CAMBRIDGE SYSTEMATICS

Addressing Climate Change Adaptation in Regional Transportation Plans

A Guide for California MPOs and RTPAs

final

report

prepared for

California Department of Transportation

prepared by

Cambridge Systematics, Inc.

with

ESA PWA
W & S Solutions

February 2013

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555 12th Street, Suite 1600
Oakland, CA 94607

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List of Acronyms

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
Caltrans	California Department of Transportation
Cal EMA	California Emergency Management Agency
CEQA	California Environmental Quality Act
CNRA	California Natural Resources Agency
CTC	California Transportation Commission
DEM	Digital Elevation Maps
DOT	Department of Transportation
ENSO	El Niño/Southern Oscillation
EIS	Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FHWA	United States Federal Highway Administration
GCM	General Circulation Model
GDP	Gross Domestic Product
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gases
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
MTP	Metropolitan Transportation Plan
NBI	National Bridge Inventory
NCAR	National Center for Atmospheric Research
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanographic and Atmospheric Administration
OPC	Ocean Protection Council
RCM	Regional Climate Model
RTPA	Regional Transportation Planning Agency
RTP	Regional Transportation Plan
SACOG	Sacramento Area County of Governments
SANDAG	San Diego Association of Governments
SB 375	Sustainable Communities and Climate Protection Act of 2008
SCAG	Southern California Association of Governments

SCS	Sustainable Communities Strategy
SRES	IPCC Special Report: Emissions Scenarios
TRB	Transportation Research Board
USGS	United States Geological Survey

Executive Summary

The reality of a changing climate means that transportation and planning agencies need to understand the potential effects of changes in storm activity, sea levels, temperature, and precipitation patterns; and develop strategies to ensure the continuing robustness and resilience of transportation infrastructure and services. This is a relatively new challenge for California's MPOs and RTPAs – adding yet one more consideration to an already complex and multifaceted planning process. In that light, this guide is intended to support planning agencies in incorporating the risks of climate change impacts into their existing decision-making, complementing the broader planning and investment processes that MPOs and RTPAs already manage.

This guide was designed to account for the varying capacities and resources among MPOs and RTPAs, featuring methods that can be used by organizations seeking to conduct a more sketch-level assessment of the risk and vulnerability of the regional transportation assets to climate impacts, or in-depth analysis that incorporates separate stakeholder processes and geospatial analyses. It is oriented to provide information for two types of audiences.

- A Basic User, a MPO or RTPA conducting climate impact assessments and/or climate vulnerability and risk assessments for the very first time. This pathway is appropriate for agencies with limited resources and GIS capability.
- An Advanced User, a MPO or RTPA that has experience with climate impact assessments, has strong interagency partnerships with universities, natural resources agencies or public works departments and have more staff resources and technical tools to dedicate to the effort.

For both of these user types, this guide is a resource to help MPOs and RTPAs to:

- Assess the relative risks to their transportation system infrastructure and services of different climate stressors (sea-level rise, temperature changes, precipitation changes, extreme weather events);
- Conduct an asset inventory and vulnerability assessment of existing infrastructure;
- Incorporate climate impact considerations into future long-range transportation planning and investment decisions.

Currently, there is no requirement to date to incorporate climate adaptation into regional transportation planning. Nevertheless, this guide provides information and tools to help MPOs/RTPAs anticipate the incorporation of climate assessment and adaptation into future planning efforts.

PART I. BACKGROUND INFORMATION

1.0 Introduction

1.1 Purpose of this Guide

California is susceptible to a wide range of climate change effects, including increase in temperatures, earlier snowpack melt, changed precipitation patterns, increased severity of wildfires, sea-level rise, extreme weather events, and numerous changes and effects on biodiversity and habitats. The *2010 California Regional Transportation Plan Guidelines* issued by the California Transportation Commission highlights only brief information on the adaptation of the regional transportation system to climate change.[1]

Through Senate Bill 375, transportation and land use have become increasingly linked with climate change mitigation, or managing the reduction of greenhouse gases (GHG). However despite the legislative requirement surrounding climate mitigation, Caltrans is also focused on addressing climate change adaptation, or efforts that respond to the *impacts* of climate change, and would like to support the metropolitan planning organizations (MPOs) and regional transportation planning agencies (RTPA) to do the same.

The Cal-Adapt web portal and the recently published draft *California Climate Change Adaptation Policy Guide* by the California Natural Resources Agency (CNRA) produces a set of reliable climate information to assist MPOs and RTPAs in addressing climate change in regional transportation plans and metropolitan transportation plans (this document will refer to both as RTPs). However, there is still a gap in linking statewide climate information to transportation planning.

This guide helps MPOs and RTPAs in California to better incorporate climate assessment and adaptation into the long-range planning process. This guide provides information for MPOs and RTPAs to make a preliminary assessment of the main climate impacts in their regions, with the opportunity to delve into more rigorous analysis by incorporating local data and information and identifying resources for in-depth analysis.

Although there is no requirement to date to incorporate climate adaptation into regional transportation planning, this guide provides information and tools to help MPOs/RTPAs anticipate the incorporation of climate assessment and adaptation into future planning efforts.

