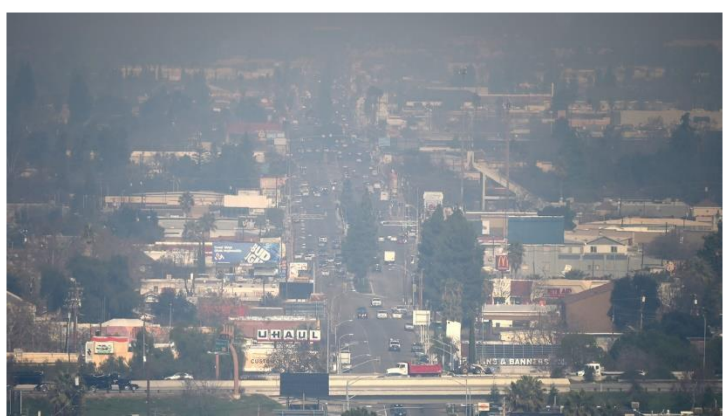
Co-Benefits: Increased access to cooling centers and other community resources such as free transit to cooling centers.

Resources:

- The Cal Office of Emergency Services (OES) has a cooling center checklist in their Contingency Plan for Excessive Heat Emergencies.
- The U.S. Centers for Disease Control and Prevention's report titled "The Use of Cooling Centers to Prevent Heat-Related Illness," offers additional guidance on how and when to hold cooling centers.

Mitigating Air Quality Impacts

Figure 7: Poor Air Quality in Fresno



Source: Fresno Bee

Brief Description: Air quality worsens in high-heat environments (Fann, et al., 2016). Given temperature projections, it is important to improve air quality as it is expected to worsen over time. One way to mitigate air quality impacts is to adopt transportation technologies and practices that limit pollution and emissions, such as early adoption of battery electric buses in place of diesel emission vehicles (transit bus fleets must be zero emission by 2040).

Transportation agencies and local jurisdictions can also strive to reduce energy consumption through adopting more sustainable practices. Taking small steps to increase energy efficiency can have a large impact over time. Building energy auditing and weatherization are simple and cost-effective ways to understand building energy use and take actions to reduce consumption. An energy audit is an assessment of how much energy a building uses. Weatherization is the act of making minor building upgrades to mechanical systems, health and safety systems, the building shell, and electrical baseload, to increase the building's efficiency. Upgrades may include replacing hot water systems with newer devices, insulating hot water pipes, changing lighting to LEDs, and installing new/additional insulation. Installing renewable energy systems like solar arrays are another way to reduce fossil fuel consumption. Transportation agencies can also use roadside landscaping to improve surrounding air quality, while reducing greenhouse gas emissions.

Relevance to Transportation System: Passengers

Co-Benefits: Long-term community health benefits, environmental quality

Resources:

- The Fourth National Climate Assessment chapter on Climate and Health discusses the relationship between air quality and high heat in detail.
- The California Air Resources Board offers resources on sustainable transportation strategies, which can help mitigate air quality issues, including case studies that reflect best practices.
- The Office of Energy Efficiency and Renewable Energy provides useful information on energy auditing and weatherization.
- The Environmental Protection Agency has conducted research specifically on how roadside vegetation strategies can be employed to improve surrounding air quality.

Multilingual Notification During Poor Air Quality Events

Brief Description: When the Air Quality Index (AQI) indicates poor air quality, it is important that all residents be notified. By distributing air quality alerts and notifications in multiple languages, and via multiple communication methods, including social media, television, radio, and newspapers, local jurisdictions can help to reduce exposure to poor air quality to reduce the risk of health implications.

Relevance to Transportation System: Passengers

Co-Benefits: Improved equity and inclusivity of community health benefits

Resources: The Federal Communications Commission published a report on recommendations for multilingual emergency alerting.

Pavements

Higher average temperatures and higher extreme maximum temperatures can impact the level of service and useful life of pavement, due to warping, cracking, rutting and shoving. Caltrans and the California State Transportation Agency consider minimum and maximum air temperatures in a region when choosing a binder for a pavement mix (Caltrans, 2019). The binder is essentially the "glue" that holds the aggregate together in pavement, ensuring that the bonds continue to hold when the pavement expands and contracts with temperature. When temperatures reach outside of these specifications, they can cause thermal cracking and pavement distortion (Qiang Li, 2011).

A flexible pavement transfers load (the weight from vehicles on the road surface) from grain to grain of the aggregate material down to the earth below, whereas a rigid pavement is made of concrete slabs that distribute the load over a wide area. Both can be distorted and damaged under higher temperatures, though the types of impacts vary between the two pavement types. Flexible pavements have an increased potential for rutting and shoving under higher average temperatures and the asphalt binder can harden with age (Sadasivam, 2019). Rigid pavements have an increased potential of curling and moisture related warping under higher average temperatures. Under extreme temperatures and high heat events, flexible pavements can experience asphalt rutting and shoving, and rigid pavement slabs can expand, causing slab buckling (Qiang Li, 2011).

Responses

Pavement Design

Brief Description: Adopting adapted pavement engineering design alternatives can mitigate the impacts the high temperatures can have on traditional pavement, and in turn maintain level of service and the useful life of the asset into the future. Engineered mitigation focuses on improving the adaptive capacity of pavements through enhancing structural resilience, improving the durability and quality of pavement materials and construction, and reducing the likelihood of the onset and progression of various forms of pavement distresses (West Riverside Council of Governments, 2019). There are several pavement engineering design strategies, including:

- Review and revise pavement design policies, as necessary, to incorporate future climate forecasts instead of historical climate records, tighten-up design criteria, and increase the design reliability to incorporate climate uncertainties in decision-making.
- Select more durable materials to withstand the adverse effects of future temperature and moisture trends.

Figure 8: Impacts of Higher Temperature on Pavement

Source: Caltrans District 8 Climate Change Vulnerability Assessment, 2019

- Encourage or enforce best practices to improve materials and construction quality.

Relevant Transportation System Component: Pavement/Roads

Co-Benefits: Context-dependent

Resources:

- AASHTO maintains a Mechanistic-Empirical Pavement Design Guide.
- FHWA LTPPBind Online is an FHWA tool that helps agencies investigate asphalt binder performance grade.

Asset Management

Brief Description: Incorporating climate projections into pavement asset management can mitigate heat-related impacts to pavement, and help to maintain level of service. Transportation agencies can utilize pavement deterioration models to identify when treatments are needed and how quickly pavement will degrade (Sadasivam, 2019). Deterioration models can be developed using predicted climate data as well as mechanistic-empirical design models currently implemented in CalME and AASHTOW are Pavement M-E for flexible and rigid pavements, respectively. Figure 9 provides an example of deterioration model results and pavement condition impacts over time (FHWA, 2016). Incorporating climate data into these models is a helpful way to understand pavement performance over its lifespan and when rehabilitation is needed. By operationalizing this data in maintenance practices Fresno County transportation agencies can improve pavement level of service countywide.

Most local jurisdictions in Fresno County use a regional pavement management system called StreetSaver to document pavement quality and condition over time. StreetSaver also has a prediction model, which projects maintenance requirements and costs up to 30 years out. Tools like StreetSaver can help track data related to location, pavement damages and distress, and lifespan that can be used to maintain and monitor pavements into the future. The tool can also be used for asset management of other non-pavement assets like signs and roadside infrastructure. Users may also explore how to integrate climate data into the StreetSaver pavement system to evaluate how maintenance requirements, pavement lifespan, and costs will change as temperatures rise.

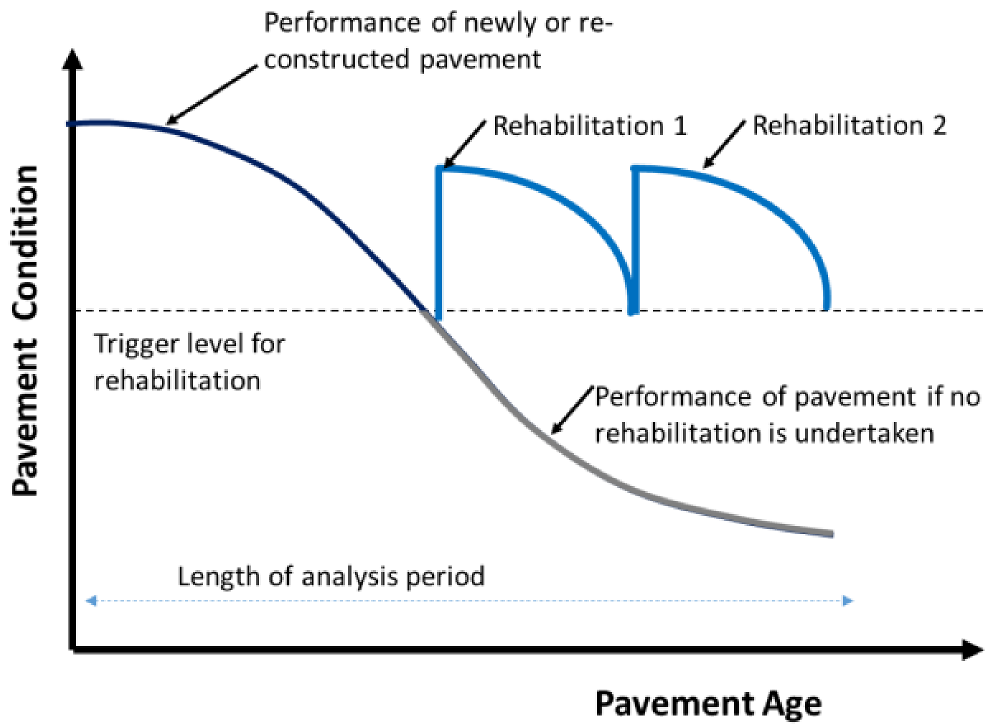
Relevant Transportation System Component: Pavement/roads

Co-Benefits: Context-dependent

Resources:

- AASHTO Mechanistic-Empirical Pavement Design Guide
- CalME, A Mechanistic-Empirical Program to Analyze and Design Flexible Pavement Rehabilitation
- StreetSaver, a tool used to document pavement performance and lifespan

Figure 9: Changing Pavement Conditions with and without Rehabilitation



Source: FHWA Temperature and Precipitation Impacts to Pavements on Expansive Soils: Proposed State Highway 170 in North Texas (FHWA, 2016)

Bus Operations

Battery Electric Buses (BEBs) are also vulnerable to heat-related impacts. BEBs are being deployed across California, due to the state's mandate to transition to 100-percent zero-emission bus fleets by 2040 to meet greenhouse gas reduction goals. Heat impacts to BEBs are not well-documented yet, but potential risks include increased energy usage, increased associated costs, decreased vehicle range, and reliability concerns for the battery. Research from the National Renewable Energy Laboratory indicates that the desired operating temperature to maximize efficiency for a BEB ranges between 59 and 95°F, meaning that as temperatures rise, BEB batteries may be operating at lower efficiencies (National Renewable Energy Laboratory, 2011). Substations, signal rooms, and electrical boxes are also at increased risk of failure outside of the temperature range for which they were designed.

