CALTRANS CLIMATE CHANGE ADAPTATION STRATEGY REPORT

Integrating Climate Adaptation into Caltrans Business Operations

Division of Transportation Planning
California Department of Transportation

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FIGURES

GLOSSARY

AASHTO: American Association of State Highway and Transportation Officials
AB: Assembly Bill
ADAP: Adaptation Decision-making Assessment Process
AMP: Advance Mitigation Program
BCA: Benefit Cost Analysis
CAL FIRE: California Department of Forestry and Fire Protection
CalOES: California Governor's Office of Emergency Services
Caltrans: California Department of Transportation
CCC: California Coastal Commission
CCCAR: Caltrans Climate Change Action Report
CCCVA: Caltrans Climate Change Vulnerability Assessment
CEQA: California Environmental Quality Act
CHAT: California Heat Assessment Tool
CIP: Culvert Inspection Program
COPC: California Ocean Protection Council
CSIWG: Climate-Safe Infrastructure Working Group
CSMP: Corridor System Management Plan
CTC: California Transportation Commission
CTP: California Transportation Plan
DEA: Division of Environmental Analysis
DSMP: District System Management Plan
EO: Executive Order
FEAR-NAHT: Framework for Enhancing Agency Resiliency to Natural and Anthropogenic Hazards and Threats
FEMA: Federal Emergency Management Agency
FHWA: Federal Highway Administration
GHG: Greenhouse Gas
ITSP: Interregional Transportation Strategic Plan
MPO: Metropolitan Planning Organization
NFIP: National Flood Insurance Program
O&M: Operations and Maintenance
PEAR: Preliminary Environmental Assessment Report
PID: Project Initiation Document
PDR: Project Development Report
RCR: Regional Concept Report
SAMNA: Statewide Advance Mitigation Needs Assessment
SB: Senate Bill
SHC: California Streets and Highway Code
SHS: State Highway System
SHOPP: State Highway Operation and Protection Program
SLR: Sea Level Rise
STIP: State Transportation Improvement Program
TAMP: Transportation Asset Management Plan
TCR: Transportation Concept Report
TMP: Transportation Management Plan
TSDP: Transportation System Development Program
VA: Value Analysis
VTrans: Vermont Agency of Transportation

EXECUTIVE SUMMARY

The 2009 State of California Climate Adaptation Strategy[1] noted that climate change effects were already occurring in California. Climate adaptation was defined in this Strategy as "efforts that anticipate and respond to the impacts of climate change – adjustments in natural or human systems to actual or expected climate changes to minimize harm or take advantage of beneficial opportunities." The Strategy also noted that all State agencies responsible for the management and regulation of public health, infrastructure, or habitat subject to significant climate change should "prepare as appropriate agency-specific adaptation plans, guidance, or criteria." Since this initial policy declaration, the State has passed additional legislation, issued Executive Orders, and developed guidance on how State agencies should prepare themselves for the challenges from climate change. Governor Newsom's Executive Order N-19-19 is an example of the most recent policy statement by requiring enhanced State efforts to reduce greenhouse gas emissions and increase resiliency to the impact of climate change by creating a Climate Investment Framework, including a strategy to align the State's investment portfolio toward such efforts.

Caltrans has other reasons for taking this initiative on climate change adaptation in addition to legislative and policy requirements. As stewards of the massive investment in the State's transportation system, Caltrans recognizes the threats and risks that changing climatic conditions could pose to one of the State's greatest assets. As seen in recent years, extreme weather conditions can disrupt and, in some cases, significantly damage highways. Caltrans' responses to these disruptions and the replacement of damaged highways results in significant fund expenditures. The costs to surrounding communities and the economy provide additional incentive to minimize extreme weather impacts on the transportation system. Caltrans recognizes that for it to adopt a leadership role in climate change adaptation, a concern for climate change impacts needs to be integrated into policy processes, planning, resource deliberations, project delivery, and performance measurements.

This report provides a "how-to-guide" for integrating climate change adaptation into Caltrans activities and decision-making. The recommendations were based on a survey and interviews of Caltrans officials; an examination of State laws, guidance, Caltrans policies, and operating procedures; and investigation into how other states are considering climate change in their own structure and decision-making processes. A framework is described that was used to assess Caltrans' capacity for mainstreaming climate change adaptation into agency decisions. As has been found in other U.S. transportation programs where climate change is becoming an important concern, enhancing an agency's capacity to address the associated issues is a prerequisite for success. This is analogous to the successful implementation of Caltrans' seismic

[1] California Natural Resources Agency. 2009. "2009 California Climate Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008." Sacramento, CA. Retrieved May 11, 2020 from https://resources.ca.gov/CNRALegacyFiles/docs/climate/Statewide_Adaptation_Strategy.pdf

program, where a multi-year and multi-capability effort has resulted in Caltrans becoming a world leader in seismic engineering.

The report recommends an implementation pathway for integrating adaptation considerations into Caltrans' procedures and processes. The pathway provided a structured, long-term, and agency-wide assessment of agency actions, and led to recommendations on improving agency capabilities in a range of functional responsibilities. The types of decision contexts covered in this section include defining Caltrans' vision and goals, planning, prioritization, environment, engineering, system operations, system maintenance, asset management, and project management. These recommendations, cumulatively, represent a strategy for improving the overall resiliency of Caltrans in putting in place the needed decision structure for meeting the challenges represented by climate change . Many of the steps in the pathway have already occurred in Caltrans, are currently underway, or are planned to be undertaken. This report completes several of these implementation pathway steps. This recommendations do not impact current programming and project development efforts.

Many of the recommendations in this report move Caltrans further along the adaptation pathway. However, some additional steps remain. In particular, the concept of risk is already an important consideration in Caltrans decision-making; however, in the context of climate change, the identification and management of climate-related risks should be viewed as a new standard, as a key factor in effective agency decision-making, and as a foundation for Caltrans' adaptation efforts. For example, project-level evaluation assessments should involve engineering-based analyses to verify asset exposure to pertinent climate hazards. If asset vulnerability is verified, adaptive measures to manage and or reduce/eliminate the risk should be evaluated. The adaptation approach includes determining the extent to which adaptation treatments could be applied to project designs that are being implemented primarily to address other concerns (e.g., improvements aimed at increasing capacity or improving safety). This also includes using lifecycle benefit/cost analysis for determining which adaptation projects or adaptive project designs should be considered.

The recommendations for change reflect slight variations on existing processes, while others require a greater shift in business and project development processes. In many ways, the recommendations suggest a different mindset for developing and implementing the programs that serve as the core of Caltrans' mandate. To implement the short- and long-term recommendations from this study successfully, Caltrans will also need to develop training and professional development activities for staff. Such opportunities would expose staff to the rationale for emphasizing adaptation and system resiliency in its programs and provide them with the knowledge and tools to guide Caltrans' evolution to a more resiliency-oriented agency.

In addition to specific recommendations on change, the report summarizes some of the key State policies, Executive Orders (EOs), and procedures that are most relevant to Caltrans' adaptation efforts. Expected future climatic conditions for each climate stressor that could potentially affect Caltrans activities and their possible consequences are discussed. In addition, the report discusses how Caltrans should coordinate with other agencies and stakeholders in furthering its adaptation strategy. The final section outlines future steps for Caltrans to integrate climate adaptation factors into decision-making processes, procedures, and projects. The appendix presents conceptual descriptions of the types of adaptation projects that Caltrans will likely be paying more attention to in future years in response to changing climatic conditions.

The specific recommendations for each of these contexts include:

<u>Organizational Responsibility</u>

1. Create an organizational structure in Caltrans with the authority, credibility, and accountability for integrating climate change adaptation into Caltrans' business operations and transportation investment decision-making. Currently, the agency lacks a systematic and programmatic approach to climate change and climate resiliency. This type of approach would require participation from many different functional units within Caltrans.

2. Each major program from planning, programming, project delivery, maintenance, and operations should be assigned responsibility for implementing the respective recommendations of this study, and develop appropriate procedures, guidelines, resources, and organization structure to maintain an effective and productive effort on climate adaptation and transportation resiliency. A point of contact should be identified for each program. The implementation plan for each unit should include recommendations for needed staff training.

<u>Vision/Goals/Policy Direction</u>

3. For the next update to the Strategic Management Plan (SMP), Caltrans should adopt an explicit goal (with corresponding objectives) that commits to climate change adaptation strategies. This could be a stand-alone goal or contained within a strategic goal that focuses on broader transportation system resiliency. One possible statement could be similar to what has been adopted by other state departments of transportation (DOT's):

   <u>Goal:</u> A transportation system that is resilient, reliable, and responsive to system disruptions.

   <u>Action:</u> "Proactively assess, plan, invest in, operate, and maintain the State's transportation system to protect system assets from extreme weather and, over the long term, climate change threats."

   If a specific climate adaptation goal is not desired, the strategic objectives of the adopted goals should call out climate adaptation and system resilience concerns.

Planning

4. The climate change planning function in the Division of Transportation Planning should be aligned with the State Planning Office. Long-range planning, including the California Transportation Plan, is a required statewide planning process that provides proper functional context and a process for climate change and adaptation planning along with the GHG reduction efforts should be developed. Planning activities should provide similar emphasis to adaptation and GHG emission reduction strategies. The adaptation section should include, at a minimum, the following information:
   a) What climate change trends could affect the transportation system being examined?
   b) What are the potential impacts to the transportation system? To the broader community that depends on a reliable transportation system?
   c) What are the types of strategies and actions that can be taken to protect or minimize these impacts?
   d) What steps (including collaboration with Caltrans' partners) are necessary to implement such strategies and actions?
5. System planning guidelines should address climate change adaptation and guide the development of system planning documents, such as District System Management Plans and Corridor Plans. Caltrans should develop more detailed guidance (other than that provided in the Corridor Planning Handbook) on how to include climate change adaptation and system resiliency into corridor planning studies. Such guidance could include such topics as:
   a) Using the District adaptation exposure results currently being developed to identify assets vulnerable to future climate change disruptions
   b) Using "system use" and not just "physical damage"' as a key criterion for prioritization of proposed actions, thus recognizing the importance of the State Highway System (SHS) to the State and local economy. System use should include criteria that are relevant to rural communities such as freight movement and lifeline service routes, not just volumes of use
   c) Using the recommended benefit/cost assessment approach (discussed below) for identifying cost effective projects incorporating uncertainties and user impacts
   d) Applying risk metrics to the identification of project alternatives (and if appropriate conceptual project designs
   e) Identifying community lifeline strategies (e.g., evacuation routes) for when emergencies occur

6. Caltrans should undertake a pilot planning study similar to the Colorado Department of Transportation's (CDOT's) where system resilience enhancement and risk minimization are included as the primary focus or is at least incorporated as an important goal of the study. The pilot study would serve as a "proof-of-concept" for such an approach, identifying the most appropriate means of including climate change concerns into its economic analysis efforts, which might vary by technique. Such efforts should include adaptation benefits as part of every application.

7. Caltrans should incorporate economic analysis in adaptation planning to prioritize project selection or alternatives on the State Highway System affected by climate change. Economic analysis tools that apply the life cycle cost analysis (LCCA), benefit cost analysis (BCA), or economic impact analysis (EIA) methodology should account for climate change to make the analysis more robust and better demonstrate how limited resources are being allocated effectively.

8. Examine the Project Initiation Document (PID) guidelines to consider explicitly where it is feasible to incorporate adaptation system considerations as part of project justification (e.g., definition of "need"). Many of the sections of the existing PID guidelines and Project Development Procedures Manual should be modified to do this. Including such an explicit consideration in the guidelines provides a "place" for adaptation concerns as a project proceeds along the project development process. One criterion that should be considered as part of the "need" definition would be whether a proposed project sits in an exposure area or whether it serves as an evacuation route from such an area.

9. In the longer term, once this Caltrans Adaptation Strategy Report and the District Adaptation Plans are adopted, modify the PID guidelines to incorporate both documents as official plans that should be considered as part of the purpose-and-need statement and in the early design considerations.

<u>Project Funding</u>

10. Develop a strategy in coordination with other key participants in the funding program development process for developing a climate change adaptation funding category for projects that are undertaken for such purposes.

<u>Prioritization</u>

11. Explicitly consider adaptation criteria into investment decision-making. A methodology for doing so could be targeted on prioritizing adaptation needs and projects themselves or based on metrics for identifying adaptation treatments that are included as part of project designs being developed in response to other primary criteria (e.g., capacity expansion or safety).

12. Priority in project adaptation investments should be given to those projects, 1) where current extreme weather-related disruptions occur and thus becomes a

need for Caltrans action, 2) where other project investments are occurring anyway and where incremental investment could have a positive impact on enhancing SHS resiliency, 3) given the importance of an asset where projections show increased extreme weather threats in the future, and 4) for locations where loss of service would result in significant community impacts.

<u>Environment</u>

13. Examine how the consideration of climate change adaptation can be better incorporated into the environmental process given existing practice and regulations, with the focus on both impacts to communities (e.g., changes in flooding characteristics) and impacts to the transportation system (e.g., system resiliency).

14. Develop stand-alone guidance (or include additional technical guidance in the existing requirements) that focuses on how climate change adaptation (perhaps along with GHG emissions reduction) can be incorporated into environmental analysis similar to other guidebooks referenced by the Division of Environmental Analysis (DEA). For example, more guidance on wildfire hazards is needed.

15. In recognition of the important role of environmental resource agencies in project development and permits, initiate a dialogue with such agencies to further develop and finalize procedures for incorporating uncertainty, climate change risk, and risk-based design into environmental documents.

<u>Engineering and Design</u>

16. Examine Caltrans design manuals and guidebooks to incorporate new guidance on how adaptive design concepts can be used for climate-safe infrastructure project development. This would include how risk and climate change uncertainty should be considered as a key design input, and how the potential consequences of asset failure can be included in design decisions. This would entail a trade-off assessment for those projects that are so critical to transportation system performance that even a short-term disruption would result in significant impacts (even though the likelihood of such an event might be small).

17. Establish a method for changing design guidance that would focus on the impacts caused by various climate stressors on various assets. The CTC defined four asset classes as "focus areas" in accordance with California Government Code—pavement, bridges, culverts, transportation management systems (TMS)—that should be the focus of modified design guidance.

18. Examine the Caltrans value analysis (VA) process to make sure that the costs of future disruptions to the system and to system users include the possibility of climate change-related disruptions. This also means considering such costs and associated risks as part of the life-cycle analysis.

19. New standards and methodologies may need to be developed with other State agencies so that there is uniformity in understanding, use, and applicability of such methods. Training then needs to be developed and imparted to various function in the Department.

System Operations

20. Although Caltrans is not responsible for non-State roads, work closely with the Governor's Office of Emergency Services and other key agencies and jurisdictions to examine the experience with evacuations associated with the 2018 wildfires and identify lessons learned in terms of how evacuation routes and their operations can be effectively put into place. This would also involve assessing the implications for road design standards (i.e., how to promote adaptive designs to provide capacity for evacuations when necessary).
21. Designate resources toward working with communities in determining effective evacuation planning that incorporates estimating expected travel demand, capacity estimation, access closure strategies, and effective public information to limit loss of life/damage during extreme events.

Maintenance

22. The Caltrans culvert maintenance program is growing with new funding provided in State legislation. Given the vulnerability of culverts, pumps and tide gate repair/replacement in areas affected by flooding and sea level rise (SLR), and erosion/debris/landslides after wildfires, give priority to ensuring vulnerable assets in especially high-risk areas are maintained at high levels. The focus of the new investment is on in-place culverts and other equipment. Those assets located on critical facilities and where capacity will not likely withstand future water flows should be prioritized for replacement.
23. Examine changes in maintenance practices where assets that are prone, for example, to fire or riverine damage could be efficiently and systematically replaced to reduce future risks. For example, Caltrans has already replaced in some districts wood guardrail with metal guardrail. Training for maintenance staff on new or modified maintenance practices should be developed.
24. Examine repair orders and determine those assets where recurring past damages may be better addressed through new resilient design options.
25. Undertake a pilot culvert vulnerability analysis in areas identified in the district adaptation study, collecting data on potential surrounding environmental risks (flood levels, levee failure), past maintenance concerns, and estimated consequences (overall disruption) to determine where replacements may be needed. Although placed in this section covering maintenance, this study could be led by others in Caltrans. The intent of the pilot study is to determine the risk to key Caltrans facilities of undersized culverts (with respect to future hydraulic conditions). A determination will need to be made to see if increasing the size of

a culvert could potentially cause upstream or downstream private property damage (such as higher flows or higher velocities) or if other mitigation measures need to be incorporated.

Asset Management

26. Once the district adaptation studies are finished, Caltrans will have much better information on the risks facing the SHS and where high levels of exposure to different climate hazards exist. This information should be used to develop performance measures, criteria and/or factors that are consistent across districts relating to climate change adaptation (and system resiliency) leading to defined "Needs", that can be part of the asset management decision-making process. This would include developing and incorporating estimates of quantified physical life-cycle risk (in dollars) associated with climate risk, as well as a consideration of broader economic and community impacts. The focus of these efforts should be on meeting the performance requirements of Senate Bill 1 (SB 1).

27. The Caltrans Project Risk Management Handbook should be periodically updated to reflect the latest information on the risks associated with extreme weather and climate change found in new studies, after-event reports, and the latest science. The initial update should include the results of the district adaptation studies.

Project Concepts

28. Adopt the California Coastal Commission's (CCC's) basic adaptation strategy categories of protect, accommodate, or retreat as a way to characterize different adaptation options to mitigate vulnerabilities in order to provide consistency in communicating Caltrans adaptation efforts.

29. The CCC identifies natural solutions (or nature-based solutions or natural infrastructure) as a preferred alternative where feasible for protecting existing endangered structures based on guidance from FHWA and other sources. Necessary specifications for the use of "soft" or natural infrastructure solutions should be developed where such solutions are appropriate and feasible to protect Caltrans assets. Standard engineering designs for natural infrastructure should also be developed.

1. INTRODUCTION

1.1 PURPOSE OF REPORT

The State of California is one of the nation's leaders in considering potential climate change effects on a wide range of governmental services and in the provision of all kinds of infrastructure. As the State's climate change policies have evolved, the California Department of Transportation (Caltrans) has provided input into policy development processes and aided in understanding the implications of these potential climate change policies on Caltrans activities. From executive leadership to district operations; from planning and programming to design, operations, and maintenance; every Caltrans unit can contribute to achieving the State's climate change goals. Indeed, Caltrans has already made important strides in sustainability and, as part of this effort, has given some consideration to climate change adaptation with the development of an Adaptation Pathway.[2]

For purposes of this report, climate change adaptation consists of those actions/ strategies taken prior to an extreme weather event or longer-term climatic change (e.g., sea level rise [SLR]) to minimize, if not avoid altogether, the impacts on an asset or facility. Examples include increasing the size of new culverts in areas likely to experience more flooding in the future or using natural infrastructure strategies to protect assets against storm surge and SLR. The term "mitigation," in the context of climate change, is typically reserved for those efforts to limit or reduce greenhouse gas (GHG) emissions, which are one of the primary causes of climate change.

Caltrans recognizes that for it to adopt a leadership role in climate change adaptation, it will need to integrate concerns for climate change into its policy processes, planning, resource deliberations, project delivery, and performance measurements. In addition, Caltrans officials the need for training of staff in new concepts and data analysis that supports the implementation of the adaptation strategy and in recognizing those that spearhead the adoption of new methods and procedures (e.g., staff members who identify strategies for protecting Caltrans' assets resulting in large savings through climate/highway disaster prevention.

The purpose of this report is to provide Caltrans with a "how-to" guide for integrating climate change adaptation into agency activities and decision-making. The report initially recommends an overall "pathway" for adopting a climate change adaptation emphasis in the agency. It then recommends how Caltrans should mainstream adaptation strategies in the different functional areas for which it has responsibility and to outline an approach where the agency can be an active partner with others in furthering the State's climate change policy and strategy. This report focuses on the

[2] Fox, D., J. Matsuo, and D. Miner. "Sustainability Roadmap 2018-2019 Progress Report and Plan Update on Meeting the Governor's Sustainability Goals for State Departments." Caltrans. Retrieved May 10, 2020 from https://green.ca.gov/Documents/CALTRANS/SustainabilityRoadmap10-31-18_rev5.pdf

State Highway System (SHS), but many of the recommendations are relevant for other Caltrans assets as well.

1.2 PROCESS FOR DEVELOPING THE REPORT

The findings and recommendations in this report are based on: 1) a review of current Caltrans efforts in climate change adaptation, and 2) outreach to Caltrans staff and stakeholders on desired agency directions in fostering a more adaptive approach to providing and managing the SHS. The review of Caltrans' current efforts included examining technical guidelines and policy statements produced by the agency, as well as those that have been issued by other State agencies.

A survey of Caltrans staff was conducted in spring of 2018 that focused on both the activities and responsibilities of the survey participants as they relate to Caltrans products, services and to Caltrans decisions. The survey participants were also asked how adaptation considerations could be better included in these decisions. The survey was followed by interviews conducted with key Caltrans managers to gather input from those who did not fill out the survey. Special focus was given to those whose responsibilities in project development and operations were particularly relevant to enhancing the consideration of adaptation in Caltrans activities, products, and services. Interviewees were also asked to identify examples of adaptation efforts, actions, or projects that illustrated the types of efforts Caltrans had already undertaken to improve transportation system resilience. In addition to these Caltrans-specific sources, information from other states on what they are doing with respect to adaptation and system resilience in their decision-making processes was also reviewed.

Additional work completed as part of this study whose results have been included in this report include:

1. An examination of how Caltrans currently includes climate change adaptation in economic analyses and what could be done to integrate adaptation into such analyses.
2. Identification of different infrastructure and natural strategy actions that could be considered by Caltrans in its capital and operations/maintenance programs.
3. Strategy guidance for collaborating with other agencies and groups in implementing the recommendations of this report.

It is important to note that Caltrans was conducting other studies at the same time this effort was underway that focused on enhancing its capabilities to meet the challenges created by climate change. As part of this larger effort, climate change exposure assessments were being conducted for each of the Caltrans districts. The purpose was to identify locations and assets that were potentially exposed to future climate change and extreme weather concerns on the SHS in each district. In addition, parallel efforts were underway at other State agencies and research institutions that, in some cases, resulted in new procedures to ensure that climate change impacts continued to be a primary consideration in effective capital investment across a range of asset types. The development process for the recommendations in this report was closely coordinated with the district exposure assessments, the subsequent work on developing adaptation plans for each district, and other State agency/research institution activities.

1.3 DEFINITIONS

Some of the key terms used in this report include the following:

- Climate Change Adaptation: Actions/strategies taken to reduce or avoid the impacts of extreme weather events or of longer-term climatic change (e.g., sea level rise) on an asset or facility. Extreme weather events are those that are larger in scale and intensity than have generally occurred historically.
- Exposure: The degree to which an asset is exposed to a threat or hazard. For example, the proportion of a roadway link projected to be inundated by a 100-year storm surge.
- Mitigation: An action taken to reduce or eliminate the impact of a project. In the context of climate change, the term "mitigation" often refers to reducing GHG emissions.
- Natural Hazards and Threats: Events arising from the natural environment that create significant disruption to the built environment and the lives of residents in the surrounding communities. Examples include earthquakes, heat waves, storm surge, snow blizzards, tropical storms, and wildfires.
- Recovery: Steps or stages a system goes through to regain its function to pre-disruption performance and/or condition.
- Reliability: System performance that is consistent over time to the extent that travel times can be predicted with some level of certainty. Reliability is one factor in a resilient transportation system.
- Resilience: The characteristic of a transportation system that allows it to withstand and recover rapidly from disruptions. For an agency, this includes an ability to anticipate, prepare for, and adapt to changing conditions.[3]
- Risk: A combination of the probability of a hazard occurring multiplied by the consequences of that hazard (typically expressed in dollars), often used to prioritize assets for more detailed assessments. Risk is a way to capture the vulnerability of the system in terms of dollars or system impacts.
- Uncertainty: In terms of statistical projections, random fluctuations in projections due to unknown values of model input variables. Uncertainty is often represented by confidence levels or error bounds in the projections.

[3] Federal Highway Administration (FHWA). 2014. "FHWA Order 5520. "Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events." Dec. 15. Retrieved May 10, 2020 from https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm

- Vulnerability: An asset’s degree of exposure to a hazard/threat and the severity of the consequences, often used to prioritize assets for more detailed assessments. Vulnerability is closely related to risk, but often expressed in a more qualitative manner.

Caltrans Seismic Program*

The evolution of Caltrans' seismic program and processes is, in many ways, similar to the process now being followed by Caltrans in climate change adaptation. In response to a Governor's Executive Order (EO) in the aftermath of the 1989 Loma Prieta earthquake, Caltrans made program and programming changes to address seismic concerns in the transportation decision-making process.

Caltrans established an extensive research and retrofit program to screen the inventory of State and local agency bridges and established performance criteria for standard bridges, toll bridges, and bridges categorized as lifeline routes and recovery routes. The established performance criteria were based on No-Collapse and Repairable Damage metrics applicable to a two-level seismic event analysis approach that includes a Functionality Evaluation Earthquake and a Safety Evaluation Earthquake. Standard bridges have been retrofitted to a No-Collapse requirement, while the lifeline and recovery route category of bridges have been retrofitted to both the No-Collapse and Repairable Damage requirements. Out of the entire inventory of 24,000 bridge structures that were initially screened, 2,200 standard bridges that required retrofitting have been retrofitted, as have all of the major toll bridges in Northern and Southern California.

Although there are important differences between climate change adaptation and seismic protection (e.g., the range of impacts and disruptions represented by the underlying phenomena), Caltrans' experience in implementing its seismic program provides an institutional memory of how changes in program emphasis can occur.

Some Key Aspects of Governor's Executive Order on Seismic Preparedness

The Director of the Department of Transportation shall:

- Prepare a detailed action plan to ensure all structures maintained by the State are safe from collapse in the event of an earthquake and that vital transportation links are designed to maintain their function following an earthquake. The plan shall include a priority listing of transportation structures scheduled for retrofit.
- Give priority consideration to seismic safety in the allocation of resources for transportation construction projects, and in the design of all State structures.
- Assign a high priority to development of basis and problem-focused research on earthquake engineering issues.

---Governor Deukmajian, "Seismic Safety," 86-90, June 2, 1990

* Caltrans seismic program components can be found at: Caltrans. 2017. Technical References. Retrieved May 10, 2020 from http://dap3.dot.ca.gov/ARS_Online/technical.php

As noted earlier, this report is focusing on climate change adaptation, although the concepts represented by each of the terms listed above can be found throughout the recommended adaptation strategies.

1.4 A PATHWAY TO INTEGRATING ADAPTATION INTO CALTRANS DECISION-MAKING

Enhancing Caltrans' capability to mainstream climate change adaptation in all of its activities requires an agency-wide perspective and an evolutionary, multi-step process that will likely occur over many years. National studies and research have just begun to examine what this path entails. Developing a pathway for this study was done recognizing that the State of California was developing its own adaptation process. However, as shown in Figure 1, the State's pathway (shown on the left) was very general, giving little direction on what a State agency should specifically do within each of the four major steps.

To provide a more detailed set of action steps, the right-hand pathway in Figure 1 was recommended for Caltrans. This pathway, adopted from a current national study on resilience in state departments of transportation (DOTs), recommends specific steps that state transportation agencies should take to assess their own agency's capacity for providing resilience improvements to the transportation system. This framework is recommended to Caltrans as an overall structured, long-term, agency-wide strategy for integrating adaptation concerns into its activities (hereafter referred to as the Caltrans Climate Adaptation Framework or Framework). The Framework was

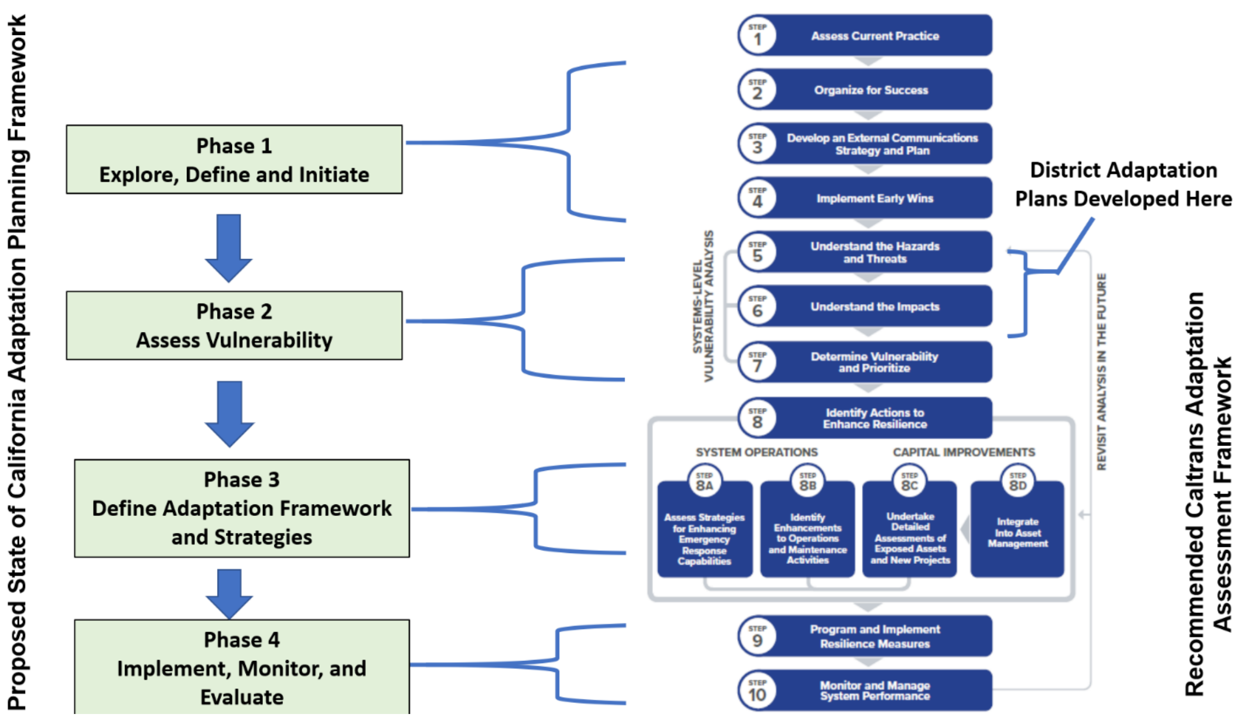

FIGURE 1: RECOMMENDED CLIMATE ADAPTATION ASSESSMENT PROCESS FRAMEWORK

developed to guide a comprehensive assessment of agency actions; that is, it recommends a process for assessing agency capabilities, followed by implementing enhancements to agency actions to improve the overall resiliency of the agency from multiple perspectives within a DOT.

Steps 1 through 4 of the Framework represent numerous activities that are currently underway at Caltrans to establish a foundation for considering climate change adaptation and for developing policies that will help jumpstart adaptation actions throughout the agency. Step 1, *Assess Current Practice*, and Step 4, *Implement Early Wins*, will be addressed as part of this study. This study comprehensively reviewed the climate adaptation laws, policies, and activities currently in place in State government or underway at Caltrans. The study also identified numerous no-regrets adaptation actions ("early wins") that can be taken in the near term to enhance Caltrans efforts at climate change adaptation. Several of these actions touch on elements of Step 2, *Organize for Success*, and Step 3, *Develop an External Communications Strategy and Plan*. A communications strategy and plan for climate change is being developed as part of a Caltrans pilot project with the Federal Highway Administration (FHWA). This project is creating strategies and approaches to better disseminate climate change information and ensure that stakeholders in California have a full understanding of how to ensure the resiliency and viability of the SHS in the future.

Steps 5 to 7 are shown as *Systems-Level Vulnerability Assessment* in that together they provide Caltrans information on where exposed and vulnerable assets are found in the SHS.

Step 5, *Understand the Hazards and Threats*, is the first step where detailed technical analyses are performed, in this case, to help identify the assets exposed to various climate stressors. This step has been partially completed as part of another study for a subset of the assets and hazards in District 2, which will ultimately be produced as an update to the Caltrans District 2 Adaptation Priorities Report. The initial exposure and project prioritization information generated in the District 2 Report was used as input into this report (to give a sense of the type of information that will soon be available to Caltrans). Vulnerability assessment reports and adaptation plans for all the districts will be available by the end of 2020 (and are viewed in this report as valuable input into efforts recommended in later sections.

Step 6, *Understand the Impacts*, is focused on the implications of the exposure identified in Step 5. This includes conducting an indicators approach to determining risks to the system—assessing whether an asset might be exposed to a climate stressor, the timing of that impact, and how additional factors like asset condition and/or use may indicate a high-risk asset. Developing an understanding of these considerations and how such factors can be considered by Caltrans suggests areas where Caltrans might focus its resources to clarify potential risks through more detailed engineering assessments. This is part of the prioritization methodology described in Step 7.

Step 7, *Determine Vulnerability and Prioritize,* identifies the assets and locations where initial, more detailed analyses are needed to further understand impacts and examine different strategies for mitigating such impacts. Priorities could be assigned by asset, asset category, or location on the State Highway System. In addition to project design strategies, this step identifies areas where Caltrans can improve its capabilities to enhance its climate adaptation efforts, e.g., in emergency management and response, operations and maintenance, and in the relationship between the asset management program and adaptive design efforts. The prioritization approach considers both the nature of the exposure identified in Step 5 (its severity, extensiveness, and timing) and the consequence information developed in Step 6, introducing risk as a key factor in effective agency decision-making. The goal of the prioritization effort is to identify which assets should be further examined to fully understand the potential risks to the system given that resource constraints prevent all assets from being examined simultaneously. The intent would be that the highest-priority assets from this step would be evaluated first and then lower-priority assets examined later, with all assets that could be affected by long-term climate change assessed over time

In Step 8, *Identify Actions to Enhance Resiliency*, the Framework shows three parallel tracks: (1) emergency response (Step 8A); (2) operations and maintenance processes and procedures (Step 8B); and (3) assessment of exposed assets that will enhance system resiliency (Steps 8C). In addition, the relationship between asset management and capital projects is shown as Step 8D. This latter relationship reflects another path Caltrans can use to identify projects that should receive more detailed assessment with respective to adaptive design. Step 8C involves engineering-based analyses to verify asset exposure to pertinent climate hazards and, if exposure is verified and the potential impacts to the system are consistent with those identified, the development and evaluation of adaptive measures to manage and or reduce/eliminate the risk.

District Adaptation Priorities Reports being developed in 2019 will provide information associated with Steps 5, 6, and 7 in the Framework. This information is designed to allow District officials to identify where priority attention should be given to assets that are exposed to future climate change stresses.

Once specific adaptation measures have been identified, be they operational measures or capital improvements, these projects can then be programmed (Step 9). In addition, this analysis could determine the extent to which adaptation treatments could be applied to project designs that are being implemented primarily to address other concerns (e.g., capacity improvements). Steps 9 and 10 focus on continuous monitoring of system resiliency to track progress toward enhancing adaptation and cost-effectively managing assets over their lifespans. It is also important to note that many of the recommended actions in this report rely on better advance planning and systemwide decision making relating to the effects of climate change and resiliency of the transportation system in the longer term.

1.5 REPORT ORGANIZATION

As noted earlier, this report is organized primarily to be a "how-to" guide for Caltrans officials to integrate climate change adaptation considerations into the organization. Section 2 summarizes some of the key State policies, Executive Orders, and procedures that are most relevant to Caltrans' adaptation efforts. Section 3 describes the expected future climatic conditions for each climate stressor that could potentially affect Caltrans activities and the possible consequences of each. Section 4 recommends steps Caltrans can take to incorporate adaptation concerns into its decision-making processes. The types of decision contexts covered in this section include defining Caltrans' vision and goals, planning, prioritization, environment, engineering, system operations, system maintenance, and asset management. Section 5 discusses how Caltrans should coordinate with other agencies and stakeholders in furthering its adaptation strategy. Section 6 introduces different types of adaptation projects that Caltrans will likely be paying more attention to in future years given changing climatic conditions. More detailed information on these project types is found in stand-alone appendix A. Section 7 outlines future steps for Caltrans to integrate climate adaptation factors into decision-making processes, procedures, and projects.

2. ADAPTATION-RELATED POLICIES AND PROCEDURES RELEVANT TO CALTRANS

California has been on the forefront of addressing the risks posed by climate change since the passing of the landmark "California Global Warming Solution Act (Assembly Bill 32 [AB32])," which required a statewide reduction in GHG emissions to 1990 levels by 2020.[4] Since the bill's passage into law in 2006, the State of California has set the stage for climate change policy across the United States. California has since passed new policies to reduce GHG emissions and to take action on the projected impacts of the changing climate on the State's infrastructure, people, and resources. These policies affect how Caltrans does business and how the agency sets its own path towards resiliency.

To date, there is no adopted, singular framework for California agencies to incorporate climate change into decision-making; each agency designs its own strategy. However, the guidance provided from the State through policies, procedures, and guidance documents helps Caltrans shape its own vision for incorporating climate change into decision-making.

As of the development of this Adaptation Strategy Report, the policies, procedures, and associated guidance documents listed below are the most relevant to Caltrans' climate change adaptation activities. These are ordered from most recent to oldest.

2.1 STATE LEGISLATION

Several laws have directed State agencies to consider climate adaptation as part of their activities. The following are the most relevant to adaptation (Note: see "Sustainability Roadmap 2018-2019 Progress Report and Plan Update on Meeting the Governor's Sustainability Goals for State Departments" for a more complete list of all laws that relate to Caltrans' sustainability and adaptation efforts):[5]

THE ROAD REPAIR AND ACCOUNTABILITY ACT OF 2017 (SENATE BILL 1 [SB 1]) provided substantial funding for improving the State's transportation system. In addition, it requires that transportation funding be used where feasible to preserve, protect, and reduce environmental impacts through the use of (among other factors) project features that promote project adaptation to "withstand the negative effects of climate change and make the asset more resilient to impacts such as fires, floods, and sea level rise."[6]

ASSEMBLY BILL 2800 (AB 2800, passed in 2016) requires State agencies to take climate change impacts into account during all infrastructure planning, design, construction, investments, operations and maintenance. The bill also required the formation of a

[4] Air Resources Board (ARB), Retrieved May 10, 2020 from https://ww3.arb.ca.gov/cc/ab32/ab32.htm

[5] Fox, D., J. Matsuo, and D. Miner. Op cit.

[6] Ibid.