Responses

Power Redundancy

Brief Description: Given that BEBs may contend with efficiency and performance challenges in high-heat conditions, transit agencies can consider having on-site power generation, on-site power storage, and or multiple power sources connected to the BEB charging facility (National Academies of Sciences, Engineering and Medicine, 2018). Additionally, high-heat days pose risks to the efficacy of the energy grid in general, which BEBs need to charge. To mitigate this risk, transit agencies can consider supporting local or regional efforts to develop micro-grids for energy resilience and to be able to reliably charge BEB fleets. Fresno County Rural Transit Agency (FCRTA) received a grant for an electrical grid analysis study for rural Fresno County to assess whether the current grid system is sustainable and can support EV charging infrastructure countywide. This plan, which is expected to be completed in January 2022, will provide local cities with valuable information, such as areas in greatest need of electrical grid improvements and the associated costs, areas with greatest capacity, and best locations for EV charging infrastructure.

Relevant Transportation System Component: Battery-electric buses/transit service

Co-Benefits: Resilient energy grid

Figure 10: Fresno County Rural Transit Agency Electric Bus

High Heat Event Response Planning

Brief Description: Given that battery efficiency is affected by temperature, there are limited design changes that can be made to reduce this risk.[2] Bus operators should develop a response plan for high heat events, which leverage power redundancy strategies noted above. This plan will be dependent upon the needs of the operator and community, but it may consider:

- Maintaining and charging "back-up" BEBs in advance of high-heat projections,
- Maintaining and deploying alternative fuel source fleets, such as hybrid and diesel buses during high-heat events,
- Charging buses more frequently, and
- Altering bus routes/directing service to higher ridership routes.

Individual driver performance (e.g. how fast they drive, how they start and stop the vehicle) also affects battery range and operator training is another way to preserve battery life during high heat.

Relevant Transportation System Component: Battery-electric buses/transit service

[2] Heat affects battery performance, but not as drastically as cold temperatures. See this CityLab article for some examples of transit agencies struggling with BEBs in cold weather.

Resources: TCRP Synthesis 130, Battery Electric Buses—State of the Practice

Precipitation and Flooding

Flood Impacts

Flooding can have severe impacts to the transportation network and its users. Flooding refers to a longer-term event where a low-lying area may inundate for days or weeks at a time due to ongoing rainfall, snowmelt, and/or rising water bodies. Flash floods refer to rapid flooding of an area due to extreme rainfall over a short period. Both can lead to roadway inundation, pavement damage/reduced pavement life, erosion of roadbeds and earthworks, washouts and sinkholes, overloaded and clogged drainage infrastructure, among other impacts. Each of these impacts leads to travel delays and their associated costs, along with response and repair time/costs.

Engineered Responses

Adjust Precipitation/Discharge Projections Used in Design

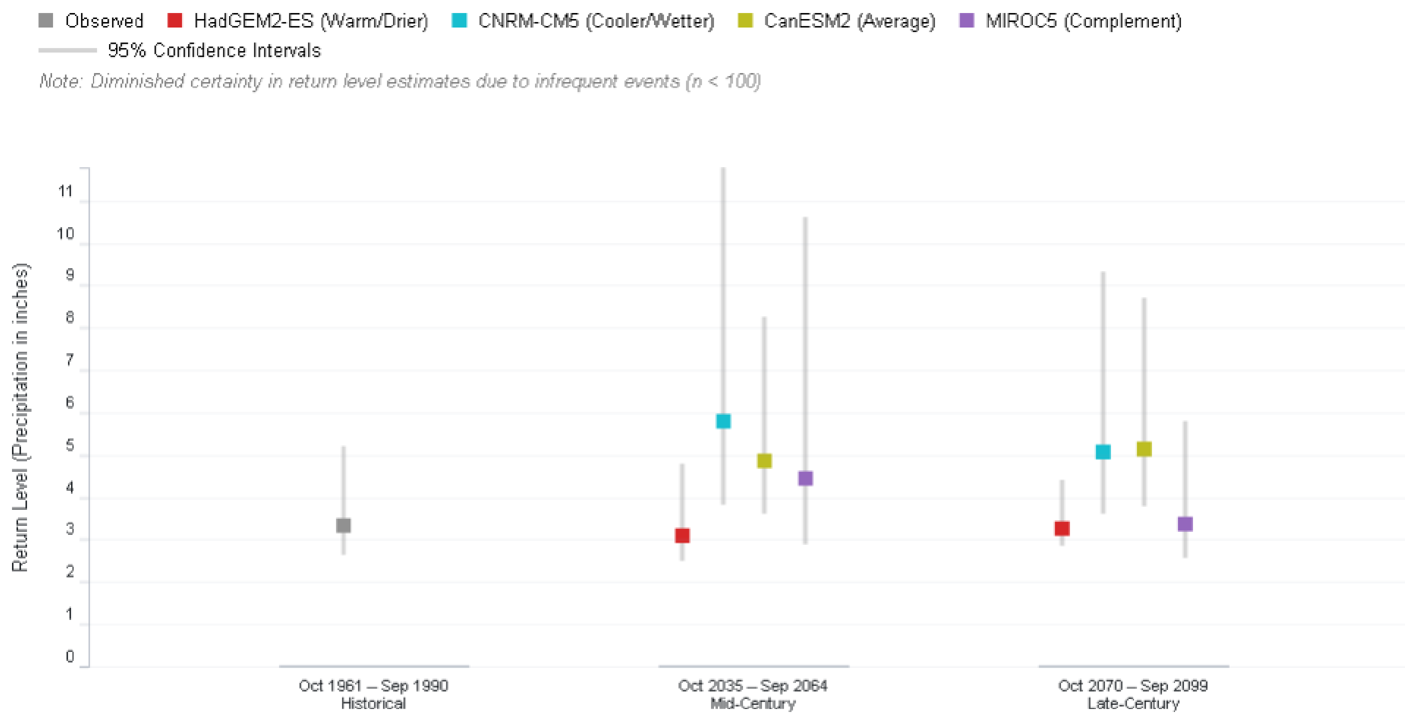
Brief Description: Transportation infrastructure is designed based on assumptions of the hydrology of the natural environments interacting with it. These assumptions tend to be based on historical observations of precipitation, runoff, and discharge (e.g., flow) rates. Existing practice often involves designing to discharge rates that are developed using historical discharge rates. Historical discharge rates can be observed directly or estimated using historical precipitation observations across a watershed that drains into an asset's location. If precipitation patterns change, if historical estimates contain errors, then assets can be under-designed; that is, they fail to meet their normal design standards (West Riverside Council of Governments, 2019).

Thus, one adaptation strategy is to adjust precipitation and discharge inputs into design. The FHWA Hydraulic Engineering Circular No. 17, 2nd Edition (HEC-17), entitled *Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience*, suggests methods for doing this (FHWA, 2016). Chapter 7 discusses different levels of discharge analysis. The levels, which range from less to more analytically intensive, are:

- **Level 1:** Use historical discharges and analyze future changes qualitatively
- **Level 2:** Use historical discharges with confidence limits and analyze future changes qualitatively
- **Level 3:** Use historical discharges with confidence limits and quantitative future precipitation projections
- **Level 4:** Use projected discharges with confidence limits
- **Level 5:** Use projected discharges with confidence limits and expanded evaluations, such as custom site-specific projections in land use and climate

To help illustrate some of these values conceptually, Figure 11 shows historical and future projected precipitation depths for the 50-year event over a 24-hour duration in Fresno County (California Energy Commission, 2019). The leftmost section shows historical precipitation (the gray square) with confidence intervals (gray bars), and the two right sections show future precipitation values (colored squares) and their confidence intervals (gray bars) for two different timeframes under several different climate models. Per the discussion in the "Processes and Resources" section earlier in this document, it is strongly recommended that multiple climate scenarios be assessed when incorporating future projections into design.

Figure 11: Historical and Future Projected 50-Year Precipitation Depths for Fresno, CA



- Source: Cal-Adapt. Data: LOCA Downscaled CMIP5 Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado, Boulder).

Relevant Transportation System Components: Bridges, culverts, drainage infrastructure

Co-Benefits: Context dependent

Resources:

- FHWA HEC-17
- NOAA Atlas 14 is a commonly used historical source for estimates of gridded precipitation rates organized by duration and frequency.
- LOCA (Locally Constructed Analogues) for future daily downscaled climate projections generated by the Scripps Institution of Oceanography that can be processed into extreme precipitation and discharge projections.
- Cal-Adapt Extreme Precipitation provides downloadable projected extreme precipitation values and confidence intervals for different locations across California.