Climate-Safe Infrastructure Working Group made up of engineers and architects with relevant experience in infrastructure and climate change. Caltrans was represented in the working group and contributed to the working group's 2018 report, *Paying it Forward: The Path Toward Climate-Safe Infrastructure in California*. This report recommended the State adopt a climate policy where flexible adaptation pathways are:

> "… realized through a variety of strategies, in multiple stages over the course of decades … (it) accounts for the full life-cycle costs of infrastructure and uses a multi-sectoral, systems approach. It prioritizes infrastructure investments based upon the greatest risks and investment gaps, as well as where investment can most reduce inequality and increase opportunity. For highly vulnerable, long-lived infrastructure, State agencies should consider climate change impacts associated with a high-emissions scenario while continuing to implement all applicable State laws related to stringent GHG emissions reductions."[7]

This report recognized the importance of State infrastructure and the Caltrans system as an important foundation for the community/economic viability of the State, and thus, a need to ensure its long-term resilience to system disruptions.

ASSEMBLY BILL 1482 AND SAFEGUARDING CALIFORNIA (AB 1482, passed 2015) requires all State agencies and departments to prepare for climate change impacts through continued collection of climate data, consideration of climate factors in State investments, and the promotion of reliable transportation strategies. The bill also requires that the State's Safeguarding California Plan, or the State's climate adaptation strategy, be revised every three years. The Safeguarding California Plan includes transportation as one sector that needs to be assessed for climate change vulnerabilities.

ASSEMBLY BILL 398 AND CAP-AND-TRADE (AB 398, passed 2017): The AB 32 Scoping Plan identified cap-and-trade as one of the strategies for California to reduce GHG emissions as required by AB 32. The current cap-and-trade program began in January 2012 and is managed by the California Air Resources Board (CARB).[8] AB 398 was approved in July 2017 to extend the program until 2030.

ASSEMBLY BILL 398 AND CAP-AND-TRADE (AB 398, passed 2017): The AB 32 Scoping Plan identified cap-and-trade as one of the strategies for California to reduce GHG emissions as required by AB 32. The current cap-and-trade program began in January

[7] Climate-Safe Infrastructure Working Group (CSIWG). 2018. Paying it forward: The Path Toward Climate-Safe Infrastructure in California. Report of the Climate-Safe Infrastructure Working Group to the California State Legislature and the Strategic Growth Council. Sacramento, CA: CNRA, Publication number: CNRA-CCA4-CSI-001. Retrieved May 10, 2020 from https://resources.ca.gov/CNRALegacyFiles/docs/climate/ab2800/AB2800_ES_FINAL.pdf

[8] ARB, Retrieved May 10, 2020 from https://ww3.arb.ca.gov/cc/capandtrade/capandtrade.htm

2012 and is managed by the California Air Resources Board (CARB).[9] AB 398 was approved in July 2017 to extend the program until 2030.[10]

CALIFORNIA COASTAL ACT:[11] The California Coastal Act enabled the California Coastal Commission (CCC) or local government agencies with certified Local Coastal Programs (LCPs) to adopt legal requirements relating to how SLR was to be considered when developing in a coastal environment. The Commission and LCPs evaluate Caltrans permit applications for consistency with California Coastal Act policies related to resources like wetlands, visual resources, or coastal hazards. Coastal Hazard Policy requirements include the evaluation of SLR (Coastal Act Sections 30006.5; 30335.5; 30253; 30235; 30001; 30001.5). Guidance on how to do this when designing projects is provided in the Commission's Sea Level Rise Policy Guidance, *Interpretative Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits*.[12]

It is also important to note the recently updated California Ocean Protection's Strategic Plan.[13] This plan included recommendations and targets that will affect Caltrans, including:

- Ensure California's coast is resilient to at least 3.5 feet of sea-level rise by 2050, as consistent with the State's SLR Guidance Document as appropriate for a given location or project.
- Develop recommendations to the Legislature towards a dependable, adequate source of state funding for planning grants, technical assistance, and project implementation support for state and local governments and non-profits leading on SLR response.
- Update the State of California's SLR Guidance in 2023 and every five years thereafter to incorporate best available science and projections, and continually improve integration of changing ocean conditions into California's State government policies, planning, and operations.
- Identify pilot projects across the state that represent a diversity of locations, with variable size and scale, and demonstrate the efficacy of various SLR and

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[9] ARB, Retrieved May 10, 2020 from https://ww3.arb.ca.gov/cc/capandtrade/capandtrade.htm

[10] Cap-and-trade requires companies to buy permits to release GHG emissions, with a cap on how many permits can be purchased. Funds from the permit purchases are used to support California projects that reduce GHG emissions, such as the California High-Speed Rail project, low-carbon transportation, low-income weatherization, water and energy efficiency, urban forestry, and other programs that are part of the California Climate Investments Program. While these funds primarily drive GHG mitigation-focused projects, there is an opportunity to include adaptation initiatives into the program. See TransForm, Retrieved May 10, 2020 from https://www.climatebenefitsca.org/

[11] California Coastal Commission. 2020. California Coastal Act. Retrieved May 11, 2020 from https://www.coastal.ca.gov/laws/

[12] California Coastal Commission. 2018. Sea Level Rise Adopted Policy Guidance. Retrieved May 10, 2020 from https://www.coastal.ca.gov/climate/slrguidance.html

[13] California Ocean Protection Council. 2019. Strategic Plan to Protect California's Coast and Ocean 2020–2025. Retrieved May 11, 2020 from http://www.opc.ca.gov/webmaster/ftp/pdf/2020-2025-strategic-plan/OPC-2020-2025-Strategic-Plan-FINAL-20200228.pdf

extreme event adaptation strategies by 2021 and begin project implementation immediately thereafter, consistent with existing laws and policies.

- Starting in 2020, provide scientific guidance to partner agencies on the potential impacts of sea-level rise on contaminated sites and how current models could be used to inform site-specific decision-making.
- In conjunction with ongoing efforts, develop a site-specific infrastructure resiliency plan focused on state roads, railroads, wastewater treatment plants, water supply facilities, ports, and power plants by 2023.

One of the cumulative results of this legislation record has been the development of State plans and policies focused on enhancing sustainability, and in some cases, promoting climate adaptation efforts among State agencies. For example, the *Safeguarding California Plan* resulting from some of the early climate legislation was one of the first multisectoral climate plans in the country.[14] One of the major purposes of this plan was to ensure that all core functions of government take into account the risks a changing climate posed to California. California's statewide climate assessments (with the fourth edition recently released) were a direct result of this legislation and Executive Orders.

2.2 EXECUTIVE ORDERS (EOS)

The following EOs are directly relevant to climate adaptation as it relates to Caltrans activities Although not listed here, there are other EOs, e.g., EO B-16-12 (zero-emission vehicles) and EO B-18-12 (zero-net-energy for new construction projects) that are an important part of Caltrans' sustainability portfolio as well:

EO B-30-15 establishes GHG emission reduction targets for the State. Part of the EO addressed adaptation actions on the part of State agencies. In particular, State agencies were directed to: 1) incorporate climate change impacts into the State's Five-Year Infrastructure Plan; 2) update the *Safeguarding California Plan*—the State climate adaptation strategy—to identify how climate change will affect California infrastructure and industry, and what actions the State can take to reduce the risks posed by climate change; 3) factor climate change into State agencies' planning and investment decisions; and 4) implement measures under existing agency and departmental authority to reduce GHG emissions.[15]

The EO also requires the consideration of climate change in all State investment decisions. This policy is the first to require a consideration of climate change impacts themselves, not just emissions reductions. The EO expanded on this requirement by specifying that State agencies should use full life-cycle cost accounting when planning adaptation actions, prioritizing adaptation actions that also reduce GHG emissions, considering the State's most vulnerable populations, prioritizing natural

[14] California Natural Resources Agency. 2009. "Safeguarding California: Reducing Climate Risk." Retrieved May 10, 2020 from https://resources.ca.gov/CNRALegacyFiles/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf

[15] Office of the Governor. 2015. Retrieved May 10, 2020 from https://www.ca.gov/archive/gov39/2015/04/29/news18938/

infrastructure solutions, and using flexible approaches where possible to avoid inappropriate adaptation.

EO S-13-08 directs State agencies to plan for SLR for construction projects having design lives extending to 2050 and/or 2100. It specifically states that the Business, Transportation, and Housing Agency assess the vulnerability of the State's transportation systems to SLR. The EO also initiated the first California Sea Level Rise Assessment Report and required the development of a State Climate Adaptation Strategy, which later became the Safeguarding California Plan.[16]

EO N-19-19, signed on September 20, 2019, requires the redoubling of the State's efforts" to reduce greenhouse gas emissions and mitigate the impacts of climate change while building a sustainable, inclusive economy."[17] The EO directs the California State Transportation Agency to leverage over $5 billion of its capital and operations budgets to lower fuel consumption and GHG emissions from the transportation sector. This includes strategies for lowering vehicle miles traveled, such as supporting housing development near available jobs, and supporting active modes of transportation such as biking and walking.

EO B-40-17 and EO B-37-16, motivated by the severe drought occurring in California during the 2014-2017 time period, focus on actions to use water more wisely, eliminate water waste, and strengthen local drought resilience. The intent was to make "water conservation a way of life." State agencies were to develop strategies and policies to implement the requirements of the EOs as appropriate for their area of responsibility.[18]

2.3 CALTRANS POLICIES AND GUIDANCE

Caltrans, as an organization, first started addressing concerns associated with climate change in 2007 with the creation of its Climate Change Branch. Since then, Caltrans has established internal policies and guidance regarding climate change adaptation. The following is a collection of the most relevant actions, starting with the most recent.

METROPOLITAN PLANNING ORGANIZATIONS (MPO) AND REGIONAL TRANSPORTATION PLANNING AGENCY (RTPA) GUIDANCE: Caltrans developed a guide for California MPO and RTPA that outlined methods to incorporate adaptation into Regional Transportation Plans. Caltrans recommended in this document that every MPO and RTPA follow the basic evaluation steps of: 1) assessing the effects of climate conditions in their region; 2) considering how their five most important transportation assets could be affected; and 3) developing adaptation strategies for further study and inclusion in the Regional Transportation Plan.

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[16] Georgetown Climate Center, Retrieved May 10, 2020 from https://www.adaptationclearinghouse.org/resources/california-executive-order-s-13-08-requiring-state-adaptation-strategy.html

[17] Office of the Governor. 2019. Retrieved May 10, 2020 from https://www.adaptationclearinghouse.org/resources/state-of-california-executive-order-n-19-19.html

[18] California Water Boards. Retrieved May 10, 2020 from https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/executive_orders.html

CALIFORNIA COASTAL COMMISSION (CCC) AGREEMENT: Caltrans signed an agreement with the CCC and its Integrated Planning Team to ensure effective collaboration between the agencies, particularly in considering SLR impacts. The agreement recognized that both the CCC and Caltrans have leadership roles in addressing SLR that complement each other. The CCC noted that Caltrans should follow the CCC's Sea Level Rise Policy Guidance in planning coastal infrastructure development, which provides guidance on an adaptation planning process for Local Coastal Programs and Coastal Development Permits.

GUIDANCE ON INCORPORATING SLR provided initial criteria for determining whether SLR needs to be incorporated into project programming and design. Factors that should be considered include the project design life, the existence of alternative routes, anticipated travel delays, evacuations, traveler safety, and environmental constraints. SLR projections for this guidance are adopted from the Ocean Protection Council's (OPC) guidance.[19]

It is important to note the legal requirements related to the California Coastal Act on the consideration of SLR. There are specific legal requirements from the CCC or local government agencies with certified Local Coastal Programs (LCPs) on SLR. The Commission and LCPs evaluate Caltrans permit applications for consistency with California Coastal Act policies related to resources like wetlands, visual resources, or coastal hazards. Coastal Hazard Policy requirements include the evaluation of SLR (Coastal Act Sections 30006.5; 30335.5; 30253; 30235; 30001; 30001.5). Guidance on how to do this when designing projects is provided in the Commission's Sea Level Rise Policy Guidance, *Interpretative Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits*.[20]

It is also important to note the recently updated California Ocean Protection's Strategic Plan.[21] This plan included recommendations and targets that will affect Caltrans, including:

- Ensure California's coast is resilient to at least 3.5 feet of sea-level rise by 2050, as consistent with the State's SLR Guidance Document as appropriate for a given location or project.
- Develop recommendations to the Legislature towards a dependable, adequate source of state funding for planning grants, technical assistance, and project implementation support for state and local governments and non-profits leading on SLR response.

[19] California Ocean Protection Council, Retrieved May 10, 2020 from http://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/

[20] California Coastal Commission. 2018. Sea Level Rise Adopted Policy Guidance. Retrieved May 10, 2020 from https://www.coastal.ca.gov/climate/slrguidance.html

[21] California Protection Council. 2019. Strategic Plan to Protect California's Coast and Ocean 2020–2025. Retrieved May 11, 2020 from http://www.opc.ca.gov/webmaster/ftp/pdf/2020-2025-strategic-plan/OPC-2020-2025-Strategic-Plan-FINAL-20200228.pdf

- Update the State of California's SLR Guidance in 2023 and every five years thereafter to incorporate best available science and projections, and continually improve integration of changing ocean conditions into California's State government policies, planning, and operations.
- Identify pilot projects across the state that represent a diversity of locations, with variable size and scale, and demonstrate the efficacy of various SLR and extreme event adaptation strategies by 2021 and begin project implementation immediately thereafter, consistent with existing laws and policies.
- Starting in 2020, provide scientific guidance to partner agencies on the potential impacts of sea-level rise on contaminated sites and how current models could be used to inform site-specific decision-making.
- In conjunction with ongoing efforts, develop a site-specific infrastructure resiliency plan focused on state roads, railroads, wastewater treatment plants, water supply facilities, ports, and power plants by 2023.

Although not guidance per se, the Caltrans section of the "Sustainability Roadmap 2018-2019 Progress Report and Plan Update on Meeting the Governor's Sustainability Goals for State Departments," identifies the progress that has been made in satisfying State legislation and Executive Orders with respect to sustainability. A Climate Adaptation Roadmap was outlined as part of the overall Sustainability Roadmap that was intended to integrate climate change adaptation into all planning and investments (although the Climate Adaptation Roadmap primarily focused on buildings).[22] The State road section in the Roadmap highlighted the following topics as part of Caltrans' adaptation efforts: 1) use of natural infrastructure as an adaptation strategy, and 2) use of full life-cycle cost accounting as part of project prioritization. The Roadmap also reported on the progress of incorporating climate change adaptation into transportation planning efforts and plans, with results showing that this had been completed for most plans with many of the plans reported as having done so. The review of these plans revealed that GHG emission reduction received the most attention, although the latest California Transportation Plan did discuss the need for adaptation.

These are just a selection of the most relevant guidance for Caltrans in considering climate change adaptation activities. As presented, there is a substantial legislative, EO, and policy foundation for considering climate change adaptation in Caltrans. This guidance will likely grow as Caltrans continues to implement its path toward achieving a more resilient transportation system.

[22] Fox, D., J. Matsuo, and D. Miner. "Sustainability Roadmap 2018-2019 Progress Report and Plan Update on Meeting the Governor's Sustainability Goals for State Departments." Caltrans. Retrieved May 10, 2020 from https://green.ca.gov/Documents/CALTRANS/SustainabilityRoadmap10-31-18_rev5.pdf

3. EXPECTED FUTURE CLIMATIC CONDITIONS AND POTENTIAL CONSEQUENCES

Climate change has become a defining challenge of our time. The impacts of climate change on the planet's natural systems are leading to changes in weather conditions—with increasing global temperatures triggering rising sea levels and extreme weather conditions that are occurring more regularly than predicted from historic weather records. From the perspective of the Caltrans adaptation strategy recommended in this report. it is important to understand the likely future climatic conditions that could affect Caltrans' program and what these conditions might mean for decisions made today.

3.1 TEMPERATURE RISE, EXTREME HEAT AND COLD, AND DROUGHTS

Temperatures across California have risen steadily over the last century. Average temperatures during the period of 1986 to 2016 have increased by 1 to 2.9°F above those recorded during the 1901 to 1960 time frame, varying by location.[23] There is confidence that these increases in temperature, which are consistent with projections for global temperature rise, will continue into the future.

The rising average temperatures across California are a direct result of the continued increase in GHG emission concentrations in the atmosphere, the range of which is represented by different GHG emissions scenarios.[24] Using the global climate models selected by California and an assumed mid-range emissions scenario (RCP 4.5 -- where substantial reductions in GHG emissions would be undertaken in the near term), the average maximum daily temperatures are projected to increase by 2.5 °F from 2006 to 2039 and by 5.6 °F by the end of century (2070 to 2100).[25] Using these same models and an assumed business-as-usual emissions scenario (RCP 8.5 – where GHG emissions continue to increase into the future), the average maximum daily temperatures over these same time periods are projected to increase by 2.7°F and 8.8°F, respectively. Projected changes in maximum daily temperature rise differ depending upon geography, with greater increases occurring in the California interior away from the coast, and the cooling influence of the ocean. These changes in maximum

[23] Bedsworth, Louise; Cayan, Dan; Franco, Guido; Fisher, Leah; Ziaja, Sonya. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCCA4-2018-013.

[24] The emission scenarios are defined by Representative Concentration Pathways (RCPs). These RCPs provide multiple scenarios of greenhouse gas concentrations in the atmosphere, depending upon the success of global efforts to reduce these emissions. Two of the commonly used RCPs are RCP 8.5, which represents "business as usual," and RCP 4.5, which represents a decline in emissions after mid-century. These RCPs are applied through downscaled Global Climate Models (GCMs) to project temperature rise and other future conditions for California. There are 10 GCMs commonly applied for California, as they are the most representative of California's climate.

[25] The models used for the analysis were those found in the California's Fourth Climate Change Assessment. The data was processed for several models that represent California well, however, one model was selected as the median for the entire state. This was done for display purposes in the analysis and subsequent reports. Any policy recommendations should involve a scenarios approach considering the results of multiple models.

temperatures will likely have serious implications for the number of high heat days experienced each year throughout the State, and in specific areas like the Central Valley.

In some cases, increased episodes of temperature extremes could include an increase in the number of days/nights with freezing temperatures. The impact of extreme cold on vegetation could include the dying off of some vegetation due to increased frosts thus leaving soil without vegetative covering, contributing to mudslides and erosion. Increased ice on roadways is also a traffic hazard.

Rising temperatures may also have an impact on precipitation and its volatility. There is no strong scientific consensus on how temperature changes might affect precipitation trends, but the majority of the models are projecting less frequent, more extreme daily precipitation events and an increase in the number of dry years. Even with increasing levels of precipitation, warming air temperatures are expected to increase moisture loss from soils and contribute to drier conditions. The results of 32 of the global models available for California projected that the incidence of extreme dry years may triple under the worst-case emissions scenario (RCP 8.5). While there are large differences in precipitation projections for California across the models, the models tend to project more frequent, longer droughts and more extreme winter storm events.

The drought from 2011 to 2016 may be an indication of future conditions. During this period, California experienced its driest and warmest year since records began (2014), its second driest and warmest year (2015), and unprecedented low Sierra Nevada snowpack levels (2013 to 2015). Recent studies have suggested that climate change is at least partially responsible for the lack of precipitation in the winters from 2013 to 2015, and that this event may be an example of future dry spells to come as droughts are exacerbated by increased heat.[26] There is also evidence to suggest that rising temperatures are exacerbating droughts in California.[27]

3.1.1 POTENTIAL IMPACT ON ASSETS

In general, the direct effects of higher temperatures themselves will not have as significant impacts on Caltrans' assets as some of the other climate stressors (such as extreme precipitation). Higher temperatures could affect the properties and performance of some of the materials used by Caltrans in its construction program, including pavements, and rails. High temperatures can cause pavement heave or warping, track buckling, and affect the lifespan of such assets. Rising temperatures will also decrease soil moisture, which could affect retaining walls, foundations, and soil-stabilizing foundations.

Absolute minimum air temperature and the average maximum temperature over seven consecutive days were assessed as part of the statewide Vulnerability Exposure

[26] Bedsworth et al, 2018. Op cit.

[27] Diffenbaugh, N. S., D. L. Swain, and D. Touma. 2015. "Anthropogenic warming has increased drought risk in California." Proceedings of the National Academy of Sciences 112 (13): 3931-3936. Retrieved May 10, 2020 from https://www.pnas.org/content/112/13/3931

Assessment study, as these are direct inputs into asphalt pavement design. Both temperature metrics were projected to increase over the coming century, with the average maximum temperature over seven consecutive days being projected to increase by up to 14 °F in more inland districts under the highest GHG emissions scenario. These changes in temperature may alter the designations in current Caltrans pavement regions, which were drawn based upon historical low and high temperatures, and are used to determine pavement mixes that will remain viable for extended periods, maximizing these investments.

3.1.2 POTENTIAL IMPACT ON OPERATIONS

Operational impacts from rising temperatures and extreme heat could include the issuance of slow or stop orders for California railways; increased maintenance needs due to pavement, rail, and other materials damage; and increased landscaping needs (see Potential Impact on Landscaping and Vegetation). Indirect impacts of higher temperatures include rising electrical demands for air conditioning and more frequent instances of blackouts or brownouts as electrical demand increases across the State. While it is difficult to project how electrical prices will fluctuate over time, increased electrical demand could lead to higher rates and increased operational costs for Caltrans.

Cycles of wet season or extreme storms followed by extreme heat or dry weather that provide additional fuel for wildfire, and then mudslides can result in serious disruptions to highway operations, as well as damage to highway assets. Many State highways have been closed due to the danger of nearby wildfires and/or from limited smoke-related visibility. Many others have experienced mudslides and rockslides that have required temporary road closures.

3.1.3 POTENTIAL IMPACT ON WORKFORCE

One of the most immediate impacts of increasing temperatures will be on the health of those working outdoors. High heat days and longer periods of extreme heat could lead to health risks for Caltrans construction, maintenance, landscaping, emergency response, and other outdoor workers, including contractor employees. These same risks might also occur for Caltrans workers in workspaces that are not air-conditioned. The Occupational Safety and Health Administration (OSHA) recommends indoor temperature control in the range of 68 to 76 °F and that outdoor workers take precautions when temperatures fall in a range of 91°F to 103°F. Days over the 91°F temperature threshold recommended by OSHA will become more frequent in the future. For example, 91°F days in the Sacramento area are projected to increase from 66 to 138 days per year by the end of the century (defined as the 2070-to-2099 timeframe), assuming the worst-case GHG emissions scenario. Tools such as the Cal-Adapt extreme heat tool and the California Heat Assessment Tool can be used to project the frequency and duration of high-heat events over the coming decades.

3.1.4 POTENTIAL IMPACT ON LANDSCAPING AND VEGETATION

Higher temperatures will lead to moisture loss from soils and vegetation and contribute to drier conditions overall. This may lead to increased plant mortality, shifts in habitat, and increased wildfire risk. Recent drought conditions have also led to increased bark beetle infestations and tree mortality—an estimated 102 million trees died in California during the 2011 to 2016 drought. In response, Caltrans was required to "identify areas of the State that represent high hazard zones for wildfire and falling trees" and "remove dead or dying trees in those high hazard zones."[28]

3.2 PRECIPITATION AND FLOODING

California's precipitation levels vary naturally from year to year—in fact, experiencing the largest year-to-year precipitation variability across the contiguous United States.[29] Models are projecting that this variability will likely be exacerbated due to climate change, with "less frequent but more extreme daily precipitation" and year-to-year precipitation becoming even more volatile.[30] [31] California's Fourth Climate Change Assessment concluded that most of California is expected to experience increased precipitation during the wet season by about 5 to 15 percent over the coming century. However, in Southern California, annual precipitation amounts are expected to remain largely the same along the coast and decrease inland.

California's natural variability in year-to-year precipitation is due, in part, to atmospheric river events in the winter months. A more intense, but shorter wet season and increased whip swing from wet to dry years and vice versa have been predicted by some.[32]These events are the source of most of the State's precipitation for the whole year. As temperatures rise, these atmospheric rivers are expected to hold more moisture, which may lead to extreme, heavy precipitation events. To better understand how infrequent, heavy storm events could change over time, the potential changes to the 100-year storm event were assessed in the statewide Vulnerability Exposure Assessments. Using a median model and the business-as-usual GHG emissions scenario, the study found that the 100-year precipitation depth was projected to increase by an average of 2 to 3 percent across the State, meaning more rainfall during these events. This percent change in the 100-year precipitation depth identified in the climate data is much higher in some locations, mainly along the coast and in the Sierra Nevada mountains. The highest percentage increase is indicated for Mono County, where there is a 30-percent projected increase in 100-year storm precipitation depth by 2085.

[28] Brown, Governor Edmund. 2015. "Proclamation of a State of Emergency." Executive Office, State of California. Oct. 30. Retrieved May 10, 2020 from https://www.ca.gov/archive/gov39/2015/07/31/news19053/index.html

[29] He, M., A. Schwarz, E. Lynn, and M. Anderson (California Department of Water Resources). 2018. Projected Changes in Precipitation, Temperature, and Drought across California's Hydrologic Regions. California's Fourth Climate Change Assessment. Publication number: CCCA4-EXT-2018-002. Sacramento, CA.

[30] Bedsworth et al, 2018. Op cit.

[31] Swain, D.L., B. Langenbrunner, J.D. Neelin, and A. Hall. 2018. "Increasing precipitation volatility in 2018 twenty-first-century California," Nature Climate Change, 8, 427-433, doi: 10.1038/s41558-018-0140-y.

[32] Ibid.

3.2.1 POTENTIAL IMPACT ON ASSETS

The Federal Emergency Management Agency (FEMA) uses the 100-year flood, or "base flood," as a national standard for its National Flood Insurance Program (NFIP). Caltrans is required to use floodplain maps created through the NFIP to determine if highway alternatives will encroach into the base floodplain, and if so, ensure Caltrans construction does not raise the base floodplain.[33] The 100-year flood is also used as a design flood for scour analyses and for setting structural elevations.[34] The 50-year, 200-year, and 500-year events are also considered in Caltrans structural designs.

FLOODING ON SR 138, DISTRICT 6

As described above, these flood events will likely change over time, becoming more extensive and/or more frequent. However, the current design storms and floodplains used by Caltrans are based on historical records of past rainfall. As extreme precipitation events change over time, this historical information on flooding will become less relevant and its use as a basis for design less desirable, particularly given the long lifetime of transportation assets. Relying upon these historical sources may lead to many current and future assets being undersized, resulting in increased flooding, washouts, scour, erosion, and bridge/culvert failure.

3.2.2 POTENTIAL IMPACT ON OPERATIONS

More frequent flooding and landslides on the SHS will likely have a significant impact on SHS operations, including more frequent road closures, a need for more extensive SHS user information, and a larger number of Director's Orders facilitating emergency response. Flooding and landslide events are also inherently dangerous for Caltrans staff and the public, as road closures and poor weather/road conditions lead to increased congestion, traffic accidents, risky driver behavior, and stranded vehicles. For example, the Louisiana Department of Transportation and Development reported that 12 people were killed by driving into flood waters during heavy rain events in 2016, and that the capacity of the agency to effectively respond to emergencies was limited in part due to staff's personal decisions (caring for family members/property).[35]

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[33] Caltrans. 2010. "Highway Design Manual, Chapters 800 – 890, Highway Drainage Design Chapter 800 – General Aspects, Topic 801." Retrieved May 10, 2020 from https://dot.ca.gov/programs/design

[34] Caltrans. 2017. "Hydraulic Design for Structures Over Waterways." Memo to Designers 16-1, Dec. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/memotodesigner/f0006651-mtd-16-1-final.pdf

[35] American Association of State Highway and Transportation Officials (AASHTO). 2018. "Resiliency Case Studies: State DOT Lessons Learned." May. Washington DC. Retrieved May 10, 2020 from https://environment.transportation.org/pdf/rsts/aashto_resiliency%20_case_studies.pdf

SR 58 MUDSLIDE, DISTRICT 9

Heavy snowstorms, which are still expected to happen at high elevations, may also lead to increased accidents and congestion, given snowy and icy conditions. Caltrans staff may need to conduct more frequent or intensive maintenance during snow/ice conditions, such as plowing and de-icing. Additional resources may be needed to prepare for and respond to these types of events, including staff time, equipment, and road treatment stores (e.g. salt brine). Faster snowpack melt and runoff could also lead to flooding and landslide risk for the SHS in the Sierra Nevada and other mountainous regions, though snowpack is expected to decline substantially with future warming.[36]

3.3 WILDFIRES AND LANDSLIDES[37]

As temperatures rise and average rainfall and snowfall are reduced, soil and vegetation lose more moisture to the air and the length of time the ground is covered by snow is reduced, thus increasing the risk of wildfires. California's Fourth Climate Change Assessment reported that climate change has increased the area burned by wildfires in the western United States by roughly double what it would have been between 1984 and 2015 without the changes in climate.[38] The Fourth Climate Change Assessment also noted that warmer temperatures along with fire suppression efforts have caused uncharacteristically severe fires to have "negative ecosystem impacts such as regrowth failure, habitat loss, reduced carbon storage, and reduced water quality" in forested areas."[39]

Humans have an active role in creating wildfire conditions through fire suppression and accidental ignition. Eighty-five percent of all fires are started by people, with most wildfires starting along the urban-wildland interface where people live.[40] A wildfire model developed for California's Fourth Climate Change Assessment used projected population scenarios; assumed statistical proxies for human influences on ignition; and a pairing among changing vegetation characteristics, land surface characteristics, and historical fire records to model future conditions.[41] With an assumed worst-case GHG

[36] Bedsworth et al, 2018. Op cit.

[37] There are many different types of earth movement that can cause damage to Caltrans' infrastructure, and mitigating each type of movement will have a different solution (see appendix A.2).

[38] Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K. Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, and B.H. Udall, 2018: Southwest. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1101–1184. doi: 10.7930/NCA4.201

[39] Westerling, Anthony Leroy. (University of California, Merced). 2018. Wildfire Simulations for California's Fourth Climate Change Assessment: Projecting Changes in Extreme Wildfire Events with a Warming Climate. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-014.

[40] Bedsworth et al, 2018. Op cit.

[41] Bedsworth et al, 2018. Op cit.

emissions scenario, the model showed a "77 percent increase in mean area burned in California (compared to 1961 – 1990) by the end of the century." The model also found that extreme wildfires (10,000 hectares or greater) could occur 50 percent more often.

Recent events have demonstrated that wildfires on the urban-wildland interface can be massively destructive in terms of deaths, injuries, and lost structures. The Camp (November 2018 in Butte County) and Tubbs (October 2017 in Napa and Sonoma County) Fires both top the list for California's most destructive wildfires. (It is interesting to note that both of these fires occurred during what used to be the wet season). The Camp Fire killed 85 people, destroyed 18,804 structures, and burned 153,336 acres before it was put out. The Tubbs Fire, the second most destructive, killed 22 people, destroyed 5,636 structures and burned 36,806 acres.[42]

WILDFIRE CLOSES US 395, DISTRICT 9

As significant as such impacts are for local residents, these types of major fire events have even broader-reaching impacts in major urban areas due to smoke plumes spreading across the State. These indirect impacts were demonstrated as the Camp Fire was still burning when Bay Area and Central Valley residents experienced prolonged periods of unhealthy air from the Camp Fire plume. The Sacramento Metropolitan Air Quality Management District documented 13 consecutive days of unhealthy air and the second-highest Air Quality Index (AQI) reading the city has ever recorded of 314 AQI (the scale reaches 500 AQI). Even short-term exposure to unhealthy air can lead to respiratory symptoms and deteriorating chronic conditions. A recent study of smoke exposure during California's 2015 wildfire season found a positive association between wildfire smoke and emergency room visits related to cardiovascular, cerebrovascular, and respiratory disease in north and central California. These impacts were greatest in adults 65 or older, but asthma-related visits affected all age groups.[43]

3.3.1 POTENTIAL IMPACT ON ASSETS

Wildfires can have direct impacts on Caltrans assets by burning buildings, guardrails, retaining walls, and signage; and melting other assets such as plastic irrigation lines and culverts. In addition, wildfires can create ideal conditions for landslides by burning or killing vegetation, leaving slopes exposed and destabilized. Wildfires can also cause hydrophobic soil conditions leaving a layer of ash and crush of mineralized soil caused

[42] CAL FIRE. 2019. "Top 20 Most Destructive California Wildfires." Feb. 19. Retrieved May 10, 2020 from https://www.fire.ca.gov/media/5511/top20_destruction.pdf

[43] Wettstein, Z., S. Hoshiko, J. Fahimi, R. Harrison, W. Cascio, and A. Rappold. 2018. "Cardiovascular and Cerebrovascular Emergency Department Visits Associated with Wildfire Smoke Exposure in California in 2015." Journal of the American Heart Association. Apr 17; 7(8): e007492. Retrieved May 10, 2020 from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6015400/

by burned plant materials coating soil particles[44] and by burning away organic material in the soil.[45] These combined conditions can lead to increased runoff causing mudslides and landslides, which can damage and cut off portions of SHS roads. Wildfires and landslides can also lead to debris accumulation that ends up in roadways, drainage infrastructure, and/or waterways.

3.3.2 POTENTIAL IMPACT ON OPERATIONS

Wildfires, and landslides that can follow, affect operations by causing road closures, which lead to congestion, delays, and detours. Wildfires also require expensive emergency responses from Caltrans to clear debris, replace damaged infrastructure, and stabilize slopes. For example, Caltrans initiated a Director's Order following the Camp Fire for emergency funds totaling $24,000,000. The funds were needed to repair and rehabilitate State Routes 32, 70, 88, 149, and 191 in Butte County by removing dead and hazardous trees, hydroseeding and installing slope protections on steep hillsides, installing debris racks to stop debris from entering waterways and drainage infrastructure, and replacing damaged roadside infrastructure like guardrails, fencing, signage, and electrical equipment.[46] Another operational concern is identifying and managing evacuation routes.

3.3.3 POTENTIAL IMPACT ON WORKFORCE

Smoke from wildfires can have far-reaching human impacts, causing "induced morbidity, mortality, and lost productivity."[47] Caltrans employees who live or work near wildfires may suffer acute or chronic health impacts from poor air quality. In addition, staff might be in the path of wildfires, and need to evacuate their homes. Caltrans has responded to these events in the past by closing district offices so that staff could stay inside their homes and/or prepare to leave if necessary.

3.3.4 POTENTIAL IMPACT ON LANDSCAPING AND VEGETATION

Fire is an important part of California's natural ecosystems. For example, chaparral ecosystems are well adapted to wildfire and will regenerate through the root crown or seeds lying dormant in the soil that germinate following a fire.[48] The Giant Sequoia of the Sierra Nevada are also dependent upon fire for seed germination; new seedlings will not grow without it.[49] After decades of fire suppression in the West, the U.S. Forest Service and its partners have slowly started to implement controlled burns on public

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[44] California Water Science Center (CWSC). 2017. "Wildfires, Water, and CAWSC Science." Retrieved May 10, 2020 from https://ca.water.usgs.gov/highlights/2017/10/wildfires-water-quality

[45] Pacific Biodiversity Institute. 2009. "Fire Ecology." Retrieved May 10, 2020 from http://www.pacificbio.org/initiatives/fire/fire_ecology.html

[46] See pages 21 – 22 of the Caltrans District 3 Vulnerability Assessment for more information on the Caltrans Camp Fire response.

[47] Westerling et al. 2018. Op cit.

[48] U.S. Forest Service. Undated. "Fire in chaparral ecosystems." Pacific Southwest Research Station. Retrieved May 10, 2020 from https://www.fs.fed.us/psw/topics/fire_science/ecosystems/chaparral.shtml

[49] National Park Service. 2015. "Giant Sequoias and Fire." Retrieved May 10, 2020 from https://www.nps.gov/seki/learn/nature/fic_segi.htm

lands to improve forest health. Periodic low- intensity fires are important for clearing accumulated underbrush, recycling nutrients, managing pests and disease, and stimulating species reproduction. Reintroducing these types of wildfires to California ecosystems can also reduce the risk of extreme wildfires that burn entire stands of trees, which are becoming more common. Caltrans' landscaping and the vegetation adjacent to the SHS might benefit from low-intensity fires that simulate natural events to avoid more catastrophic major wildfires.

3.4 SEA LEVEL RISE, STORM SURGE, AND CLIFF RETREAT

A rising sea level is one of the most obvious and impactful threats from climate change around the world. Since 1900, global average SLR has been between 7 and 8 inches (16-21 cm) and about half of this rise has occurred in just the last 25 years.[50] Scientists have been trying to project how this rate of rise will continue over the coming century, especially considering the many uncertain variables that affect SLR, such as thermal expansion, ice sheet melt, and temperature rise. As of 2018, most climate studies predict that it most likely that SLR will be less than 4 feet through 2100; a larger amount is possible, but unlikely.

WATER ENCROACHMENT ON SR 1, DISTRICT 5

In California, the OPC has developed a set of new SLR projections specific to the California coastline incorporating the latest advancements in sea level rise modeling.[51] These new projections also account for improved understandings of ice loss from the Greenland and Antarctic ice sheets, which are melting faster than previously anticipated. The OPC developed projections for 11 different SLR scenarios in 12 locations along the California coast. For the San Francisco Bay, the most likely SLR scenario (66 percent probability that SLR will be between these values) ranges from 0.6 to 1.1 feet by 2050 and 1.0 to 3.4 feet by 2100. The OPC also included an extreme scenario, which does not have an associated likelihood, called the H++ scenario. For San Francisco Bay, the H++ scenario suggests 10.2 feet of SLR by the end of the century.

Another major impact from SLR is cliff retreat and coastal erosion. California's rocky coastline is an iconic feature of the State; coastal highways like SR 1 are well known for their scenic views. It is natural for California cliffs to change over time, but SLR will

[50] U.S. Global Change Research Program (USGCRP). 2018. "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment." Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. Retrieved May 10, 2020 from https://nca2018.globalchange.gov/chapter/2/

[51] California Ocean Protection Council (COPC). 2018. "State of California Sea-Level Rise Guidance." Retrieved May 10, 2020 from http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

accelerate the process. Caltrans is doing an analysis of cliff retreat for its statewide Vulnerability Exposure Assessment to understand how coastal highways will be affected. To date, Caltrans has completed its analysis for Southern California and found that Highway 1 will be the most vulnerable portion of the SHS. It is estimated that about 5 miles of Highway 1 could erode under 1.64 feet (0.5 m) of SLR. For context, there is a 1-in-200 chance that this SLR height would be reached in Los Angeles by 2050.