Enhance Drainage Capacity

Brief Description: Enhancing drainage capacity of new or existing infrastructure is an option for addressing anticipated increases in flood risk.[3] This could entail upsizing culverts, retention basins, gutters, or other drainage-related infrastructure. It could also involve properly maintaining existing infrastructure so that it remains free of debris and able to accommodate water according to its design (see Figure 12).

Relevant Transportation System Components: Culverts, channels, gutters, retention basins, inlets, pipes, pumps, other drainage infrastructure

Co-Benefits: Stormwater management

Resources:

- Caltrans Highway Design Manual, Chapters 800-890 Highway Drainage Design
- FHWA Hydraulic Design of Highway Culverts (HDS) 5: Hydraulic Design of Highway Culverts
- FHWA Hydraulic Engineering Circular (HEC) 22: Urban Drainage Design Manual
- FHWA Maintenance of Drainage Features for Safety

Figure 12: Caltrans District 10 Clogged Culvert

Source: https://twitter.com/i/web/status/844630478585942016

Increase Scour Prevention

Brief Description: Scour is the "erosion of streambed or bank material due to flowing water" (US DOT FHWA, 2012). If it occurs at the base of a structure, such as bridge abutments or piers, it can compromise the structure's integrity. When increased flows are anticipated over a structure's useful

[3] See "Adjust Precipitation/Discharge Projections Used in Design" for more information on how to assess potential increases in flood risk associated with climate change.

life[4], one response option is to increase the scour protection measures at the facility. The Key Resources listed below describe common countermeasures for bridge scour, such as river training structures, armoring, foundation/pier strengthening, and monitoring.

Relevant Transportation System Components: Bridges, culverts, other structures interacting with flowing water

Co-Benefits: Context dependent

Resources:

- FHWA Hydraulic Engineering Circular (HEC) 18: Evaluating Scour at Bridges
- FHWA HEC-23: Bridge Scour and Stream Instability Countermeasures Experience, Selection and Design Guidance

Figure 13: Bridge Abutment Scour

Source: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12003.pdf

Elevate Infrastructure

Brief Description: Elevating planned or existing infrastructure is another adaptation option for areas with expected increases in flood risks.[5] This strategy can apply to a variety of infrastructure types

[4] See "Adjust Precipitation/Discharge Projections Used in Design" for more information on how to assess potential increases in flood risk associated with climate change.

[5] See "Adjust Precipitation/Discharge Projections Used in Design" and "Designate Future Floodplains" for more information on how to assess potential increases in flood risk associated with climate change.

including roadways, bridges, transit stops, maintenance facilities, and other structures.

Relevant Transportation System Components: Roadways, bridges, transit stops, other structures

Co-Benefits: Context dependent

Resources: Caltrans Highway Design Manual, Chapters 800-890 Highway Drainage Design

Channelization

Brief Description: One of the more intensive strategies for addressing riverine flooding is channelization. Expanding an existing channel or digging a new channel creates an additional passage for water flow, increasing the carrying capacity of a river or other water body. Channels can also refer to open ditches dedicated to drainage. Channels can be lined with different materials, such as concrete, rock riprap, or vegetation (TxDOT, 2019).

Relevant Transportation System Components: Roadways or other infrastructure adjacent to rivers, drainage channels

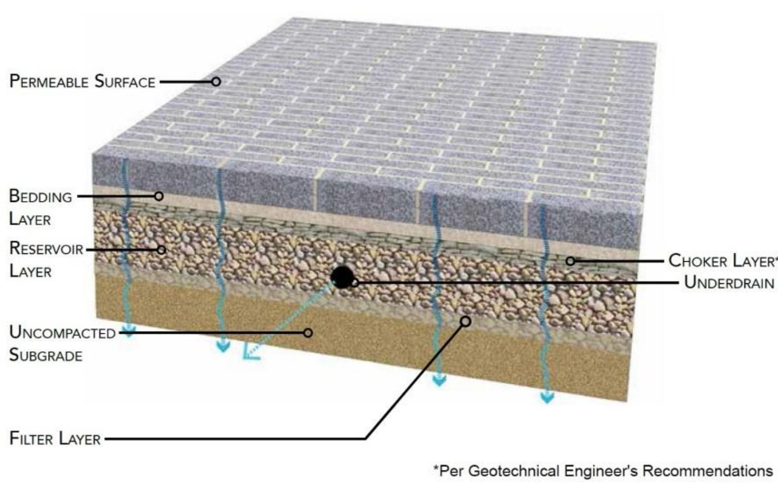
Co-Benefits: Natural environment through habitat enhancement (particularly for vegetation lined channels), stormwater management

Resources: Caltrans Highway Design Manual, Chapters 800-890 Highway Drainage Design

Install Permeable Pavement

Brief Description: This strategy refers to pavements composed of materials that are relatively pervious to water. By capturing stormwater that would otherwise flow across road surfaces, permeable pavements can reduce peak flows, lessen the strain on drainage systems, and recharge groundwater, where it can be filtered naturally by the soil (US DOT FHWA, 2015). Most permeable pavements are have higher initial costs than traditional pavements and are used to manage stormwater in "low-traffic, low-speed applications, such as shoulders or parking lots." Permeable pavement need to be regularly maintained so that sediment does not accumulate and prevent the infiltration of water.

Figure 14: Permeable Pavement



Source: San Diego County, 2019

Relevant Transportation System Components: Pavement (particularly low-volume, low-speed areas)

Co-Benefits: Natural environment, stormwater management

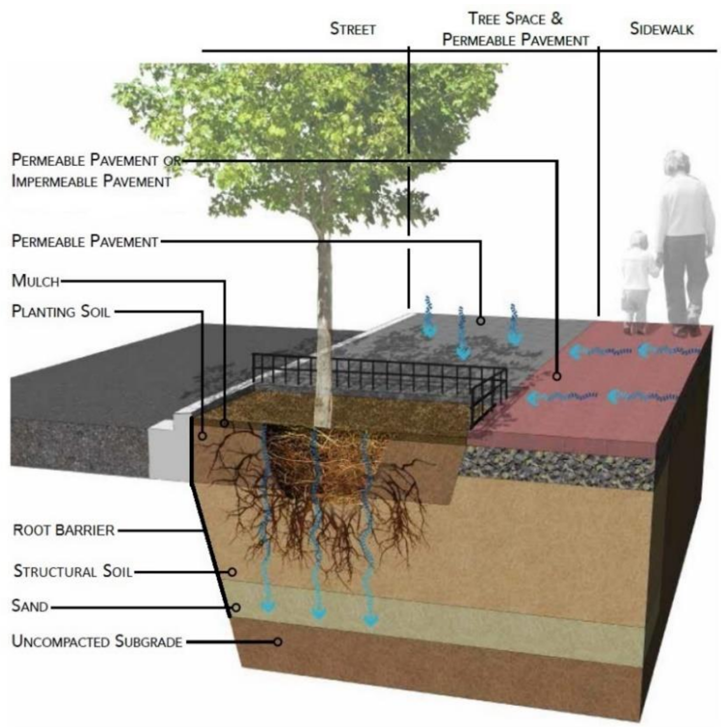
Resources:

- Caltrans Pervious Pavement Design Guidance
- FHWA Toward Sustainable Pavement Systems: A Reference Document (Chapter 6)

Natural Responses

Install Tree Wells

Figure 15: Tree Well Components



Source: https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/watershedpdf/Dev_Sup/County_BMPDM.pdf

Brief Description: Tree wells or basins can help capture stormwater and provide a dedicated space for tree growth in urban or suburban streetscapes. Features of tree wells can include permeable pavement, mulch, uncompacted planting soil, structural soil (mix of stone and soil), sand, structural cells (lattice structure supporting sidewalk and providing space for uncompacted soil), and uncompacted subgrade.

Relevant Transportation System Components: Urban/suburban streets and sidewalks

Co-Benefits: Preservation of natural environment and creation of green space, greenhouse gas mitigation, stormwater management, heat/air quality mitigation (See Extreme Temperature section earlier in this document), community/placemaking.

Resources:

- County of San Diego BMP Design Manual
- Tree Fresno Tree Selection Guide
- The US EPA has a webpage dedicated to information on rain gardens.

Install Bioretention Areas and BioSwales

Brief Description: Bioretention areas, also called rain gardens or bioinfiltration areas, are depressions in the earth that consist of plants, organic matter, and often an engineered substrate, which is used to capture and filter stormwater and sediment captured from nearby impervious surfaces. These areas help slow runoff and foster groundwater infiltration. Bioretention features can also include tree wells (see Figure 15 above), planter boxes, curb extensions, or bioswales (Water Environment Research Foundation, n.d.). Vegetated swales are "long, shallow vegetated depressions, with a slight longitudinal slope. As water flows through the swale, it is slowed by the interaction with plants and soil, allowing sediments and pollutants to settle out. Water soaks into the soil and is taken up by plants, and may infiltrate further into the ground if the soil is well drained" (EPA, 2009). Plants chosen for bioretention areas and bioswales should be native or regional. In California, many native species are accustomed to receiving heavy rainfall, followed by long periods of drought, and therefore are convenient for use in a rain garden or bioswale (Metzger, n.d.). However, choosing plants is site-specific and depends upon conditions like soil type, sunshine, and root structure. Consulting local landscapers and gardeners is important to choose the right mix of plant species. The University of California Agriculture and Natural Resources (UCANR) connects academics and members of California communities to study and address agricultural and natural resource issues. UCANR's Fresno County Cooperative Extension could provide useful advice and consultation on this topic.

Relevant Transportation System Components: Urban/suburban streets and sidewalks

Co-Benefits: Natural environment, stormwater management

Resources:

- FHWA Hydraulic Engineering Circular (HEC) 22: Urban Drainage Design Manual
- National Association of City Transportation Officials Urban Street Stormwater Guide
- County of San Diego BMP Design Manual
- This Ecological Landscape Alliance article provides some useful information on how to choose plants for a bioretention/bioswale
- UCANR's Fresno County Cooperative Extension

Figure 16: Bioswale

Source: https://nacto.org/wp-content/themes/sink_nacto/views/design-guides/retrofit/urban-street-design-guide/images/bioswales/carousel//unknown_unknown_3.jpg

Bank Vegetation/Seeding

Brief Description: Planting native species along riverbanks can protect against erosion and decrease the magnitude of floods. These plants can prevent erosion, trap sediment, and slow flood waters.

Relevant Transportation System Components: Rivers/streams adjacent to or crossing roadways, bridges, culverts

Co-Benefits: Natural environment, greenhouse gas mitigation

Resources:

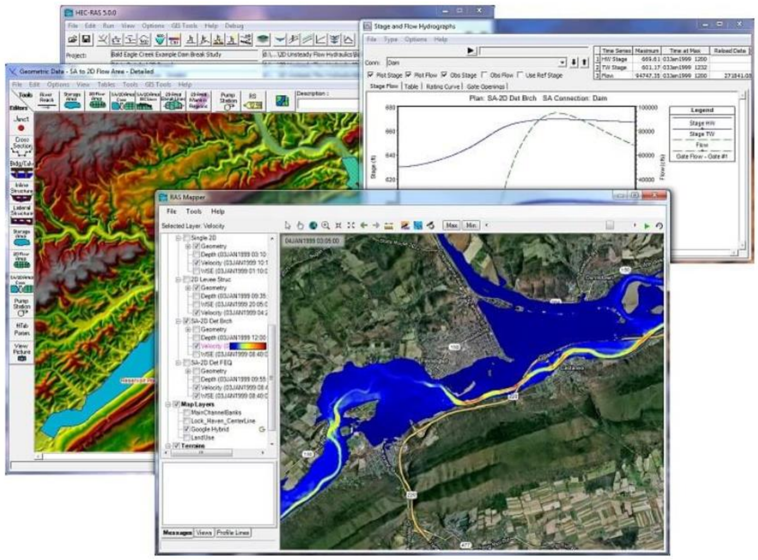
- Caltrans Erosion Control Toolbox: Specifying Seed and Plant Species
- California Riparian Habitat Restoration Handbook

Land Use Responses

Designate Future Floodplains

Brief Description: Floodplains are a crucial information source used in locating and managing transportation infrastructure and other development. However, except for some coastal floodplains, virtually all floodplains in the U.S. are based on historical climate information rather than future climate projections. These include the FEMA Floodplain Insurance Rate Maps (FIRMs). Therefore, one adaptation strategy is to develop future floodplains based on modeled projections. This strategy is very similar to the "Adjust Precipitation/Discharge Projections Used in Design" strategy in that it also uses forecasted future precipitation and discharge projections as an input for decision making.

Figure 17: HEC-RAS Software for Floodplain Modeling



Source: https://www.hec.usace.army.mil/software/hec-ras/

Relevant Transportation System Components: All

Co-Benefits: Context dependent

Resources:

- United States Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) documentation on floodplain modeling.
- FEMA Guidelines and Standards for Flood Risk Analysis and Mapping note that FEMA FIRM floodplains are based on observed data regarding the historical climate rather than projected future climate conditions.

Minimize and Avoid Development in Flood Hazard Areas

Brief Description: Agencies and jurisdictions can restrict or avoid the location of development in floodplains. Development can refer to transportation facilities specifically or to other public ally- or privately-owned structures and improved property. The California Adaptation Planning Guide mentions several relevant practices that agencies can consider (CalEMA, CA NRA, 2012):

- Use floodplains (from FEMA or other sources) for determining general plan policies and zoning patterns,
- Participate in the Community Rating Service system, which reduces rates for flood insurance purchasers,
- For flood-prone Severe Repetitive Loss communities, pursue flood mitigation assistance grants designed to reduce flood exposure,
- Restrict allowable densities in hazardous areas,
- Cluster development or set it back from flood hazard areas,
- Transfer allowable density from hazardous sites to safer areas,
- Modify proposed parcel boundaries and street locations to avoid hazardous areas,
- Require multiple ingress and egress points for emergency access and evacuation.

Relevant Transportation System Components: All

Co-Benefits: Natural environment, public safety

Resources:

- California Adaptation Planning Guide, Identifying Adaptation Strategies
- State of California Hazard Mitigation Plan

Land Acquisition /Exchange

Brief Description: Jurisdictions can offer to acquire flood-prone property from owners in exchange for comparable land elsewhere or cash. This can be a potentially cost-effective option when properties or the infrastructure that serves them incur or are expected to incur substantial, repetitive flood-related costs. Heavy coordination and sufficient funding are important aspects of this strategy. There are several FEMA programs that can help fund flood-prone land acquisition.

Figure 18: Home Relocation

Source: https://www.fema.gov/media-library-data/20130726-1446-20490-0539/FEMA511-complete.pdf

Relevant Transportation System Components: All

Co-Benefits: Natural environment, stormwater management, greenhouse gas mitigation

Resources:

- FEMA, Reducing Damage from Localized Flooding
- Environmental Law Institute, Prioritizing Future Floodplain Acquisitions: Maximizing Opportunities for Habitat Restoration, Community Benefits, and Resilience

Wetland Conservation/Restoration Areas

Brief Description: Conserving or restoring natural wetland areas can serve as a flood mitigation strategy for transportation infrastructure. Natural riverine floodplains, which can include ecosystems such as freshwater marshes, swamps, bogs, and fens, can absorb floodwater and prevent erosion (Kumar, 2017).

Relevant Transportation System Components: All

Co-Benefits: Natural environment, stormwater management, and greenhouse gas mitigation.

Resources:

- EPA Wetlands Protection and Restoration
- California Riparian Habitat Restoration Handbook

Wildfire

Direct Infrastructure Damage

Wildfires are a risk to the operations of existing transportation infrastructure and key facilities. In many instances, infrastructure was not designed to withstand direct wildfire impacts such as burning and high heat, or secondary impacts of wildfires like subsequent debris flows.

Responses

Maintain Defensible Space & Protect Critical Assets

Brief Description: Defensible space is a strategy for transportation planners to reduce the risk of structural damage to transportation assets in the event of a wildfire, particularly for critical assets such as arterial roads and evacuation routes. This strategy helps to reduce the risk of fire hazard and enables firefighters to defend the asset (University of California Cooperative Extension, 2009). Providing defensible space is a strategy that can be widely applied and is an especially important strategy for critical structures and evacuation routes and major roadways. Maintaining defensible space is a year-round process, which requires resources and coordination and time and monetary resources.

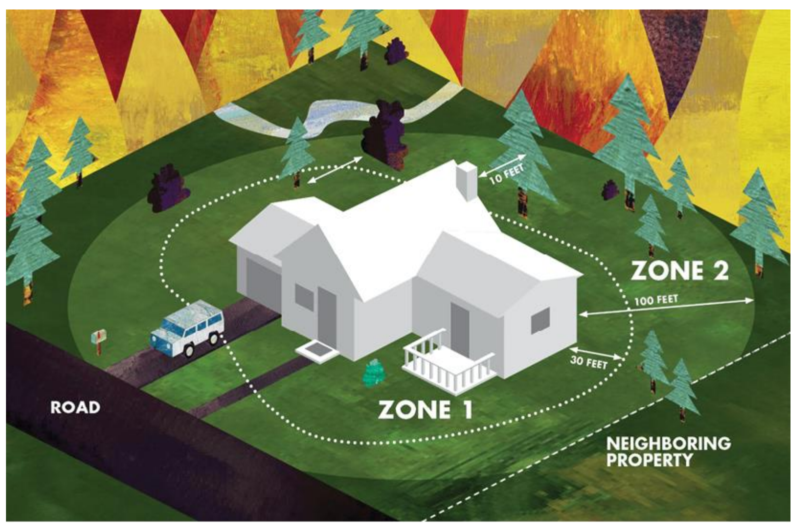
Relevant Transportation System Components: Facilities, Roadways, Transit Assets such as bus shelters

Co-Benefits: Reduce fire risk and risk of property damage in the county more broadly

Resources:

- California Public Resources Code 4291 establishes requirements for maintaining defensible space for property owners.
- Cal Fire offers guidance on how to protect properties and assets, which can be useful to inform maintenance activities.

Figure 19: Defensible Space Zones



Source: CalFire

Remove Post-Wildfire Debris

Brief Description: Post-wildfire debris removal is a longer-term recovery strategy to reduce the severity of post-fire flooding events, which can be exacerbated by post-wildfire debris flows (West Riverside Council of Governments, 2019). To defend transportation assets, transportation agencies can remove potentially dangerous debris following a wildfire event when reduced vegetation can increase the velocity of flooding events and debris flows. This strategy is often implemented outside the transportation right-of-way; however, transportation managers can be involved in implementation to help prevent damage to transportation assets, disruptions to transportation service, and barriers to evacuation routes (USGS, n.d.).

Key actions for post-wildfire debris removal include:

- Employing best-available monitoring and data collection to identify areas susceptible to future debris flows.
- Employing best-available data to predict future debris flows.
- Establishing and continuing to maintain barriers, such as riprap, in areas determined to be susceptible to future debris flows.
- Reforesting immediately following a wildfire event.
- Regularly monitoring areas burned by wildfire years after the event.
- Coordinating with property owners and other stakeholders.