Most of California's population lives in low-lying coastal counties and as sea levels rise, these communities will be increasingly threatened. Initial impacts will include periodic flooding during high- tide or storm events and more frequent and accelerated erosion. Over time, this will lead to permanent inundation of some coastal areas, which will either need to adapt or retreat. Inland areas will also be affected by the loss of coastal areas and with saltwater intrusion of waterways. Communities surrounding the Sacramento-San Joaquin River Delta will be especially vulnerable to rising sea levels. Many of these communities are protected by levee systems, some of which are outdated and unregulated, to prevent flooding. As sea levels rise, there will be increasing pressure on this system. Without more maintenance and regulation on these levees, some of California's most disadvantaged populations could be inundated or flooded, along with the surrounding SHS.[52]

3.4.1 POTENTIAL IMPACT ON ASSETS

One of the most threatening aspects of SLR is future inundation of the SHS, local roadways, and other Caltrans assets. Such flooding would have major impacts on how the transportation network is used and operated. Before an asset is permanently inundated, there will be periods of flooding during high-tide and storm events, which will cause temporary road closures. Storm surge events may also contribute to debris on the SHS and in drainage infrastructure, bridge scour, increased erosion, washouts, and asset degradation. After permanent inundation, there is not much that can be done to recover the asset.

Coastal erosion and cliff retreat will wear away at Caltrans assets on the coastline, possibly triggering landslides, and causing unstable foundations and washouts. Caltrans has already relocated a portion of Highway 1 south of San Francisco due to coastal erosion and heavy maintenance was required to keep the roadway open. Highway 1 was relocated to two tunnels that avoided the most treacherous part of the coast, called Devil's Slide.[53]

3.4.2 POTENTIAL IMPACT ON OPERATIONS

Caltrans will likely need to increase maintenance activities on coastal portions of the SHS to respond to damage caused by SLR, storm surge, and/or cliff retreat. For example, bridges along the coastline may need additional inspection and maintenance due to wave run-up, scour, and erosion. The Trancas Creek Bridge on Highway 1 is currently scour critical due to a combination of heavy rain, wave run up, and washouts from storm

[52] See pages 23-24 of the District 3 Vulnerability Assessment for more on sea level rise impacts in the Delta.

[53] For more information on the Devil's Slide project see page 31 of Caltrans District 4 Vulnerability Assessment.

events, and will need to be replaced soon.[54] Caltrans will also need to plan for the long-term impacts of SLR and consider rerouting portions of the SHS where there are frequent closures due to flooding, or otherwise protect the road segments with engineered or natural infrastructure actions.

[54] See pages 35-36 of the District 4 Vulnerability Assessment to learn more about the Trancas Creek Bridge Replacement project.

Like other forecast changes in climate, projections of SLR vary, depending in part on the assumptions made regarding future concentrations of GHGs and how the earth's systems will respond. The Ocean Protection Council's (OPC) Sea Level Rise Guidance: 2018 Update provides the most up-to-date SLR scenarios for locations across the California coastline. The figure below shows the SLR projections for San Diego, showing a total of seven different scenarios for the same tidal gauge, including an extreme estimate, two low probability estimates, and a range of more likely targets. While SLR will vary across the California coast, the rates of rise shown in the figure are consistent with what is expected across the California coast, the rates of rise shown in the figure are consistent with what is expected across the state.

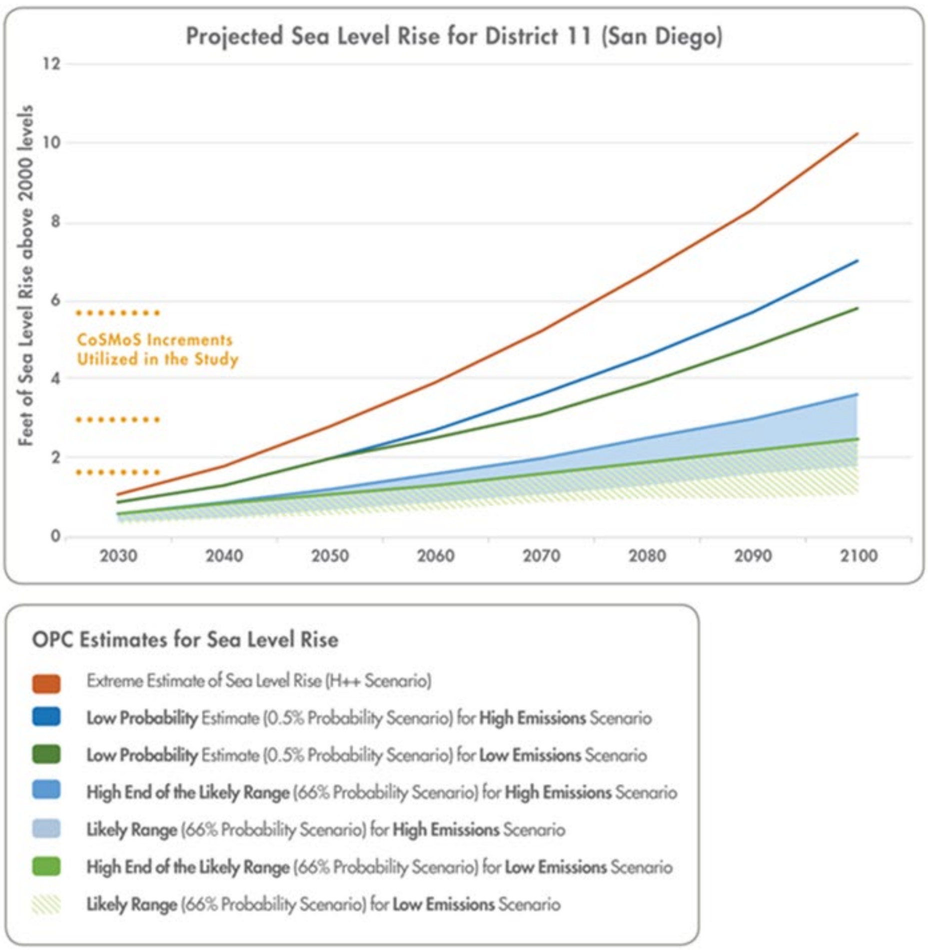


FIGURE 2: OPC SEA LEVEL RISE PROJECTIONS FOR SAN DIEGO

4. RECOMMENDED ACTIONS FOR INTEGRATING CLIMATE CHANGE CONCERNS INTO CALTRANS DECISION-MAKING

Caltrans has a well-developed decision-making process from planning to project development to implementation to maintaining the asset after construction. The planning process is where system analysis and needs assessment are performed and the initial project conception occurs, which becomes more refined as it moves through the planning process. The planning process is guided by detailed guidance on the steps that are necessary during the planning phase. For project delivery, an overview of the project delivery process can be found in *How Caltrans Builds Projects*,[55] with more specific up-to-date information in Caltrans' *Project Development Procedures Manual*.[56] This latter reference provides general information on the process, specific information on the steps in the project development process, and detailed information on the procedures involved in each step. For example, Chapter 8 in the *Manual* provides detailed project milestone information that corresponds to key decisions within the project development process.

4.1 CHARACTERIZING THE KEY AREAS OF RECOMMENDATIONS

A simplified version of the key components of Caltrans decision processes was developed to structure this assessment. Importantly, the assessment specifically looks at decisions occurring at the beginning of project conceptualization (e.g., planning), adaptation-related decisions that precede planning (such as overall Caltrans strategic management direction), decisions within the project delivery process, and those that follow project delivery (such as asset management and maintenance). The general areas of decision-making, and the structure of this report's recommendations include:

- Organizational Responsibility
- Vision/Goals/Policy Direction
- Planning
- Project Prioritization
- Environment
- Project Design
- System Operations
- System Maintenance
- Asset Management
- Project Concepts

[55] Caltrans, 2011. How Caltrans Builds Projects. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/2011-how-caltrans-builds-projects-a11y.pdf

[56] Caltrans. Project Development Procedures Manual. Retrieved May 10, 2020 from https://dot.ca.gov/programs/design/manual-project-development-procedures-manual-pdpm

These components are fairly aggregate. In other words, "planning" and "maintenance" include many different responsibilities focusing on targeted contributions to Caltrans activities. It was assumed, however, that the recommendations for each functional area were relevant for all of the work occurring in that function.

The following sections describe the recommended climate change adaptation actions that Caltrans could consider as part of its effort to provide a more resilient SHS capable of adapting to climate change.

4.2 ORGANIZATIONAL RESPONSIBILITY

The recommendations presented in this report are aimed at Caltrans responsibilities in many functional areas. Implementing these recommendations will be the responsibility of each division/office/district head of the respective units. However, for Caltrans to become more engaged in climate change adaptation (and transportation system resilience, more generally), there is a need for central responsibility having the authority and mandate to implement changes to Caltrans procedures and processes. Caltrans initially created the Climate Change program in the Division of Transportation Planning to support the agency's climate change adaptation efforts. In addition, it created the Deputy Director for Sustainability position to focus on the importance of sustainability efforts in Caltrans. These efforts go beyond what most state DOTs have done in either the sustainability or climate change policy areas. The Climate Change Branch hosts quarterly meetings with representatives from all 12 districts and Headquarters functional units to discuss the latest information on climate change.

Some state DOTs have taken organizational steps to enhance their efforts at transportation system resilience and/or climate change. Their efforts are indicative of the types of organizational structures and responsibilities that have been created around the United States. Some examples include:

Utah DOT (UDOT): The primary focus of UDOT's transportation system resilience efforts is to integrate system resilience factors and concepts into key agency planning and decision-making processes. For example, UDOT is one of the nation's leaders in integrating system resilience concepts into transportation planning efforts, especially corridor planning (see Figure 3). As noted in its guidance, "The (resilience) process will be an integral part of corridor planning and will enable the department to address risk and resiliency at the enterprise level and aid us in achieving our strategic goals. This process will engage region staff and focus participants in identifying risks during the planning phase."[57]

Florida DOT (FDOT): FDOT has created the Florida Resilience Subcommittee as part of the effort to update the Florida Transportation Plan. The charge of the Resilience Subcommittee is to:

[57] Utah DOT. 2018. Website. "Program Development; Performance." Retrieved May 10, 2020 from https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4138

- Discuss themes, trends, and planning implications of transportation system resilience in Florida.

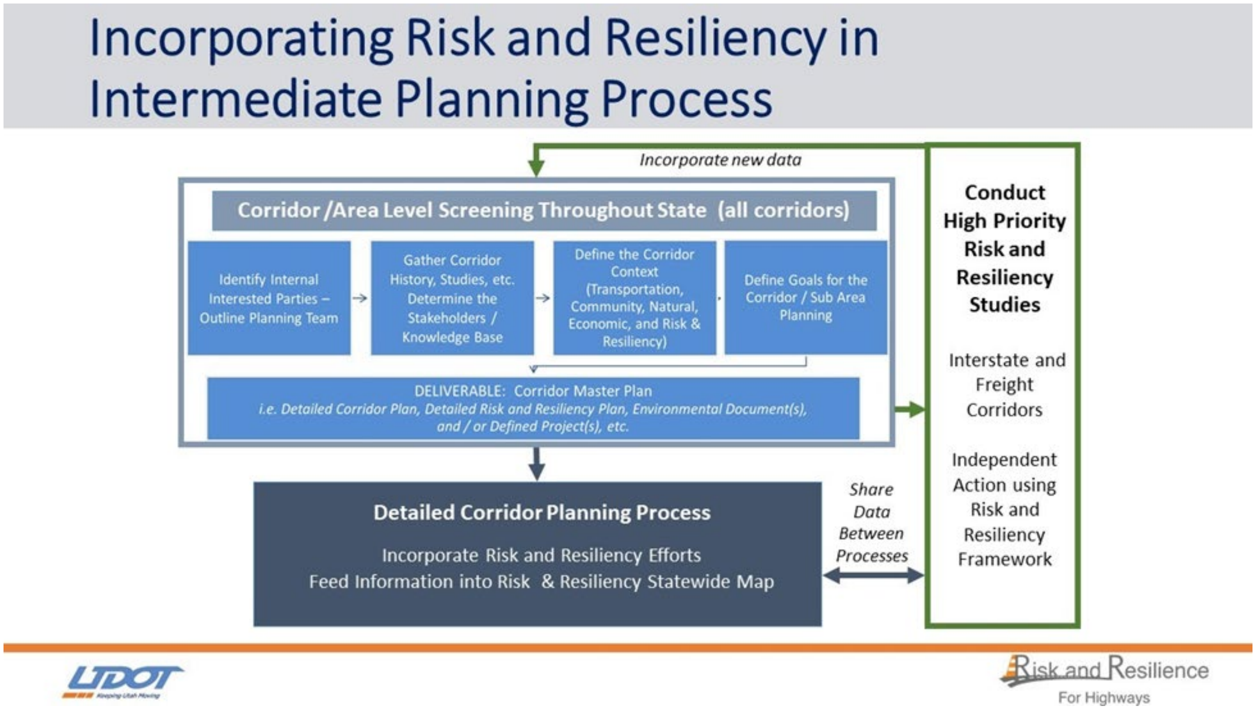


FIGURE 3: UDOT'S CORRIDOR PLANNING AND CONSIDERATION OF SYSTEM RESILIENCE

- Review and provide input, as requested, on related plans and processes, including those from FDOT and other partners.
- Serve as transportation system resilience subject matter experts for the FTP-SIS Steering Committee and provide updates to the committee as needed.[58]

Colorado DOT (CDOT), Maryland DOT (MDOT), Minnesota DOT (MnDOT), and Oregon DOT (ODOT): Several state DOTs have created resilience or climate change organizational positions and/or processes that transcend an individual unit's responsibilities. Maryland DOT, for example, has established the climate change program manager position in the State Highway Administration, whose mandate is to enhance Maryland DOT's climate adaptation efforts throughout the agency.

MnDOT has created the Office of Sustainability and Public Health, whose chief reports directly to the director's chief of staff. ODOT has created a Sustainability Council that has representatives from all functional areas in the DOT. The council prepares quarterly progress reports on ODOT sustainability and climate change adaptation activities.

[58] Florida DOT. 2019. Website. "Resilience Subcommittee." Retrieved May 10, 2020 from http://floridatransportationplan.com/resilience_committee.htm

Perhaps the most extensive institutional commitment to transportation system resilience and climate change is found in CDOT. CDOT has created the position of resilience program coordinator in the Division of Transportation Development to provide "guidance to and support department staff in implementing resilience activities, directing and implementing resilience research and creating a knowledge base of guidance and best practices for resilience in transportation."[59] The coordinator reports to an Executive Oversight Committee and executive-level Resilience Work Group, and ultimately, to the Transportation Commission.

The State of California's efforts on seismic safety after the Loma Prieta earthquake is an example of how Caltrans was tasked with changing its procedures, organizational structure, and outcomes as per a Governor's EO. Some of the key aspects of this response are shown in the sidebar. There are similarities between the climate adaptation efforts and those undertaken for Caltrans' seismic program. Interestingly, an action plan for how Caltrans was going to consider seismic safety in agency operations was part of the EO. Focusing on the project prioritization process was another. Ultimately, Caltrans' seismic program ended up in Engineering Services as a separate unit, having specific responsibilities in terms of engineering design and project development.

These examples, along with interviews with the officials responsible for each initiative, lead to the following five key lessons on what it takes to establish an effective institutional structure and corresponding processes for leadership in transportation system resilience and climate change adaptation.

- The institutional responsibility (referred to hereafter as the "position") should have a direct connection to agency leadership (e.g., MnDOT's sustainability officer reporting to the DOT's chief of staff).
- The position should have authority for identifying and guiding implementation of resilience/climate change adaptation efforts across the entire agency.
- Staff resources should be available to support the decisions and implementation efforts associated with the position.
- The position should be viewed as the "point of contact" for external stakeholders for system resilience and climate change adaptation in the agency.
- The position should be augmented by institutional structures that provide opportunities for other agency managers to collaborate in developing agency directions and implementation strategies (e.g., the Resilience Subcommittee at FDOT or Working Group at CDOT).

The key lesson from experiences from other states and Caltrans is that organizational responsibility, authority, and accountability are critical for Caltrans to integrate climate

[59] Colorado DOT. 2018. "Building Resilience into Transportation Infrastructure and Operations." Division of Transportation Development. Retrieved May 10, 2020 from https://www.codot.gov/programs/planning/documents/plans-projects-reports/projects/resilience_program/policy-directive-pd-1905.0

change adaptation into its decision-making and supporting processes. For example, having a program manager and leadership unit that can work across programs will be a key element for successful implementation of a climate change adaptation strategy. Organizational changes should be made to enhance and strengthen the emphasis on climate change adaptation within the agency.

RECOMMENDATION 1

Create an organizational structure in Caltrans with the authority, credibility, and accountability for integrating climate change adaptation into Caltrans' business operations and transportation investment decision-making. Currently a systematic and programmatic approach to climate resiliency is lacking. This would necessarily require the participation of many different functional units within Caltrans.

RECOMMENDATION 2

Each major program from planning, programming, project delivery, maintenance, and operations should be assigned the responsibility for implementing the respective recommendations of this study and develop appropriate procedures, guidelines, resources and organization structure to maintain an effective and productive effort on climate adaptation and transportation resiliency. A point of contact should be identified for each program. The implementation plan for each unit should include recommendations for needed staff training.

4.3 CALTRANS' STRATEGIC VISION, GOALS, AND POLICY DIRECTION

For Caltrans to evolve into a more climate adaptation-oriented agency, it needs to begin at the outset of the decision-making processes with explicitly stated priorities included in its vision and goal/objectives. With the historic wildfires that have occurred over the past several years, as well as never-before-seen extreme heat and extreme flooding events, including a concern for climate adaptation and system resiliency into the vision and goals should a high-priority action.[60]

The current 2015-2020 Strategic Management Plan outlines the following vision and associated goals.

[60] It is informative that of the 114 responses to the survey of Caltrans officials conducted for this study, 23 Caltrans staff (20 percent of the respondents) identified "needed policy guidance" as the most important step forward. This number climbed to 68 (60 percent) when the respondents were allowed to select five topics that they felt should be highlighted in this Climate Change Adaptation Strategy Report.

Vision: "A performance-driven, transparent, and accountable organization that values its people, resources, and partners and meets new challenges through leadership, innovation, and teamwork."

Goals:

- Safety and Health: Provide a safe transportation system for workers and users and promote health through active transportation and reduced pollution in communities.
- Stewardship and Efficiency: Money counts. Responsibly manage California's transportation-related assets
- Sustainability, Livability and Economy: Make long-lasting, smart mobility decisions that improve the environment, support a vibrant economy, and build communities, not sprawl.
- System Performance: Utilize leadership, collaboration, and strategic partnerships to develop an integrated transportation system that provides reliable and accessible mobility for travelers.
- Organizational Excellence: Be a national leader in delivering quality service through excellent employee performance, public communication, and accountability.

Although adaptation and system resiliency could be associated with each of the goals, only two objectives within these goals could be conceivably linked to a resilient transportation system. Under the "sustainability, livability and economy" goal, one of the objectives was "Improve economic prosperity of the State and local communities through a resilient and integrated transportation system," with this being defined primarily through efficient freight movement. Under "System Performance" one of the objectives was "Improve travel time reliability for all modes." Given the challenges California faces in terms of transportation system disruptions, a more direct link between climate change adaptation/resiliency and minimizing the impacts of system disruptions is recommended.

As noted by one of those interviewed for this study, "if Caltrans is to be serious about climate change adaptation, there needs to be a call for action." Such a call begins with the vision and goals. A recommendation for a climate change adaptation/system resiliency goal raises the question of how a new goal would be prioritized in relation to other Caltrans goals. At an agency level, such prioritization is ultimately a Caltrans leadership decision, unless legislative action preempts agency action. Having a resilience or adaptation goal as part of the Caltrans goals set is important at the study or project level when project selections are being prioritized or project designs are being undertaken. For example, one could envision in climate stressor exposure areas—areas defined in the on-going Caltrans Vulnerability Study as exhibiting potentially climate change-oriented, at-risk conditions for Caltrans assets—that resilience and adaptation concerns should be part of the decision-making. This would link these types of decisions to the agency goal. In other words, goals serve many purposes, but one of

RECOMMENDATION 3

For the next update to the Strategic Management Plan (SMP), Caltrans should adopt an explicit goal (with corresponding objectives) that commits to climate change adaptation strategies. This could be a stand-alone goal or contained within a strategic goal that focuses on broader "transportation system resiliency." One possible statement could be similar to what has been adopted by other state departments of transportation (DOT)s:

> Goal: A transportation system that is resilient, reliable, and responsive to system disruptions.
>
> Action: Proactively assess, plan, invest in, operate, and maintain the State's transportation system to protect system assets from extreme weather and, over the long term, climate change threats.

If a specific climate adaptation goal is not desired, the strategic objectives of the adopted goals should call out climate adaptation and system resilience concerns.

their more important roles is to guide agency decisions on what these decisions should be aiming to achieve. Having a resilience or adaptation goal as part of Caltrans' goals set sends a message to staff and other decision-making participants that such a concern is important as part of the many subsequent decisions associated with Caltrans actions.

4.4 PLANNING

Planning within Caltrans includes many responsibilities that are particularly relevant and essential to considering climate adaptation in Caltrans decisions. Figure 4 shows the major plans and planning efforts that occur in Caltrans planning. Planning conducts studies that identify future transportation needs, possible strategies for meeting these needs, and works with key stakeholders in developing transportation strategies to improve overall mobility in the State.

The statewide long-range planning program in Caltrans' Division of Transportation Planning and the California Transportation Plan (CTP) provide a framework and collaborative process to understand and shape the future of the State highway network and transportation system in California. Working with Caltrans districts and partner agencies, the program advocates for and advances innovative solutions for shaping future mobility and access while addressing the State's goals of reducing GHG emissions and improving SHS climate resiliency. The program feeds into and carries over the goals of the Strategic Management Plan and ensures that the plan's emphasis areas are followed through in modal plans, system plans, and other planning documents. The program also monitors the implementation of these plans. Given its guiding principles and planning horizon, a long-range planning program is critical for any climate change adaptation effort and its integration into Caltrans business operations.

The plans developed and used by Caltrans were examined to identify how climate change adaptation is currently considered.

4.4.1 LONG-RANGE PLANS

California Transportation Plan (CTP): Caltrans develops the CTP, the State's long-range transportation plan (the Office of State Planning facilitates the development and preparation of the plan). [61] The CTP 2040, released in 2016, noted that it was the first such plan to address climate change, with attention given to both reducing GHG emissions (mitigation) and adaptation (although GHG emission reduction receives more attention). Recommendations included:

1. Expand State and regional resiliency planning and climate change impact studies of SLR, storm events, and other climate change outcomes that affect the future of communities, infrastructure, and ecosystems.
2. Develop a project-level checklist to evaluate facility risks and vulnerability due to climate change impacts at the time funding is programmed and incorporate project design features to improve resiliency of facilities and infrastructure.
3. Incorporate system impacts from climate change, risk, and vulnerability assessments into collaborative and proactive construction, operations, and maintenance activities to provide affected agencies and freight partners with the ability to adapt and recover from climate change events.

The CTP suggested that improvements to the California transportation system should include:

> "Reducing long-run repair and maintenance costs by using 'fix it first,' smart asset management, and life-cycle costing to maintain the transportation infrastructure in good condition—this should include developing a comprehensive assessment of climate-related vulnerabilities, and actions to ensure system resiliency and adaptation to extreme events."

The CTP 2050 to be released by December 2020 is more robust in its climate adaptation objectives and includes information generated by vulnerability assessments and the adaptation strategies report.

[61] Caltrans. 2016. California Transportation Plan. Retrieved May 10, 2020 from http://www.dot.ca.gov/hq/tpp/californiatransportationplan2040/Final%20CTP/FINALCTP2040-Report-WebReady.pdf

4.4.2 SYSTEM PLANNING

System planning, through its multiple products, provides a regional and interregional context for the framework set by the CTP acting as the foundation for statewide long-range planning. It supports project initiations, project development, and operational improvement through policies, procedures, tools, analysis, training, technical assistance, and development of a work program and a statewide list of priority projects.

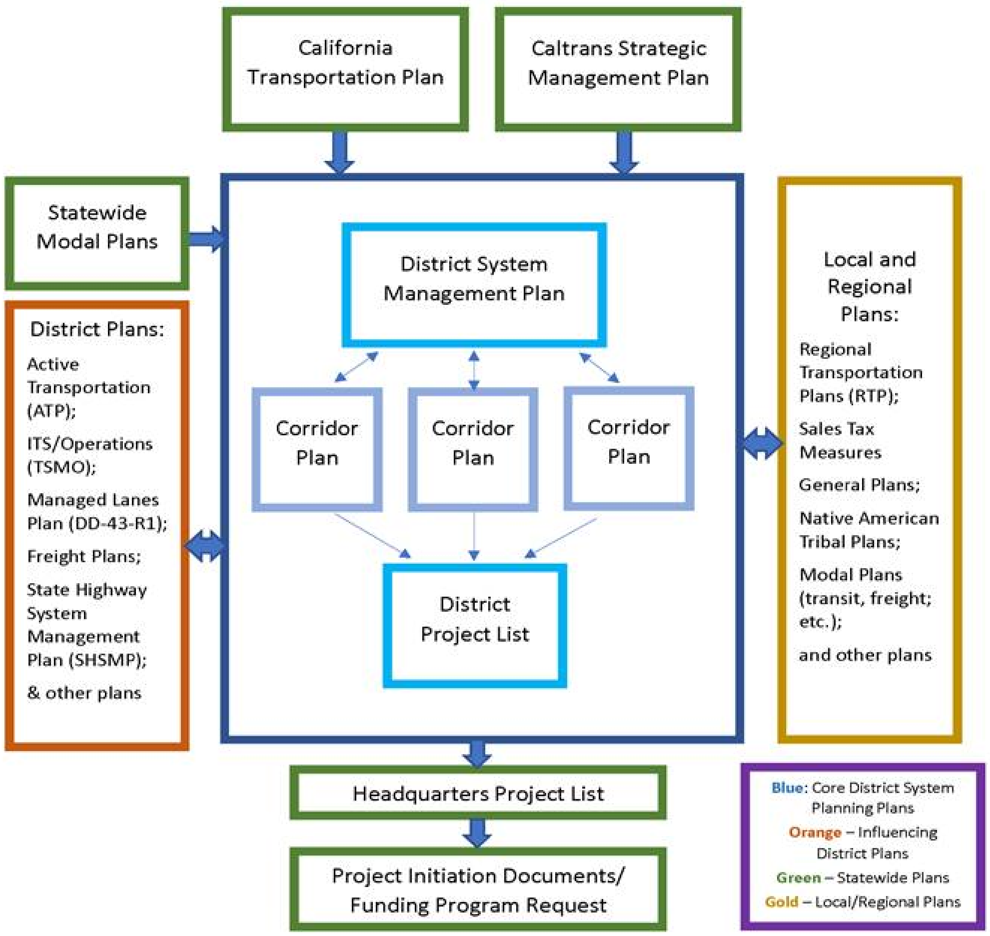


FIGURE 4: CALTRANS INVOLVEMENT IN PLANNING

Interregional Transportation Strategic Plan (ITSP): The ITSP is an important product of system planning. The most recent ITSP was approved by the California Transportation Commission (CTC) and published in 2015. The ITSP recommends priorities for improvements of greatest interregional merit for 11 Strategic Interregional Corridors identified as part of the plan.[62]

As noted in the ITSP, the planning and implementation of interregional transportation improvements requires balancing multiple goals consistent with the CTP. The system must: 1) be multimodal, including bicycle and pedestrian modes; 2) serve a variety of travel purposes (i.e., "Complete Streets"), including freight movement, tourism, and active travel; and 3) improve livability, sustainability, environmental health, and transportation options. In addition, the vision of the ITSP was developing a "well-developed, high-quality, multimodal interregional State highway and intercity passenger rail network that serves as the backbone for the movement of people and goods throughout California."

4.4.3 DISTRICT PLANS

The District System Management Plan serves as an internal and external communications tool identifying Caltrans priorities and strategies for route and system improvement.[63] A route concept report (RCR) or transportation concept report (TCR) identifies current operating conditions, future deficiencies, route concept and concept level of service (LOS), and improvements for a route or corridor. A Transportation System Development Program (TSDP) identifies a reasonable comprehensive and effective range of transportation improvements on both State highways and in modal categories. At this time, the development of RCRs, TCRs, and TDSPs have largely been phased out in favor of more flexible and holistic Comprehensive Multimodal Corridor Plans which consider several factors beyond just the transportation system.

4.4.4 CORRIDOR STUDIES

Corridor planning in most states and metropolitan areas represents a very important opportunity to substantively consider particular topics or concerns. It provides a much more "on-the-ground" perspective of the kind of issues facing the transportation system. It is easier to understand the specific needs facing the system, and it is often easier to get the public involved in the process when those involved can relate to specific issues, problems, and suggested improvements.

Caltrans issued a Corridor Planning Process Guide in 2020 that was intended to replace the Transportation Concept Report guidelines.[64] As noted in the Guide, the Guide "corridor plans (or Corridor Plans) identify and recommend transportation strategies and improvements in coordination with Caltrans' planning partners, resulting in a range of pre-Project Initiation Document (PID) project candidates and non-project strategies

[62] Caltrans. 2015. Interregional Transportation Strategic Plan. Retrieved May 10, 2020 from http://www.dot.ca.gov/hq/tpp/offices/omsp/system_planning/documents/Final_2015_ITSP.pdf

[63] Caltrans. District System Management Plan (DSMP). Retrieved May 10, 2020 from https://dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/guidelines-procedures/district-system-management-plan-2013

[64] Caltrans. 2020. Corridor Planning Process Guide. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/system-planning/systemplanning/corridor-planning-process-guide-12-24-2019-a11y.pdf

that achieve Caltrans goals and objectives." It is important to note that information has been added to the Transportation Planning Information Scoping Sheet for the early consideration of climate stressors. The Guide also incorporated climate considerations as part of a corridor planning effort. However, accomplishing this would be helped with more detailed guidance on how to address adaptation and resiliency measures into corridor planning studies.

Beyond the adaptation/resiliency considerations included in the final Handbook, there are many adaptation/resilience-oriented actions that can be taken in a corridor study that Caltrans can encourage such studies to consider. Table 1 shows how the linkage between adaptation/system resiliency could be incorporated into corridor planning.

Several bellwether states in transportation system resilience have piloted system resilience corridor studies (such as CDOT, ODOT and UDOT). These pilot corridor studies have illustrated how risk mitigation strategies can be considered in the planning process and relate to the types of decisions that could be taken "on the ground" (usually by district offices). Figure 5 shows an example of such a corridor analysis from CDOT. As illustrated, CDOT identified segments along I-70 where risk was measured as risk cost per lane-mile of all threats (including avalanches, rockslides, flooding, high winds, etc.). This information was used by CDOT officials (e.g., maintenance managers) to prioritize where efforts were needed to reduce the risk of disruption (e.g., maintaining the condition and performance of critical culverts).

It is likely that corridor studies similar to that undertaken by CDOT will be the state-of-the-practice in the near future with respect to incorporating system resiliency considerations into decision-making.

The following recommendations provide more depth of coverage for adaptation in transportation plans than what is currently found. It is recognized that transportation plans cover a range of issues and that climate change and resilience is often but one such issue. However, given the challenges Caltrans has faced in the past, and will likely face more so in the future with respect to extreme weather events, climate adaptation and system resiliency should receive more attention in all transportation plans for which Caltrans has responsibility. The basic foundation for the recommendations on planning is that climate change adaptation efforts must be included in the long-range and district planning efforts in order for Caltrans to integrate this policy goal throughout agency decision-making.

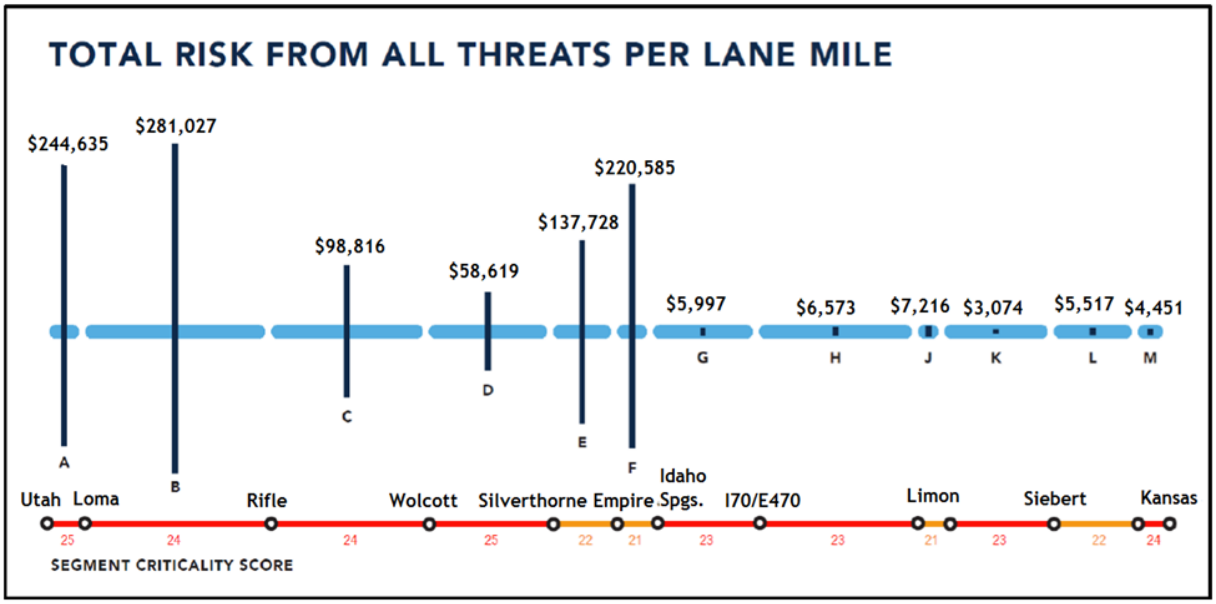
Inherent in Caltrans considering climate change adaptation more systematically in its planning efforts is the need to educate other stakeholders about the importance of climate adaptation and system resiliency. This was one observation that was consistently noted by Caltrans staff during the interviews. Many of Caltrans' projects require collaboration and coordination with other agencies and stakeholders who could influence successful project implementation. Caltrans needs to ensure that key stakeholders are aware of the need for, and importance of, including (and paying for) adaptation actions.

Note that implementing these planning recommendations could just be a matter of the planning cycles catching up with individual planning documents. For example, the CTP, which discusses climate adaptation, was published in 2016. The ITSP was published in 2015. Presumably the next update of the CTP and ITSP will reflect the concerns and policy priorities relating to climate adaptation. Given that the results of the district exposure and adaptation studies will be completed by then, there should be a great deal of information available on how planned investments could be affected by climate change. Given the importance of the CTP, it is particularly important that this document provide more information on climate adaptation strategies and actions that Caltrans and others are taking to address adaptation challenges.

Programmatically, climate adaptation should be embedded in statewide long-range transportation planning to ensure proper organizational structure and support network statewide.

TABLE 1: CORRIDOR PLANNING STEPS AND CLIMATE CHANGE AND SYSTEM RESILIENCY

	Explanation	**Linkage to Adaptation and System Resilience**
Scoping	The Corridor Plan's scope frames the overall corridor planning effort, defines the corridor partnership and helps determine appropriate analysis tools. This phase will result in a defined corridor team, agreement on the deficiencies and potential opportunities that will be considered, and a comprehensive set of goals, objectives, and performance measures for the corridor.	Consider exposure to potential climate change hazards as part of the planning scope. An initial list of such hazards should be included in the scope, along with appropriate analysis methods to analyze the related risks.
Information/ Data Collection	Corridor information is collected and organized to inform an understanding of the corridor context, as well as current and future conditions. This information outlines the corridor description; basic system characteristics of the corridor; and its unique elements within a larger regional, state, and national context.	Collect information on potential climate change hazards in the corridor, and the relationship of such an assessment to other transportation and non-transportation plans.
Assess Performance	A performance assessment is conducted to clearly outline system performance and performance trends, and the results interpreted to highlight the relationship between identified problems and their causes.	Include past system performance disruption and potential characteristics of future disruptions in the performance assessment. This should include such factors as estimated potential economic costs of such disruptions, the impact on lifeline and evacuation routes, and the feasibility of potential adaptation strategies.
Identify Potential Projects and Strategies	Potential projects and strategies are identified for analysis and evaluation	Include project characteristics and stand-alone adaptation projects and strategies that could be considered in the corridor to reduce climate change-related risks. This includes noting where incremental project changes could be made to make a project meeting primarily other goals to improve corridor system resiliency.
Analyze Improvement Strategies	Possible improvement projects and strategies are grouped into scenarios to be evaluated. A corridor analysis is then conducted to evaluate the impact of potential investments on corridor performance.	Include adaptation strategies and projects in the analysis, both as stand-alone projects and as part of other project scopes.
Select and Prioritize Actions	Decisions are made on which corridor projects and strategies to recommend; those recommended are given an expected implementation time frame. The outcome is a recommended set of solutions for the corridor that address the identified problems and opportunities.	Include climate change adaptation and system resiliency as part of the prioritization criteria.
Publish Corridor Plan	The corridor planning process is documented with the publication of the Corridor Plan. The adopted corridor plan documents how a corridor is performing, why it is performing that way, and recommends projects and strategies that achieve the corridor goals and objectives agreed upon by its partners.	Highlight in the plan the potential benefits of the improvements to system resiliency from the adaptation strategies being recommended.
Monitor and Evaluate Progress	Ongoing reporting on corridor performance is conducted to evaluate the effectiveness of recommended projects and strategies on corridor performance over time. Corridor objectives may also be re-assessed and refined by the corridor team.	Include system resiliency performance metrics in the monitoring, including revisiting corridor planning assumptions concerning future disruptions.



Source: Colorado DOT. 2017. I-70 Corridor Risk & Resilience Pilot. Denver, CO. Nov. 30. Retrieved May 10, 2020 from https://www.codot.gov/programs/planning/documents/plans-projects-reports/reports/i70rnr_finalreport_nov302017_submitted_af.pdf

FIGURE 5: COLORADO DOT CORRIDOR STUDY ON ENHANCING CORRIDOR RESILIENCY

RECOMMENDATION 4

The climate change planning function should be aligned with the state planning function. Long-range planning, including the California Transportation Plan, is a required statewide planning process that provides proper functional context and a process for climate change and adaptation planning along with GHG reduction efforts. Planning activities should provide similar emphasis to climate change adaptation and GHG emission reduction strategies. The adaptation section should include, at a minimum, the following information:

a. What climate change trends could affect the transportation system being examined?

b. What are the potential impacts to the transportation system? To the broader community that depends on a reliable transportation system?

c. What are the types of strategies and actions that can be taken to protect or minimize these impacts?

d. What steps (including collaboration with Caltrans' partners) are necessary to implement such strategies and actions?

RECOMMENDATION 5

System planning guidelines should address climate change adaptation and guide the development of system planning documents, such as District System Management Plans and Corridor Plans. Caltrans should develop more detailed guidance (other than that provided in the Corridor Planning Handbook) on how to include climate change adaptation and system resiliency into corridor planning studies. Such guidance could include such topics as:

a. Using the District adaptation exposure results currently being developed to identify assets vulnerable to future climate change disruptions

b. Using "system use" and not just "physical damage"' as a key criterion for prioritization of proposed actions, thus recognizing the importance of the State Highway System (SHS) to the State and local economy. System use should include criteria that are relevant to rural communities such as freight movement and lifeline service routes, not just volumes of use

c. Using the recommended benefit/cost assessment approach (discussed below) for identifying cost effective projects incorporating uncertainties and user impacts

d. Applying risk metrics to the identification of project alternatives (and if appropriate conceptual project designs

e. Identifying community lifeline strategies (e.g., evacuation routes) for when emergencies occur

RECOMMENDATION 6

Caltrans should undertake a pilot planning study similar to the Colorado Department of Transportation's (CDOT's) where system resilience enhancement and risk minimization are included as the primary focus or is at least incorporated as an important goal of the study. The pilot study would serve as a "proof-of-concept" for such an approach, identifying the most appropriate means of including climate change concerns into its economic analysis efforts, which might vary by technique. Such efforts should include adaptation benefits as part of every application.

4.4.5 ECONOMIC ANALYSIS

Economic analysis is a systematic examination of how scarce resources can be effectively allocated. In the context of transportation economic analysis, it accounts for benefits and costs of a policy or project by quantifying the potential impacts to the economy or society. Extreme weather and climate change present transportation agencies with an additional challenge when considering a policy or asset. Economic analysis is a crucial tool where extreme weather and climate change can be factored into an overall evaluation when attempting to navigate these decisions.

Context

Several economic analysis tools and assessment methods are used by Caltrans for various purposes that are relevant to climate adaptation.

Life cycle cost analysis (LCCA): LCCA considers costs over the expected life of an asset, from creation to disposal. In the context of adaptation, it is an important tool for analyzing the cost effectiveness of alternative improvement, maintenance, or repair options for an asset. Climate-driven events can impact the life-cycle of an alternative, making it less cost-effective over the useful life of an asset. Thus, climate change should be factored into the evaluation of alternatives when performing LCCA. Moreover, State agencies must account for climate change as California EO B-30-15 mandates that "State agencies shall take climate change into account in their planning and investment decisions and employ full life-cycle cost accounting to evaluate and compare infrastructure investments and alternatives." LCCA can help account for the full life-cycle accounting of costs to Caltrans of action or inaction on an asset. LCCA is used within Caltrans for evaluation purposes such as asset management, equipment management, maintenance, and engineering services.

Benefit cost analysis (BCA): BCA is used to quantify and compare societal benefits and costs associated with a policy or a project. The primary purpose of a BCA is to identify the benefits that will accrue with project investment as compared to the costs incurred. At the project level, Caltrans uses the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) to examine project-level benefits and costs for State projects such as capacity improvements, lane additions, and transit projects. BCA can be applied when projects are at the planning stage, or near the design stage; it can be used for choosing amongst different alternatives, or justify that benefits outweigh costs associated with a project. Caltrans also uses BCA to evaluate conceptual projects that are being submitted to grant programs such as The Road Repair and Accountability Act of 2017 (Senate Bill 1 [SB 1]) and Federal discretionary programs like the Infrastructure for Rebuilding America and the Better Utilizing Investments to Leverage Development programs.

With respect to climate adaptation, BCA compares the lifecycle costs for assets and associates them with adaptation actions that should be taken under two scenarios: 1) if no adaptation actions are taken versus 2) the lifecycle costs of each adaptation alternative. In the context of adaptation planning and project-level decisions, BCA can provide decision makers with information on the expected benefits of adaptation strategies as compared to project costs.[65]

Economic impact analysis (EIA): Economic impact analysis (EIA) examines the effect of a policy, project, or asset (i.e., frequent maintenance or asset disruption) on the overall economy in a defined region—in particular, how it affects business and household income. EIA looks at the economic value of a policy, project, or asset, including impacts that involve the flow of money and how it circulates through the economy. EIA measures direct changes in income to business and households resulting from an investment but also indirect and induced changes in income. Indirect impacts refer to changes in income to businesses supplying or supporting the businesses that are directly impacted. Induced impacts refer to changes in wages of workers at affected business that in turn are spent in the economy.

Caltrans has piloted an approach for assessing the broader socioeconomic impacts of transportation asset disruption. Caltrans District 1, for example, assessed the regional impact of a portion of U.S. 101 being disrupted due to a landslide. The pilot assessed detour costs and broader impacts to travelers, businesses, and communities. The analysis used travel volume data along the corridor and the Transportation Economic Development Impact System (TREDIS) to assess economic impacts. This is the type of analysis that should be conducted to illustrate the economic costs of disrupted highway operations.

Recommendation

In the context of adaptation planning and adaptation project development, economic analysis is typically applied after the vulnerability impact assessment is completed, and at-risk facilities are identified. The economic impact analysis should be applied to prioritize the impacted sites, facilities, or assets statewide (i.e., based on functional significance and magnitude of impact). Then, mitigation strategies or adaptation solutions should be developed for select prioritized at-risk facilities to maximize the allocation of resources. BCA or LCCA should then be applied to compare alternative adaptation solutions for each prioritized site. Each alternative solution would receive a benefit-cost ratio (BCR) or a net present value (NPV) under different climate scenarios. The alternative solution that has the highest BCR or NPV across scenarios could be chosen. This information would then be used for programming purposes to compare adaptation projects across the State and prioritize the most cost-effective investments.

There are several places where Caltrans could incorporate climate risk into its analyses where appropriate and thus better serve its mission and meet other State requirements:

- As part of Cal-B/C, which would then enable climate risk to be considered when doing detailed adaptation assessments of existing assets or when project grant applications are submitted or required by Caltrans to fund projects.

[65] Because BCA used for climate adaptation necessarily examines both lifecycle costs and lifecycle benefits, it is sometimes referred to as Lifecycle Benefit Cost Analysis (or LCBCA).

- As part of EIA undertaken or required by Caltrans, which would enable an assessment of climate risk's impact on an economy. This could lead to procedures that incorporate climate uncertainty and long-term change into an assessment framework for use by planning, design, and asset management professionals within Caltrans.

For reference, methods for including climate change considerations into economic analyses have been examined by many different groups. Some notable resources include: 1) "Moving Forward with Incorporating "Catastrophic" Climate Change into Policy Analysis" (U.S. Environmental Protection Agency {USEPA});[66] 2) Economic Analysis Primer (FHWA);[67] 3) Road Weather Management Benefit Cost Analysis Compendium (FHWA);[68] and 4) "Synthesis of Approaches for Addressing Resilience in Project Development," especially the section on "Conducting Economic Analyses" (FHWA).[69] These references discuss different ways of including uncertainty into economic analysis methods, such as risk assessment, consideration of opportunity costs of road disruptions, modification of discount rates to account for uncertain outcomes, use of scenarios, tradeoff analysis, and the use of Monte Carlo simulation to estimate likely time frames of adaptation benefits. Some of these methods are more appropriate for BCA and life-cycle costing versus other analysis methods. One of the initial steps that could be taken by Caltrans in its existing BCA approach is to conduct sensitivity analyses on the discount rates to reflect the uncertainty associated with the timing of disruptions and the level of benefits that would accrue from an investment in adaptive designs.

With respect to the framework outlined earlier, once vulnerabilities are assessed, at-risk facilities are identified, a prioritization list is created, and mitigation adaptation strategies are developed, one should conduct an economic analysis. For example, the results of a benefit-cost analysis (e.g., the benefit-cost ratio or net present value) should be used to come up with an overall adaptation investment score based on which adaptation alternatives are most effective.

By adopting an approach that incorporates climate change life-cycle benefits and costs into its decision-making, Caltrans can further its stewardship mission, meet the requirements of EO B-30-15, and make California's transportation system more resilient.

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[66] Elizabeth Kopits, Alex L. Marten, Ann Wolverton. "Moving Forward with Incorporating "Catastrophic" Climate Change into Policy Analysis," Working Paper # 13-01, National Center for Environmental Economics, U.S. Environmental Protection Agency, Washington DC. January, 2013. Retrieved May 10, 2020 from https://www.epa.gov/sites/production/files/2014-12/documents/incorporating_catastrophic_climate-change_into_policy_analysis.pdf

[67] Doug Sallman, Erin Flanigan, Krista Jeannotte, Chris Hedden, and Dorothy Morallos, " Operations Benefit/Cost Analysis Desk Reference." (especially section on non-recurring events). Office of Operations (HOP), Federal Highway Administration (FHWA), Report FHWA-HOP-12-028, Washington DC. Retrieved May 10, 2020 from https://ops.fhwa.dot.gov/publications/fhwahop12028/index.htm

[68] Michael Lawrence, Paul Nguyen, Jonathan Skolnick, Mathies Wahner. "Road Weather Management Benefit Cost Analysis Compendium." Office of Operations, FHWA, Report FHWA-HOP-16-093, April 2017. Washington, DC. Retrieved May 10, 2020 from https://ops.fhwa.dot.gov/publications/fhwahop16093/index.htm

[69] Anne Choate, Brenda Dix, Beth Rodehorst, Angela Wong, Wendy Jaglom, Jake Keller, Justin Lennon, Chris Dorney, Ravi Kuchibhotla, Jagannath Mallela, Suriyanarayanan Sadasivam, and Scott Douglass. "Synthesis of Approaches for Addressing Resilience in Project Development." Report FHWA-HEP-17-082. FHWA. Washington DC. July 2017. Retrieved May 10, 2020 from https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/synthesis/page00.cfm

It can lead to more objective, comprehensive, and careful investment decisions, and can facilitate an informed dialogue with agency leadership and stakeholders on costs and policy implications of climate change.[70]

RECOMMENDATION 7

Caltrans should incorporate economic analysis in adaptation planning to prioritize project selection or alternatives on the State Highway System affected by climate change. Economic analysis tools that apply the life cycle cost analysis (LCCA), benefit cost analysis (BCA), or economic impact analysis (EIA) methodology should account for climate change to make the analysis more robust and better demonstrate how limited resources are being allocated effectively.

4.4.6 PROJECT INITIATION

Project Initiation Documents (PIDs) are required prior to approval for Caltrans projects expected to cost more than $1 million or projects having "high complexity." A PID can also be considered as a project scoping document. PIDs emerge out of the many planning activities that precede their development, and feed directly into project lists for further consideration in project delivery. The type of information and policy considerations that feed into the PIDs can thus be important factors in defining which projects to proceed with.[71]

PIDs serve the following functions:

- Document a project's purpose and need, where need is defined as a transportation deficiency and purpose relates to the objectives that will be met to address the transportation deficiency
- Describe the approach that will be taken to meet or reduce transportation deficiencies[72]

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[70] See Tim Grose, "Caltrans Climate Action Report: Incorporating Climate Change Risk into Economic Analysis: Task 2.3.3 Deliverable." Dec. 19, 2018 for an overview of the approaches that can be used to incorporate climate change risk into economic analysis.

[71] Caltrans. "Project Initiation," Project Development Procedures Manual, Chapter 9. Sept. 28, 2018. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/design/documents/pdpm-chapters.pdf#page=273; see also Division of Project Development, chapter on project initiation. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/project-management/documents/workplan_standards_guide_a11y.pdf

[72] An example of a climate change-specific hazard and how it can be incorporated into Caltrans decision-making process is the guidance on sea level rise (*Guidance on Incorporating Sea Level Rise*). According to the guidance, " Sea level rise (SLR) will likely lead to multiple changes to the physical environment beyond a simple increase in sea surface elevation …. This is an important observation relating to the change in CEQA guidance described above. The intent of this guidance is to plan ahead to assess project vulnerability and reduce anticipated risks associated with SLR, thus affecting project development decisions. If the impact analysis and related adaptation measures are not planned for in advance, there is risk of not being able to obtain necessary approvals and permits, which could potentially delay project delivery in the ready to list phase of a project." Thus, not only does the consideration of SLR in project

- Record the existing information, initial assumptions, identified risks, and constraints that drove the development of the project work plan
- Document the scope, cost, and schedule of a project
- Obtain approval for inclusion of a project into a programming document or to get conceptual approval of a project-funded-by-others.[73]

The 2018 PID guidance includes a long list of project characteristics that are recommended for discussion in the PID. The following requirements (taken from the PID guidance) are related to the potential consideration of climate change adaptation projects or adaptation-related project characteristics.

- As decision-making documents, "PIDs must identify the key issues of the transportation deficiency, any major elements that should be investigated, and the effort and resources needed to complete the studies and implement the project."
- A pre-PID meeting is required to "communicate a shared view of the project and to establish an understanding of the procedures, roles, and responsibilities before the project initiation process."
- A "purpose-and-need" statement is required as part of the PID documentation. "The project's purpose-and-need statement must be as comprehensive and as specific as possible … The purpose statement should clearly describe both planned expectations for the State's transportation system and sponsor's goals (note the link to the importance of having a resilience goal as part of Caltrans' goals statement)." The purpose-and-need statement may need to be refined, as appropriate, until approval of the project. A key factor in refining a purpose-and-need statement is the participation of a broad range of Caltrans functional units, community representatives, and public stakeholders."
- A subsection on the primary deficiencies should discuss deficiencies that relate directly to the purpose-and-need statements and a subsection should be prepared on secondary deficiencies (including, but not limited to "existing roadside area conditions to identify deficiencies and develop a preliminary cost for each improvement, maintenance vehicle pull-outs, access roads, topsoil reapplication, erosion control, slope rounding, nonstandard features, architectural features, landscaping features, maintenance items, etc.").
- Known design deficiencies are to be identified, with given examples being, "structures with nonstandard vertical or horizontal clearances; inadequate bridge railing; pavement in need of rehabilitation; deteriorated or inadequate drainage systems; narrow or deteriorating shoulders; lack of continuity or the deficiencies of bicycle or pedestrian facilities; replacement landscaping; ramp

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development link to design concept/mitigation decisions, but it also relates to Caltrans' perceptions on environmental process risk.

[73] Caltrans. "Project Initiation" op cit. p. 9-4.

metering; nonstandard guardrail; maintenance worker safety; and seismic retrofit requirements."

- The process should "obtain and review existing reports, studies, mapping or other information" and "identify additional data requirements for project scoping."
- The project development team is to "use risk management processes to establish assumptions that are made until the data is available."
- "The project purpose is the set of project objectives that will be met, which addresses the transportation deficiency (in other words, the project need). It is important to identify the primary and secondary objectives that are met by this project."
- A section should address the coordination and consistency of the proposed purpose-and-need statement with statewide, regional, and local planning efforts.
- Initial studies are to focus on the physical characteristics of the project area; engineering features; and standards required to develop a project, such as floodplain mapping, including an analysis of the potential floodplain impact due to the proposed improvements.
- Design standards are applied equally to all projects on the SHS regardless of the sponsoring agency or the type of funding involved…." (however) during development of projects, various constraints often require deviation from design standards."
- Discuss high-risk issues that can "affect an alternative (for example, local opposition and environmental compliance) or could affect the estimated resources and delivery milestone dates)." An examination of the Project Risk Management Handbook: A Scalable Approach, to which this section refers, shows little attention to future climate change risks.
- Briefly describe environmental issues that influence the project design, schedule, or cost. Include permit requirements, mitigation, and construction work windows.

As noted above, the PID guidance suggests that the PID process identify high-risk concerns that can affect an alternative (for example, local opposition and environmental compliance) or could affect the estimated resources and delivery milestone dates. Other types of risks are not identified. There is no explicit callout for the consideration of system resiliency or climate change adaptation except in the case of SLR. However, Caltrans' more general guidance on risk management suggests the following:

- Identifying threats and opportunities for a project can begin as early as the initial planning phases, but the PID phase is when the risk register for the project is first developed.

- At the PID stage, environmental risks are first identified in the Preliminary Environmental Assessment Report (PEAR) prepared for the project and transferred to its risk register. The PEAR or Mini-PEAR will discuss assumptions and list any environmental risks that were identified during this stage of the process.
- It may be necessary to start with a broad and general list of risks at the PID phase, and then become more specific as the project progresses.

The State Highway Operation and Protection Program (SHOPP) has been affected by extreme weather events for many years. Winter storm damage and the need to expedite permanent restoration projects in 2017 resulted in additional funding being put into the program. With respect to project initiation and project delivery, the SHOPP has its own guidelines.[74] There are important differences between the State Transportation Improvement Program (STIP) or non-SHOPP PIDs and the SHOPP Project Initiation Reports (PIRs) in that non-SHOPP PIDs tend to involve other stakeholders whereas SHOPP PIRs are generally more under the direct influence of Caltrans Districts.

With respect to climate change adaptation considerations in SHOPP projects, Caltrans has made significant progress in incorporating such factors into SHOPP PIRs. SHOPP interim guidance has been issued reflecting the requirements of SB 1.[75] Previous PIR guidance for multi-objective SHOPP projects required performance-based asset management documentation, including a "climate change consideration" section as follows:

> CLIMATE CHANGE CONSIDERATION
>
> Are climate change and adaptation features included? ☐ Yes ☐ No If no, you must provide a rationale:
>
> Both climate change mitigation, GHG reduction and adaptation measures that respond to climate risks shall be identified and must be implemented where appropriate and feasible.

In addition, the guidance requested that the application discuss project-specific topics for the Programmable Project Alternative, including anticipated accommodation for a long list of project characteristics. This list included one topic relating to climate adaptation---floodplain issues. No additional guidance was available for those concerned about adaptation analyses and example adaptation strategies.

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[74] Eligible projects include major capital improvements that are necessary to preserve and protect the State highway system and are consistent with the TAMP. All SHOPP PIDs must address projects in the approved financially constrained State Highway System Management Plan (SHSMP). Projects included in the SHOPP program shall be limited to improvements relative to the maintenance, safety, operation, and rehabilitation of State highways and bridges that do not add a new traffic lane to the system, and to advance mitigation projects. Streets and Highways Code Section 2030 (b)(1)(D) states that complete street components, including active transportation purposes, pedestrian and bicycle safety projects, transit facilities, and drainage and stormwater capture projects are SHOPP-eligible in conjunction with any other allowable project (California Transportation Commission, State Highway Operation and Protection Program Guidelines, Draft, March 28, 2019).

[75] Caltrans. Interim SHOPP PIR Guidance (Updated as 2/28/2020). Retrieved May 10, 2020 from https://dot.ca.gov/programs/transportation-planning/project-initiation-documents/project-initiation-report-pir-guidance

As per the new PIR interim guidance, SB 1 required Caltrans to address four Sustainability Provisions on projects to the extent feasible and cost-effective. For all projects, regardless of funding source, Caltrans shall consider:[76]

- Use advanced technologies and material recycling techniques that reduce greenhouse gas emissions through material choice and construction method
- Use advanced technologies and communications systems (for example, infrastructure-to-vehicle communications for connected and autonomous vehicle systems) and support for ZEV charging infrastructure

For all projects that receive Road Maintenance & Rehabilitation Account funds (including SHOPP, Local Street & Road, Local Partnership, and Active Transportation projects), projects should:

- Include features to better adapt, assets to withstand climate change impacts, such as fires, floods, and sea level rise
- Incorporate complete streets elements such as pedestrian and bicycle facilities

The SHOPP PIR template has been changed to include fields that reflect the attention given to the Sustainability Provisions (if any of the provisions were not addressed, reasons for not doing so must be given.

Other important climate change adaptation requirements in the PIR interim guidance include:

- High-impact risks and the responses to these risks are to be identified. If more than one alternative is being considered, each alternative must have its own Risk Register.
- Climate change mitigation to reduce greenhouse gas (GHG) emission and adaptation measures that respond to climate change risks shall be implemented where appropriate and feasible.
- A climate change adaptation section has been added that requires an evaluation of a project's risk associated with an identified list of climate change stressors. Key language from this section relating to adaptation include:[77]
    - "If the project is at risk from any of these stressors, identify and describe the likelihood, timing, and consequences associated with projected changes in climate within the project area. Discuss how the design alternatives and materials used incorporate appropriate elements in projects to ensure that the project can withstand, avoid, and/or adapt to projected climate change impacts appropriately. This section need not be extensive, but should identity potential issues that will affect the cost,

[76] Ibid. p. 9.

[77] Ibid, p. 19.

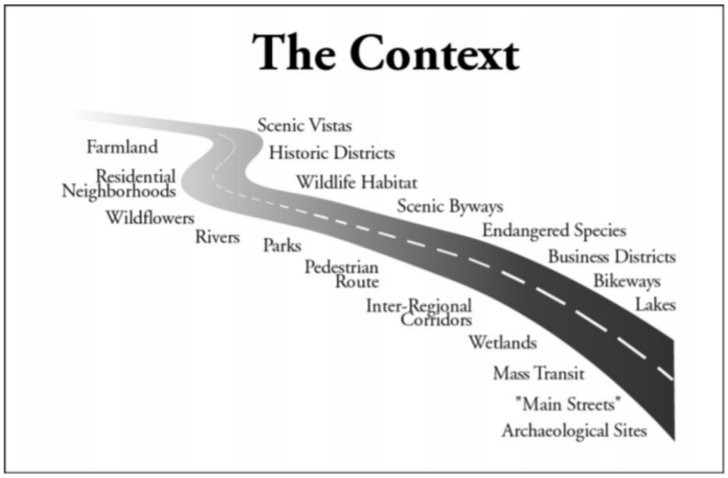
schedule and scope of the project such that the information should be included in the PIR."

  - "When identifying how to incorporate resiliency into a PIR, consider AASHTO's resilience definition, which is: *The ability to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events.* Adverse events include, but are not limited to, wildfire, precipitation, temperature events, storm surge, and sea level rise."

- Appendix B of the interim guidance provides useful information on the types of climate change stresses that should be considered as part of the PIR and references to data sources and stress-specific guidance.[78]

Given the importance of PID documentation for a project moving through the project development process, this is one of the more critical entry points into Caltrans' project pipeline. Combined with a desire for consistency among the many different planning documents, the development of the district-level adaptation reports, and this report on Caltrans' adaptation strategy, PID documentation guidelines should be consistent with these different reports and adopted actions. For example, by the time any changes to the PID guidelines could be made, the district climate exposure reports should be completed. One criterion that could be considered as part of the "need" definition would be whether a proposed project sits in an exposure area or whether it serves as an evacuation route from such an area. For example, Figure 6 shows the current information in the *Project Development Procedures Manual* on "establishing the context" for a project. This type of information should be amended to include vulnerability, exposure, or resilience characteristics. In addition, it is important to note that requiring inclusion of system resiliency elements in a PID document should also be informed on how to design a resilient or adaptive project. Expanding the type of information required in a PID to include climate adaptation factors will increase the amount of time associated with the completing a PID.

[78] Ibid, p. 31.



Source: Caltrans. 2018. Project Procedures Manual.
http://www.dot.ca.gov/design/manuals/pdpm/chapter/chapt09.pdf

FIGURE 6: "ESTABLISHING THE CONTEXT" FOR PROJECTS, PROJECT PROCEDURES MANUAL

RECOMMENDATION 8

Examine the Project Initiation Document (PID) guidelines to consider explicitly where it is feasible to incorporate adaptation system considerations as part of project justification (e.g., definition of "need"). Many of the sections of the existing PID guidelines and Project Development Procedures Manual should be modified to do this. Including such an explicit consideration in the guidelines provides a "place" for adaptation concerns as a project proceeds along the project development process. One criterion that should be considered as part of the "need" definition would be whether a proposed project sits in an exposure area or whether it serves as an evacuation route from such an area

RECOMMENDATION 9

In the longer term, once the Caltrans Adaptation Strategy Report and the District Adaptation Plans are adopted, modify the PID guidelines to incorporate both documents as official plans that should be considered as part of the purpose-and-need statement and in the early design considerations.

4.4.7 PROJECT FUNDING FOR CLIMATE CHANGE ADAPTATION PROJECTS

There is no dedicated State transportation funding for climate change adaptation strategies. This is a critically important factor when considering the implementation of any agency's strategy toward adaptation, especially for a transportation agency where much of the funding is categorically defined. Grant money thus far has only paid for adaptation planning studies, not projects. This is an important planning and policy consideration. The most expensive climate strategies cannot be funded through the SHOPP and developed through the traditional PID process. This would require interaction with the Secretary's Office, California Transportation Commission, Governor's Office, and the legislature. **Until an "adaptation funding" source of funds is identified for project implementation, successful adaptation actions will most likely be part of the project design for projects that are carried forward for other reasons. In addition, until design guidance is updated, project development teams will not have the resources available to guide their work with respect to adaptation.**

RECOMMENDATION 10

Develop a strategy in coordination with other key participants in the funding program development process for developing a climate change adaptation funding category for projects that are undertaken for such purposes.

4.4.8 SUMMARY FOR PLANNING

The major recommendations for the transportation planning function within Caltrans is to: 1) provide a proper organizational structure for climate change planning to support statewide implementation through information, data, procedures, tools, analysis, training, technical assistance, communication, and monitoring; 2) incorporate more directly the consideration of climate change adaptation and resiliency into the preparation of planning documents; and 3) realign the climate change function with the State planning function. The requirement for consistency among plans and the information being developed by the current Caltrans study should provide ample opportunity for such consideration to be supported with good technical information. Having said this, while it is important to incorporate adaptation considerations into planning processes and documents, this does not address the important fact that there is no dedicated State transportation funding for adaptation strategies. Grant money thus far has only paid for adaptation planning studies, not projects.

4.5 PROJECT PRIORITIZATION

Project prioritization processes and criteria are some of the most important influences on what types of projects any transportation agency produces. As such project prioritization is one of Caltrans' greatest challenges in integrating climate adaptation concerns into decision making. Additional work is needed to develop prioritization approaches to achieve such integration. For adaptation strategies that require incremental additional costs - such as a larger size culvert - prioritizing the strategies are relatively straight-forward. Where a more involved strategy is needed, such as raising or changing the alignment of a route due to sea level rise, prioritizing the investment is well outside of the scope of what Caltrans currently does in the SHOPP. This might require a new funding source to consider such strategies.

There are several processes within the Caltrans decision-making structure that require project priorities to be established, including, as noted above, in the PID process. Deciding to advance a project into project development, determining investment priorities for the capital program, and identifying project priorities within the asset management program are examples of different prioritization processes. Each considers a range of factors that affect the ultimate desirability of a project for that stage of decision-making.

The Caltrans seismic program again provides an example of how a prioritization process is used to identify which assets need to receive priority seismic retrofit. Caltrans used the State bridge database and the following algorithm to prioritize where retrofit investment should occur first. It is interesting to note that the variables used in this algorithm—activity, hazard, impact, and vulnerability—are similar to those being used in the district adaptation studies.

$$\text{Priority} = (\text{Activity})(\text{Hazard})[0.6(\text{Impact}) + 0.4(\text{Vulnerability})]$$

Perhaps the most comprehensive prioritization process in Caltrans is found in the SHOPP program. Historically, the funds for SHOPP projects were allocated based on program requirements. The SHOPP Investment Plan is a combination of investments from the: 1) Major Maintenance Program; 2) SHOPP (including the Road Maintenance and Rehabilitation Funds); and 3) Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies (FASTLANE) funds, each having its own evaluation criteria.[79] One of the most important steps Caltrans could take to influence the consideration of climate change adaptation and system resiliency projects in decision-making is to incorporate adaptation-oriented criteria into the project prioritization methodology.

An important consideration in project prioritization is for Caltrans to identify those factors that are more important than others. With respect to climate change, there are two major types of impacts—those that are already occurring due to recurring events (that is, Caltrans knows where disruptions occur and knows how to respond), versus those that are likely to occur in the future based on projections of future climatic conditions. Priority for investments should be given to those project impacts where system disruptions are already known, such as coastal areas that are already affected by flooding/SLR/storm surge. Data on such events are already available and can be used to identify where investments should occur.

The major observation from this discussion on project prioritization is that the prioritization criteria and how they are combined into a prioritization rating or score provide an

[79] In recognition of the need for a different prioritization methodology for selecting project priorities given performance-based requirements from Federal and State legislation, a study was undertaken that linked project priorities directly to the Caltrans strategic goals described in the Strategic Management Plan (2015-2020). Five subject matter expert teams were convened to: 1) divide each goal into a number of underlying strategic objectives, 2) determine the weight of each strategic objective within its strategic goal, independent from the other teams and the other strategic goals, 3) define a methodology to calculate a project's score toward each strategic objective, and 4) present an equation that combines the objective scores into a goal score. The study explicitly acknowledged the different consequences of asset failure. As noted in the study report, "the impact to the highway of a culvert washout is significantly more than the failure of a loop detector." The recommended prioritization approach has not yet been implemented within Caltrans.

important entry point into Caltrans decision-making. Thus, one of the most important steps Caltrans could take to influence the consideration of climate change adaptation and system resiliency projects in investment decisions is by incorporating adaptation-oriented criteria into all of its project prioritization methodologies.

A prioritization methodology for focusing more detailed engineering analysis on the most beneficial climate change adaptation projects has been recommended as part of this study, in essence a screening tool. As noted in this effort, "the Caltrans Climate Change Vulnerability Assessment (CCCVA) and this Caltrans Climate Change Action Report (CCCAR) have identified hundreds of Caltrans assets that will be exposed to sea level rise, storm surge, coastal cliff retreat, wildfire, temperature extremes, and riverine flooding this century." Given this, an indicators approach to prioritizing the locations for further analysis was recommended. In this approach, metrics capture: 1) the nature of the asset's exposure to each relevant hazard (timing, severity, extensiveness and/or certainty of impact occurring); 2) the consequences of that exposure (in terms of the sensitivity of the asset to damage and/or impacts to the traveling public; e.g., volume of traffic on the affected roadway); and 3) programming considerations that affect how rapidly adaptation can be accomplished (if necessary). It was recommended that the metrics be compiled mathematically into an individual asset score.

RECOMMENDATION 11

Explicitly consider adaptation criteria into investment decision-making. A methodology for doing so could be targeted on prioritizing adaptation projects themselves or based on metrics for identifying adaptation needs and treatments that are included as part of project designs being developed in response to other primary criteria (e.g., capacity expansion or safety).

RECOMMENDATION 12

Priority in project adaptation investments should be given to those projects, 1) where current extreme weather-related disruptions occur and thus becomes a need for Caltrans action, 2) where other project investments are occurring anyway and where incremental investment could have a positive impact on enhancing SHS resiliency, 3) given the importance of an asset where projections show increased extreme weather threats in the future, and 4) for locations where loss of service would result in significant community impacts.

4.6 ENVIRONMENT

The Division of Environmental Analysis (DEA) administers Caltrans' responsibilities under federal and state environmental law. The Program develops and maintains Caltrans environmental standards, policies, procedures, and practices that are implemented by the Departments 12 Environmental Branches. Program staff work with the districts to identify and assess the effects of Caltrans projects on the state's natural and cultural environments, and identify ways to avoid or mitigate those effects.

DEA acts as the Department compliance lead and assists the Districts and transportation partners in:

- Complying with state and federal environmental laws;
- Encouraging the public to participate in the environmental evaluation process;
- Determining the environmental consequences of our activities;
- Proposing prudent, feasible and cost effective strategies and alternatives to avoid or minimize adverse impacts of the Departments activities, and;
- Ensuring the mitigation selected is appropriate.

The Standard Environmental Reference (SER) is an on-line resource to help state and local agency staff plan, prepare, submit, and evaluate environmental documents for transportation projects. The SER contains information appropriate to all transportation projects developed under the auspices of Caltrans, and to all local agency highway or local streets and roads projects with funding or approvals by the Federal Highway Administration (FHWA).

Information available on the SER is provided in many formats and is organized to reflect the needs of the intended user. Guidance is available for general environmental topics with additional volumes for cultural resources, biological resources, community impacts assessment, and coastal requirements. Policy memoranda are provided on other key environmental issues, as are forms and writing templates. Information regarding how climate change (GHG emissions and adaptation analysis) is considered for transportation projects on the State Highway System are provided in Annotated Outlines for use by environmental practitioners.

With the passage of Senate Bill 97 in 2007, California's lawmakers expressly recognized the need to analyze greenhouse gas emissions as a part of the CEQA process. SB 97 required OPR to develop, and the California Natural Resources Agency to adopt, amendments to the CEQA Guidelines addressing the analysis and mitigation of greenhouse gas emissions. Those amendments became effective on March 18, 2010 and revised again effective December 28, 2018.

Caltrans has included climate change analysis for CEQA in environmental documents since 2009. Because there are no specific laws that require consideration of climate change adaptation in environmental documents, Caltrans climate change analysis has been primarily focused on the analysis and reduction measures of greenhouse gas emissions while also including consideration of adaptation and Sea Level Rise based on *Caltrans Guidance on Incorporating Sea Level Rise For use in the planning and development of Project Initiation Documents (2011).*

With the continued interest and emphasis for the State of California to address future climate conditions in investment decisions, DEA continues to monitor and provide relevant guidance for consideration of climate stressors such as sea level rise, flooding and wildfire and incorporate updated information in to guidance.

Environmental impact consideration is one of the milestones in the project development process where climate change adaptation can influence the scope and design of Caltrans projects. For this reason, incorporating adaptation concepts and guidance earlier into planning documents is still important.

The DEA also offers guidance on an environmental risk register for projects having potential environmental risks. Per this guidance:

> "Project risk is known uncertainty and/or an uncertain event or condition that, if it occurs, would have a positive or negative effect on at least one project objective. Risk management is the process of planning for, identifying, analyzing, responding to, monitoring, and managing project risk, as well as advising project decision makers, or those who have been empowered to provide direction or take action where risk is involved. It is intended to result in the effective management of project risks during the entire project life cycle, from project inception through the completion of construction and long-term mitigation and monitoring requirements."[80]

The use of the risk based analysis could be expanded to include climate stressors and the potential need for incorporation of adaptation measures.

Any recommendation for expansion or enhancement of climate change adaptation in environmental analysis should realize the challenges and opportunities of addressing climate change/SLR at the district level. The environmental permitting process and how one would consider adaptation in the context of a project (e.g., working with permitting agencies in addressing SLR) will be important for securing project permits. Developing a Caltrans technical guidebook or providing additional guidance on how adaptation should be considered in the context of project development and environmental permitting should receive priority from Caltrans in translating the results of this study into actionable procedures (Note: this observation was made by several district officials interviewed for this study).

RECOMMENDATION 13

Examine how the consideration of climate change adaptation can be better incorporated into the environmental process given existing practice and regulations, with the focus on both impacts to communities (e.g., changes in flooding characteristics) and impacts to the transportation system (e.g., system resiliency).

[80] Caltrans. 2018. Environmental Risk Register Guidance. Environmental Management Office. April 11. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/f0005505-env-risk-mngmt-a11y.pdf

RECOMMENDATION 14

Develop stand-alone guidance (or include additional technical guidance in the existing requirements) that focuses on how climate change adaptation (perhaps along with GHG emissions reduction) can be incorporated into environmental analysis similar to other guidebooks referenced by the Division of Environmental Analysis (DEA). For example, more guidance on wildfire hazards is needed.

RECOMMENDATION 15

In recognition of the important role of environmental resource agencies in project development and permits, initiate a dialogue with such agencies to further develop and finalize procedures for incorporating uncertainty, climate change risk, and risk-based design into environmental documents.

4.7 ENGINEERING/PROJECT AND STRUCTURAL DESIGN

Caltrans' Division of Design provides the procedures, policy, standards, guidance, technical assistance, and training needed to facilitate California transportation improvements and system integrity."[81] Caltrans' Division of Engineering Services is responsible for the design, construction, and oversight of bridge and other transportation structures. The survey of Caltrans staff for this study identified project design and project-level planning as two of the top three areas where functional units within Caltrans could provide more opportunities for better considering climate change adaptation. In addition, a recent report from the Climate-Safe Infrastructure Working Group to the California State Legislature noted that "infrastructure projects are often years to even decades in the making. Where and what to prioritize, to what standards of performance climate-safe-infrastructure should be built and planning and deciding about them in a transparent and inclusive fashion requires effective project management and coordination."[82]

Given the potential of different future climatic conditions or exposure to unexpected threats, the standard approach of transportation practice of relying on historic experience for design environmental conditions raises a challenging question of how such practice might have to change to be more adaptive. The FHWA has recognized this with respect to climate change and extreme weather threats by suggesting an

[81] Caltrans. Division of Design. Website. Retrieved May 10, 2020 from http://www.dot.ca.gov/design/

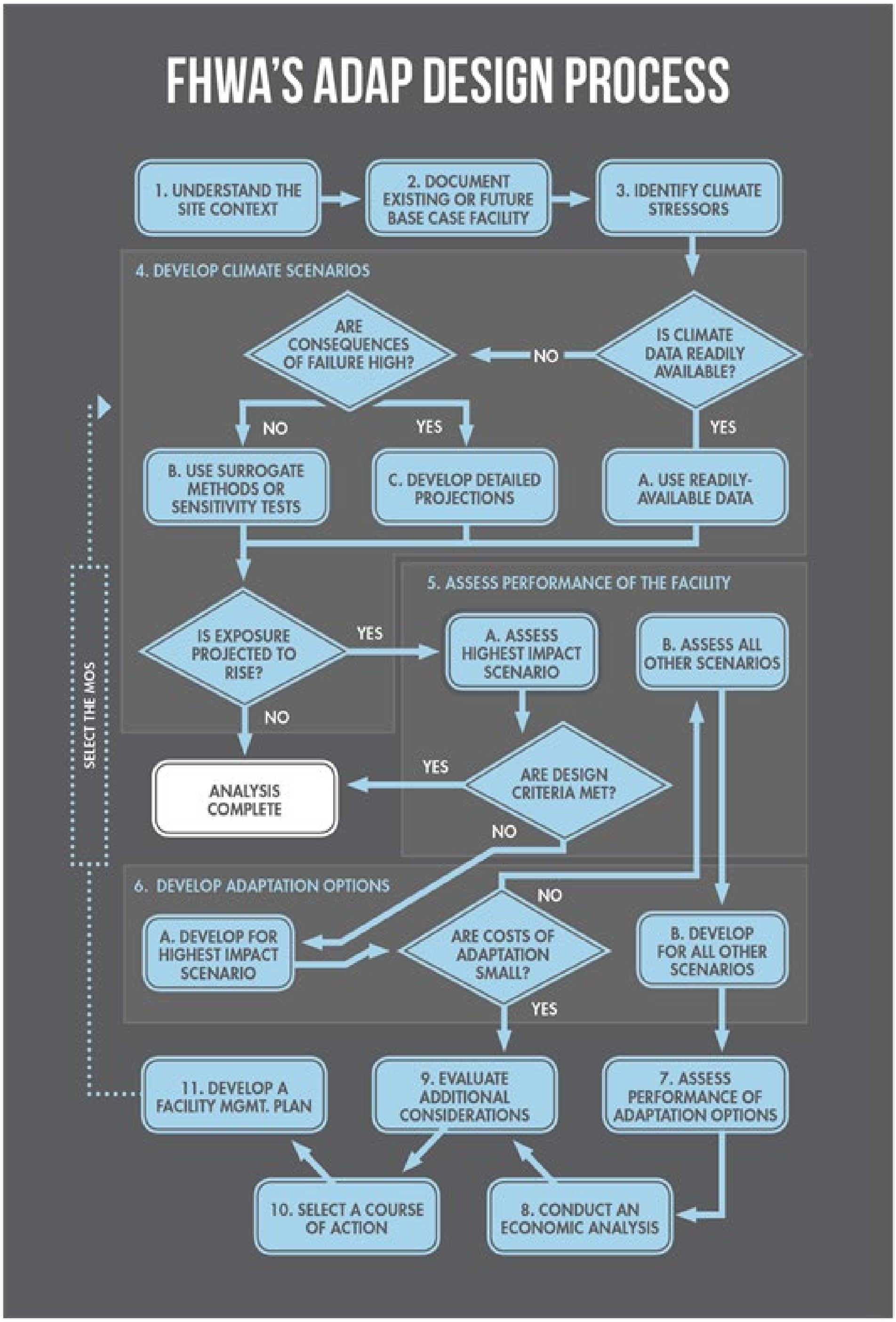
[82] Climate-Safe Infrastructure Working Group (CSIWG). Op cit.