Figure 20: Post-Wildfire Debris Removal Northern California

Source: Society of American Military Engineers

Relevant Transportation System Components: Roadways, ancillary transportation assets such as bus shelters and guardrails

Co-Benefits: Context-dependent

Resources: Cal Recycle and the California Environmental Protection Agency have guidance on how to properly transport and dispose of debris.

Size Culverts, Bridges, and Drainage Infrastructure to Account for Wildfire Exposure

Brief Description: Post-wildfire debris flows can cause damage to culverts, bridges, and drainage infrastructure, since debris flows can overwhelm the design capacity of these assets. By sizing infrastructure to account for and accommodate “bulked” flows— mass movement of primarily rocks, debris and soils—jurisdictions can minimize damage. To design assets based on bulked flows, jurisdictions can apply a bulking factor to peak (clear water) flow rates to determine the total or bulked peak flow, offering a safety factor in the sizing of culverts. Engineered mitigation strategies for increases in stormwater volume and peak flows due to debris include (West Riverside Council of Governments, 2019):

- Design of new culverts using appropriate bulking factor.
- Retrofit of existing culvert capacity through enhanced inlet design.
- Increasing existing culvert capacity through replacement or addition of a culvert barrel(s).
- Construction of sediment/debris capture mechanism at, or upstream of, the culvert entrance (inlet riser pipe, desilting/debris basin).

Relevant Transportation System Components: Culverts, bridges, drainage infrastructure

Co-Benefits: Context-dependent

Resources:

- Caltrans District 5 Draft Climate Change Vulnerability Assessment
- United States Army Corps of Engineers' Method (Tatum Method) for determining bulked flows for use in appropriate sizing detention basins, debris basins, and culverts.
- Los Angeles County Department of Public Works (LADPW) Flood Control District Method for determining single storm event debris production and bulking factor rates.
- The FHWA Hydraulic Engineering Circular No. 9, "Debris-Control Structures," shows types of debris control structures and provides a guide for selecting the type of structure suitable for various debris classifications.

Choose Appropriate Materials for Wildfire Prone Areas (for Drainage, Signage, etc.)

Brief Description: In wildfire prone areas, jurisdictions can use fire-resistant materials, such as concrete pipes and steel, to build and replace drainage infrastructure in order to reduce damage and loss of service of these assets. Additionally, jurisdictions can consider replacing existing plastic culvert pipe inlet structures (plastic flared end sections) with concrete headwalls in these areas. Other assets that can be protected by replacing them with wildfire/heat resistant materials include ITS signage and cables and any wooden sign posts, fencing, earthworks supports, walls, etc. (West Riverside Council of Governments, 2019).

Figure 21: Metal Pipe and Concrete Headwall Post-Fire

Source: Caltrans District 8 Climate Change Vulnerability Assessment Summary Report, 2019

Relevant Transportation System Components: Culverts, ancillary transportation assets such as signs and guardrails

Co-Benefits: Stormwater management

Resources: FEMA's Wildfire Hazard Mitigation Handbook for Public Facilities

Evacuation

Wildfires can trigger the need for evacuations and can inhibit the ability of populations to evacuate high-risk areas by damaging or disrupting the level of service of transportation and infrastructure. This is particularly true for the eastern parts of Fresno County, which are forested and mountainous regions. Two types of strategies are available to Fresno County to prepare for evacuations: 1) emergency and communication responses, and 2) operations and design responses.

Emergency and Communication Responses

Maintain and Update Community Emergency Response and Communication Plan

Brief Description: An up-to-date and collaboratively-produced community emergency response and communication plan can help to facilitate effective emergency response and evacuation in the event of a wildfire. This plan should be coordinated across other agencies and stakeholders, and it may also be a part of a city or county emergency operations plan that covers all sectors.

Examples of best practices include (West Riverside Council of Governments, 2019):

- Clear communication plan for coordination between agencies across jurisdictions, with adjacent municipalities or counties, and overarching organizations, such as Cal OES, Caltrans, and Cal Fire. It should cover communication with emergency services personnel and other sectors involved with emergency management, in addition to within the transportation sector.
- Command structures and transfer of command protocols for hazard events.
- Multiple and redundant modes of communication, including plans for when communications and power grids are offline.

Additional best practices can be found in the resources listed below.

Relevant Transportation System Components: Roadways

Co-Benefits: Collaboration and relationship-building amongst key management agencies in the county

Resources:

- Fresno County Master Emergency Services Plan
- State of California Emergency Plan
- Standardized Emergency Management System
- National Response Framework
- National Incident Management System
- FHWA's primer on Concept of Operations (CONOPS) for emergency response outlines important emergency planning and operations considerations specifically for transportation managers.

Figure 22: Evacuation Stakeholders

Source: FHWA Using Highways for No-Notice Evacuations, Ch. 5

Identify Key Evacuation Corridors and Bottlenecks

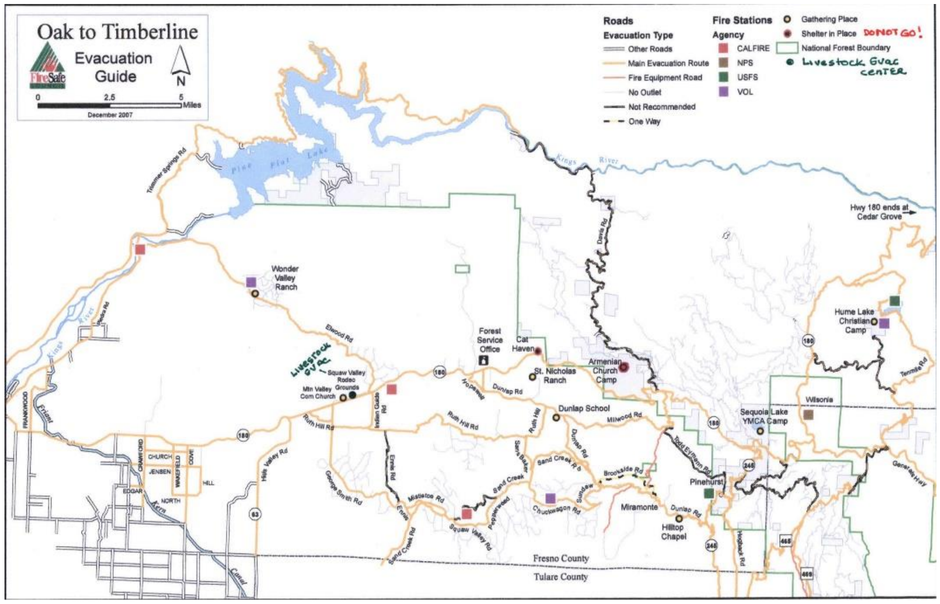
Brief Description: To develop and effective evacuation plan, jurisdictions must have a strong understanding of how the transportation network might be used in the event of a hazard. Decision-makers need to understand several aspects of the transportation network, including (West Riverside Council of Governments, 2019):

- The capacity of roadways and other infrastructure.
- The locations of high hazard risk areas, such as fire- or flood-prone areas and where people could be evacuated to if those hazards were to occur.
- The patterns of travelers by time of day and mode and the typical origin-destination numbers.
- The potential origin-destination numbers patterns during hazard events at different times of day on different modes. Decision-makers can grasp and understanding of these patterns by using knowledge of typical numbers and patterns, high hazard risk areas, and where people would need to be evacuated to.
- The characteristics and locations of potential evacuees, such as languages spoken and potential mobility restrictions.
- The portions of the network that would be susceptible to disruption from hazards (e.g., roadway blockage or bridge failure).
- The redundancy of the transportation network (i.e., availability of alternative routes).

- The expected roadway volumes and timing based on both typical and hazard origin-destination patterns, including the volumes and timings when vulnerable assets are disrupted.
- The locations of chokepoints, such as intersections/interchanges, road narrowing, etc.

After developing an understanding of how the transportation network might be used during an evacuation event, by utilizing traffic demand models and microsimulation models, an evacuation plan can be developed. This plan can include actions for addressing potential vulnerabilities, such as capacity constraints, populations with special mobility needs, and asset failure points.

Figure 23: Oak to Timberline Evacuation Guide



Source: Fresno County Sheriff

Relevant Transportation System Components: Roadways, Bridges

Co-Benefits: Public safety, improved working knowledge of the transportation system to inform planning and maintenance

Resources: Cal OES, Evacuation & Transportation Planning Guidance

Transit Services to Help Facilitate Evacuation

Brief Description: Transit services are essential for the mobility of county residents in the event of an evacuation, particularly for vulnerable populations to reduce the risk to human life (Transportation Research Board, 2008). Using transit vehicles for evacuee transport is an especially important consideration, as buses will be able to transport more evacuees at one time than personal vehicles. In addition, some evacuees may not have access to a car at all, or cannot drive themselves, and will need assistance. Deploying paratransit services is especially important. Operating transit services to support evacuation efforts requires upfront planning, such as making transit vehicles available and making sure transit staff is available to operate buses and manage operations.

Figure 24: PRIDE Private Transit Service Responding to Wildfire Evacuees in Placer County

Source: PRIDE Industries

In the case of the Tubbs Fire, the Santa Rosa CityBus service was critical in evacuating hospitals and senior care facilities such as the Kaiser Permanente Santa Rosa Medical Center and Fountaingrove Assisted Living Facility. Santa Rosa CityBus employees were prepared for such an event because of annual drills and trainings and each bus operator had directions on their ID cards telling them where to go in case of an emergency. Overall "CityBus helped evacuate nearly 400 people within the first 12 hours of the crisis" and their support did not stop there, as buses helped the Sonoma County Emergency Operations Center move evacuees over the next couple weeks following the fire (California Transit Association, 2019).