Adaptation Decision-making Assessment Process (ADAP) that offers "a risk-based tool to aid decision makers in determining which project alternative makes the most sense in terms of life cycle cost, resilience, regulatory and political settings, etc."[83]

Figure 7 shows the recommended ADAP approach from the FHWA. The first five steps of the ADAP process cover the characteristics of the project and design context. The district Vulnerability Assessments are working through the first five steps in ADAP approach. These five steps should be addressed for every exposed facility during asset-level analyses.

Step 5 conducts a more detailed assessment of the performance of the critical facility in the context of environmental stresses. ADAP recommends using GHG emissions scenarios when assessing future performance, with a recommendation of using the highest-impact scenario in the analysis. This does not necessarily correspond to the highest temperature range, or largest storm event. In this case, the analysis should determine which emission scenarios and stresses will have the greatest effect on a facility. For example, a 20-year storm may cause greater impacts than a 100-year storm, depending on wind and wave directions. If the design criteria of the facility are met even under the highest impact scenario, the analysis is complete. Otherwise, the process moves onto developing adaptation options.

[83] FHWA, ADAP, Retrieved May 10, 2020 from https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm



Source: FHWA, ADAP, Washington DC. Retrieved May 10, 2020 from https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

FIGURE 7: FHWA'S ADAPTATION DECISION-MAKING ASSESSMENT PROCESS (ADAP)

Options would then be developed for adaptive designs for the highest-impact scenario. If these options are affordable, they can move to the final steps of the process. If they are not, other options can be considered to identify more affordable solutions. These alternative design options will need to move through additional steps to critique their performance and economic value. Then, they move to the final steps of the process. These last three steps are critical in implementing adaptive designs. Step 9 considers other factors that might influence adaptation design and implementation. For example, California EO B-30-15 requires consideration of:

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- Full life-cycle cost accounting;
- Maladaptation;
- Vulnerable populations;
- Natural infrastructure;
- Adaptation options that also mitigate GHG; and
- Use of flexible approaches where necessary.

This step in the ADAP process allows for the opportunity to consider potential impacts of the project outside of design and economic considerations, including how it might affect the surrounding community and environment. After evaluating these additional considerations, a course of action can be identified and a facility management plan implemented.

The previously mentioned report from the Climate-Safe Infrastructure Working Group also recommended that State infrastructure agencies update relevant criteria to provide a more adaptive design approach. As noted in the report,

> "Simply identifying which standards need to be updated—and doing so—will not get the job done on its own, however. There is much more to building climate-safe-infrastructure than simply updating standards, though that is an important process. The real change will come from using different types of standards and deploying them in practice throughout the infrastructure planning, design and operation and maintenance (O&M) process."

The Caltrans Division of Design notes that Caltrans' Highway Design Manual allows "for flexibility in applying design standards and approving design exceptions that take the context of the project location into consideration; which enables the designer to tailor the design, as appropriate, for the specific circumstances while maintaining safety." One example of Caltrans' approach to flexible design is a 2014 technical memorandum entitled "Design Flexibility in Multimodal Design," which highlights the flexibility available for multimodal design. There have also been attempts at providing more flexibility in the design of Complete Streets. As noted by the Division of Design on its website, design flexibility "recognizes the value of other guidance in supporting planning and design decisions made by State and local decision makers statewide." However, design approaches have been based on well-defined procedures and processes for updating, and if change is desired, one needs to: 1) provide additional guidance; 2) modify current design handbooks; or 3) change/provide greater flexibility for the design input parameters (such as the return periods for such events as storms). For example, Caltrans' Geotechnical Manual, which lays out the investigation and mitigation of landslides and rockfalls, is the basis for engineered strategies.[84] With respect to specifications, Caltrans has made some changes already. For example, Caltrans practice is now to replace any plastic pipes (after wildfires) with more fire-resistant pipe materials and is considering the use of all-steel posts for signs and guardrails.

An example of a process for considering modifications in standard design practice is found in Caltrans' April 2019 "Caltrans Seismic Design Criteria, Version 2.0."[85] This guidance outlines a process in terms of steps and who is involved when changes to earthquake design criteria are considered.

One of the opportunities in the process for considering non-standard practices is found in a "design standard decision document" (known as "design exceptions" in other states), which is used to document engineering decisions made regarding a proposed design that deviates from a design standard. Although such an approach is a possible means of allowing flexibility in design, it is not the most desirable given the extent of climate change-related impacts Caltrans will be facing in the future. Instead, a method for changing design guidance should be established based on impacts of various stressors on various assets.[86] [87]

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[84] Caltrans. Geotechnical Manual. Chapters updated with different dates. Sacramento, CA. Retrieved May 10, 2020 from https://dot.ca.gov/programs/engineering-services/manuals/geotechnical-manual

[85] Caltrans. 2019. "Caltrans Seismic Design Criteria, Version 2.0." Sacramento, CA. Retrieved May 10, 2020 from https://dot.ca.gov/programs/engineering-services/manuals/seismic-design-criteria

[86] The California Transportation Commission defined four asset classes as "focus areas" in accordance with California Government Code (Caltrans SHS Management Plan, 2017). The four asset classes are pavement, bridges, culverts, transportation management systems (TMS). Most projects will include one or more of these asset classes.

[87] When asked how the design process could be made more amenable to climate-adaptive design, the engineering staff surveyed for this study noted that changing design guidance would be the best way to do so. In addition, it was emphasized by Caltrans officials that updating or modifying design standards must be followed by appropriate training

Another design analysis process that is important for the consideration of adaptation projects is value engineering, or value analysis (VA) as it is called in Caltrans. The purpose of a VA study is to improve value by sustaining or improving performance attributes (of the project, product, and/or service being studied), while at the same time reducing overall cost (including life-cycle operations and maintenance expenses). VA can be useful to the consideration of adaptation projects if one adopts a life-cycle perspective on the associated project benefits and costs.

According to existing Caltrans policy, VA must be considered on all projects over $25 million.[88] In addition, Caltrans guidance notes that formal VA should be completed "as early in the process as possible, but only after adequate information has been generated to complete a high-level evaluation of various alternatives." In addition, VA is ideally performed "to analyze proposed corridor improvements prior to narrowing the suite of alternatives (or phasing of project improvements) for further development."

Some states, however, have implemented a value engineering process that has been detrimental to the consideration of adaptation projects. The reason is that some states included additional project elements beyond what was necessary to address expected climate change threats. Once the project entered into value engineering, these elements were removed to "save costs."

Adopting a credible life-cycle analysis of the costs would help in this regard. This should include expected costs to Caltrans and system users if a disruption occurs. According to Caltrans guidance, "a life-cycle cost analysis takes into account various current and future financial obligations and impacts of a particular design, including initial costs, future maintenance costs, future rehabilitation costs, and costs of the user (motorists and the movement of goods)."[89] The project alternative with the lowest life-cycle cost is considered to have the lowest financial impact to the State.

Although the normal procedure in most states is to wait until late in the process to conduct value engineering, with respect to adaptation projects, it would better to conduct the assessment as early as is practicable. As has been mentioned before, linking such an analysis to an agency adaptation goal will be critical, as will having a methodology that shows potential costs of asset failure to the system and to system users as part of the VA process (see inset earlier on "Incorporating Climate Change Risk into Economic Analysis" and the source document).

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demonstrating the need, methodology and applicability of the updated standards. Training should include time-lines for implementation of the adopted new standards.

[88] The Federal mandate is $50M for highway projects ($40M bridge projects) on the National Highway System using Federal funds. However, Caltrans has lowered the guidelines to $25M to capture efficiencies for SB-1 mandates. These are only for Caltrans-administered projects. An exception process exists for projects between $25M and $50M, but all projects over $50M must use value analysis. All locally-administered highway projects must meet the Federal thresholds.

[89] Caltrans. Life Cycle Cost Analysis. Retrieved May 10, 2020 from https://dot.ca.gov/programs/maintenance/pavement/concrete-pavement-and-pavement-foundations/life-cycle-cost-analysis

RECOMMENDATION 16

Examine Caltrans design manuals and guidebooks to incorporate new guidance on how adaptive design concepts can be used for climate-safe infrastructure project development. This would include how risk and climate change uncertainty should be considered as a key design input, and how the potential consequences of asset failure can be included in design decisions. This would entail a trade-off assessment for those projects that are so critical to transportation system performance that even a short-term disruption would result in significant impacts (even though the likelihood of such an event might be small).

RECOMMENDATION 17

Establish a method for changing design guidance that would focus on the impacts caused by various climate stressors on various assets. The CTC defined four asset classes as "focus areas" in accordance with California Government Code—pavement, bridges, culverts, transportation management systems (TMS)—that should be the focus of modified design guidance.

RECOMMENDATION 18

Examine the Caltrans value analysis (VA) process to make sure that the costs of future disruptions to the system and to system users include the possibility of climate change-related disruptions. This also means considering such costs and associated risks as part of the life-cycle analysis

RECOMMENDATION 19

New standards and methodologies may need to be developed with other State agencies so that there is uniformity in understanding, use, and applicability of such methods. Training then needs to be developed and imparted to various function in the Department.

4.8 SYSTEM OPERATIONS

Caltrans' Office of System Operations provides guidance on system operations to assure that the SHS operates safely, smoothly, and efficiently.[90] The focus of the unit is on operating the existing transportation system and deploying technology and implementing new strategies to prepare for future challenges to safe and efficient operations. The types of decisions relating to operations are thus not as related to climate change hazards as other decision processes, except in the case of operational strategies for responding to disruptions, such as motorist information and communication, alternative routes, and evacuation routes. An adopted Transportation Management Plan (TMP) provides guidance to Caltrans districts and other units regarding how planned disruptions (such as road closures and for incidents that might occur during the road construction) should be handled. The guidelines help define protocols if a transportation management center is in an affected area. With respect to the project development process, a designated TMP manager coordinates the preparation of TMP information that is included in the PID phase of project development.

With respect to operations during unexpected disruptions, the Office of Systems Operations has identified "Routes of Significance" satisfying Federal requirements for metropolitan areas with more than one million population. Part of this designation is the consideration of routes serving as major evacuation pathways following a major disruption or emergency. A Real-Time System Management Information Program gathers and makes available information for traffic and travel conditions. For smaller metropolitan areas and rural areas, evacuation routes are identified by Caltrans districts, county, and local governments, often using guidance from FEMA and FHWA. Any additional guidance on such concerns would need to include input from all of these sources to be relevant to different geographic and varying hazard contexts.

Non-planned disruptions on State roads are under the responsibility of Caltrans' traffic management centers (one in each district). These centers are designated as the point of contact for State roads; and sometimes offer capabilities to local governments for coordinating evacuations when State and local roads are part of the evacuation strategy. As was pointed out by several Caltrans officials, Caltrans does not control local streets and how capacity can be provided for evacuation purposes (especially an issue when local streets are redesigned for other purposes). However, Caltrans does have an important responsibility to support local governments through Local Assistance on Federal-aid and other State programs, and by providing planning grants. With respect to operations, Caltrans could serve as a resource to local communities in conveying the importance of the evacuation purpose for communities that are in areas that are highly vulnerable to extreme risk such as wildfires.

More broadly, Caltrans should develop guidance for local communities on the type of climate adaptation strategies can be considered for local roads, and the expected benefits of adopting such strategies. Caltrans provides adaptation planning grants to

[90] Caltrans. Office of System Operations. Website. Retrieved May 10, 2020 from http://www.dot.ca.gov/trafficops/tm/

local governments and can make data layers and tools used for the Caltrans vulnerability assessments available to the local governments to assist them. Statewide coordination of adaptation planning, include evacuation planning, could be done through Caltrans in conjunction with California Governor's Office of Emergency Services (CalOES).

RECOMMENDATION 20

Although Caltrans is not responsible for non-State roads, work closely with the Governor's Office of Emergency Services and other key agencies and jurisdictions to examine the experience with evacuations associated with the 2018 wildfires and identify lessons learned in terms of how evacuation routes and their operations can be effectively put into place. This would also involve assessing the implications for road design standards (i.e., how to promote adaptive designs to provide capacity for evacuations when necessary).

RECOMMENDATION 21

Designate resources toward working with communities in determining effective evacuation planning that incorporates estimating expected travel demand, capacity estimation, access closure strategies, and effective public information to limit loss of life/damage during extreme events.

4.9 SYSTEM MAINTENANCE

Caltrans' Division of Maintenance has responsibility for maintaining Caltrans' 350,000 acres of right of way, 212,000 culverts (20.3 million linear feet), 15,133 centerline miles of highway and 13,063 State highway bridges. Specific responsibilities include snow removal, shoulder repair, tree cutbacks, vegetation control and landscape maintenance, signal maintenance, rock blasting, bridge bracing, pavement sealing and repair, guard rail and sink hole repair, support of emergency traffic control, electrical maintenance, fire hazard reduction, erosion protection, avalanche control, pavement markings, sign installation, culvert and drain cleaning, response to storm damage and incidents, among many others. The Division of Maintenance uses an Integrated Maintenance Management System that allows staff to better control and monitor maintenance-related activities.

The 2019 Highway System Management Plan is the latest plan that integrates maintenance, rehabilitation, and operation strategies into a single management plan, while also satisfying some key Federal asset management requirements.[91] The focus of

[91] Caltrans. 2019. Highway Systems Management Plan. Retrieved May 10, 2020 from https://dot.ca.gov/programs/asset-management/state-highway-system-plan

the plan is on a performance-based approach for assigning priorities and in monitoring progress. This performance approach allows Caltrans to identify expected level of achievement. For example, the plan noted that the funding provided in the latest State funding legislation would achieve 90 percent of culverts to be in good or fair condition by 2027. This legislation targeted pavement, bridges, culverts and Transportation Management System element condition for investment priorities. These mandates have resulted in a shift in priorities. For example, SHOPP investment weighting has shifted to the stewardship category.

The plan recognizes three levels of what is called the "asset management structure." Field maintenance responds to day-to-day maintenance demands, with an estimate of every dollar spent on preventive maintenance effectively delays the need for an equivalent $3 in rehabilitation or $8 in reconstruction cost or replacement of pavement in the future. The second level, called the major maintenance program, invests more than $330 million annually to extend the life of physical assets through timely repair and preservation activities. The third level is asset rehabilitation or replacement, which will be discussed in the next section.

SHOPP needs are determined by using a performance management gap analysis, which includes the following steps:

1. Establish the asset inventory or deficiency level.
2. Establish the current and projected future condition/performance level of each objective.
3. Establish targets to achieve desired asset performance levels.
4. Perform a gap analysis between the projected condition/performance and the performance targets.
5. Estimate the cost to close the performance gaps.

At the plan level, investment dollars are aggregated from individual asset analysis that determines asset category needs. For the preventive maintenance and major maintenance programs, one does not know where in the highway system such needs will occur in the future, thus project-specific listings are not available when determining desired investment levels. For SHOPP, the magnitude of investment in each of the areas is "determined based on many factors. These factors include programmed work, current condition, judicial or legislatively mandated funding levels, consequences of inaction, past investment levels and preservation needs versus rehabilitation consideration. The establishment of investment levels also considers the impact on the system of the investment, the existing pipeline of work, expected deterioration rates, and expected growth in inventory."[92]

Of the many responsibilities for the Division of Maintenance, perhaps the most important one for climate change adaptation is culvert maintenance. As noted in the plan,

[92] ibid.

"culvert damage or failure can seriously damage or close roadways, create the need for extensive repairs and threaten the mobility and safety of the traveling public." It is interesting to note that as of 2017, of the culverts inventoried, approximately 65 percent were in good condition, 23 percent were in fair condition and 12 percent were in poor condition. Ongoing inspections are adding between 8,000 and 12,000 drainage assets to the statewide inventory annually and should be complete by 2027.

HPDE culverts had completely melted in many cases

FIRE AFTERMATH ON CULVERTS AND GUARDRAIL, DISTRICT 1

The focus of the plan investment in culverts is to replace or rehabilitate in-place those culverts and drainage pump plants that are in poor condition and those in the fair condition category where serviceability has been lost because of age, wear, or degradation. Upgrades or modifications of culverts, drainage pumping plants, and highway drainage systems to increase flow or improve drainage alignment are being considered, but the priority is clearly focusing on culverts and pumping plants in poor condition. Focusing on culverts should be a top priority for the Division of Maintenance given experience from around the nation with extreme precipitation events. Vermont, for example, learned from its experience with Superstorm Irene that the weak links in the state's highway network were inadequate and clogged culverts. Many of these culverts failed, taking the road segment with them, and in some cases, isolating communities for days. Caltrans does have an inspection program designed to prioritize potential culvert projects based on condition, cost, and traveler delay. Culverts are also vulnerable during wildfires if they are made of materials like plastic, which are prone to melt during wildfires, and thus should be considered as part of the inspection program where appropriate.

Caltrans districts have recognized the importance of culverts as well. In District 11, Interstate 8 experienced a culvert collapse that shut down two eastbound travel lanes. Forensic investigation showed that water infiltration and sedimentation had caused the fill surrounding the culvert to fail, thus creating a sinkhole and collapsing the freeway shoulders. The reconstruction of this segment of freeway took approximately nine months and cost $6 million. Another location on I-8 (at Tavern Road). saw joints fail because of sedimentation, leading to a $7.5 million project to place another culvert under the freeway.

Due to increased culvert failure, the Division of Maintenance developed and implemented a formal statewide Culvert Inspection Program (CIP) to inventory, assess, and map all the culverts on the SHS. District 11 began an inspection program of all the culverts on the SHS, many of which were put in place more than 50 years ago. Much had changed over this period, especially expansion in urban areas (with large amounts of impervious surfaces). Over a 15-year period, no inspections of inside the culverts had been undertaken. Funds from SB 1 are being used to conduct this statewide inspection, rating culverts as good/fair/poor.

Although culvert inspection is important, when new projects are built (or culverts replaced) in areas potentially vulnerable to higher levels of flooding in the future, one should determine whether culvert/pipe design is adequate for future flows. For example, the Vermont Agency of Transportation (VTrans), in response to the disruption to the state road network caused by Superstorm Irene (and the failure of numerous culverts) now requires a hydraulic study for any culvert with a diameter of 3 feet or more (the logic being that culverts of that size are most likely in a catchment area that might be exposed to higher levels of precipitation in the future).

There are many different actions that the Division of Maintenance could consider to be more sensitive to climate change risks. For example, the Maryland State Highway Administration identified a range of activities that it should take to reduce disruption risk (some of which are the responsibility of the agency's maintenance division): change all signal wires to mast arms, pilot snow hoods on light-emitting diode (LED) stoplights, enhance the culvert and stormwater maintenance program and provide additional funding, streamline environmental regulations relating to culvert cleaning and repair, install monitoring devices on vulnerable slopes, review erosion and sedimentation standards, and increase tree-trimming activities.

RECOMMENDATION 22

The Caltrans culvert maintenance program is growing with new funding provided in State legislation. Given the vulnerability of culverts, pumps and tide gate repair/replacement in areas affected by flooding and sea level rise (SLR), and erosion/debris/landslides after wildfires, give priority to ensuring vulnerable assets in especially high-risk areas are maintained at high levels. The focus of the new investment is on in-place culverts and other equipment. Those assets located on critical facilities and where capacity will not likely withstand future water flows should be prioritized for replacement.

RECOMMENDATION 23

Examine changes in maintenance practices where assets that are prone, for example, to fire or riverine damage could be efficiently and systematically replaced to reduce future risks. For example, Caltrans has already replaced in some districts wood guardrail with metal guardrail. Training for maintenance staff on new or modified maintenance practices should be developed.

RECOMMENDATION 24

Examine repair orders and determine those assets where recurring past damages may be better addressed through new resilient design options.

RECOMMENDATION 25

Undertake a pilot culvert vulnerability analysis in areas identified in the district adaptation study, collecting data on potential surrounding environmental risks (flood levels, levee failure), past maintenance concerns, and estimated consequences (overall disruption) to determine where replacements may be needed. Although placed in this section covering maintenance, this study could be led by others in Caltrans. The intent of the pilot study is to determine the risk to key Caltrans facilities of undersized culverts (with respect to future hydraulic conditions). A determination needs to be made to see if increasing the size of a culvert could potentially cause upstream or downstream private property damage (such as higher flows or higher velocities) or if other mitigation measures need to be incorporated.

4.10 ASSET MANAGEMENT

Caltrans adopted a transportation asset management plan (TAMP) in 2018. As noted in this document, "the plan describes the vision for how good asset management will help to deliver broad transportation goals and fundamental objectives supported by information on current asset conditions, the desired conditions in the future, and the likely conditions given future funding scenarios."[93] Similar to other states, the TAMP is based on asset performance targets, and thus, the gaps in meeting the targets. Life-cycle planning and cost estimates are provided that feed into project prioritization.

[93] Caltrans. 2019. California Transportation Asset Management Plan. January. Fiscal Years 2017/18-2026/27. Retrieved May 10, 2020 from https://dot.ca.gov/programs/asset-management/california-transportation-asset-management-plan

And similar to other states, the Caltrans asset management program a portals to extensive databases on asset condition and program process requirements.[94]

The asset management approach includes life cycle planning that was required by federal legislation (Moving Ahead for Progress in the 21st Century--MAP-21). Life cycle planning as applied in asset management involves linking risks to an asset's life cycle. By so doing, this helps to initiate actionable "Needs" for consideration as part of asset management prioritization. Climate adaptation risks need to be considered in such an approach such that "Needs" can be attached to projects for climate change adaptation purposes. As an example, if a particular location is experiencing repeated landslides due to heavy precipitation, there is a "Need" to fix the slope to protect the highway. A climate adaptation "Need" can then be attached to a potential project to address the problem, and be included in the asset management prioritization process.

Of particular importance for the TAMP, SB 1 codified performance measures and targets for four primary TAMP asset classes: pavement, bridges, culverts, and Transportation Management Systems (TMS) elements. The performance targets included in SB 1 direct that over the next 10 years not less than:

- 98 percent of pavement on the SHS be in good or fair condition
- 90 percent of culverts be in good or fair condition
- 90 percent of TMS units be in good condition
- An additional 500 bridges be fixed

In the discussion of risks, the TAMP acknowledges that risks include "day-to-day concerns such as risks that assets will deteriorate faster than expected or projects will cost more than budgeted, to the potentially catastrophic risks of asset failure caused by factors such as natural disasters. Climate change also presents a looming risk that will exacerbate all weather-related risks." In fact, the TAMP spends considerable time discussing the risks associated with natural disasters. The plan recommends project managers use the Project Risk Management Handbook to determine how such risks can enter into project development and prioritization. With respect to the types of risks identified in the plan, those associated with extreme weather and climate change included the following risk management elements:

- Incorporate potential impacts of climate change and new technologies into long-term planning (SLR, extreme weather events, changing asset needs to support automated and connected vehicles etc.)
- Identify and inventory external risks to existing infrastructure (e.g., seismic evaluations, security assessments, bridge scour programs)

[94] Caltrans. 2020. Asset Management. Website. Accessed May 16, 2020 from https://dot.ca.gov/programs/asset-management

- Infrastructure inspection, replacement or retrofit programs to mitigate risks (e.g., slope stabilization, alarms to deter copper theft, operational changes to reduce wind loading)
- Implement operational and emergency response programs to minimize impacts of asset failures because of external threats (e.g., staff training and planning, staging resources for response)
- Programs to review and evaluate construction standards to ensure reasonable incorporation of resiliency to external threats

It is important that the risks associated with extreme weather and climate change as presented in the Project Risk Management Handbook be periodically updated as new studies, after-event reports, and improved science provide more information on the needs, impacts, and consequences of extreme weather-related events. The next iteration of such updates should use the results of the District Climate Adaptation Plans to inform this process. A risk matrix for TAM and TAMS should include scores and priority ratings relating to climate adaptation "Needs" that could be used in TAMS scenario analysis.

The TAMP included the location of bridges and landslides that required frequent repair and reconstruction due to emergency events (as per Federal regulations). The bridges were only those suffering from multiple high-load hits. Having such information for other types of disruptions (e.g., periodic flooding) would be useful to project prioritization as well.

The TAMP outlines an impressive asset management strategy for Caltrans. In the section discussing risks, the TAMP responds to a commenter identifying a risk associated with future climate change hazards. The response in the TAMP is that the asset management staff would work with the climate change staff to ensure that such considerations are included in the asset management program. Given the importance of the asset management program in guiding Caltrans investments, it serves as another important entry point into Caltrans decision-making.

However, as indicated earlier about how steps that happen earlier in Caltrans' project development process can influence later consideration of adaptation strategies, if one wants to see adaptation projects in the asset management, program funding is a key issue. As noted earlier, until an "adaptation funding" source of funds is identified for project implementation, successful adaptation actions will most likely be part of the project design for projects that are carried forward for other reasons. In addition. Implementing adaptation strategies through asset management would need the creation of asset categories and classes for climate adaptation strategies so that budgets for this type of work can be established.

RECOMMENDATION 26

Once the district adaptation studies are completed, Caltrans will have much better information on the risks facing the SHS and where high levels of exposure to different climate hazards exist. This information should be used to develop performance measures, criteria and/or factors that are consistent across districts relating to climate change adaptation (and system resiliency) that can be part of the asset management decision-making process. This would include developing and incorporating estimates of quantified physical life-cycle risk (in dollars) associated with climate risk, leading to defined "Needs", as well as a consideration of broader economic and community impacts. The focus of these efforts should be on meeting the performance requirements of Senate Bill 1 (SB 1).

RECOMMENDATION 27

The Caltrans Project Risk Management Handbook should be periodically updated to reflect the latest information on the risks associated with extreme weather and climate change found in new studies, after-event reports, and latest science. The initial update should include the results of the district adaptation studies.

The previous pages have identified entry points into some of Caltrans' key decision-making processes. In some cases, these recommendations can be implemented now. In other cases, implementation should await the results of the district adaptation studies. However, it is clear from the review of Caltrans' decision-making processes that they are linked to one another substantively, and connected throughout the planning, project development, and asset management processes. The processes are also highly dependent on guidance on how certain factors and considerations should be addressed in Caltrans' standard operating procedures. The strategy for doing so must be considered carefully to avoid a backlash relating to "Not another requirement!" or "There is no funding to do this."

4.11 PROJECT MANAGEMENT

The Division of Project Management (DPM), as part of the Project Delivery Program, will have a significant role to play in implementing many of the recommendations of this report, including leadership and participation in various work groups and development of policies, guidance, tools and training of project managers and support staff.[95] According to the Division of DPM website, the major activities of DPM staff include:

[95] Caltrans. 2020. Project Management. Website. Retrieved May 10, 2020 from https://dot.ca.gov/programs/project-management

- Managing and Reporting - Monitor and report on the delivery status of the portfolio of projects. Provide performance reports on the delivery of the portfolio.
- Workload - Develop the overall workload and budget for the transportation improvement project portfolio. Develop and implement the tools, formulas, and standards used to estimate the resources necessary to deliver each project.
- Project Management Improvement - Develop and implement processes and tools to improve the management of these projects. Each Transportation Improvement Project has a Project Manager who is responsible for the project's delivery.
- Skill Development - Develop, conduct, and manage training courses to improve the skills of the 8,500+ staff working on these projects.

As can be seen in this list, DPM is an important group for implementing many of the recommendations of this report. DPM needs to work with all the Project Delivery Divisions (especially Design) to assist in the development of training and guidance, especially with respect to management and mitigation of climate change risks. DPM should expect the same or slightly greater magnitude of impact to workload that has been experienced with the latest attempt to add complete streets elements to projects. DPM involvement in value analysis studies and participation on planning teams with other Divisions would also likely increase.

TORO CREEK BRIDGE BEFORE AND AFTER RECONSTRUCTION, DISTRICT 5

5. COORDINATION WITH PARTNER AGENCIES AND OTHER STAKEHOLDERS[96]

Besides noting the importance of climate adaptation to the State, *Paying it Forward: The Path Toward Climate-Safe Infrastructure in California,* also recommended that State agencies implement a process for coordinating climate resilience policies as well as an institutional mechanism for coordinating their policies to "take advantage of synergies, address potential conflicts, and learn from one another."[97]

As the State's climate change policies have evolved, Caltrans has been a participant in providing input into the policy development processes. Many of these efforts have involved interaction and collaboration with numerous governmental agencies and other organizations. Much of this interaction has occurred among State agencies, but collaboration between different levels of government and with representatives of different governmental and private sectors has also occurred. Federal and State agencies that are particularly important for Caltrans' adaptation strategy include:

- California Coastal Commission (CCC)
- California Department of Fish and Wildlife (DFW)
- California Department of Forestry and Fire Protection (CAL FIRE)
- California Environmental Protection Agency (Cal EPA)
- California Natural Resources Agency
- Federal Emergency Management Agency (FEMA)
- Federal Highway Administration (FHWA)
- Governor's Office of Emergency Services (CalOES)
- Governor's Office of Planning and Research
- US Army Corps of Engineers
- US Forest Service

The focus of the Climate Adaptation Strategy outlined earlier was on what Caltrans should be doing to advance its own consideration of adaptation strategies in its decision-making processes. Caltrans will need to consider whether additional collaboration with external stakeholders would help advance the implementation of adaptation strategies internally. However, the position of Caltrans in State government and in the transportation profession/industry in California (and nationally) suggests that

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[96] This chapter is based on a memorandum from Angela Wong, Charlotte Cherry, and Beth Rodehorst to Tracey Frost, Caltrans, "Task 2.2.2 Identify Best Practices to Coordinate Adaptation Activities Among State, Local and Regional Partners to Encourage Collaboration: Alignment and Unified Adaptation Strategies that Protect Communities and Ecosystems Within the Area of Expected Impact." March 14, 2019 (Revised)

[97] CSIWG, 2018. Op cit.

it can also be a leader in motivating and guiding others in addressing their own adaptation challenges.

The level of collaboration for climate adaptation will vary by the focus of the adaptation effort. Many of the types of adaptation projects or policies that Caltrans might implement could be done internally, with the participation of primarily internal units in the agency. Many others, however, might benefit from (or require) a much broader participation of different agencies and groups. Incorporating climate adaptation considerations into plan and program guidance, for example, would be part of a larger participatory process for the plan itself. Collaboration can result in efficiencies by sharing information on the wide range of expertise required, building from existing work, and avoiding conflicting and incompatible adaptation efforts. Additionally, climate change will result in impacts across other sectors and geographies that could cascade and affect the resilience of transportation assets given infrastructure interdependencies.[98] In some cases, the most effective or cost-effective adaptation strategies are not in Caltrans' jurisdiction. For example, protection of a highway from storm surge and coastal erosion may require coastal barriers on land over which Caltrans does not have jurisdiction.

Caltrans is aware of cross-jurisdictional decision-making processes given the many years of experience Caltrans staff have been involved with other State, regional, and local agencies. However, climate adaptation efforts could be very different from the normal collaborative planning processes that Caltrans is used to. The scientific foundation for identifying the most cost-effective strategies is different (and often hard to understand) from what is found in current transportation planning practice. The concept of risk and the trade-offs that should be considered and the levels of uncertainty associated with future projections are different from the short-term (relative to climate forecasts) projections of future travel demand that serve as a cornerstone of transportation planning. Given the often broad expanse of climate change risks, such as wildfires that occur over large tracts of land, an active engagement of different interested parties could result in a pooling of resources and expertise. This could lead to the implementation of mutually supporting policies and actions that together will augment Caltrans' adaptation actions and enhance community and transportation system resilience across the State.

Some actions Caltrans might consider in adopting a State leadership role in climate adaptation include the following:

1. Build an understanding of external stakeholders' climate risks and adaptation efforts. Given the interdependencies among networks across sectors and jurisdictions, it is important for Caltrans to understand what others view as key climate risks and what they are doing or not yet doing to address these risks. Caltrans can then map how these risks and activities affect Caltrans' operations

[98] California Natural Resources Agency (NRA). 2019. Safeguarding California Plan: 2018 Update. Sacramento, CA. Retrieved May 10, 2020 from https://www.slc.ca.gov/sea-level-rise/safeguarding-california-plan-2018-update/

and assets under a changing climate to identify priority stakeholders with whom to network and collaborate.

2. Use existing information exchange channels on climate change adaptation to network with adaptation champions. These channels can include existing working groups, coalitions, and workshops where Caltrans can establish relationships with specific points of contacts who are working on adaptation and foster relationships for future collaboration. For example, Caltrans' participation in the Integrated Climate Adaptation and Resiliency Program is vital to build an understanding of, contribute to, adaptation activities across the State. The Alliance of Regional Collaboratives for Climate Adaptation, which represents leading regional collaboratives in California, is another potential resource for Caltrans districts to connect with regional and local decision-makers.

3. Early coordination concepts with climate change adaptation partners should be identified and pursued by Caltrans. One of the recommendations coming out of AB 1282 is that early coordination is a critical component for successful permitting; early coordination with agencies such as the California Coastal Commission (CCC), especially focused on SLR, can be used as a way to integrate the consideration of potential vulnerabilities and adaptation options at the very beginning of a project development process.

4. Regularly participate in external requests to collaborate on adaptation initiatives. Collaborative relationships are two-way streets. Caltrans has opportunities to provide input on adaptation initiatives that are outside of its jurisdiction but that would contribute to the resilience of transportation services. Participation in external adaptation projects and programs can also continue to foster relationships with stakeholders and enhance Caltrans' understanding of the stakeholders' approaches and initiatives on adaptation. Caltrans does not have unlimited resources to participate in every collaboration request, but a priority system could be developed that provides guidance to Caltrans staff on what types of collaboration efforts would be encouraged.

5. Leverage Caltrans-led adaptation projects or programs as an opportunity to convene stakeholders. Most of the pilot teams under the FHWA Climate Resilience Pilot Program convened advisory groups to engage stakeholders and vet data and approaches.[99] For example, the Caltrans District 1 pilot project technical advisory group was composed of experts from local transportation planning agencies who contributed to the vulnerability assessment and adaptation process. The District 1 pilot team also established a stakeholder group for input from other regional land managers and jurisdictions who were not necessarily transportation experts. Many FHWA pilot teams found these types of partnerships useful and continued to collaborate after the conclusion of the FHWA program.

[99] FHWA. 2016. 2013-2015 Climate Resilience Pilot Program: Outcomes, Lessons Learned, and Recommendations. Retrieved May 10, 2020 from http://www.trb.org/Main/Blurbs/174874.aspx

6. Consider engaging in or establishing an ongoing task force or multi-agency stakeholder process. Although collaborative relationships do not necessarily need to be formalized, long-term task forces or stakeholder processes demonstrate commitment to collaboration on adaptation beyond a specific project or program. For example, the multi-sector and cross-jurisdictional *Adapting to Rising Tides* program has fostered robust collaborations in the Bay Area and tested and refined adaptation planning methods through numerous projects since 2010.

7. Promote a closer collaboration between practitioners and climate science community to: 1) work collaboratively on narrowing the range of uncertainties in climate data; 2) work toward consistency in a climate database and information between different jurisdictions and users of the data i.e., State, local and regional agencies; and 3) promote open access to available data requiring collaboration among governments, local authorities, and the private sector.

With respect to the broader community, public outreach and engagement can generate numerous benefits for the transportation adaptation, including: 1) gathering valuable local community input and perspectives; 2) building trust and fostering a transparent process; 3) creating community buy-in; and 4) building awareness and momentum for resilience projects. Such a strategy, however, should be based on clearly articulated goals and strategies for any public engagement. Goals for public engagement could include, for example, educating the public on climate impacts and Caltrans' resilience activities, gathering input on priority transportation vulnerability concerns, and collecting feedback on proposed adaptation investments. Depending on the goal, the strategies for engagement should be tailored to that end. For example, engagement efforts to collect local input need to be thoughtfully structured to elicit information that can be useful for decision-making.

One factor for successful engagement, as found in other efforts in the country, is engaging the public early and often in the adaptation process. Engaging the public throughout the project cycle can help build a transparent process and create community buy-in. Another success factor was using creative approaches to engage the public. These might include interactive workshops, focus groups, role playing, game play, photo contests, charrettes, and the use of social media. Such efforts should be aligned with the communication plan developed by the Division of Transportation Planning.[100]

In summary, there are many opportunities for Caltrans to work with other agencies and groups to foster more attention to the State's climate change policy. With recent natural disasters in California, the public is probably more aware of the risks and threats associated with climate change than ever before. This provides an opportunity for

[100] Caltrans and Eastern Research Group, Inc. 2020. California Department of Transportation Climate Change Communication Guide. Climate Change Branch, Division of Transportation Planning. March. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/caltransclimatecommunicationguidepdf-a11y.pdf

Caltrans to foster support for its climate adaptation strategy and put in place the communications and information strategy that highlights its efforts in meeting public expectations.