Relevant Transportation System Components: Passengers

Co-Benefits: Benefits include short and long-term public health outcomes by removing people from high-risk environments

Resources:

- TCRP Special Report 294, The Role of Transit in Emergency Evacuation
- Caltrans, Rural Transit Emergency Planning Guide
- TCRP Report 160, Paratransit Emergency Preparedness and Operations Handbook

Community Engagement and Public Education

Brief Description: A foundational element of evacuation planning in response to wildfires is ensuring that the public has the opportunity to inform and is aware of the plans and strategies in place to respond to these emergencies. The public needs to be aware of what the evacuation routes are and what services, like transit, are available to them. Additionally, the public are aware of the nuances and concerns in their own community, such as where vulnerable populations live and further which languages need to be used in communicating emergency messages. These pieces of information and others can help to inform a more effective and efficient emergency response and evacuation process. Fresno COG has already conducted extensive public outreach through the Fresno County TNVA, which is a first step in getting individuals involved in developing adaptation strategies.

Relevant Transportation System Components: Passengers

Co-Benefits: Public trust

Resources:

- Fresno County Regional Transportation Network Vulnerability Assessment, Public Outreach Synopsis
- ICLEI Resource Guide, Outreach and Communications

Figure 25: Fresno COG TNVA Public Outreach Pop-Up Event

Operations and Design Responses

Implement Transportation Design Strategies for Evacuation Events

Brief Description: Roadway design can have major implications for how well it functions in the event of an emergency. For example, shoulders can function as additional lanes for emergency vehicles. Dynamic shoulders can also be opened to additional vehicles in case of an evacuation. Median breaks and crossovers can also be used by emergency vehicles and can be necessary to redirect traffic during an emergency. Both dynamic shoulders and median breaks/crossovers can be used when facilitating "contraflow" lanes, which is a lane that is used to direct traffic in the opposite direction of the way it would normally go. Opening contraflow lanes is useful in the event of an evacuation because it can relieve congestion and allow more people to exit dangerous areas over a given timeframe. Evacuations can be streamlined by implementing these other potential transportation design strategies (West Riverside Council of Governments, 2019):

- Broadening roadways that are key evacuation routes,
- Maintaining defensible space along key evacuation routes to minimize fire hazards and act as a fire break (see the section on direct infrastructure damage),
- Establishing and creating emergency pull-off or refuge areas for emergency vehicles or evacuees,
- Installing and using heat-resistant intelligent transportation systems (ITS) to communicate information to passengers during an evacuation,
- Installing mile markers to assist emergency responders and evacuees during an evacuation to identify locations when people are without cell service and to serve as a marker for the side of the road when it is dark or smoky,
- Monitoring traffic and debris with closed circuit television (CCTV) or similar systems to also respond and provide redundancy in case of system disruption,
- Using adaptive signal control (ASC) systems to adjust traffic lights and other signals to high volumes during hazard events, and provide redundancy in case of system disruption.
- Establishing Traffic Management Centers (TMCs) and develop contingency plans for loss of power and communications.

Relevant Transportation System Components: Roadways, roadway corridors/right-of-way.

Co-Benefits: Enhanced public safety and streamlined evacuations.

Resources:

- The Federal Highway Administration (FHWA) released a guidance document on Evacuation Transportation Management in 2006, which provides information on advanced evacuation planning, identifying resources, roles, and responsibilities, and step by step guidance on facilitating evacuation from start to finish.
- FHWA's Designing for Transportation Management and Operations: A Primer includes a section on "Design Considerations for Specific Types of Operation Strategies," which covers how transportation project design can influence operations strategies.

Implement Transportation Operations Strategies for Evacuation Events

Brief Description**:** There are many operational responses that can help facilitate an efficient and successful evacuation. Some of these strategies rely on the design changes and equipment that discussed in the section above. For example, contraflow lanes may not be possible unless there are median breaks which allow vehicles to cross to the other side of a roadway. Using dynamic shoulders for emergency vehicles or evacuee traffic may not be feasible if the shoulder was not designed for these vehicle loads. Other operational strategies include (West Riverside Council of Governments, 2019):

Figure 26: Florida Emergency Response Vehicle Using Shoulder

Source: FDOT

- Adjusting signals to direct and manage traffic during evacuation events,
- Stocking and utilizing deployable signs and barriers to direct traffic,
- Operating transit services to transport evacuees, as discussed in the section above,
- Designating lanes (such as shoulder lanes) for emergency vehicles,
- Coordinating and managing timed evacuation from areas with heavy volumes and high potential for congestion and bottlenecks,
- Planning for closure of road lanes or ramps leading into hazard areas,
- Coordinating additional on-call maintenance support for debris clearing during events,
- Establishing and operating temporary traffic control points staffed by emergency management personnel.

Relevant Transportation System Components: Roadways, roadway corridors/right-of-way.

Co-Benefits: Enhanced public safety and streamlined evacuations.

Resources:

- FHWA's Evacuation Primer includes information on planning considerations to resolve issues ahead of time, and improve evacuation scenarios.
- FHWA's Evacuation Transportation Management report on operational concepts of evacuation.

Implement General Plan Safety Elements Through Zoning and Subdivision Practices That Provide Adequate and Redundant Evacuation Routes in Wildfire Hazard Areas

Brief Description: Jurisdictions can leverage land use planning and zoning practices to reduce risk and to improve resilience in high-hazard areas, which can be folded into the safety element of their general plan to meet the SB 379 requirements. Land use planning can minimize risk in several ways such as (West Riverside Council of Governments, 2019):

- Prohibiting development in high-risk areas through zoning and overlay controls.
- Limiting the types of development in high to moderate risk areas for open space or recreation, reducing the potential impacts of natural hazard events.
- Applying appropriate development controls in moderate and lower risk areas such as setbacks and lot sizes, as well as maximum densities and site coverage (Bajracharya, Childs, & Hastings, 2011).
- Transferring allowable density to areas that are less at risk of wildfires (CalEMA, CA NRA, 2012).
- Encouraging development in areas with multiple access routes, or ensuring that new, wildfire-prone development includes at least two access routes.

Relevant Transportation System Components: Roadways, Right-of-way, Bridges

Co-Benefits: Improved accessibility to employment and essential services

Resources:

- California Adaptation Planning Guide: Identifying Adaptation Strategies (2012) provides insights into possible land use strategies that can be used to address multiple climate hazards.
- The California Hazard Mitigation Plan has examples of different hazard mitigation strategies.

In-Place Shelters for Areas Without Redundant Evacuation Routes

Brief Description: If populations live in areas that are not easily accessible by multiple evacuation routes, Fresno County can reduce the risk to life during a wildfire by providing shelter-in-place facilities in these regions. Shelter in-place is defined as, "The use of a structure to temporarily separate individuals from a hazard or a threat (FEMA, 2019)." As a result, a shelter in-place strategy can be requiring residents to stay in their homes or to have residents in an isolated community meet at a proximate centralized location to seek shelter.

Relevant Transportation System Components: Roadways/Bridges/Evacuation Routes

Co-Benefits: Reduced congestion on evacuation routes, reduced costs of wildfire events

Resources: FEMA's Planning Considerations: Evacuation and Shelter-in-Place (2019) provides an overview on the topic and examples to learn from.

Figure 27: Shelter In-Place Sign

Landslides

There are around 20 different types of landslides that commonly occur in California, ranging in type because of various soil conditions, triggers, size, and speed. While some landslides may cause more severe impacts, each type can cause direct impacts to transportation infrastructure. Several landslide response and preparation strategies are explained in more detail below.

Direct Infrastructure Damage

There are many different types of landslides, but they generally fall into five common classifications: earth flows, debris flows, debris slides, rock slides, and rock falls (CGS, 2019). Deep-seated landslides, which were assessed as part of the Fresno County Transportation Network Vulnerability Assessment, fall into the earth flow and rock slide categories. Each of these five, general landslide types are included in California landslide inventory mapping, which is done to identify locations of past slides and potential future failures (CGS, 2019).

- **Earth flow:** Made up of fine-grained soils cohesively flow down a moderately steep slope. Slow moving, normally only a couple millimeters or centimeters per day.
- **Debris flow:** Made up of coarse-grained soils that are non-cohesive. These are large and move quickly; they can cause devastating impacts.
- **Debris slide:** Made up of coarse-grained soil on very steep slopes. These slides have a greater mass than debris flows and can move at meters per week or faster.
- **Rock slide:** Made up of moving bedrock that occurs on relatively steep slopes. These slides can vary greatly in size and can be caused by many triggers.
- **Rock fall:** Made up of boulders and rock masses detached from a steep slope. These occur on slopes made of hard and fractured rock and are extremely dangerous.

Each of these types of slides can cause direct transportation infrastructure damage by cracking pavement and compromising roadbeds, destroying roadway signage and guardrails, interrupting utility networks, destroying embankments and earthworks, clogging corridors and drainage with debris, causing road closures, and generating associated public safety and travel concerns. While landslides of a larger scale can cause major and unavoidable impacts, there are strategies that can be applied more broadly to monitor landslide activity, mitigate risks, and prepare responses.

Responses

Implement Zoning and Subdivision Practices that Restrict Development in Landslide Hazard Areas

Brief Description: The most straightforward solution to risks and impacts posed by landslides is to avoid hazard areas entirely. By adopting local codes and ordinances to protect steep slopes, there are inherent protections granted to the public, natural resources, and infrastructure. Fresno County zoning ordinances specify that private property in dangerous areas, such as “areas too steep to build upon” can be designated as an Open Conservation Land Use District, but otherwise do not cite specific zoning requirements related to steep slopes (Fresno County, 2018). Other counties and cities have adopted ordinances to restrict development on steep slopes, which Fresno County may consider to protect property. Allegheny County in Pennsylvania, for example, limits development on slopes between 25 and 40 percent, does not allow any development on slopes between 15 and 40 percent located within conservation areas, and prohibits all development on slopes exceeding 40 percent (US EPA, 2014).

Relevant Transportation System Components: Drainage infrastructure, roadways, bridges, facilities, earthworks.

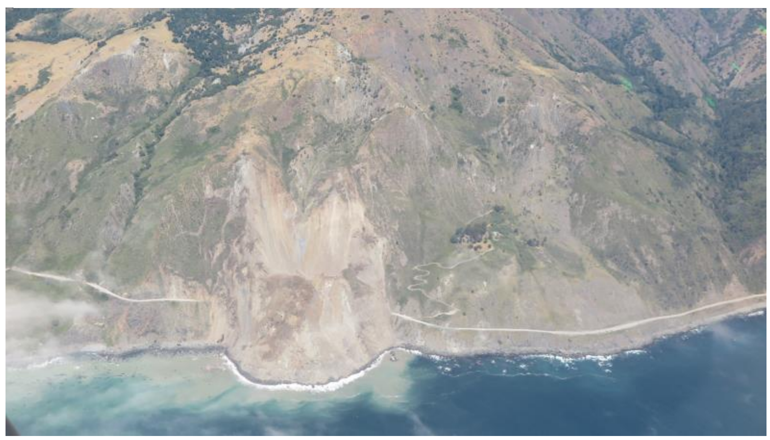
Co-Benefits: Benefit to public safety by limiting exposure to slide risk areas, preservation of natural areas, cost savings from reduced maintenance, recovery, and response needs.

Resources: The California Adaptation Planning Guide: Identifying Adaptation Strategies report identifies the following adaptation strategy to avoid risks from flooding and landslides: "WM 5: Implement general plan safety elements through zoning and subdivision practices that restrict development in floodplains and landslide hazard areas (CalEMA, CA NRA, 2012)."

Slope Stability Monitoring

Brief Description: Monitoring slope stability, especially in active or historically active slide zones, is a relatively easy way to understand and prepare for potential slide risk. Early warnings of instability can allow for timely evacuation and response, and can be lifesaving if vulnerable areas are blocked off ahead of time. This was the case in Big Sur, California, when multiple landslides wreaked havoc on the State Highway System in 2017. Caltrans detected the first signs of slope instability before the massive Mud Creek slide buried a third of a mile of the Pacific Coast Highway and preemptively stopped traffic on the roadway (AASHTO, 2018) (USGS, 2017). Now that the highway is re-opened, Caltrans continues to monitor the area by using a variety of techniques that provide real-time movement analysis.[6] USGS is also helping Caltrans to monitor the slide by taking aerial photos and creating Digital Elevation Models (DEMs) of the slide area (USGS, 2017)

Figure 28: Mud Creek Slide, Big Sur, CA



Source: Caltrans District 5

Relevant Transportation System Components: Drainage infrastructure, roadways, bridges, facilities, earthworks.

Co-Benefits: Benefit to public safety by preemptively identifying slide risk.

Resources:

[6] Information provided by Caltrans District 5.

- The *Draft Caltrans District 5 Vulnerability Assessment Summary Report* will provide useful information on the 2017 Central Coast landslides and how the district responded. The report will also provide information on the monitoring equipment used in the Mud Creek Slide area.
- The *Geomorphology* journal article "Assessment of ground-based monitoring techniques applied to landslide investigations" provides a detailed look at monitoring landslides and their triggers, and the results summarize the performance of different monitoring techniques.

Asset Design Changes in At-Risk Areas

Brief Description: Altering transportation asset design can help mitigate risks from landslides by addressing landslide triggers, such as heavy precipitation, prolonged rainfall, rapid runoff, and wildfire. Design strategies can also be applied to avoid landslide impacts altogether and to increase the resilience of infrastructure in landslide risk areas. Some general design strategies used to prevent or prepare for landslide impacts include (Johnson, 2019):

- **Enhanced drainage:** Provide sufficient drainage for surface and subsurface runoff. Heavy precipitation can lead to erosion, washouts, and slope instability. This is applicable for all five landslide types.
- **Debris flow catchment:** Mitigate likelihood of debris flow by maintaining slope stability. Install debris flow catchment infrastructure like debris flow catchment fences across drainage channels.
- **Reduce driving/resistance force:** These are two ways to reduce overall slide risk by manipulating the slope itself. Reduce driving force by moving material from the top of a slide mass to reduce the weight. Increase resistance force by adding fill to the base of a slope to increase the weight at the bottom of a potential slide area. Adjusting the weights in this way can reduce risk of a slide by relieving potential energy at the top of a slope.
- **Subsurface drainage:** Provide subsurface drainage to help reduce driving force and increase the strength of material in a slide zone.
- **Avoiding at-risk areas**: Avoid slide areas where possible. Where it is unavoidable, consider design changes to keep as much construction outside of the slide zone as possible. For example, Caltrans re-built the Pfeiffer Canyon Bridge to a single span bridge after a landslide damaged one of its central columns (AASHTO, 2018).

Relevant Transportation System Components: Drainage infrastructure, roadways, bridges, facilities, earthworks

Co-Benefits: Benefit to public safety by reducing slide risk

Resources:

- The California Geological Survey (CGS) provides helpful background information on types of landslides, landslide mapping/inventory, and recently reporting landslides.
- The American Association of State Highway and Transportation Officials (AASHTO) Resiliency Case Studies: State DOT Lessons Learned report provides two landslide examples and Department of Transportation (DOT) responses: a rockfall in Colorado and multiple coastal landslides in the Central Coast of California.

Natural Infrastructure Solutions

Brief Description: In addition to design changes, there are natural infrastructure or "green" solutions that can be applied to increase slope stability, decrease runoff, and reduce landslide risk overall. These strategies include:

- **Vegetation and seeding:** Seed slopes to provide additional stabilization and reduce surface runoff (Native Plant Solutions, 2016). Plant roots will help keep surface soils in place, but do not necessarily protect against deeper slides (EPA, 2014).
- **Runoff management:** Place vegetation at the top of a slope to absorb runoff and reduce the velocity of water flow (EPA, 2014). Berms and trenches can also be used to direct runoff, absorb surface water, and reduce erosion (Lynn Highland, 2008).
- **Bioengineering and biotechnical stabilization:** Bioengineering is the use of vegetation to stabilize slopes. When combined with structural components such as textiles, stones, terraces, and berms it is called biotechnical stabilization. Both techniques are used to reduce erosion and driving force (EPA, 2014).

Relevant Transportation System Components: Drainage infrastructure, roadways, bridges, facilities, earthworks

Co-Benefits: Greenhouse gas reductions, enhanced air and water quality, creation of green, blue, and open space

Resources:

- See the Caltrans Construction Manual, Chapter 4, Section 21 on "Erosion Control" for standards and recommendations related to landscaping, materials use, and construction practices.
- The Environmental Protection Agency (EPA) report Addressing Green Infrastructure Design Challenges in the Pittsburg Region provides useful background information on natural infrastructure solutions to steep slopes and associated challenges.
- The USGS Landslide Handbook – A Guide to Understanding Landslides provides background information on the different types of landslides, how to evaluate landslide risk, and different mitigation strategies, including natural and engineered strategies.

Maintain and Update a Clean-Up/Debris Management Plan

Brief Description: Having a plan in place in case of a slide is another way to ensure that transportation infrastructure can be restored and re-opened to traffic as soon as possible. In another Caltrans example, the agency applied this tactic following the Montecito debris flows. Given that there was some early warning that there would be a debris flow due to heavy storms in the Thomas Fire burn scar, the agency began organizing resources before disaster struck. Caltrans closed highways and lined up contractors in preparation for the event, to accelerate debris removal from state highways (Hendrix, 2018).

Relevant Transportation System Components: Drainage infrastructure, roadways, bridges, facilities, earthworks.

Co-Benefits: Benefit to public safety by clearing debris, more efficient use of resources.

Resources:

- The Caltrans Landslide Management Plan: Landslide Management Activities and Best Management Practices, released in 2013, provides best management activities for landslide prevention, response, and repair/clean-up.
- The EPA report, Planning for Natural Disaster Debris, heavily focuses on pre-disaster efforts to plan for natural disaster related debris management.

Regional Project Examples

The adaptation strategies summarized above can be applied in a variety of situations and projects. A project does not specifically need to be designed as a response to climate change to incorporate these responses. Adaptation strategies and general principles can be woven into planned and ongoing projects whenever there is a relevant climate change related hazard or risk that will affect that area.

A selection of project types and project examples were chosen from the 2018 Fresno COG RTP to demonstrate how climate change could be considered in project planning and adaptation strategies can be layered into project execution. There are five project types provided in the 2018 RTP:

- Bike and Pedestrian
- Transit
- Streets and Roads
    - Capacity Increasing
    - Maintenance
    - Operations

There are thousands of projects in the RTP, distributed among these five project types. One example from each project type is highlighted here to provide site-specific demonstrations of how: 1) climate stressors can be evaluated in project planning, 2) potential adaptation strategies are relevant to those projects, and 3) co-benefits stem from those responses and provide broader value for the Fresno region. These are not intended to be adaptation strategy recommendations for these sites, but rather sets of strategies that could be considered and evaluated using the principles outlined in this memo.

Bike and Pedestrian

Lake Joallan Class I Shared Use Path

Project ID: FRE501587

Agency: City of Firebaugh

Estimated completion date: 2035

Project description: In Firebaugh, along the San Joaquin River and Lake Joallan between the River Ln Trail Head and the end of the Birch Drive shared use path, construct Class I shared use path and trail amenities.