6. CLIMATE ADAPTATION PROJECT CONCEPTS

There are many opportunities where incremental changes can be made in existing Caltrans procedures that could have a significant impact on enhanced consideration of climate change adaptation in decision-making. Other strategies might need more involved changes (e.g., changes in design processes or design standards), but would refocus some of Caltrans' efforts to be more adaptive to the challenges of a changing environment, leading ultimately to a more resilient transportation system.

Ultimately, the measure of Caltrans' near-term success in improving the resilience of the SHS with respect to climate change is in implementing adaptation projects. The project pipeline described earlier includes the participation of many different units in Caltrans. Thus, although the development of adaptation-sensitive transportation plans occurs at the beginning of the project pipeline, the actions taken in this step can reverberate down the project pipeline, potentially influencing project characteristics. Alternatively, understanding what types of projects and strategies Caltrans will be implementing in response to climate change sends a message up the project development process relating to the type of information and support needed to produce such projects.

Although this section focuses on the possible types of adaptation strategies that can be considered during the project development process. It is important to note that this section does not include a discussion of the need to evaluate Caltrans closed contaminated sites and Aerially Deposited Lead (ADL) burial sites in light of potential climate change-related threats. Sea level rise, for example, may result in the need to remove residual contamination before it is inundated or impacted by a rising water table.

To give a sense of the range of the potential project strategies and designs, the project types described in Appendix A were selected to represent different types of climate stressors given different design challenges. One of the actions Caltrans should consider is to adopt the CCC's basic adaptation strategy categories of protect, accommodate, or retreat as a way to characterize different adaptation options to mitigation vulnerabilities in order to provide consistency in communicating Caltrans adaptation efforts.

The adaptation project descriptions found in Appendix A include:

- Coastal armoring strategies and nature/natural design strategies along the coast from SLR, surge, erosion (cliff retreat, beach erosion)
- Landslide protection measures
- Pavement design in higher temperatures and other changing conditions

- Bridge reconstruction and elevation of roads in at-risk flood zones (taking into account future flood levels) in inland flooding areas
- Drainage area enhancement (including more than just modifying a culvert, like storage or diversion)
- Culvert replacement with higher flow capacity and to address debris concern in areas where wildfires occur
- Drought-tolerant/fire-resistant landscaping and implementation of clear zones
- Identification of natural vegetated areas that are at risk, and vegetation thinning or selective clearing to reduce the risk of a roadside ignited wildfire

The project descriptions in Appendix A are not intended as an all-inclusive listing of what Caltrans might have to do with design approaches for the situations portrayed; every project design will be specific to a particular location and to the design parameters at that location. However, they are intended to provide Caltrans and others with a sense of the climate adaptation challenges it will be facing in future years.

Natural infrastructure, or sometimes referred to as nature-based solutions, is one of the climate change adaptation strategies being used by many communities.[101] Natural infrastructure is defined as "[preserved or restored] ecological systems or the utilization of engineered systems that use ecological processes to increase resilience to climate change, manage other environmental hazards, or both" as defined by State policy.[102] The concept of natural infrastructure includes hybrid solutions that integrate engineered aspects into restored or created natural features. In many instances, combinations of natural features with engineered systems may yield benefits beyond those achieved individually. A wide variety of terminology describes the similar fundamental concept, such as: Low Impact Design (LID), nature-based solutions, nature-based infrastructure, green infrastructure, natural and nature-based features, engineering with nature, building with nature, and working with nature. Where appropriate, natural infrastructure strategies are described

> Caltrans is already familiar and working with natural infrastructure strategies. EO B-30-15 directs State entities to consider climate change in its plans and investments, with a guiding principle to give priority to natural infrastructure solutions. The EO guidance provides general direction to State agencies on how natural systems can enhance the resilience of a given project or plan and how projects and plans can be designed to enhance the resilience of natural systems. The same principle to prioritize natural infrastructure solutions is embedded in California's Climate Adaptation Strategy. In alignment with State policy, Caltrans is working on pilot adaptation projects with local partners to identify natural infrastructure design solutions.

[101] Memorandum from Beth Rodehorst, Angela Wong, Samantha Heitsch, Charlotte Cherry, ICF to Tracey Frost, "Natural Infrastructure Strategies to Reduce Climate Change Impacts to Caltrans Assets", Division of Transportation Planning, Caltrans. Feb. 1, 2018; and Sam Veloz, 2018. Toward Natural Infrastructure to Manage Shoreline Change in California. Retrieved May 10, 2020 from http://asbpa.org/wpv2/wp-content/uploads/2018/11/E1.Veloz_Sam.pdf

[102] California Code. (2015). Public Resource Code Section 71154(c)(3). Retrieved May 10, 2020 from https://codes.findlaw.com/ca/public-resources-code/prc-sect-71154.html

as part of the projects presented in the appendix. The following sections provide general information on applying natural infrastructure strategies.

Natural infrastructure strategies should be considered early in planning and design with input from relevant decision-making entities and affected stakeholders.[103] There are many opportunities for these strategies when the conversation starts early and includes participation from relevant decision-making entities and affected stakeholders. Consideration of natural infrastructure strategies should ideally occur in the ongoing long-range transportation planning process, as opposed to during the implementation and O&M phases.[104] For instance, if nature-based solutions are only seriously evaluated in the National Environmental Policy Act (NEPA) process, it will likely be too late to be fully integrated into project design. Caltrans will also need to engage key partners early in the process. Landscape architects (LAs) are specifically trained in 'natural infrastructure' planning and design and should be consulted and involved as part of all phases of natural infrastructure planning and project development.

Right-of-way can be a significant barrier for implementing robust natural infrastructure strategies that require adequate space; Caltrans will need to engage with relevant partners early to navigate jurisdictional challenges. For example, an eroding marsh adjacent to a road might be a candidate for a natural infrastructure strategy and would require coordination with the owner of the marsh prior to the recession of the shoreline reaching the road right-of-way.

As with other adaptation solutions, Caltrans can also consider natural infrastructure strategies opportunistically. To do so, Caltrans should preemptively establish mechanisms to identify and leverage the most opportune situations for integrating natural infrastructure strategies. It would be beneficial to ensure the appropriate information and decision-making frameworks are in place to allow consideration and implementation of natural infrastructure (such as noted above involving landscape architects in the project development process) . A best practice is to apply the concept of “flexible adaptation pathways,” which refers to the implementation of adaptation actions over time to allow for adjustment of actions based on new information or circumstances rather than predetermining a set of adaptation investments based only on what is known today.[105] The approach can involve tracking information to identify potential trigger points that indicate when the need for an

[103] FHWA. 2019. Implementation Guide on Nature-Based Solutions for Coastal Highway Resilience. Retrieved May 10, 2020 from https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/implementation_guide/fhwahep19042.pdf

[104] FHWA. 2018. Natural Environment and Implementing Eco-Logical. Retrieved May 10, 2020 from https://fhwaapps.fhwa.dot.gov/planworks/Application/Show/10

[105] See, Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. A., & & Campbell, B. (2014). Reconceptualizing adaptation to climate change as part of pathways of change. Global Environmental Change, 28, 325-336. Retrieved May 10, 2020 from https://asu.pure.elsevier.com/en/publications/reconceptualising-adaptation-to-climate-change-as-part-of-pathway; Haasnoot, M., Kwakkel, J. H., Walker, W. E., & Maat, J. 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change, 23(2), 485-498. Retrieved May 10, 2020 from https://www.sciencedirect.com/science/article/pii/S095937801200146X; and Wilby, R. L., & Dessai, S. 2010. Robust adaptation to climate change. Weather, 65(7), 180-185. Retrieved May 10, 2020 from https://www.researchgate.net/publication/228034950_Robust_Adaptation_to_Climate_Change

adaptation decision is approaching and identifying decision-making processes to facilitate adaptation.[106]

Lastly, project teams should carefully consider the timing of implementation of the natural infrastructure to align with timeframes of the natural systems. The implementation schedule should be aligned with the growing or spawning seasons of the target habitats. For example, the timing of vegetation plantings or reef restoration should be scheduled based on the local growing seasons.

National practice and experience in California have led to some important lessons with respect to using natural infrastructure in mitigating environmental conditions. These include:

- Hybrid approaches, which combine nature-based components with gray engineered systems, are particularly important. Nature-based features may mitigate hazards under low to moderate intensity events. The use of traditional gray infrastructure in combination with nature-based approaches could enhance resilience of the infrastructure and the ecosystem to higher intensity events. Examples of coastal hybrid approaches include pocket beaches with artificial headland breakwaters or walls buried beneath dune systems to protect upland infrastructure.
- The structural design of hybrid approaches, selection of natural materials, and ecological context and needs should be considered carefully. In cases where gray infrastructure and nature-based features are combined, the design of the gray components should be scaled proportionally to account for the benefits provided by the nature-based components. Additionally, it is important to select the appropriate materials and design the nature-based components to be consistent with the surrounding ecology to avoid unintended negative consequences. Factors such as fill materials, vegetation with respect to the setting and elevation, and the placement of the structures will dictate system performance. Ecologists should be included in the design process to make sure that the designed system matches the local ecology and morphology so that it enhances the habitat value and function.
- Transportation practitioners should consider proactively preserving natural features that already offer resilience benefits. Natural systems already play an important role in protecting built infrastructure. Transportation practitioners might not consider the protection provided by natural features until the systems begin eroding or become otherwise damaged. Often, gray infrastructure solutions are implemented to fill the gap. Whenever possible, Caltrans should proactively preserve natural features that are already providing resilience benefits. Preservation of natural features may be more cost-effective than gray

[106] Bruzgul, J., Kay, R., Rodehorst, B., Petrow, A., Hendrickson, T., Bruguera, M., . . . Revell, D. (2018). Potential Climate Change Impacts and Adaptation Actions for Gas Assets in the San Diego Gas and Electric Company Service Area. California's Fourth Climate Change Assessment.

infrastructure solutions; maintaining the health of natural systems can allow them to continue to provide protection with little additional cost or effort.

- Natural infrastructure strategies can decrease the environmental impact of projects (compared with their grey infrastructure alternatives) while also offering a suite of co-benefits. Natural infrastructure strategies can prove to be a more cost-effective solution in some cases. In addition to increasing the resilience of an asset or area to a specific climate-related hazard, natural infrastructure can provide a variety of economic, social, and environmental benefits as described above. Natural infrastructure strategies can also be used to meet multiple agency objectives.
- Natural infrastructure strategies need to be monitored over time as part of an adaptive management program. As with other adaptation strategies, natural infrastructure strategies may require actions to maintain the long-term functioning and performance of the system. Adaptive management entails revisiting the project and making iterative adjustments over time as conditions change. Consistent monitoring of the performance provides key information to enable the department to identify potential problems and make modifications over time. For example, monitoring shoreline position, elevation, erosion, stem density, and species health of coastal natural infrastructure strategies is an important input into eventual decisions on what strategies might be most appropriate.

RECOMMENDATION 28

Adopt the CCC's basic adaptation strategy categories of protect, accommodate, or retreat as a way to characterize different adaptation options to mitigate vulnerabilities in order to provide consistency in communicating Caltrans' adaptation efforts.

RECOMMENDATION 29

The CCC identifies natural solutions (or nature-based solutions or natural infrastructure) as a preferred alternative where feasible for protecting existing endangered structures based on guidance from FHWA and other sources. Necessary specifications for the use of "soft" or natural infrastructure solutions should be developed where such solutions are appropriate and feasible to protect Caltrans assets. Standard engineering designs for natural infrastructure should also be developed.

7. NEXT STEPS

Caltrans' Sustainability Roadmap and, in particular, the adaptation section laid out some important steps Caltrans was taking to incorporate adaptation concerns into the day-to-day operations of the agency. (It is important to note that the structure and resourcing for implementing the Roadmap have not yet been agreed upon.)One of the major efforts in this Roadmap was to incorporate adaptation as a concern into Caltrans plans and other decision-making documents. The recommendations in this report are consistent with the Roadmap strategy. Those recommendations are repeated here. Together, they lay out the steps that Caltrans should take to enhance its adaptation efforts and to improve the resiliency of the transportation system.

<u>Organizational Responsibility</u>

1. Create an organizational structure in Caltrans with the authority, credibility, and accountability for integrating climate change adaptation into Caltrans' business operations and transportation investment decision-making. Currently, the agency lacks a systematic and programmatic approach to climate change and climate resiliency. This type of approach would require participation from many different functional units within Caltrans.

2. Each major program from planning, programming, project delivery, maintenance, and operations should be assigned responsibility for implementing the respective recommendations of this study, and develop appropriate procedures, guidelines, resources, and organization structure to maintain an effective and productive effort on climate adaptation and transportation resiliency. A point of contact should be identified for each program. The implementation plan for each unit should include recommendations for needed staff training.

<u>Vision/Goals/Policy Direction</u>

3. For the next update to the Strategic Management Plan (SMP), Caltrans should adopt an explicit goal (with corresponding objectives) that commits to climate change adaptation strategies. This could be a stand-alone goal or contained within a strategic goal that focuses on broader transportation system resiliency. One possible statement could be similar to what has been adopted by other state departments of transportation (DOT's):

   <u>Goal:</u> A transportation system that is resilient, reliable, and responsive to system disruptions.

   <u>Action:</u> "Proactively assess, plan, invest in, operate, and maintain the State's transportation system to protect system assets from extreme weather and, over the long term, climate change threats."

If a specific climate adaptation goal is not desired, the strategic objectives of the adopted goals should call out climate adaptation and system resilience concerns.

Planning

4. The climate change planning function should be aligned with the state planning function. Long-range planning, including the California Transportation Plan, is a required statewide planning process that provides proper functional context and a process for climate change and adaptation planning along with GHG reduction efforts. Planning activities should provide similar emphasis to climate change adaptation and GHG emission reduction strategies. The adaptation section should include, at a minimum, the following information:
   a) What climate change trends could affect the transportation system being examined?
   b) What are the potential impacts to the transportation system? To the broader community that depends on a reliable transportation system?
   c) What are the types of strategies and actions that can be taken to protect or minimize these impacts?
   d) What steps (including collaboration with Caltrans' partners) are necessary to implement such strategies and actions?
5. System planning guidelines should address climate change adaptation and guide the development of system planning documents, such as District System Management Plans and Corridor Plans. Caltrans should develop more detailed guidance (other than that provided in the Corridor Planning Handbook) on how to include climate change adaptation and system resiliency into corridor planning studies. Such guidance could include such topics as:
   a) Using the District adaptation exposure results currently being developed to identify assets vulnerable to future climate change disruptions
   b) Using "system use" and not just "physical damage"' as a key criterion for prioritization of proposed actions, thus recognizing the importance of the State Highway System (SHS) to the State and local economy. System use should include criteria that are relevant to rural communities such as freight movement and lifeline service routes, not just volumes of use
   c) Using the recommended benefit/cost assessment approach (discussed below) for identifying cost effective projects incorporating uncertainties and user impacts
   d) Applying risk metrics to the identification of project alternatives (and if appropriate conceptual project designs

e) Identifying community lifeline strategies (e.g., evacuation routes) for when emergencies occur

6. Caltrans should undertake a pilot planning study similar to the Colorado Department of Transportation's (CDOT's) where system resilience enhancement and risk minimization are included as the primary focus or is at least incorporated as an important goal of the study. The pilot study would serve as a "proof-of-concept" for such an approach, identifying the most appropriate means of including climate change concerns into its economic analysis efforts, which might vary by technique. Such efforts should include adaptation benefits as part of every application.

7. Caltrans should incorporate economic analysis in adaptation planning to prioritize project selection or alternatives on the State Highway System affected by climate change. Economic analysis tools that apply the life cycle cost analysis (LCCA), benefit cost analysis (BCA), or economic impact analysis (EIA) methodology should account for climate change to make the analysis more robust and better demonstrate how limited resources are being allocated effectively.

8. Examine the Project Initiation Document (PID) guidelines to consider explicitly where it is feasible to incorporate adaptation system considerations as part of project justification (e.g., definition of "need"). Many of the sections of the existing PID guidelines and Project Development Procedures Manual should be modified to do this. Including such an explicit consideration in the guidelines provides a "place" for adaptation concerns as a project proceeds along the project development process. One criterion that should be considered as part of the "need" definition would be whether a proposed project sits in an exposure area or whether it serves as an evacuation route from such an area.

9. In the longer term, once this Caltrans Adaptation Strategy Report and the District Adaptation Plans are adopted, modify the PID guidelines to incorporate both documents as official plans that should be considered as part of the purpose-and-need statement and in the early design considerations.

<u>Project Funding</u>

10. Develop a strategy in coordination with other key participants in the funding program development process for developing a climate change adaptation funding category for projects that are undertaken for such purposes.

<u>Prioritization</u>

11. Explicitly consider adaptation criteria into investment decision-making. A methodology for doing so could be targeted on prioritizing adaptation needs and projects themselves or based on metrics for identifying adaptation treatments that are included as part of project designs being developed in response to other primary criteria (e.g., capacity expansion or safety).

12. Priority in project adaptation investments should be given to those projects, 1) where current extreme weather-related disruptions occur and thus becomes a need for Caltrans action, 2) where other project investments are occurring anyway and where incremental investment could have a positive impact on enhancing SHS resiliency, 3) given the importance of an asset where projections show increased extreme weather threats in the future, and 4) for locations where loss of service would result in significant community impacts.

Environment

13. Examine how the consideration of climate change adaptation can be better incorporated into the environmental process given existing practice and regulations, with the focus on both impacts to communities (e.g., changes in flooding characteristics) and impacts to the transportation system (e.g., system resiliency).

14. Develop stand-alone guidance (or include additional technical guidance in the existing requirements) that focuses on how climate change adaptation (perhaps along with GHG emissions reduction) can be incorporated into environmental analysis similar to other guidebooks referenced by the Division of Environmental Analysis (DEA). For example, more guidance on wildfire hazards is needed.

15. In recognition of the important role of environmental resource agencies in project development and permits, initiate a dialogue with such agencies to further develop and finalize procedures for incorporating uncertainty, climate change risk, and risk-based design into environmental documents.

Engineering and Design

16. Examine Caltrans design manuals and guidebooks to incorporate new guidance on how adaptive design concepts can be used for climate-safe infrastructure project development. This would include how risk and climate change uncertainty should be considered as a key design input, and how the potential consequences of asset failure can be included in design decisions. This would entail a trade-off assessment for those projects that are so critical to transportation system performance that even a short-term disruption would result in significant impacts (even though the likelihood of such an event might be small).

17. Establish a method for changing design guidance that would focus on the impacts caused by various climate stressors on various assets. The CTC defined four asset classes as "focus areas" in accordance with California Government Code—pavement, bridges, culverts, transportation management systems (TMS)—that should be the focus of modified design guidance.

18. Examine the Caltrans value analysis (VA) process to make sure that the costs of future disruptions to the system and to system users include the possibility of

climate change-related disruptions. This also means considering such costs and associated risks as part of the life-cycle analysis.

19. New standards and methodologies may need to be developed with other State agencies so that there is uniformity in understanding, use, and applicability of such methods. Training then needs to be developed and imparted to various function in the Department.

System Operations

20. Although Caltrans is not responsible for non-State roads, work closely with the Governor's Office of Emergency Services and other key agencies and jurisdictions to examine the experience with evacuations associated with the 2018 wildfires and identify lessons learned in terms of how evacuation routes and their operations can be effectively put into place. This would also involve assessing the implications for road design standards (i.e., how to promote adaptive designs to provide capacity for evacuations when necessary).

21. Designate resources toward working with communities in determining effective evacuation planning that incorporates estimating expected travel demand, capacity estimation, access closure strategies, and effective public information to limit loss of life/damage during extreme events.

Maintenance

22. The Caltrans culvert maintenance program is growing with new funding provided in State legislation. Given the vulnerability of culverts, pumps and tide gate repair/replacement in areas affected by flooding and sea level rise (SLR), and erosion/debris/landslides after wildfires, give priority to ensuring vulnerable assets in especially high-risk areas are maintained at high levels. The focus of the new investment is on in-place culverts and other equipment. Those assets located on critical facilities and where capacity will not likely withstand future water flows should be prioritized for replacement.

23. Examine changes in maintenance practices where assets that are prone, for example, to fire or riverine damage could be efficiently and systematically replaced to reduce future risks. For example, Caltrans has already replaced in some districts wood guardrail with metal guardrail. Training for maintenance staff on new or modified maintenance practices should be developed.

24. Examine repair orders and determine those assets where recurring past damages may be better addressed through new resilient design options.

25. Undertake a pilot culvert vulnerability analysis in areas identified in the district adaptation study, collecting data on potential surrounding environmental risks (flood levels, levee failure), past maintenance concerns, and estimated consequences (overall disruption) to determine where replacements may be needed. Although placed in this section covering maintenance, this study could

be led by others in Caltrans. The intent of the pilot study is to determine the risk to key Caltrans facilities of undersized culverts (with respect to future hydraulic conditions). A determination will need to be made to see if increasing the size of a culvert could potentially cause upstream or downstream private property damage (such as higher flows or higher velocities) or if other mitigation measures need to be incorporated.

Asset Management

26. Once the district adaptation studies are finished, Caltrans will have much better information on the risks facing the SHS and where high levels of exposure to different climate hazards exist. This information should be used to develop performance measures, criteria and/or factors that are consistent across districts relating to climate change adaptation (and system resiliency) leading to defined "Needs", that can be part of the asset management decision-making process. This would include developing and incorporating estimates of quantified physical life-cycle risk (in dollars) associated with climate risk, as well as a consideration of broader economic and community impacts. The focus of these efforts should be on meeting the performance requirements of Senate Bill 1 (SB 1).

27. The Caltrans Project Risk Management Handbook should be periodically updated to reflect the latest information on the risks associated with extreme weather and climate change found in new studies, after-event reports, and the latest science. The initial update should include the results of the district adaptation studies.

Project Concepts

28. Adopt the California Coastal Commission's (CCC's) basic adaptation strategy categories of protect, accommodate, or retreat as a way to characterize different adaptation options to mitigate vulnerabilities in order to provide consistency in communicating Caltrans adaptation efforts.

29. The CCC identifies natural solutions (or nature-based solutions or natural infrastructure) as a preferred alternative where feasible for protecting existing endangered structures based on guidance from FHWA and other sources. Necessary specifications for the use of "soft" or natural infrastructure solutions should be developed for where such solutions are appropriate and feasible to protect Caltrans assets. Standard engineering designs for natural infrastructure should then be developed.

Over the longer term

Many of the recommendations in this report, along with those in the Climate Adaptation Roadmap, move Caltrans along a path of integrating climate change considerations into decision-making. Some steps still remain, primarily reflect in steps 8 and beyond. In particular, undertaking more detailed adaptive designs for vulnerable assets in the capital improvement track will be a true test as to the commitment of Caltrans to considering climate change adaptation in decision-making. These assessments will involve engineering-based analyses to verify asset exposure to pertinent climate hazards and, if vulnerability is verified, evaluate adaptive measures to manage and or reduce/eliminate the risk. Once specific adaptation measures have been identified, the projects can then be programmed depending on available funding and identified needs. In addition, this analysis could determine the extent to which adaptation treatments could be applied to project designs that are being implemented primarily to address other concerns (e.g., improvements aimed at increasing capacity or improving safety).

The final steps in the Framework that focus on the monitoring of system resilience to track progress toward achieving Caltrans' adaptation program are also important future efforts for Caltrans. This includes defining performance metrics relating to system resiliency for monitoring system performance as well as metrics for monitoring adaptation and resilience actions undertaken by Caltrans.

In addition, in many ways, the recommendations suggest a different mindset for developing and implementing the programs that serve as the core of Caltrans' mandate. Thus, in parallel with implementing the short- and long-term recommendations from this study, Caltrans should develop training and professional development opportunities for its staff. Such opportunities would expose staff to the rationale for emphasizing adaptation and system resiliency in its programs, and provide them with the knowledge and tools to guide Caltrans' evolution to a more resiliency-oriented agency.

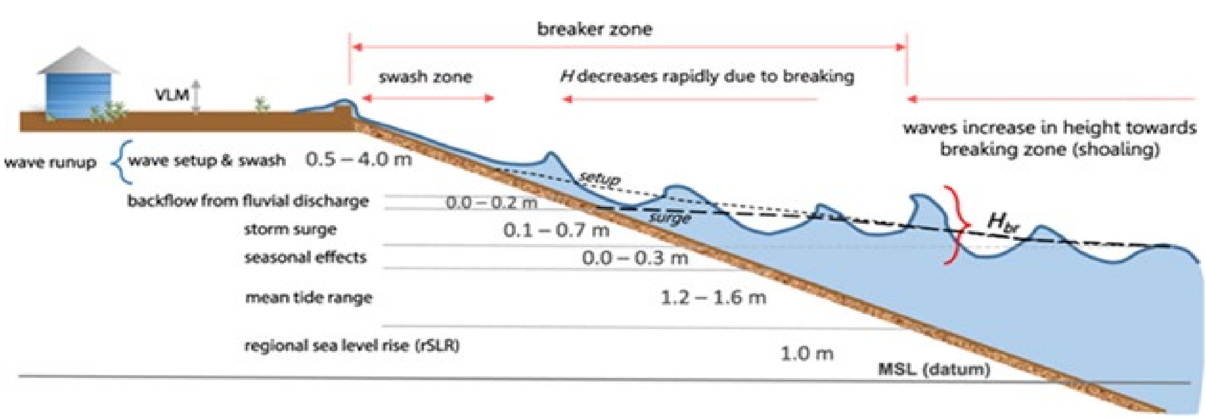
APPENDIX A

Appendix A provides more detailed information on the representative types of projects that Caltrans will likely be implementing more regularly in the future due to climate change and associated changing weather patterns. The intent of the following material is to illustrate the types of hazards and/or threats represented by different climate stressors, the potential impacts to the State Highway System (SHS) caused by these stresses, and the types of adaptation actions or strategies that Caltrans can consider to avoid or minimize the impacts. Additional work in development of more specific design guidance would be needed to implement some of the suggested strategies and approaches described in the following sections.

A.1 COASTAL PROTECTIONS FOR SEA LEVEL RISE (SLR), SURGE, AND EROSION

The consequences of SLR will be felt in multiple ways, including permanent inundation, increasing flooding from high tide events and storm surge, and accelerated coastal erosion. Erosion impacts will primarily take the forms of beach erosion and cliff undermining/retreat caused by more frequent flooding and wave energy impacting the shoreline.

SLR will vary somewhat along the California coast depending on local factors. Figure A-1 demonstrates how a variety of conditions ultimately cause flooding for varying conditions and determine the measure of total water level in a given location, including regional SLR, tides, seasonal effects, storm surge, vertical land motion, and wave height. This figure was created by the U.S. Geological Survey (USGS) to illustrate how its Coastal Storm Modeling System (CoSMoS) models potential future coastal flooding from SLR and storm surge by integrating local factors and coastal changes.



Total water level =
rSLR + tides + seasonal effects + storm surge + wave setup + wave swash + fluvial discharge backflow

FIGURE A-1: COMPONENTS THAT AFFECT TOTAL WATER LEVEL (USGS)

FUTURE PROJECTIONS

SLR projections vary, depending in part on the assumptions regarding future concentrations of greenhouse gas (GHG) emissions in the atmosphere and how the Earth's systems will respond to warmer conditions. The Ocean Protection Council's (OPC) *Sea Level Rise Guidance: 2018 Update* provides the most up-to-date SLR projections for various scenarios for locations along the California coastline.[107]

As sea levels rise, water will reach farther inland, eventually creating inundation in areas that were previously dry and may not have been protected during design. The inundation of coastal areas is also likely to worsen during periods where storm surge may be higher and extend farther inland. This is also a concern given the expectation that that the frequency and intensity of storm events may increase over time. Rising sea levels and storm surge are expected to increase the rates of beach erosion and cliff retreat[108]. For cliffs, erosion undermines the support for the cliff itself and eventually results in collapse and retreat.

The information below summarizes general projections of the climate stressors that may contribute to more frequent or severe coastal impacts. The symbols indicate the change in direction of each stressor based on statewide projections over the coming century. An arrow pointing upwards indicates that the trend is increasing.

Sea level rise – **Anywhere from 1 to 10 feet of SLR is projected to occur by the end of century in California**, depending upon a range of variables including GHG emission concentrations and rates of melting land ice. According to the *California's Fourth Climate Change Assessment*, there is an extremely low probability of the 10-foot level being reached. The highest probability is in the 1- to 3.4-foot range with a 5 percent chance it can be as high as 4.4 feet.

Storm surge – Higher water levels mean higher storm surges. This may be further complicated as there **is medium-high confidence that the intensity of heavy precipitation events will also increase over time,**[109] thus contributing to an increase in water levels in areas near where rivers and streams empty at the shoreline.

[107] California Natural Resources Agency and California Ocean Protection Council, 2018 update. "State of California Sea-Level Rise Guidance." Retrieved May 10, 2020 from http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

[108] Cliff retreat is caused by the impact of waves on the base of a cliff or a sandy beach, which carves out a portion of the cliff or beach by eroding sand, rock, and soil over long periods of time.

[109] L. Bedsworth, D. Cayan, G. Franco, L. Fisher, and S. Ziaja. 2018. *Statewide Summary Report. California's Fourth Climate Change Assessment*. California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission. Publication number: SUMCCCA4-2018-013.

Beach erosion - USGS scientists predict that **without human intervention, 31 to 67 percent of Southern California beaches may become completely eroded** (up to existing coastal infrastructure or sea-cliffs) by the year 2100 under scenarios of SLR of 1 to 2 meters.[110]

Cliff retreat – As seas rise, cliffs retreat. "**Bluff retreat projections by 2100 are 32.8–98.4 feet for SLR ranging from 3.4–6.6 feet**, with an increase in retreat rates of 180 percent for the 6.6-foot SLR scenario as compared to the historical rates in Southern California. Lower SLR scenarios result in less, but not insignificant erosion: for example, 1.6 feet of SLR results in 46 feet of beach loss and 36 feet of cliff retreat. An additional 55.8–118.1 feet of beach erosion was predicted during the storm simulations."[111]

SHS IMPACTS

While there are yet no significant impacts to the SHS from SLR alone, there have been several incidents that suggest what these impacts might be. The following descriptions were reported by several Caltrans districts in their Vulnerability Assessments:

- District 7: In 2010, high surf conditions damaged the Pacific Coast Highway (PCH), including drainage infrastructure and rock slope shore protection. Other storm events have led to erosion, scour, and washouts on the PCH:
    - A heavy storm event caused scour to the Trancas Creek Bridge, which exposed the bridge's footings. Following an inspection, the bridge was found to be scour-critical and vulnerable to a 10-year storm.
    - Wave run-up led to erosion of the embankment between the PCH and Las Tunas State Beach.
- District 11: District 11's portion of I-5 is located mainly in the coastal zone and crosses several lagoons, rivers, and creeks. The interstate has recently experienced erosion from storm surge where it crosses coastal lagoons.
- District 12: SR 1 flooded in 2008 due to high water levels during a storm event.

ADAPTATION AND RESPONSE STRATEGIES FOR COASTAL EROSION

Typical adaptation and response strategies used to harden the coastline and protect the SHS from SLR-related flooding and erosion are shown in Table A-1, which also

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[110] US Geological Survey (USGS). 2017. Disappearing beaches: Modeling shoreline change in Southern California. Retrieved May 10, 2020 from https://www.usgs.gov/news/disappearing-beaches-modeling-shoreline-change-southern-california

[111] P. Barnard, L. Erikson, A. Foxgrover, J. Hart, P. Limber, A. O'Neill, M. Ormondt, S. Vitousek, N. Wood, M. Hayden & J. Jones. 2019. "Dynamic flood modeling essential to assess the coastal impacts of climate change." *Scientific Reports* 9–4309. Retrieved May 10, 2020 from https://www.nature.com/articles/s41598-019-40742-z

indicates the type of coastal hazard it can be applied to. While "grey infrastructure," or engineered solutions, are standard responses to coastal hazards, the State of California has begun to emphasize the importance of minimizing hardened approaches and to use more "green" or natural infrastructure solutions. For the purposes of this report, the following strategies should be considered as various tools within a menu of options that will likely be used in conjunction with one another as well as with natural infrastructure strategies.

One of the key considerations in adaptive designs (and in choosing which designs to pursue) is accounting for the uncertainty in future directions. We know with some certainty the direction of change but are uncertain about the magnitude. This uncertainty makes it challenging and essentially risky to plan for a specific amount of SLR. One should consider a range in values. This puts an emphasis on strategies that perform well under a wide set of circumstances. Natural infrastructure adaptations often perform well under such range.

TABLE A-1: COASTAL HAZARD TYPES ADAPTATION AND RESPONSE STRATEGIES

ADAPTATION AND RESPONSE STRATEGIES	APPLICABLE COASTAL HAZARDS			
	Sea Level Rise	Storm Surge	Beach Erosion	Cliff Retreat
Sea Walls and Bulkheads	●	●	▪	●
Revetments and Slope Erosion Protection	●	●	▪	●
Groins and Jetties	●	●	●	●
Living Shorelines / Shoreline Stabilization	▪	●	●	●
Living Breakwaters & Reefs	●	●	●	●
Barrier Islands	●	●	●	●
Maritime Forests	▪	●	▪	●
Sand & Rock Beaches	▪	●	●	●
Dunes	●	●	▪	▪
Seagrass Beds	▪	▪	●	▪

NOTE 1: NATURAL INFRASTRUCTURE SOLUTIONS ARE INDICATED IN GREEN

ENGINEERED STRATEGIES

Sea Walls and Bulkheads

--Sea Level Rise --Storm Surge --Cliff Retreat

Sea walls and bulkheads are structures built to protect an asset and generally resist the forces of wave erosion. They tend to be either massive concrete or engineered fill structures (sea walls) or a retaining structure to support an asset subjected to somewhat lower levels of erosive force (bulkhead). Consequently, sea walls are typically more massive and more capable of resisting greater wave forces than a bulkhead. Design parameters for these types of facilities are well established (scour depth, design wave energy, etc.); however, for resilient design and adaptation, assumptions should incorporate updated parameters based on the anticipated conditions for the future. Based on the variability of the coastline conditions, these structures must be designed on a site-specific basis to ensure that they are appropriately incorporated into a given site.

Revetments and Slope Erosion Protection

-- Sea Level Rise --Storm Surge --Cliff Retreat

Revetments and slope armoring are among the most common engineered protection actions in a coastal zone. Benefits include long-term protection for a specific facility, as well as the traveling public. Large rock slope protection is the most widely used and tested method. The key elements include placement of core rock to provide the structural core of protection and placing large stones, boulders, or rip rap as the outer protective layer for the installation. Design parameters for these types of facilities are well established (scour depth, design wave energy, etc.). For resilient design and adaptation designs, design assumptions and parameters should be updated based on anticipated conditions in the future.

Groins and Jetties

--Sea Level Rise --Storm Surge --Beach Erosion --Cliff Retreat

Groins and jetties typically extend into the sea adjacent to a road or highway. These structures are used to encourage beach formation by trapping sand transported by near-shore currents. These structures accumulate sand on the "upstream" side as the structure intercepts sand being transported along the shore from repeated wave action. Through such accumulation, the structures protect against SLR, storm surge, beach erosion, and cliff retreat. Site-specific considerations become important in designing these structures as the direction of littoral drift can change along the coastline. Another consequence of interrupting the littoral drift is that erosion nearly always increases downstream of the structure as the sediment that normally protects that part of the coast is being removed from circulation as it accumulates on the upstream side. Careful planning of downstream consequences is important to the overall success of a given design. As with other engineered solutions, design parameters for these types of facilities are well established; however, for resilient design and adaptation, assumptions should incorporate updated parameters based on the anticipated future conditions.

NATURE-BASED SOLUTIONS

The following natural infrastructure solutions identify various nature-based strategies that can help protect the SHS from SLR, storm surge, and erosion. While the strategies may serve to reduce damage and slow natural processes, including rising seas, beach retreat, and cliff erosion, none of the strategies can stop these ecological occurrences from happening entirely. The various natural design strategies can assist asset managers in mitigating the impacts of these natural events, thereby reducing costs and quality of life implications.

Given that the strategies will have different effects at different sites, they need to be implemented across California's widely variable coastline in site-specific ways. A critical step in the process of determining which strategies are most suitable is assessing shore and coastal conditions, including seasonal temperatures, submarine and upland topography, and beach and cliff profiles.

SR 1 Prior to Realignment

SR 1 After Realignment

FIGURE A- 2: RELOCATION OF SR 1 AWAY FROM COAST, DISTRICT 5

Where one segment of coastline may have the appropriate width of shore for dunes and a living shoreline, another segment may have a steep cliff profile where only a seagrass bed and oyster reef may be deployed. For the purposes of this report, the following strategies should be considered as various tools within a toolbox that are often used in conjunction with one another as well as with engineered “grey” infrastructure.

Living Shorelines / Shoreline Stabilization

-- Storm Surge --Beach Erosion --Cliff Retreat

Living shorelines often combine several nature-based strategies to create a shoreline that captures the benefits of natural infrastructure solutions for coastal protection. These shoreline stabilization combinations are site-specific and may include different types of vegetation. Living shorelines can also take a hybrid approach and combine green and grey infrastructure (structures, armatures, aggregates and geotextiles) where appropriate.[112] Living shorelines are most effective when they use native vegetation and are designed in such a way to blend with their surrounding ecosystem.

Shoreline vegetation can provide benefits to coasts during both storm and non-storm conditions by dissipating wave energy, reducing water velocity, reducing flood depth, and minimizing net sediment loss. The vegetation thereby reduces flood and erosion risk while increasing infiltration in these coastal areas in a managed approach. Marshes reduce storm surge by lowering wave heights further inland, slowing the flow of water

[112] FHWA. 2019. Op cit.

traveling across the vegetation, and trapping sediment so that land loss is mitigated. Marsh vegetation can provide the maximum benefit when water levels are below the tops of the plants. When marshes are submerged, they are less effective at attenuating waves and reducing flood depth.