Main climate stressors of concern: Temperature rise is a concern and relevant climate stressor across Fresno County. Some areas may suffer more severe impacts from the UHI effect, which will likely be a greater concern from the Fresno-Clovis metropolitan area. The greatest change in temperature rise is expected in the eastern portion of the county, in the Sierra Nevada, as this geography historically experienced lower average and maximum temperatures. Given that temperature rise is a universal concern, it can be considered in all Fresno County transportation projects. It is especially relevant when considering impacts to bicyclists and pedestrians, who will exert themselves in the heat. Community survey results identified that walking and biking is uncomfortable in the summer months and more shade is needed along sidewalks/roadways.

Flooding is another concern for this trail construction project, as it will follow the San Joaquin River and the trail may flood periodically.

See the Fresno County Regional TNVA Final Technical Memorandum for more information on future projections and exposed transportation assets in Fresno County.

Potential adaptation strategies:

There are several adaptation strategies worth considering for trail construction projects, including:

Temperature responses:

- Shaded protection from structures and vegetation to ensure bicyclist and pedestrian comfort/health and safety during high heat events
- Air quality impact mitigation for bicyclist and pedestrian comfort/health and safety
- Multilingual notifications during poor air quality events for bicyclist and pedestrian health and safety

Co-benefits include improved bicyclist and pedestrian experience, reduced instances of heat health events, and reduced instances of poor air quality-related health events.

Flooding responses:

- Tree wells, bioswales, and rain gardens to mitigate flash flooding and re-direct surface runoff
- Increase gutter/drainage capacity based on future projections to accommodate heavy precipitation
- Elevate path and amenities to avoid potential seasonal flooding
- Use permeable pavements to accelerate percolation of rainfall into the soil

Co-benefits include improved bicyclist and pedestrian experience, flood control improvements on a larger scale, greenhouse gas reductions, green, blue, and open space from landscaping.

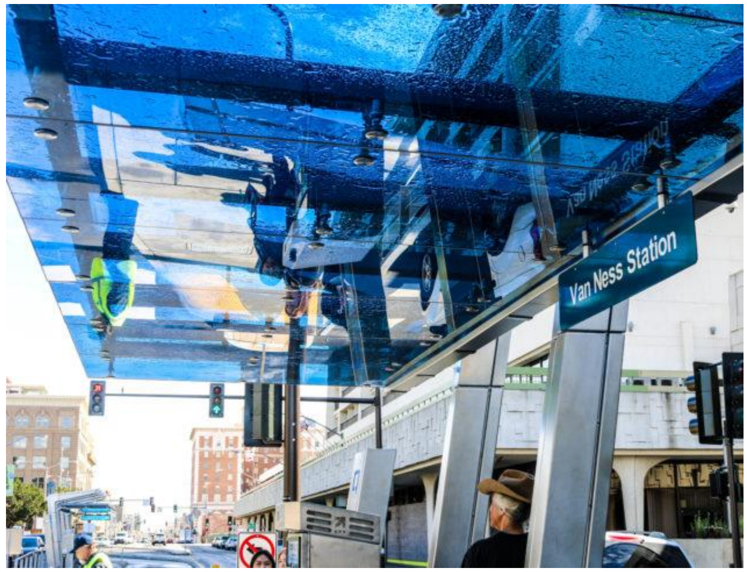
Figure 29: San Joaquin River Trailhead

Source: Photo by niicedave, licensed under CC BY-SA 2.0

Transit

Associated Transit Improvements

Figure 30: FAX Van Ness Station



Source: https://theknowfresno.org/03/02/2018/whats-fix-fax/

Project ID: FRE501099

Agency: Fresno Area Express

Estimated completion date: Unknown

Project description: Passenger amenity improvements (bus stops/stations) throughout FAX route system, including concrete improvements, shelters, lighting, signage, etc.

Main climate stressors of concern: As noted above, temperature rise is a concern and relevant climate stressor across Fresno County. Heat impacts are relevant to transit projects as riders, especially those dependent upon public transportation, because they will be disproportionately affected by heat impacts if they need to walk to/wait at transit stops in the heat.

Flooding is a concern for rural transit stops, because many stops do not have stormwater systems or adequate drainage to convey surface runoff. This was an issue that came up in survey and interview results with members of the community. Standing water at transit stops can make them hard to access during winter months.

See the Fresno County Regional TNVA Final Technical Memorandum for more information on future projections and exposed transportation assets in Fresno County.

Potential adaptation strategies:

There are several adaptation strategies worth considering for transit stop upgrades, including:

Temperature responses:

- Shaded protection from structures and vegetation to ensure rider comfort during high heat
- Benches and other bus stop amenities to ensure rider comfort during high heat

Co-benefits include: improved rider experience, reduced instances of heat health events, equitable distribution of resources – if transit stop improvements are focused in low-income, disadvantaged, or heat vulnerable communities in Fresno County.

Flooding responses:

- Tree wells, bioswales, and rain gardens to mitigate flash flooding and re-direct surface runoff
- Increase gutter/drainage capacity based on future projections to accommodate heavy precipitation

Co-benefits include flood control improvements on a larger scale, greenhouse gas reductions, green, blue, and open space from landscaping.

Streets and Roads – Capacity Increasing

Belmont-Cornelia to Marks: 2 LU to 5 LU

Project ID: FRE500634

Agency: City of Fresno

Estimated completion date: 2035

Project description: 2 LU to 5 LU with bike lanes, gutter, curbs and sidewalks.

Figure 31: Belmont Avenue from Cornelia to Marks

Main climate stressors of concern: Temperature rise is a concern and relevant climate stressor across Fresno County. Heat can not only impact the health and safety of the public, but the long-term viability of certain materials such as pavements. A capacity increasing project such as this one can incorporate strategies that mitigate heat impacts to the public and to pavements.

Flooding is a concern especially in locations without existing drainage. As this capacity increasing project will also add gutters, there is an opportunity to incorporate strategies that reduce flood impacts to the roadway, bike lanes, sidewalks, and the users of those transportation options.

See the Fresno County Regional TNVA Final Technical Memorandum for more information on future projections and exposed transportation assets in Fresno County.

Potential adaptation strategies:

There are several adaptation strategies worth considering for capacity increasing projects, including:

Temperature responses:

- Plant shade trees along street and sidewalk to ensure bicyclist and pedestrian comfort/health and safety during high heat events

Co-benefits include improved bicyclist and pedestrian experience and reduced instances of heat health events.

Flooding responses:

- Install tree wells, bioswales, and rain gardens to mitigate flash flooding and re-direct surface runoff

- Increase gutter/drainage capacity based on future projections to accommodate heavy precipitation

Co-benefits include flood control improvements on a larger scale, greenhouse gas reductions, green, blue, and open space from landscaping.

Streets and Roads – Maintenance

Replace Bridge No. 42C0264-Jose Basin Road Over Bald Mill Creek

Project ID: FRE130082

Agency: Fresno County

Estimated completion date: 2035

Project description: Bridge no. 42C0264, Jose Basin Rd, over Bald Mill Creek, 2.3 mi northeast of Auberry Rd. Replace existing one lane bridge with two lane bridge.

Figure 32: Jose Basin Road Bridge over Bald Mill Creek

Main climate stressors of concern: The Jose Basin Road Bridge crossing lies in a rural part of the county in Auberry, California. The roadway crosses through forests in the Sierra Nevada, making it inherently exposed to wildfire risk. Wildfires can damage roadways and supporting infrastructure, while also cutting off corridors needed for evacuation.

The Bald Mill Creek crossing also inherently creates a flood risk in the event of heavy precipitation and runoff. Flooding can impact the bridge approaches and debris can damage/erode bridge substructure.

See the Fresno County Regional TNVA Final Technical Memorandum for more information on future projections and exposed transportation assets in Fresno County.

Adaptation strategies:

There are several adaptation strategies worth considering for bridge replacement projects, including:

Flooding responses:

- Adjust discharge/flow estimates used for assessing water levels and scour
- Account for post-wildfire debris in design of bridge substructure

- Understand consequences of design storm exceedance
- Use risk-based design based on expected future precipitation conditions and consequences

Co-benefits include flood control improvements on a larger scale, improved stormwater management, enhanced public safety during heavy precipitation and flood events.

Wildfire responses:

- Consider the bridge's use in evacuation planning
- Implement transportation design strategies that will facilitate smoother evacuation
- Consider operational responses at the site that will facilitate smoother evacuation

Co-benefits include enhanced public safety during wildfires and evacuations.

Streets and Roads – Operations

Drainage

Project ID: FRE501841

Agency: Caltrans

Estimated completion date: 2023

Project description: Replace and reline culverts.

Main climate stressors of concern: Precipitation and flooding is the primary stressor of concern for culverts and drainage infrastructure. Increased frequency and severity of heavy precipitation events may lead to events that exceed the design capacity for existing culverts.

See the Fresno County Regional TNVA Final Technical Memorandum for more information on future projections and exposed transportation assets in Fresno County.

Adaptation strategies:

- Adjust precipitation and discharge projections used in culvert design
- Enhance drainage capacity of culverts

Co-benefits include flood control improvements on a larger scale and improved stormwater management.

Next Steps

Fresno COG and its stakeholders can use this toolkit of adaptation strategies to identify implementable and beneficial responses to climate change impacts across the region. These strategies can be applied to planned or current projects, or may even stand alone as their own projects in future rounds of the RTP. And more broadly, Fresno County jurisdictions can incorporate the findings of this memorandum and the Fresno County Region TNVA into the Safety Elements of their General Plans to satisfy the requirements of SB 379. The information summarized in this memorandum and other Fresno County Region TNVA deliverables will be compiled into a final report for use by Fresno COG, its stakeholders, and the public.

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