Living shorelines protect against damage caused by SLR and erosion by buffering wave energy and increasing the shoreline elevation through sediment deposition from tidal waters.[113] The effectiveness of living shorelines depends on their component strategies. For example, the effectiveness of a marsh for reducing wave heights is influenced by the horizontal distance (between asset and water) covered, proving to be not as effective if water levels are above the target asset's elevation. Generally, living shorelines require little maintenance after establishment and are less costly than grey infrastructure alternatives.[114]

Case Study: Cardiff Beach Living Shoreline Project in Encinitas, CA

The Cardiff Beach Living Shoreline Project is a hybrid coastal protection project in Encinitas, CA. The shore that runs between Restaurant Row and South Cardiff State Beach is vulnerable to coastal flooding during storms. Sea level rise is projected to increase damage and vulnerability of the beach and upland infrastructure. This project combines dune restoration with buried rip rap to protect Highway 101 from storm damage. The project involves updating existing rock revetments, adding cobble materials in front of the rip rap, building sand dunes, and planting dune species to increase dune stability. Sand for the dune restoration is sourced from dredging in the San Elijo Lagoon. Additional project benefits include bolstering coastal dune habitat and creating a pedestrian path along the beach.

Living Breakwaters & Reefs

-- Sea Level Rise -- Storm Surge -- Beach Erosion -- Cliff Retreat

Similar to living shorelines, living breakwaters are designed to attenuate wave energy by creating an offshore barrier that reduce the effects of flooding and erosion, particularly during storm events. 'Living' breakwaters differ from traditional breakwaters in that they are made of natural habitat components, including places for oyster and hard coral colonization and space for other marine and aquatic species to shelter and find food. Some living breakwaters can also grow vertically as sea level rises.

[113] National Oceanic and Atmospheric Administration (NOAA). n.d. Living Shorelines. NOAA Habitat Blueprint. Retrieved May 10, 2020 from https://www.habitatblueprint.noaa.gov/living-shorelines/

[114] FHWA. 2018. Nature-Based Solutions for Coastal Highway Resilience. Report FHWA-HEP-18-037. Retrieved May 10, 2020 from http://media.coastalresilience.org/SC/FHA_Coastal_Highway_Resilience.pdf

Offshore reefs can significantly attenuate waves through transmission, breaking, and energy dissipation due to friction. Reefs may also modify sediment erosion and distribution patterns by reducing wave height. While they do not directly reduce storm surge, they can change mean water level due to wave breaking. Reefs may be completely submerged (subtidal) or submerged only at high tide (intertidal). Both subtidal and intertidal reefs perform similarly to breakwaters in terms of wave transmission and wave attenuating capabilities. However, while reefs do not substantially reduce storm surge, they can contribute to changing the sea levels due to wave breaking.[115] Living breakwaters and reefs help promote a layered system of defense, restoration, and habitat-enhancing features that reduce coastal risk and erosion from wave energy and slow the impact of rising water levels.

Barrier Islands

-- Sea Level Rise -- Storm Surge -- Beach Erosion -- Cliff Retreat

Barrier islands are generally long stretches of sandy land that run parallel to the mainland, thereby serving as a layer of protection providing wave attenuation and/or dissipation and reducing mainland exposure to severe storm impacts.[116] They are the first line of defense in extreme weather events, absorbing the initial force of storms while also providing shelter for estuaries and marshes between islands and the mainland.[117]

Barrier islands shift in size and shape over time, constantly forming and reforming in response to wave action. New islands may emerge and disappear as sea levels rise and fall or when sediment deposition raises the ocean floor. While the islands themselves are adaptable, any built structure on the island could very well be washed away as sea levels rise and storm events increase in intensity.

Maritime Forests

- Storm Surge - Cliff Retreat

Maritime forests refer to upland coastal areas largely composed of trees, bushes, and other plants. The salt-tolerant, wooded habitats contain many mammals, reptiles, birds, and other animals while providing a transitional protective zone along the shore to bordering natural and developed areas. They act as a windscreen and mitigate the force of waves hitting the coast.

While there are few tools to predict how maritime forests affect wave and storm surge, some studies suggest that maritime forests can reduce wave height and attenuate and/or dissipate wave action at the shore. The effectiveness of forests to reduce wave height and storm surge depends on the width of the forest along the coast.

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[115] ibid.

[116] U.S. Army Corps of Engineers. 2013. Coastal Risk Reduction and Resilience. Civil Works Directorate. Retrieved May 10, 2020 from https://www.swg.usace.army.mil/Portals/26/docs/PAO/Coastal.pdf

[117] World Economic Forum (2018). Barrier islands protect coastlines – but they are also vulnerable. Retrieved May 10, 2020 from https://www.weforum.org/agenda/2018/09/barrier-islands-protect-coastlines-but-they-are-also-vulnerable/

As sea levels and shorelines change over time, so too will the footprint of maritime forests, which migrate to maintain upland conditions while remaining within the sea's saltwater spray, tolerant to periodic inundation. Root systems of maritime forest plants help stabilize the shoreline at sea level and atop cliffs by trapping sediment and conserving nutrients and groundwater in the soil. Though the greatest coastal erosion typically occurs at cliffs where there is relatively deep water nearshore and waves hit land at a relatively high angle, the vegetative cover of maritime forests can act as a sediment binder upland to resist erosion and keep cliffs intact longer than barren cliffs and upland areas.[118]

Sand & Rock Beaches

-- Storm Surge -- Beach Erosion -- Cliff Retreat

Beaches can serve as a coastal buffer in protecting upland infrastructure and habitat by slowing waves at the shoreline and inland water transfer. During a storm, the beach serves as erodible material when storm water levels are at or below the beach berm elevation. As the beach berm becomes submerged, the beach dissipates wave energy through friction and wave breaking. Projects have demonstrated that a wider beach with higher berms can be effective at reducing damage to infrastructure by reducing flooding on the mainland. Thus, beach widening through nourishment (the process of pumping sand or sediment directly onto or adjacent to an existing, eroding beach) can be an effective way to increase this protection.

"Pocket beaches" are small beaches between headlands or bluffs formed to control shoreline position and prevent erosion and beach loss through sediment accretion. "Cobble beaches" use rock, driftwood and other natural materials to break up the energy of waves and slow erosion of beaches and cliffs.

Dunes

--Sea Level Rise -- Storm Surge

Dunes, and particularly vegetated dunes, provide protection during storm events by dissipating wave energy and reducing storm surge flooding and saltwater intrusion behind the dunes. As with beaches, dunes also consist of a reservoir of sand that protects upland infrastructure until the dune is overwashed. The volume of sand above water levels and the elevation of the crest are the two key characteristics relating to their protective capacity. A higher cross-shore area between any development and the shoreline and higher crest elevation will provide greater protection against waves and winds, though even low dunes have been seen to protect up to nearly 1,000 feet of lowlands behind them.[119]

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[118] R. Morton. 2003, "An overview of coastal land loss with emphasis on the southeastern United States," U.S. Geological Survey

Open File Rep., 03-337. Retrieved May 10, 2020 from https://pubs.usgs.gov/of/2003/of03-337/landloss.pdf

[119] Governor's Office of Planning and Research, California Energy Commission, and California Natural Resources Agency. 2018. California's Coast and Ocean Summary Report. California's Fourth Climate Change Assessment. Retrieved May 10, 2020 from https://www.energy.ca.gov/sites/default/files/2019-11/Statewide_Reports-SUM-CCCA4-2018-011_OceanCoastSummary_ADA.pdf

Studies suggest that vegetated dunes can decrease erosion and retreat rates by providing sand storage and by transporting surplus sediment to sand bar systems that in turn induce wave breaking further offshore, thus reducing destructive forces onshore. Vegetation can trap deposited sediment and contribute to the overall growth of the dune while providing habitat and inland protection against salt water intrusion and windy conditions. Dunes provide the added benefits of water filtration and sediment storage, which aid in reducing storm surge-related damage and contamination.[120]

Seagrass Beds

-- Beach Erosion

Seagrasses and flowering plants that carry out their entire life cycles underwater are only found in shallow waters where photosynthesis can occur.[121] Seagrass beds and meadows provide important habitat and food for fish; invertebrates; and herbivorous grazers, including turtles and manatees. These ecosystems provide protection to coastal communities by increasing sediment deposition and holding sediment in place thanks to their dense root systems. The grass' vertical structure slows wave velocity and height, acting as an erosion buffer for both beaches and cliffs, preventing erosion by slowing ocean currents and breaking waves further away from the shoreline. As sea level rises, the efficacy of sea grass beds—already minor—will be further reduced.

A.2 LANDSLIDE RISK AND PROTECTION MEASURES

Twenty different types of landslide movements can occur in California, with the most common classifications being earth flows, debris flows, debris slides, rock slides, and rockfalls:[122]

- An **earth flow** occurs when fine-grained soils cohesively flow down a moderately steep slope. These types of slides are typically initiated by periods of prolonged rainfall. Earth flows are slow moving, normally only a couple millimeters or centimeters per day.
- A **debris flow** is characterized by coarse-grained soils that are non-cohesive. These are usually caused by periods of intense rainfall following a period of less-intense precipitation, or by rapid snow melt. These flows move quickly, travel long distances, and can make devastating impacts to infrastructure.
- A **debris slide** is made up of coarse-grained soil that occurs on extremely steep slopes. These slides have a greater mass than debris slides and can move at a rate of meters per week or faster. A heavy rainstorm or series of storms may trigger debris slides.

[120] USDOT FHWA. 2018. Op cit.

[121] Oceana. n.d. Seagrass Bed. Marine Science and Ecosystems. Retrieved May 10, 2020 from https://oceana.org/marine-life/marine-science-and-ecosystems/seagrass-bed

[122] California Department of Conservation. "Landslides." Website. Retrieved May 10, 2020 from https://www.conservation.ca.gov/cgs/landslides

- A **rock slide** is a landslide made up of moving bedrock that occurs on relatively steep slopes. These slides can vary greatly in size and can be triggered by many different factors.

- A **rockfall** is caused when large boulders and rock masses become detached from a steep slope. Where slopes are made of hard and fractured rock, rockfalls can be extremely dangerous. Heavy rain, earthquakes, and frost wedging[123] can trigger these types of landslides.

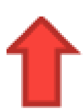
These types of landslides are typically included in landslide inventory mapping, which show past locations of slope failures and landslides. Past events are viewed as one indication of possible locations for future landslides.

phenomena. As heavy rain events and wildfires become more frequent and severe, the potential for triggering landslides increases. This is especially true in the case of the above five landslides as they can all be directly triggered by heavy rainfall.

The sections below summarize general projections of the climate stressors that may contribute to more frequent or severe landslides. The symbols indicate the change in direction of each stressor based on statewide projections over the coming century. An arrow pointing upwards indicates that the trend is increasing, and a question mark notes that the projections are still too uncertain to delineate a clear trend.

FUTURE PROJECTIONS

Future landslide risks were not addressed in the Caltrans Vulnerability Assessments given the limits on data availability. However, such analyses combine landslide susceptibility data with projections of precipitation metrics associated with past landslides in a region. Wildfire burn projections can also be incorporated, given that fires can remove stabilizing surface cover and, in some cases, decrease the ability of soil to absorb water.[124] Even without detailed analyses of future landslide risks, changes in precipitation patterns could be an important consideration in predicting such



- **Wildfire – Acres burned by wildfire has been increasing over the last 30 years and this trend is projected to continue.** Modeled future projections show a "77 percent increase in mean area burned… by the end of the century" under the RCP 8.5 emissions scenario.[125]

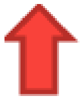
- **Intense, Short-term Rainfall -** California annual precipitation and the intensity of heavy precipitation events have shown no significant trends over the last 100 years, and projecting future changes is uncertain. However, California's Fourth Climate Change Assessment

[123] Repeated freezing and thawing of water that leads to cracking and weathering.

[124] USGS. California Water Science Center. "Groundwater." Website. Retrieved May 10, 2020 from https://www.usgs.gov/centers/ca-water/

[125] Bedsworth et al. 2018. Op cit.

projects with **medium-high confidence that the intensity of heavy precipitation events will increase over time.**[126]



?

- **Prolonged Rainfall** – California's precipitation is already variable, with large annual variation between years. However, if rain is falling in sporadic, heavier events as is predicted for the future, this may lead to less prolonged rainfall. California's 2017 winter is an example of this, as it was characterized by several heavy storm events, rather than prolonged or more consistent precipitation.[127]

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- **Rapid Snowmelt** - Snowpack has been steadily declining over the last 60 years in California as temperatures rise, and has been melting earlier in the year. In addition, the amount of precipitation that falls as snow has been decreasing over time. **Projections suggest that snowpack will continue to decrease, even if overall precipitation increases. Changes to the rate of snowmelt are currently unclear.**[128]

TABLE A-2 provides a summary of the five most common classifications of landslides as described above and the changing climate stressors that can trigger or contribute to the conditions that trigger these types of slides. A more detailed, site-specific analysis would include such factors as slope elevation, soil composition, and seismic activity.

SHS IMPACTS

The California Geological Survey has developed highway corridor landslide maps to better understand SHS landslide risks. These assessments examined highway corridors representing a variety of climate and geological conditions, including: Highway 101 between Wilson Creek and Crescent City, Highway 1 between Point Lobos and San Carpoforo Creek, Highway 60 corridor in Riverside County, Highway 101 between Leggett and Piercy, and I-5 between Valencia and Gorman.[129] Each of these locations described in the report summarized local conditions and risks, and included a series of geologic and landslide maps along each corridor. These landslide hazard maps are currently used by Caltrans engineers, geologists, planners, and maintenance staff to understand and prepare for landslide risks.

TABLE A-2: CLIMATE STRESSORS AND POTENTIAL AS MAJOR CONTRIBUTOR TO LANDSLIDES, BY LANDSLIDE TYPE

LANDSLIDE TYPE	CLIMATE STRESSOR SUSCEPTIBILITY			
	Wildfire	Intense, Short-term Rainfall	Prolonged Rainfall	Rapid Snowmelt
Earth Flow	•	-	•	-

126 Ibid.

127 Ibid.

128 Ibid.

129 California Department of Conservation. 2019. Highway Corridor Landslide Hazard Mapping. Website. Retrieved May 10, 2020 from https://www.conservation.ca.gov/cgs/reviews/highways

Debris Flow	●	●	●	●
Debris Slide	●	●	●	-
Rock Slide	-	●	●	●
Rockfall	-	●	●	-

Caltrans district staff have reported a range of landslide-related impacts to the SHS in the District Vulnerability Assessments. These impacts have included damage to highway signage and guardrails, road closures, debris removal, undermining of roadbeds, debris collection in drainage infrastructure, and pavement impacts from falling rocks and debris. Some notable examples highlighted in the Caltrans Vulnerability Assessments were:

- District 9: SR 58 was closed in 2015 when the largest mudslide in District 9 in the past 15 years covered the road, trapping many cars and trucks. The depth of the mud varied from 2 feet to 12 feet along the 3,000 feet section of road affected by the closure.
- District 2: The Big French Creek Slide on Route 299 forced continued road closures over 2016 - 2017. The varied weather and the geologic nature of the landslide resulted in different types of incidents, including a series of rock slides occurred during heavy rains. Debris had to be removed from the roadway, catchment areas at the bottom of the slope excavated, and a large wall was constructed between the catchment area and the highway to catch debris.
- District 3: The 2016-2017 wet winter led to a spike in Director's Orders to respond to events triggered by heavy rain and snow. One of these events included a slip out on Route 50 near Bridal Veil Falls, which shut down both westbound lanes.

ADAPTATION AND RESPONSE STRATEGIES

The following section provides several strategies for mitigating and responding to landslides given potential changes in the climate stressors. Different types of landslides are susceptible to multiple climate stressors as well as other factors. Thus, designing an appropriate adaptation strategy is not as simple as mitigating one climate stressor. For example, addressing drainage issues on a slope susceptible to debris slides does not mean that the risk has been eliminated. Adaptation and response strategies should be applied addressing all climate stressors, current slope conditions, and other factors that may trigger a slide.

Tables A-3 and A-4 show different types of strategies based on current engineering practice as well as natural infrastructure options that Caltrans can apply in landslide risk areas.

TABLE A-3: APPLICABLE LANDSLIDE TYPES FOR ADAPTATION AND RESPONSE STRATEGIES

ADAPTATION AND RESPONSE STRATEGIES	APPLICABLE LANDSLIDE TYPES				
	Earth Flow	Debris Flow	Debris Slide	Rock Slide	Rock Fall
Enhanced Drainage	●	●	●	●	●
Debris Flow Catchment	-	●	●	▪	▪
Reduction of Driving/Resistance Force	●	-	●	●	●
Subsurface Drainage	●	●	●	●	●
Vegetation and Seeding	●	●	-	-	-
Bioengineering and Biotechnical Stabilization	●	●	-	-	-

TABLE A-4: CLIMATE STRESSORS MITIGATED BY ADAPTATION AND RESPONSE STRATEGIES

ADAPTATION AND RESPONSE STRATEGIES	MITIGATED CLIMATE STRESSORS			
	Wildfire	Intense, Short-term Rainfall	Prolonged Rainfall	Rapid Runoff
Enhanced Drainage	-	●	●	●
Debris Flow Catchment	●	●	●	●
Reduction of Driving/Resistance Force	NA			
Subsurface Drainage	-	●	●	●
Vegetation and Seeding	●	●	●	●
Bioengineering and Biotechnical Stabilization	NA			

ENGINEERED STRATEGIES

Identifying the most effective means of mitigating potential impacts from unstable/erodible slopes depends on understanding the factors that contribute to unstable conditions. In some cases, steep slopes can be stabilized by reducing the slope angle, large earthflows can be stabilized by constructing a toe berm to increase the resistance to sliding, rockfall areas can be draped with wire mesh or stabilized with rock bolts to prevent future rockfall, and erodible soil can be stabilized by planting grasses or native plants creating a root mat that helps hold soil in place. Caltrans has many decades of experience with such strategies. However, given California's breadth of landscape types and changing climatic conditions, new conditions might be faced in the future that should be considered in project designs.

It is important to note that the Caltrans Geotechnical Manual, which lays out the investigation and mitigation of landslides and rockfalls, is the basis for Engineered Strategies.[130]

Enhanced Drainage

--- Intense, Short-term Rainfall --Intense, Short-term Rainfall --Prolonged Rainfall --Rapid Runoff

Rainfall levels and intensity are factors that contribute to slope instability and erosion. Thus, a primary method of resilient landslide design is to provide enhanced drainage and infiltration design. Surface runoff and subsurface groundwater movement can result in soil instability. With sufficient drainage control, these effects can be managed or controlled using engineered solutions or enhanced natural mitigation.

Engineered systems to collect surface runoff are essential elements of safe highway design. Drainage collection designs that concentrate the erosive capacity of surface water flow by focusing the flow into much smaller drainage areas can increase slope instability or denudation. A more resilient system could incorporate both drainage collection and distribution along a highway. This strategy would reduce the potential for washouts. Long-term performance of these drainage systems depends on periodic maintenance to ensure they are operating as designed.

[130] Caltrans. Geotechnical Manual. Chapters updated with different dates. Sacramento, CA. Retrieved May 10, 2020 from https://dot.ca.gov/programs/engineering-services/manuals/geotechnical-manual

FIGURE A-3: RELOCATION OF SR 1 AWAY FROM COAST, DISTRICT 5

Debris Flow Catchment

--Wildfire --Intense, Short-term Rainfall --Prolonged Rainfall --Rapid Runoff

When slopes are subjected to focused and intense rainfall, resulting debris flows can become another type of slope instability. In many cases, by virtue of topographic contours, hillslopes themselves can also collect and focus runoff. This phenomenon is one of the primary causative factors in triggering debris flows. Mitigation of debris flows can be achieved by providing sufficient subsurface drainage to prevent failure conditions from developing. However, in some cases, the source for a debris flow is far from potential impact locations; in such a case, enhancing the drainage design in source areas might be challenging due to cost or access constraints.

Reducing the impacts of debris flows might also involve the construction of debris flow catchment fences across drainage channels to intercept debris flow and stop or slow the flows to reduce or prevent the destructive capacity of the failures (see Figure A-4). This strategy has gained more widespread acceptance in recent years as in-the-field experience has occurred. Similar to drainage systems, maintaining these debris flow mitigation measures is also critical to ensure that they remain effective.

FIGURE A- 4: EXAMPLE OF DEBRIS FLOW DETENTION FENCING AS DESIGNED (LEFT) AND HOLDING BACK DEBRIS FLOW (RIGHT)

Reduction of Driving/Resistance Force

Potential landslides that form by shear failure on a discrete plane or series of planes are usually identified as part of the design process. However, slope cuts and fills that are frequently used in highway construction can activate old dormant slides or slides that had not been identified. Mitigating such slides usually include two types of strategies: either reduce the driving forces causing the failure or increase the resistance forces that govern slide movement. An example of reducing the driving force is to excavate or remove material from the top of a slide mass so that the weight of the slide mass (a driving force) is reduced to arrest movement. An example of increasing the resistance force is to add fill to the base or toe of the slide to increase the weight that resists the forces from above, thus making it harder for the slide to move. Structures such as retaining walls soldier pile walls, soil nails, rock bolts, tie-backs, and other structural means of ground support may also be applicable mitigation measures for stabilization by increasing resistance for a specific slide. These general concepts are useful in many different types of slides.

Subsurface Drainage

-- Intense, Short-term Rainfall --Prolonged Rainfall --Rapid Runoff

Another mitigation method related to rainfall and groundwater, but also to reducing landslide driving forces, is to reduce pore-water pressures or groundwater levels. This is accomplished primarily by providing subsurface drainage (see Figure A-5). Subsurface drainage can be an effective means of stabilizing both small and large landslide locations. By providing drainage, water levels decrease, thus reducing the driving force and increasing the strength of the slide zone.

FIGURE A-5: DRAINAGE TO STABILIZE SLOPE

NATURE-BASED SOLUTIONS

In general, natural infrastructure strategies aimed at preventing slope destabilization do so by mitigating the forces that lead to destabilization, those being primarily erosion and shear forces. Heavy rain events can lead to slope destabilization and erosion, and given that extreme precipitation events are expected to increase in both frequency and intensity with climate change, such conditions will likely increase as well. Natural infrastructure has the potential to reduce slope destabilization and erosion impacts, and Caltrans is already pursuing research and implementation of natural infrastructure approaches. Caltrans has an online Erosion Control Toolbox[131] that provides numerous resources for understanding and implementing erosion control standards and techniques, most of which are nature-based, including preserving existing vegetation; improving soil health; and providing short-term and long-term cover, sediment control, stormwater treatment, planting, and steep slope techniques.

Vegetation and Seeding

--Wildfire --Intense, Short-term Rainfall --Prolonged Rainfall --Rapid Runoff

One set of strategies to reduce erosion is vegetating and seeding slopes. The roots help to hold soil in place and plants help to slow the flow of runoff. However, vegetation cannot prevent deeper landslides, as the main goal with this strategy is to provide soil stabilization – that is, a shallow portion of the slope. Best practices for vegetating and seeding slopes involve the use of native plants and ground cover.[132]

Runoff Management

Vegetation can also manage runoff when placed at the top of a slope or close to the impervious runoff source, thereby intercepting the runoff before it can make it down the slope.[133] Infiltration trenches, diversion berms, and pervious pavement can also

[131] Caltrans. 2019. "Erosion Control Toolbox." Website. Retrieved May 10, 2020 from https://dot.ca.gov/programs/design/lap-erosion-control-design/tool-1-lap-erosion-control-toolbox

[132] Denbow. 2016. Erosion Control on Steep Slopes and Embankments. October 4. Retrieved May 10, 2020 from https://www.denbow.com/erosion-control-steep-slopes-embankments/

[133] EPA. 2014. Op cit.

achieve this effect, especially if the trenches/berms direct any excess runoff away from the slope.[134] Another runoff management technique is soil enhancement: organic matter is more absorbent than inert matter, so increasing the organic matter content of the slope's soil can improve its ability to absorb runoff without eroding. Materials such as compost, aged mulch, manure, and sewer sludge can be used for this purpose.[135]

Bioengineering and Biotechnical Stabilization

The strategies described thus far work to promote slope stability by decreasing soil erosion. Another set of strategies, biotechnical stabilization, has a similar goal, but can often work by creating forces that counteract or otherwise decrease shear forces. For example, adding a berm at the toe of the slope increases downhill weight, creating a counterforce that resists slope failure.[136] Biotechnical stabilization also generally involves a greater level of labor and construction than bioengineering (the use of plant material, living or dead), as biotechnical stabilization can make use of inert structural components, such as terracing, stones, green walls, and geotextiles.

A.3 PAVEMENT DESIGN CONSIDERING HIGHER TEMPERATURES AND OTHER CHANGING CONDITIONS

The implications of adverse weather conditions on pavement condition and performance have been well established through research and field testing. With expected changes in future climatic and weather conditions, the implications to pavement design in California could be statewide and might vary by region. The combined effects of climate change-induced, long-term temperature and precipitation trends are expected to accelerate pavement deterioration and reduce pavement service life. The anticipated impacts to pavement conditions statewide would require earlier, more frequent, and more expensive maintenance and rehabilitation (M&R) actions to restore loss in pavement performance. Further, these impacts could affect the performance of the SHS, which could cause cascading impacts to System users and surrounding communities.

Ensuring that highway pavements remain durable and with good ride quality when exposed to various environmental conditions is an important consideration for Caltrans. With respect to the timing of climate change, potential impacts will occur at different times. Many of Caltrans' assets, including roadways, bridges, and culverts, will likely be in place for a long time. Decisions made today for these types of assets need to incorporate a longer-term view, so that the asset condition and performance lasts over its entire design life. This is not the case for asphalt pavement, which is replaced approximately every 20-25 years or sooner, depending on how quickly pavement condition degrades.

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[134] L. Highland, P. B. 2008. The Landslide Handbook - A Guide to Understanding Landslides. Reston, VA: U.S. Geological Survey. Retrieved May 10, 2020 from https://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf

[135] Caltrans. 2010. Green Technologies for Reducing Slope Erosion. Preliminary Investigation. Retrieved May 10, 2020 from https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/green-technologies-for-reducing-slop-erosion-pi-a11y.pdf, and Denbow. 2016. Op cit.

[136] L. Highland. 2008. Op cit.

FUTURE PROJECTIONS

Temperature and precipitation are the two most important climatic stressors posing a risk to pavement integrity. It is important to note that estimates of how climate change will affect SHS pavement design in the future is contingent upon which Intergovernmental Panel on Climate Change (IPCC) emission scenario is assumed. In addition, given the varying climatic conditions across the State, pavement impacts will differ by region.

With respect to changes in temperature, the 2018 *California Fourth Climate Change Assessment* predicts that if GHG emissions continue at their current rate, California will experience an average increase of 2.7 degrees Fahrenheit from 2006 to 2039, and 5.8 degrees Fahrenheit from 2040 to 2069. If GHG emissions are reduced at a moderate rate, the projections show that California will experience an increase in 2.5 and 4.4 degrees Fahrenheit, respectively.

With respect to changes in precipitation, California's Fourth Climate Change Assessment projects with medium-high confidence that the intensity of heavy precipitation events will increase over time. Cal-Adapt indicates that California will experience an increase in annual mean precipitation, with certain regions of the State expected to experience an increase in more extreme rainfall events. Under a moderate emissions scenario, between 2010 to 2099, California is projected to experience an annual mean precipitation of 25.5 inches, which is 1.7 inches above the historical annual mean of 23.8 inches. Under a high emission scenario, California could experience an annual mean precipitation of 28.2 inches, which is 4.3 inches above the historical annual mean within the same future time frame. That said, to date, there is no consensus on annual precipitation increase or decrease in the future, although current projections show a tendency for the northern part of California to become wetter, and the southernmost portion of California to become drier.[137] No matter the total annual average of rainfall, the scientific community does agree that precipitation is expected to start falling in more sporadic, higher-intensity events.

SHS IMPACTS

To date, no specific instances of climate-change-related impacts on pavement in California have occurred. However, as the climate continues to change, pavement across the State could become more vulnerable to deterioration and damages outlined in Table A-5. In addition to these impacts, pavement is at risk due to changes in the freeze-thaw cycle, which is related to changes in minimum and maximum temperatures.

[137] Bedsworth et al. Op cit.

TABLE A-5: CLIMATE CHANGE INDUCED IMPACTS TO PAVEMENT CONDITION

Stressor	Overall Impact	Detailed Impact
Higher average temperatures	Flexible Pavement	• Increased potential for rutting and shoving • Increased age hardening of asphalt binder
	Rigid Pavement	• Increased potential for concrete temperature-related curling & moisture warping
Higher Extreme Maximum Temperatures	Flexible Pavement	• Increased potential for asphalt rutting and shoving
	Rigid Pavement	• Increased risk of pavement blowups due to excessive slab expansion
More Extreme Rainfall	Decreased pavement stability	• Vulnerable embankment stability • Reduction in structural capacity of unbound bases and subgrade with pavements are submerged
Higher Average Annual Precipitation	Decreased pavement stability	• Reduction in pavement structural capacity due to increased levels of saturation

Source: Dylla, H. and R. Hyman. 2018. "Boosting Pavement Resilience." *Public Roads,* FHWA-HRT-19-001, Issue No: Vol. 82 No. 3, Autumn. Retrieved May 16, 2020 from https://www.fhwa.dot.gov/publications/publicroads/18autumn/04.cfm

ADAPTATION STRATEGIES AND RESPONSES

The following strategies can help protect the SHS from temperature- and precipitation-induced impacts to pavement integrity. The strategies outlined below will have different effects at different sites and should be considered for the SHS in location-specific ways. It is important to note that the pavement design process and materials specifications currently used by Caltrans are appropriate for today's environmental conditions. It seems likely, however, that climate change will require Caltrans to eventually consider changes to this process and specifications.

The consequences of climate change on pavement assets are anticipated to be statewide, often slow- changing, and non-catastrophic. Yet, they impose a persistent pressure on the agency's financial resources, as well as the ability to deliver desired condition levels. An adaptive pavement design process would include the following steps:

1. Evaluate the exposure of pavement assets to the relevant climate stressors in the region.
2. Assess the vulnerability of pavement assets to the adverse effects of these climate stressors in terms of the potential for pavement failure and gradual loss in pavement structural and functional performance.

3. Evaluate the ability of pavement assets, as designed and constructed with current engineering policies, to withstand the adverse effects of expected climate change exposure over the life of the pavement.
4. Identify mitigation measures to improve the adaptive capacity of pavement assets.
5. Implement adaptive measures for pavements in accordance with the agency's pavement management, asset management policies and other relevant decision frameworks.

While the Caltrans Vulnerability and Adaptation studies underway for all Caltrans districts address the needs of the first three steps, this section discusses the last two steps.

ENGINEERED STRATEGIES

Current pavement design approaches recognize the critical role that climate factors play in materials selection, structural thickness determination, and construction practices. 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. An array of incremental measures is contemplated to retard or compensate for climate-induced damage or accelerated deterioration that affects the design, materials selection, construction, maintenance, and rehabilitation phases of pavement design. Adaptation measures could include:

- Review and revise pavement design policies, as necessary, to incorporate future climate projections instead of historical climate records, and increase the design flexibility to incorporate climate uncertainties in decision-making. Specific design-related adaptation measures might include, but are not limited to:
    - Increasing the structural adequacy of the pavement layers to improve resistance against fatigue damage and rutting.
    - Providing a more stable foundation, such as using chemical stabilization, vertical moisture barriers, and geosynthetic reinforcement for base, subbase, and subgrade, to reduce erodibility, soil plasticity, moisture fluctuations, and shrink-swell potential.
    - Improving cross-slope and subsurface drainage systems using a combination of longitudinal, edge and transverse drains, permeable bases, drainage blankets, geosynthetics, and other appurtenances to remove excess moisture, and prevent erosion, infiltration, seepage, and loss of structural support and stability.
    - Incorporating design elements, such as shorter joint spacing and use of tied shoulders or widened slabs in jointed plain concrete pavements, and higher steel reinforcement in continuously reinforced concrete pavements, to improve overall performance.

- Select more durable materials to withstand the adverse effects of future temperature and moisture trends:
    - Increase the high-temperature grade of asphalt binder, as necessary, to improve resistance against rutting and fatigue damage.
    - Increase the use of polymer and additives in asphalt binder to improve resistance against rutting, moisture damage, and oxidative aging.
    - Increase the use of warm mix asphalt to reduce the intensity of asphalt binder age hardening.
    - Expand the use of Performance- Modified Volumetric Design for bituminous mix designs to produce balanced mix designs.
    - Expand the use of optimized concrete mix designs, such as reducing drying shrinkage in dry locations or improving the freeze-thaw durability of hardened paste in colder locations.
- Encourage best practices to improve materials and construction quality:
    - Consider tightening specification tolerances to improve quality outcomes, such as increased density for bituminous lifts
    - Encourage the adoption of best practices for construction and inspection, such as implementing better curing practices to reduce the onset of early permanent curling and shrinkage, monitoring early age behavior of concrete, monitoring thermal uniformity of bituminous materials, monitoring compaction of all pavement layers, and optimizing tack coat application to improve adhesion, etc.

At the broader level of pavement asset management, integrating climate adaptation into such decisions reflects:

- Establishing policies, data needs, and businesses process for adaptation planning.
- Undertaking vulnerability assessments to systematically evaluate the adverse impacts of climate change on pavement's failure potential or reduction in service and incorporating them in pavement asset management decision-making.
- Identifying the type and timing of maintenance and repair (M&R) treatments to ensure adequate adaptive capacity to deliver the desired levels of service at the lowest practicable life-cycle costs.
- Incorporating trade-offs and resource allocation among competing priorities (e.g., among various asset classes), and prioritizing where to invest within the pavement program; and, forecasting long-term financial needs (e.g., contingency set aside for climate change-induced repair work) and the agency's service delivery abilities for future funding levels.

Caltrans' transportation asset management plan (TAMP) identifies climate change as "a looming risk" and recognizes the need to incorporate climate change impacts in pavement life-cycle planning. As Vulnerability Assessments are being completed for the districts, Caltrans should lay the groundwork for increasing the adaptive capacity of pavement assets and incorporate climate risks in asset management decision-making.

While Caltrans' pavement M&R schedules identify life-cycle treatment options based on California roadway classification, climate regions, and pavement types for life-cycle planning purposes, both treatment timing and unit costs in M&R schedules are based on historical pavement condition and climate information. However, as climate-induced, accelerated pavement deterioration warrants earlier, more frequent, and more expensive M&R actions, there is a need for new pavement deterioration models that can capture service life and cost differentials under predicted climate trends, as shown in Figure A-6. Such models can be developed using predicted climate data as well as mechanistic-empirical design models currently implemented in CalME and AASHTOWare Pavement M-E for flexible and rigid pavements, respectively.

Such models are necessary to quantify the potential reduction in service life through deterioration forecasting and inform the timing and type of M&R actions and their associated costs at an asset level. Furthermore, these models are also foundational to incorporating climate risks in life-cycle planning, multi-objective optimization, project prioritization, and financial planning at the network level.

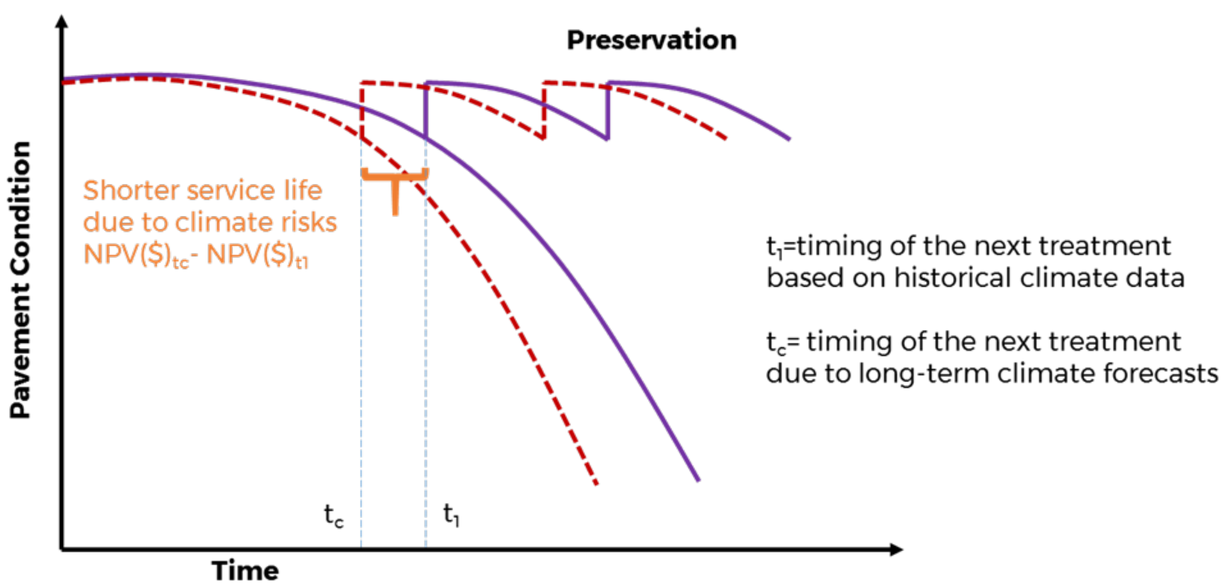

FIGURE A- 6: IMPACT OF LONG-TERM CLIMATE TRENDS ON PAVEMENT PERFORMANCE

A.4 CULVERT REPLACEMENT WITH HIGHER FLOW CAPACITY AND TO ADDRESS DEBRIS CONCERN IN AREAS WHERE WILDFIRES OCCUR

Culvert replacements in California could range from a standard cross drainage culvert up to a larger fish passage design culvert. The timing and reasons for a culvert replacement varies from routine replacements as a component of larger roadway projects, to emergency replacements of at-risk structures (structurally degraded structures or wildfire impacted areas/systems), to regulatory-mandated upgrades to address specific environmental (fish passage) concerns in sensitive environmental systems. Senate Bill 857 Requires that all existing fish passage barriers associated with a culvert or other Caltrans structure be remediated if there is a replacement, repair, or upgrade need. This may preclude replacement in-kind and require upsizing of the facility. This upsizing would address both the issues related to debris flows and climate change (SLR).

Culvert replacement guidelines are defined in Sections 810 and 820 of the Caltrans *Highway Design Manual*. Per the *Manual* "Culverts are usually considered minor structures, but they are of great importance to adequate drainage and the integrity of the highway facility. Although the cost of individual culverts is relatively small, the cumulative cost of culvert construction constitutes a substantial share of the total cost of highway construction. Similarly, the cost of maintaining highway drainage features is substantial, and culvert maintenance is a large share of these costs."

The *Manual* outlines the following primary design frequencies to be considered in culvert design:

- A 10 percent probability flood (10-year storm) with a headwater elevation at or below the culvert inlet top.
- A 1 percent probability flood (100-year storm) without headwaters rising above an elevation that would cause "objectionable backwater depths or outlet velocities."
- At a minimum, the 4 percent probability of exceedance (25-year storm) should be used for the hydraulic design of roadway runoff capture and conveyance for freeways and other highways of major importance (this criterion is not used for cross culverts). Fish passage culverts are designed based upon simulation of the stream geomorphology, with a 100-year flood to not exceed more than 50-percent of the culvert height at the upstream end.
- Culvert replacement to address fish passage barriers are designed based upon simulation of the stream geomorphology, with a 100-year flood to not exceed more than 50-percent of the culvert height at the upstream end and fully span the active channel width. This often results in a small bridge replacement rather than a culvert to address a fish passage barriers.

The *Highway Design Manual* acknowledges that selecting a design flood with a lesser or greater peak discharge may be warranted and justified by economic analysis.

Economic considerations would include the cost of providing facilities to pass peak discharges against potential damage to the highway and adjacent.

FUTURE PROJECTIONS

Section 814.2 of the *Highway Design Manual* discusses the role of rainfall in the estimation of probability-based flood events, specifically discussing the use of statistical analyses of past rainfall records in this process. This guidance assumes that future storm performance will follow historical records in storm patterns. The sections below summarize general projections of the climate stressors that contribute to stream flooding throughout the State and show how variations from the past records could be anticipated. The symbols indicate the change in direction of each stressor based on statewide projections over the coming century. An arrow pointing upwards indicates that the trend is increasing, and a question mark notes that the projections are still too uncertain to delineate a clear trend.

Intense, Short-term Rainfall - California's Fourth Climate Change Assessment projects with **medium-high confidence that the intensity of heavy precipitation events will increase over time.**[138] These storm events influence the hydrologic interactions and peak stream flow conditions on smaller watershed streams that would include culvert crossings.

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Rapid Snowmelt - Snowpack has been steadily declining over the last 60 years in California as temperatures rise and has been melting earlier in the year. In addition, the amount of precipitation that falls as snow has been decreasing over time. **Projections suggest that snowpack will continue to decrease, even if overall precipitation increases. Changes to the rate of snowmelt are currently unclear.**[139] Snowmelt effects dominate peak flooding conditions on many mountainous streams throughout the states; changes to snowpack and melt rates will substantially influence the hydrology of these streams.

Wildfire – Acres burned by wildfire has been increasing over the last 30 years and this trend is projected to continue. Modeled future projections show a "77% increase in mean area burned by the end of the century" under the RCP 8.5 emissions scenario.[140] Wildfire impacts on watershed hydrology and attendant peak flows in streams is extreme.

[138] Bedsworth et al. Op cit.

[139] Ibid.

[140] Ibid.

SHS IMPACTS

Culverts and other cross-drainage systems similarly designed are included in nearly every highway, roadway, and Interstate facility contained in the DOT inventory. The degree of future climate influence on the historic rainfall patterns and the response of peak discharges should be anticipated to vary at different geographic locations and hydrologic regions, including rainfall- and snowmelt dominated flood regions. As discussed in the *Highway Design Manual*, culverts are generally viewed as minor structures. However, the prevalence of culverts combined with the increased vulnerability of infrastructure under changing climate conditions can be anticipated to affect roadways throughout the State. Inadequately sized culverts could cause road overtopping/inundation, increased maintenance requirements for sediment and debris removal, and even roadway failure/breaching if the culvert is washed away or collapses.

Wildfire impacts on watershed and the associated vulnerability of culvert systems are of concern for roadways in wildfire-prone areas of the State. Wildfires are known to have strong influences on peak storm flows and debris flow conditions within streams. The wildfire implications on culverts will vary depending on the size and severity of the fire and the size of the contributing drainage area, but the potential risks should be understood by an engineering practitioner when considering the cost-benefit economics of various adaptive design options.

ADAPTATION AND RESPONSE STRATEGIES

Increased hydraulic capacity is the primary adaptation strategy for future flooding risk at culverts.[141] Hydraulic capacity could be increased by changes in culvert materials (concrete replacing corrugated metal), culvert shapes (boxes replacing pipes), pipe sizes, and number of pipes. Other factors driving hydraulic capacity, including culvert slope, channel bed roughness, and tailwater condition, are expected to be a function of the stream/river systems and not readily modified as part of a culvert replacement program. Under some conditions, an existing undersized culvert may provide the attenuation of peak flood flows to areas downstream of the structure. In these cases, increasing culvert hydraulic capacity could result in increased downstream flooding.

Typically, the replacement of a culvert is anticipated to occur as part of a larger roadway reconstruction project. In such cases, minor increases in culvert costs would likely not represent a substantial impact to an overall roadway reconstruction. As recommended in the *Highway Design Manual*, engineering practitioners should consider the benefits, costs, and consequences of upsized culverts to account for future changes in flows. Unintended consequences of upsized culverts could include increases in routine inspection requirements for large culverts (structures with spans over 20 feet) that fall under the requirements for routine bridge inspections.

[141] Note that such an increase in capacity may only be exercised if it has been determined that in doing so there would be no adverse impacts to private property outside Caltrans R/W. Should any adverse impacts be anticipated to private property outside the R/W resulting from enlarging culverts, then alternative mitigation measures should be considered.

Considering Caltrans standard culvert design options and fish passage remediation designs (including bridges) that require 100-year storm flows to occupy less than 50 percent of the upstream culvert height and fully span the active channel width, it is anticipated that such project design criteria will be adequate for future changes in climatic conditions. However, analysis should be conducted to ensure adequacy to future conditions.

A.5 BRIDGE RECONSTRUCTION (CONSIDERING FUTURE FLOOD LEVELS IN INLAND AREAS)

Bridge replacements follow many of the same considerations as culvert replacements including regulatory requirements such as Senate Bill 857. Following Caltrans inventory criteria, any structure with a span length of more than 20 feet is classified as a bridge. However, for the purposes of this section and following the general discussion of the DOT design manuals, bridges will include any open-bottom structure supported on a foundation, whereas any closed-bottom structure (of any span arrangement) is considered as a culvert. Significant differences between bridges and culverts are principally limited to: a) the size of the structure; b) the exposure of the bridge foundation to scour conditions; c) inclusion of scour protection measures along abutment areas (deeper foundations should be considered when fish passage is a concern); and d) the use of piers at bridges. Under California design standards, a bridge must be designed to pass the design flood with freeboard or the base flood (100-year storm event) without freeboard (freeboard is the clearance between the design water surface elevation and the bottom of the bridge undersurface). New bridge foundations are to be assessed for scour conditions for a design flood and a check flood condition.

The Caltrans *Hydraulic Design Memorandum* outlines the following primary design frequencies to be considered in bridge design:

- Bridges to be sized for conveyance of 50-year flood with freeboard, the 100-year floods without freeboard, or larger if specified by a local flood control agency.
- Bridge foundation design scour to be evaluated for the 100-year flood.
- Bridge foundation check scour to be evaluated for a minimum 200-year flood or a maximum of 500-year flood.

The *Memorandum* recommends that a range of peak flows be considered and that the design flood be established which best satisfies the specific site conditions and associated risks. The *Memorandum* also stresses that every effort must be made, if feasible, to have a bridge that improves the waterway flow area. At many bridges, the abutment may need to be protected with scour countermeasures, including side walls and/or rock slope protection, which will be evaluated against design flood conditions.

Roadway inundation from flood zones can occur when roadways are built parallel to rivers and streams or transect river floodplains. The design standard for the elevation of the roadway above the floodplain is stated in Section 817 of the Caltrans *Highway Design Manual* as the 2 percent chance flood (50-year storm) for interstate highways.

FUTURE PROJECTIONS

Section 814.2 of the *Highway Design Manual* discusses the role of rainfall in estimating probability-based flood events, specifically discussing the use of statistical analyses of past rainfall records for use in this process. This guidance assumes that future storm performance will follow historical records in storm patterns. The sections below summarize general projections of the climate stressors that contribute to stream flooding throughout the State and show how variations from the past records could be anticipated. The symbols indicate the change in direction of each stressor based on statewide projections over the coming century. An arrow pointing upwards indicates that the trend is increasing, and a question mark notes that the projections are still too uncertain to delineate a clear trend.

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Prolonged Rainfall – California's precipitation is already variable, with large annual variation between years. However, if rain is falling in sporadic, heavier events, this may lead to less prolonged rainfall. California's 2017 winter is an example of this, as it was characterized by several heavy storm events, rather than prolonged or more consistent precipitation.[142] Larger river systems (larger bridge crossings) will have peak flow conditions controlled by the sustained inflow conditions from prolonged rainfall and snowmelt, in contrast to smaller systems controlled by short intense storm events.

Intense, Short-term Rainfall -
California's Fourth Climate Change Assessment projects with **medium-high confidence that the intensity of heavy precipitation events will increase over time.**[143]

Rapid Snowmelt - Snowpack has been steadily declining over the last 60 years in California as temperatures rise and has been melting earlier in the year. In addition, the amount of precipitation that falls as snow has been decreasing over time. **Projections suggest that snowpack will continue to decrease, even if overall precipitation increases. Changes to the rate of snowmelt are currently unclear.**[144] Snowmelt effects dominate peak flooding conditions on many mountainous streams throughout the State.

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[142] Bedsworth et al. Op cit.
[143] Ibid.
[144] Ibid.

Changes to snowpack and melt rates will substantially influence the hydrology of these streams.

SHS IMPACTS

California has more than 25,000 bridges throughout the State, with Caltrans owning roughly half of the bridges, but participating in the inspection of all bridges in the State. Bridges are the most expensive and maintenance-intensive elements within any DOT's transportation network. The design, construction, and upkeep of a bridge is 10- to 30-times more expensive than a comparable distance of normal roadway. Following general development patterns, there are more bridges in the most densely developed areas of the State. However, the impacts to bridge structures in more rural areas might be felt more acutely than those in urbanized areas, given that the rural highway network is not as redundant as most urban networks. Disruptions in the rural highway network would be expected to result in long detours.

As with culverts, the vulnerability of bridges will change as precipitation patterns shift over time. The degree of future climate influence on the historic rainfall patterns and the response of peak discharges should be anticipated to vary at different geographic locations and hydrologic regions, including rainfall-dominated flood regions and snowmelt-dominated regions. In the event of increased storm floods, undersized bridges could be washed out, either via enhanced scour and differential settlement of a foundation or washout of a bridge deck from its supports. Other potential impacts could include the washout of abutment protection, resulting in the washout of approach roadways; increased risk of roadway overtopping / inundation (with the potential of stranded vehicles or vehicles swept off flooded roads); closure and detour of roadways; potential damage / breaching of elevated roadway embankments; increased maintenance requirements for debris removal; and increased maintenance needs for the repair of abutment scour countermeasures.

ADAPTATION AND RESPONSE STRATEGIES

Table A-6 shows some of the adaptation response strategies for increased bridge resilience.

TABLE A- 6: SUMMARY OF STRUCTURAL HAZARD ADAPTATION AND RESPONSE STRATEGIES

ADAPTATION & RESPONSE STRATEGIES	**APPLICABLE HAZARDS**		
	Precipitation/ Flooding	**Scour/Erosion**	**Drought**
Enhanced Superstructure Design	●	●	
Increased Freeboard Clearance	●		
Rip Rap, Lining, and Foundations		●	
Channel Design and Monitoring	●	●	●

ENHANCED SUPERSTRUCTURE DESIGN

--Precipitation/Flooding --Scour/Erosion

Bridge superstructures (deck, girders, railing, etc.) can be designed to withstand stream pressures and debris traveling at high velocities—as experienced in severe floods, mudflows and landslides—to increase the structure's ability to absorb or deflect impacts during a high flood or other severe event.

In many cases, increasing the span of a bridge is a good strategy for increased future vulnerability of the bridge. It is, however, the most-costly adaptation option. Increasing the span of bridges addresses vulnerability concerns related to freeboard and overtopping by decreasing the upstream depth of flooding (if not otherwise affected by another downstream backwater limitation), decreases scour concerns by lowering erosive velocities and flow depths, and decreases stresses on scour countermeasure/abutment protections by again lowering velocities. However, this option should be carefully considered if the span increase introduces a bridge pier into the design. If not already otherwise considered for the structure, the inclusion of a pier would represent additional new vulnerability risks for the structure, primarily due to the need to protect the new structural element. If a pier is necessary for widening, the design practitioner should consider other adaptation options prior to recommending the use of a new pier.

Except in some special scenarios, bridges are not designed for lift-off. Lift-off is a rare event where a part of a bridge, usually the superstructure, can lift off from its supports due to water flow. With high velocities, the bridge elements can be taken downstream and are likely to cause additional damage from being tossed around by currents and meandering of the channel or river. Some structure types, such as many precast girders, are prone to lift off as the superstructure is not attached to the substructure, and the majority of bridges are supported on seat-type abutments. One measure to prevent superstructure lift-off is to add anchor rods that provide positive connectivity between superstructure and substructure and prevent lift-off as the water rises and the flow velocities increase

INCREASED FREEBOARD CLEARANCE

--Precipitation/Flooding

As noted earlier, structures are designed to a 50-year flood level with a minimum value of freeboard of 2 feet. Increasing the standard for minimum freeboard clearance will provide a larger opening for water to flow through, thus reducing the flow velocity and decreasing the probability of damage to the bridge. In some cases, where bridge location area is particularly prone to flooding or where the likelihood of significant debris flow is high, structural design may call for more than the minimum freeboard.

Increased levels of bridge freeboard will add resiliency to a bridge by allowing for increased flow depths that do not impact the bridge superstructure/overtop the bridge deck. Additionally, increased freeboard will make a bridge structure more resilient to debris flow conditions, such as may be encountered in watersheds affected by wildfires. However, freeboard increases alone will not provide a notable increase in the structure resilience against foundation scour impacts or against abutment scour and the possible loss of approach roadway fill.

Alternatively, the structure could be designed to pass the 100-year flood level without freeboard. Decreasing the design flood frequency (i.e., designing for a 200-year flood level instead of a 100-year flood level) may also be considered to increase the structure's ability to withstand increasingly severe events.

RIP RAP, CONCRETE LINING, AND DEEP FOUNDATIONS

-- Scour/Erosion

Scour and erosion are chief concerns in areas where high frequency and high levels of flooding are observed or probable. Mitigation efforts are available for erosion and scour, such as rip rap (loose rock, concrete blocks or other material placed along shorelines, slopes and bridge foundations to protect from scour and erosion) or concrete channel lining, to shield bridge foundations from the eroding effects of moving water. The faster the current, the larger the rip rap must be.

In addition, deep foundations, such as drilled shafts or piles, can be used to mitigate the effects of scour and erosion. The deep foundations are designed to extend beyond the anticipated scour depth to provide support in material not susceptible to scour. Shallow foundations, such as spread footings, should be avoided in areas prone to scour unless the footing is sufficiently embedded in material not prone to scouring. Increased foundation depths and increased abutment scour countermeasure protection are measures to help increase a structure's resiliency against increased flood depths and velocities under future conditions. These adaptations could be combined with increased bridge freeboard to provide similar levels of resiliency to that obtained by increasing the span of a bridge.

CHANNEL DESIGN AND MONITORING

-- Precipitation/Flooding -- Scour/Erosion --Drought

Other measures, such as widening or increasing the cross-section of the channel at the bridge location, can help to mitigate impacts of higher flood levels and more frequent events by slowing the velocity of the water flow. Vegetated, sloped banks in channels may also help to slow erosion and absorb increased inundation.

Longer drought periods may be put to beneficial use by ensuring inspections are aligned with seasonal conditions in a way that allows inspectors to evaluate bridge foundations when the river or channel bottom is dried up. Maintenance and implementation of scour mitigation measures can be scheduled during times of lower water levels before scouring becomes unmanageable.

For roads located in chronically flooded areas, options for adaptation / mitigation of roadway overtopping include elevating the roadway, armoring roadway embankments, or relocating the facility outside of the floodplain. The roadway embankment armoring adaptation option does not prevent inundation, but can be successfully used to prevent erosion or breaching of the roadway embankment and the associated longer-term closure of the road.

ADAPTIVE DESIGN

Developing an adaptive structure design could be considered as an intermediate measure for a structure that defers on present-day capital expenditures for more resilient bridges, in lieu of adding design features that more readily allow for structural upgrades in the future to add resiliency when it is needed. This concept could include features such as abutment seats that can be capped and raised, allowing the bridge deck to be raised above future flood levels, or scour protection measures that could readily be strengthened to provide resilience against higher stream velocities.

As recommended for culverts, engineering practitioners should consider economic costs and benefits for bridge adaptation options that consider the benefits, costs and consequences of each option. The largest potential consequence of an oversized bridge structure is the additional capital investment commitment to the structure, which could have been used to upgrade other aspects of the roadway network.

A.6 DRAINAGE AREA ENHANCEMENT CONSIDERING FUTURE FLOOD LEVELS IN INLAND FLOODING AREAS)

The types of strategies included in this category are not often Caltrans' responsibility because the drainage area for water flows leading to its facilities are typically the responsibility of other governments or private citizens. Thus, community-based strategies could include flood-proof development design specifications, standards on impervious surfaces, compensatory storage, multi-purpose water retention facilities, and enhanced storm management designs.[145] Caltrans can play an important supporting role in community strategies for enhanced drainage area designs. However, for those drainage areas for which Caltrans is responsible, natural infrastructure strategies should be part of the actions considered.

[145] Association of State Floodplain Managers (ASFPM). 2013. A Guide for Higher Standards in Floodplain Management. ASFPM Floodplain Regulations Committee. March. Retrieved May 10, 2020 from https://www.floods.org/ace-files/documentlibrary/committees/3-13_Higher_Standards_in_Floodplain_Management2.pdf

FLOODPLAIN CONSERVATION/PRESERVATION

The most efficient and inexpensive natural infrastructure strategy for riverine flooding protection is often floodplain conservation and preservation.[146] Here, an existing natural floodplain is maintained in place to allow for continued delivery of ecosystem services such as flood mitigation. When undisturbed, natural riverine floodplains act as a bathtub to absorb the overflow during floods. These natural floodplains are often inland wetland ecosystems, such as freshwater marshes, swamps, bogs, and fens. Generally, wetlands are an effective option for reducing disaster risk in riverine environments in which semi-aquatic plants slow down the flow of floodwaters, soak them up, and hold soil in place.[147] Because conservation and preservation is a relatively passive strategy that does not involve new construction, there is relatively little cost. There may be an upfront cost to purchase the land and some level of maintenance involved (e.g., regular clean-ups and management of invasive species). However, the avoided costs from mitigating flood losses are generally worth these inputs.

RESTORATION OF INLAND WETLANDS

In areas that have already undergone development, restoring historic wetland ecosystems or creating new wetland ecosystems can bring the same benefits as conservation and preservation. Co-benefits include biodiversity, carbon sequestration, and societal benefits. Wetlands are diverse ecosystems, supporting a wide range of species. Wetland vegetation and sediment trap and store carbon from the atmosphere.[148] [149] Because they can trap sediment and pollution, wetlands can also improve water quality. Having natural areas such as wetlands in communities can provide opportunities for outdoor recreation (e.g., bird watching) and create aesthetically pleasing landscapes. However, because this is a more active strategy that adds natural infrastructure, it is generally more expensive and labor-intensive than conservation and preservation. Both approaches—conserving existing ecosystems or creating new ones—can carry the same flood protection benefits as well as co-benefits.

FLOOD SETBACKS

The use of floodplain ecosystems and wetlands can be combined with the more general risk mitigation strategy of flood setbacks. Flood setbacks establish a minimum vertical and/or horizontal distance between river channels and infrastructure, with the intention to keep the infrastructure out of a likely flood zone.[150] The setback area

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[146] Canadian Council of Ministers of the Environment (CCME) and ICF. 2018. *Best Practices and Resources on Climate Resilient Natural Infrastructure*. Retrieved May 10, 2020 from https://www.ccme.ca/files/Resources/climate_change/Natural_Infrastructure_Report_EN.pdf

[147] Kumar, R. T. 2017. Wetlands for disaster risk reduction: Effective choices for resilient communities. Retrieved May 10, 2020 from https://www.ramsar.org/sites/default/files/documents/library/rpb_wetlands_and_drr_e.pdf

[148] Association of State Wetland Managers. 2019. Carbon Sequestration. Retrieved January 16, 2019, from Association of State Wetland Managers. Retrieved May 10, 2020 from https://www.aswm.org/wetland-science/wetlands-and-climate-change/carbon-sequestration

[149] Kumar. 2017. Op cit.

[150] FEMA. 2018. (March 26). Alteration of a Watercourse. Retrieved May 10, 2020 from https://www.fema.gov/alteration-watercourse

between the river and the infrastructure can be a natural floodplain, achieving the benefits outlined above and protecting the nearby infrastructure from flooding. For example, a combination of a built setback levee (replacing a current, sub-standard levee) and habitat restoration along the Sacramento River in California provided flood protection while restoring 1,361 acres of riparian habitat. This drastically increased the likelihood that nearby Hamilton City would be protected from a 75-year flood event and reduced expected flood damage by more than half a million dollars annually (2004 estimate).[151]

BANK VEGETATION AND SEEDING

On a smaller scale than whole ecosystems, bank vegetation and seeding can introduce natural infrastructure along riverbanks to achieve similar benefits. This strategy involves planting native river plants along riverbanks, which can protect against erosion and decrease the magnitude of floods. The plant roots hold soil in place, while the plants themselves can trap sediment. The plants can also slow the flow of floodwaters. Installing bank vegetation can bring co-benefits similar to those from the use of natural floodplain ecosystems, including carbon sequestration, increased biodiversity, and improved aesthetics.[152] This is also a relatively inexpensive strategy, with costs largely being incurred during installation. Maintenance generally involves regularly monitoring to ensure that the plants are still healthy and in place, and to remove invasive species if needed.

IN-STREAM STRUCTURES

Another strategy to prevent erosion along riverbanks is to install in-stream structures, such as boulders and riffles, to divert water flow and reduce stream velocity. Boulders can lead to riverbed scour, which creates deeper pockets of water, thus reducing velocity in that area. Rock riffles reduce slope grade, which also reduces velocity. In addition, both boulders and riffles can improve fish habitat: boulders can create protected areas for fish, while riffles can increase downstream oxygen levels.[153] These strategies are generally low-cost and low-maintenance: once installed, management largely includes periodic inspections and relocations if necessary.

CHANNELS

The most intensive strategy for mitigating riverine flooding is channelization. Digging a new channel creates an additional passage, thereby increasing the carrying capacity of the river and diverting flow from the main watercourse. Channelization allows for more water to run through the river (instead of out and above during high-volume events) without disrupting the general river flow. Additional benefits from constructing

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[151] The Nature Conservancy. 2014. Reducing Climate Risks with Natural Infrastructure. Retrieved May 10, 2020 from https://www.cakex.org/sites/default/files/documents/CA_Reducing%20Climate%20Risks%20with%20Natural%20Infrastructure_0.pdf

[152] Native Plant Solutions. 2016. Riparian zone restoration. Retrieved May 10, 2020 from https://www.nativeplantsolutions.ca/what-we-do/riparian-zone-restoration/

[153] Massachusetts Department of Environmental Protection. 2002. Boulder Clusters and Rock Riffles, Massachusetts Clean Water Toolkit. Retrieved May 10, 2020 from http://prj.geosyntec.com/npsmanual/boulderclustersrockriffles.aspx

relief channels include habitat creation and enhancement and improved sediment transport.

BIOSWALES, VEGETATIVE SWALES, AND BIORETENTION PONDS

Bioswales, vegetative swales, and bioretention ponds are a class of natural infrastructure strategies that mitigate stormwater flood impacts by serving as an absorbent catchment for the stormwater. The plants act to attenuate water flows and hold soil in place, while the permeable ground cover allows infiltration into the soil, and possibly recharge into the water table. The main difference among the strategies in this class relates to their physical structure: bioswales and vegetative swales have milder slopes, while bioretention ponds are deeper and meant to hold small bodies of water. The two categories can work in tandem, with the swales conveying water into the ponds.

Bioswales, vegetative swales, and bioretention ponds have proven to be effective strategies. For example, a 13-foot swale can reduce about one-quarter of total rainfall runoff.[154] They are also cost-effective and are among the least expensive strategies per volume of runoff treated.[155] Bioswales, vegetative swales, and bioretention ponds can also catch and break down pollutants in stormwater, such as heavy metals. However,

[154] American Society of Landscape Architects. (2018). Retrieved from Professional Practice: Improving Water Efficiency: Residential Bioswales and Bioretention Ponds. Retrieved May 10, 2020 from https://www.asla.org/bioswales.aspx

[155] Caltrans. 2020. Erosion Control Toolbox-Biofiltration. Retrieved May 10, 2020 from https://dot.ca.gov/programs/design/lap-erosion-control-design/tool-1-lap-erosion-control-toolbox/tool-1jj-36-biofiltration

Bioswale Along Interstate 80

This bioswale was created along 80 to treat stormwater, create wetland habitat, and provide a visual transition into the surrounding forest. Used with permission. Image credit: Caltrans Landscape Architecture Program, http://www.dot.ca.gov/hq/LandArch/index_intro_to_la.htm

bioswales, vegetative swales, and bioretention ponds are not well-suited to arid conditions. In these regions, dry swales that use gravel are more appropriate.[156] The University of California, Davis has prepared a native grass database as a tool to help select the most appropriate native grass species for such uses.[157]

TREES

Trees can also help mitigate the impacts of stormwater. Trees planted near transportation infrastructure can intercept and absorb the stormwater through their roots, thereby decreasing the volume of water.[158] Tree roots also hold soil in place and prevent erosion. Key considerations in implementing trees as stormwater management strategies include species selection, planning conditions, and maintenance. When successfully installed, trees can have a variety of co-benefits, including improved air quality, enhanced habitats, mitigation of extreme heat (and therefore, decreased cooling energy usage), and improved aesthetics.

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[156] Ibid.

[157] Caltrans. 2020. Erosion Control Toolbox- Native Grass. Retrieved May 10, 2020 from https://dot.ca.gov/programs/design/lap-erosion-control-design/tool-1-lap-erosion-control-toolbox

[158] Green Infrastructure Ontario Coalition. 2016. Urban Forests. Retrieved May 10, 2020 from https://greeninfrastructureontario.org/urban-forests

A.7 DROUGHT-TOLERANT/FIRE-RESISTANT LANDSCAPING AND IMPLEMENTATION OF DEFENSIBLE SPACE

The 2017 and 2018 wildfire seasons were devastating for California. Multiple fires burned across the State each year, which appeared on CalFire's list of the state's top most destructive and deadly wildfires. The impacts these fires made on the State—in terms of lives lost, level of destruction, air quality impacts, and costs—were of such magnitude that Governor Gavin Newsom signed an EO on his first day in office (January 8, 2019) directing the California Department of Forestry and Fire Protection (CAL FIRE) and other State agencies to provide a report of the most effective policy changes the State could make to mitigate wildfires, while protecting the environment and public health.[159] The EO also called for the report to provide near-, mid-, and long-term recommendations for preventing deadly wildfires. The governor later proclaimed a State of Emergency on wildfires in March 2019.

The CalFire report, released in April 2019 in response to Governor Newson's EP, focused on the threats posed by climate change as a central theme, and noted that "While wildfires are a natural part of California's ecology, the fire season is getting longer every year—with most counties now experiencing fire season from mid-May to mid-December and several counties facing fire danger year-round. Warmer temperatures, variable snowpack and precipitation, and earlier snowmelt caused by climate change make for longer and more intense dry seasons, leaving forests more susceptible to severe fire."[160] The report also made the point that the increasing severity and frequency of large wildfires has a crippling impact on the GHG reduction efforts the State has made to date.

The increasing risk posed by climate change, in addition to other anthropogenic factors, such as more people living in the wildland-urban interface, has serious consequences for the 11 million people who live in high fire-risk areas. Mitigating and preparing for these events has become a critical focus for the State of California and its agencies.

FUTURE PROJECTIONS

The area burned by wildfires has increased with rising air temperatures over recent years, while more and more wildfires occur at higher elevations in the Sierra Nevada than ever before. The expectation is that this trend will continue (with medium-high confidence). A summary of *California's Fourth Climate Change Assessment* wildfire modeling results noted that a 77 percent increase in mean area burned is projected under the high emissions scenario (RCP 8.5) by the end of the century. This is consistent with the modeling results from the Caltrans Vulnerability Assessments, which found that more areas are projected to be burned by wildfires across the State by the end of

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[159] Governor Gavin Newsom, 2019. Executive Order N-05-19. California Office of the Governor. Retrieved May 10, 2020 from https://www.gov.ca.gov/wp-content/uploads/2019/01/1.8.19-EO-N-05-19.pdf

[160] Governor's Strike Force. 2019. "Wildfires and Climate Change: California's Energy Future: A Report from Governor Newsom's Strike Force." April 12 Retrieved May 10, 2020 from https://www.gov.ca.gov/wp-content/uploads/2019/04/Wildfires-and-Climate-Change-California%E2%80%99s-Energy-Future.pdf

century, especially in higher- altitude areas like the Sierra Nevada. That said, there are many uncertainties inherent in projecting future wildfire risk, given that there are many variables to consider, such as: the impacts of fire suppression, changing vegetation over time, massive tree die-off from droughts and bark beetle, and land use changes.

SHS IMPACTS

The following provides a summary of some of the impacts recent wildfires have had on the SHS, as reported by several Caltrans districts in their Vulnerability Assessments:

- **District 3:** The Camp Fire started on November 8, 2018, spreading quickly toward Paradise, California. It killed 86 people and burned 18,804 structures, making it the deadliest and most destructive fire in the State's history.[7] As of November 15, 2018, 42 miles of the SHS were in the Camp Fire perimeter, and major damages occurred on SR 32, 70, 88, 149, and 191 in Butte County.

- **District 7:** In 2017, the Thomas Fire (the second-largest fire recorded in California) burned in Santa Barbara and Ventura County. It started in December and burned close to 300,000 acres, destroyed 1,063 structures, and killed two people before being contained.[8] In the aftermath, heavy rains led to mudslides that triggered evacuations, road closures, traffic accidents, and the death of 21 people.[9] The district was affected by several other major fires in December of 2017, including the Creek, Rye, and La Tuna fires.

- **District 4:** The Tubbs and Nuns fires in Sonoma County and the Atlas fire in Solano and Napa counties represent three of the most destructive wildfires in California history—with a combined 143,000 acres burned, 7,800 structures damaged or destroyed, and 29 lives lost.[10] Various State highways were closed over 16 days during these events, including U.S. 101, SR 121, SR 29, SR 128, and SR 12.

ADAPTATION AND RESPONSE STRATEGIES FOR WILDFIRE

There are several prevention strategies that Caltrans can begin to apply, or expand the application of (if already using these strategies), to mitigate the risk of wildfires adjacent to the SHS.

PREVENTION

The following section outlines some strategies that can be used to prevent wildfires in Caltrans right-of-way and avoid associated damages to the SHS. Caltrans could apply these recommendations under any, or all, the following locations:

1 In mountainous areas, forest-covered lands, brush-covered lands, grass-covered lands, or land that is covered with flammable material as defined in Public Resources Code 4291.

2 In State Responsibility Areas, which are defined by CalFire as "areas where the State of California has primary financial responsibility for prevention and suppression of wildfires."[11]

3 In Moderate, High, or Very High Fire Hazard Severity Zones as defined by CalFire[12] or a local authority having jurisdiction.

4 In Medium (or Moderate), High, or Very High Concern Areas as classified in the wildfire projections created and assessed through the Caltrans Vulnerability Assessments.

DEFENSIBLE SPACE

Caltrans can avoid the ignition of a wildfire, and prevent damages in the event of a wildfire, by maintaining defensible space. Defensible space is a buffer that's created between a building and the vegetation surrounding it. This space slows or stops the spread of wildfire and additionally protects the building from radiative heat impacts.[161] For Caltrans, defensible space could be applied not only for buildings, but along the SHS right of way. In this case, the "building" would be an asset along the SHS (e.g., culvert and guardrail) or the roadway itself.

The State of California requires that defensible space be maintained by "a person who owns, leases, controls, operates, or maintains a building or structure in, upon, or adjoining a mountainous area, forest-covered lands, brush-covered lands, grass-covered lands, or land that is covered with flammable material" per Public Resources Code 4291.[162] This code defines two zones and associated criteria that need to be met within each zone to fulfill the defensible space requirement. These same zones and requirements are succinctly defined on CalFire's "Ready for Wildfire" website[15], and are summarized below as they relate to Caltrans ROW:

- Zone 1: Extends 30 feet[16] from the building/asset:
  - Remove dead vegetation
  - Remove dead or dry debris such as leaves and pine needles
  - Trim trees to keep branches at least 10 feet from other trees
  - Remove branches that hang over the building/asset
  - Remove or prune flammable shrubs nearby the building/asset
  - Remove vegetation and items that could catch fire from under decks
  - Create a separation between vegetation and other items that could catch fire
- Zone 2: Extends 100 feet out from the building/asset:
  - Cut or mow annual grass down to at least 4 inches, if not shorter
  - Create vertical spacing between grass, shrubs, and trees

[161] CAL FIRE. 2019. Maintain Defensible Space. Retrieved May 10, 2020 from https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/

[162] California Legislative Information. Public Resources Code, Section 4291. Website. Retrieved May 10, 2020 from http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=4291.&lawCode=PRC

- Create horizontal spacing between shrubs and trees
- Remove fallen leaves, needles, twigs, bark, cones, and small branches (they can be at a depth of 3 inches).

Caltrans could follow these requirements within its right of way to mitigate wildfire risk. The most precautionary way to do so would be to implement defensible space requirements in each of the four locations defined at the start of the section. Where Caltrans right of way does not extend to 100 feet on either side of the SHS, Caltrans could still create and maintain defensible space up to the property line. Caltrans may even be able to coordinate with neighboring property owners to continue that buffer beyond the public right-of-way.

FIRE-RESISTANT LANDSCAPING

Caltrans can use fire-resistant landscaping along its right-of-way and outside of its facilities to prevent fire ignition, and slow or stop the spread of an existing wildfire. Water conservation is another benefit to using fire-resistant landscaping, as plants that are fire-resistant are typically drought- tolerant natives. Fire-resistant landscaping could be used anywhere in the State, but is especially pertinent in the locations defined above.

CalFire's "Ready for Wildfire" website provides a helpful overview of how to design a fire-resistant landscape. Creating a fire-resistant landscape involves using high-moisture plants that are resistant to ignition and have a low sap content, trees that are less flammable than other species, and rock, mulch, gardens, stone walls, and other landscape features to create fire breaks. CalFire also recommends the following native plant for use in fire-resistant landscapes[163]:

- French Lavender
- Red Monkey Flower
- California Fuchsia
- Sage
- California Lilac
- Society Garlic
- Ornamental Strawberry
- Yellow Ice Plant
- Coreopsis
- California Red Bud

Caltrans can find more specific information on which species to plant depending on geography through local resources, such as a local landscape contractor. More information can also be found at a county-level by referencing the work of, or

[163] CAL FIRE. 2019. Fire-Resistant Landscaping. Website. Retrieved May 10, 2020 from https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/fire-resistant-landscaping/

partnering with, county UC Cooperative Extension services. The UC Cooperative Extension created the *Southern California Guidebook: Sustainable and Fire-Safe Landscapes in the Wildland Urban Interface* as a resource for Southern California homeowners creating fire-resistant landscapes.[164] The guidance document provides helpful information on flammable and invasive species in Southern California that should be avoided, such as:

- Castor Bean
- Artichoke Thistle
- Large Periwinkle
- English Ivy
- Algerian Ivy
- Hottentot Fig
- Eucalyptus Blue Gum
- Scotch Broom
- Spanish Broom
- Black Mustard
- Slender Oat
- Wild Oat
- Cheatgrass
- Red Brome/Foxtail Brome

The *Southern California Guidebook: Sustainable and Fire-Safe Landscapes in the Wildland Urban Interface* also provides a list of fire-resistant and/or native plants to use instead of these problem plants. This guidebook, among other resources from the University of California Cooperative Extension, could be useful references for Caltrans when planting fire-resistant landscapes.

HARDENING

Finally, Caltrans can take actions to prevent ignition and damage to Caltrans buildings and assets by using ember- and heat-resistant materials. Some of these changes are straightforward and are already being implemented by Caltrans across the State. For example, in some cases, Caltrans has replaced plastic culverts with metal ones to

[164] S. Drill, S. Quarles, V, Borel, D. Ready, J. Casanova, J. Todd, and B. Nash. 2009. *S.A.F.E. LANDSCAPES Southern California Guidebook Sustainable and Fire-Safe Landscapes In The Wildland Urban Interface*. University of California Cooperative Extension , Sept. Los Angeles, CA. Retrieved May 10, 2020 from https://ucanr.edu/sites/safelandscapes/files/93415.pdf

prevent them from melting in the event of a wildfire. Caltrans could also replace wooden elements of signs, guardrails, and fencing with metals.

In the case of Caltrans buildings, there are many actions Caltrans can, and does, take to reduce the risk of ignition from an ember and/or radiative heat. In State Responsibility Areas, State buildings are already required to use noncombustible materials and follow other criteria related to mitigating fire risk.[165] Caltrans currently meets these requirements in complying with California's Wildland-Urban Interface Building Code.

The following are several recommendations on how to harden commercial buildings to reduce wildfire risk, from the Insurance Institute for Business and Home Safety (IBHS):

- Use noncombustible materials for all signage
- Use noncombustible exterior wall cladding such as concrete and brick, ensure the start of siding is at least 6 inches off the ground
- Use windows that are dual-paned with tempered glass
- Use 1/8-inch noncombustible mesh screening over vents
- Use noncombustible materials for rooves and gutters, regularly clear these of debris
    - Select noncombustible gutters and downspouts like aluminum
    - Choose Class A fire rated roof covers based on testing to ASTM E108 or UL 790
- Use noncombustible materials for desks, such as lightweight concrete, tile, metal, and fiber cement
- Alternatively, use a combustible product that complies with California Building Code (fire-retardant treated decking that is approved by the State Fire Marshall)

[165] CAL FIRE. 2019. "Wildland Hazards & Building Codes," Website. Retrieved May 10, 2020 from https://osfm.fire.ca.gov/divisions/wildfire-prevention-planning-engineering/wildland-hazards-building-codes/