[1] Section 6.30, *Adaptation of the Regional Transportation System to Climate Change*.

1.2 The Primary Audience: MPOs and RTPAs

Regional transportation planning is long-range (20+ years), areawide planning with the purpose of guiding the region's transportation system development in a fiscally and environmentally responsible manner, consistent with the needs, preferences, and sensibilities of the community. Among the key regional transportation planning entities in California are 18 MPOs and 26 RTPAs[2]. Every county in California is served by a RTPA and every county with at least one urbanized area is also served by a MPO.

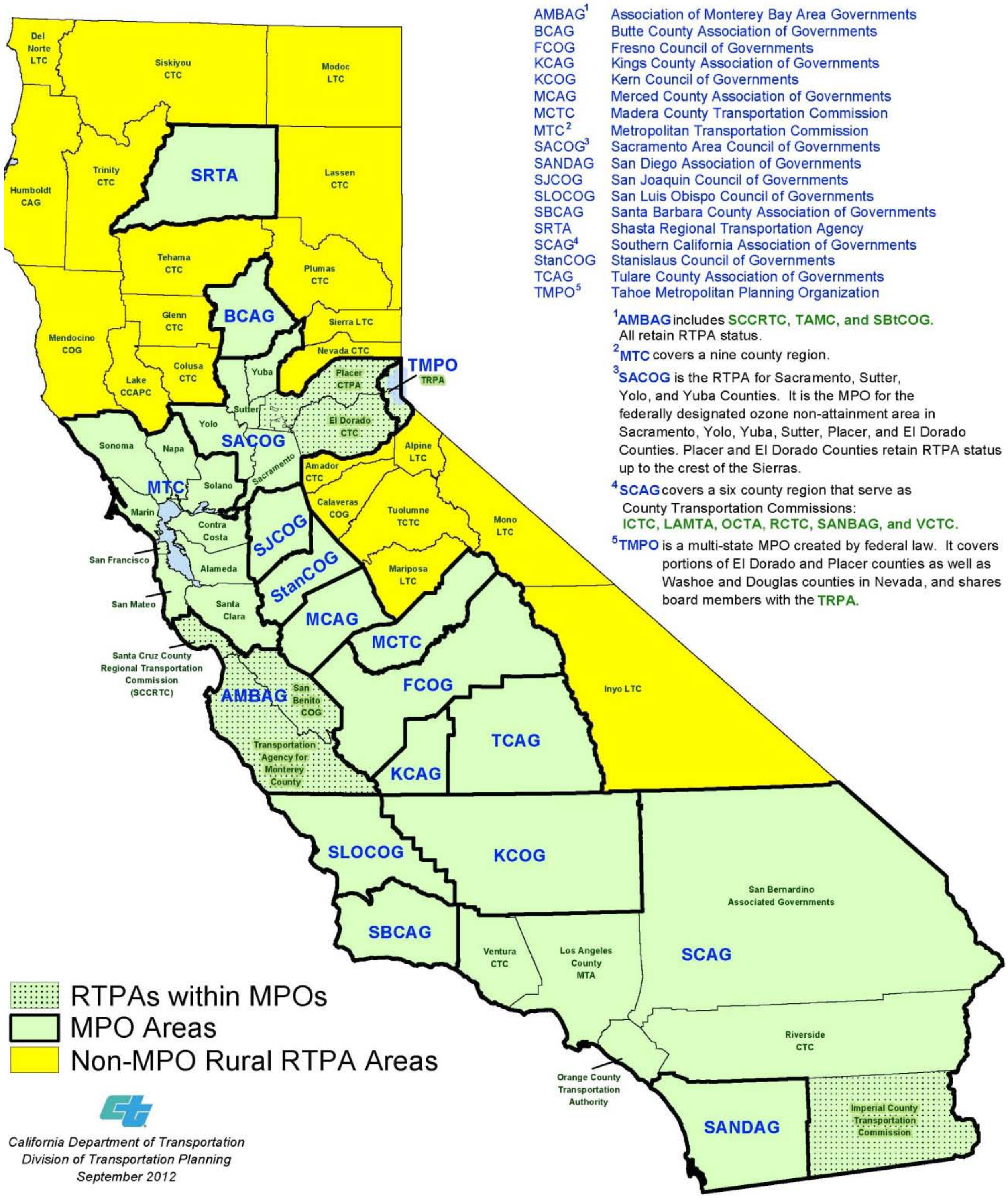
Federal law [Title 23 United States Code Section 134] defines a MPO as a forum for cooperative transportation decision-making. A MPO covers an urbanized area over 50,000 in population, but a single MPO may serve more than one urbanized area. MPOs are generally known in California as councils of government or associations of government. RTPAs are local transportation commissions, county transportation commissions, councils of government, and associations of government.

Figure 1.1 provides a map of California MPOs and RTPAs.

This guide is intended to provide California MPOs and RTPAs with an overview of climate adaptation, suggested data and information that can help them incorporate climate adaptation into the regional planning, and to provide a step-by-step process for those MPOs/RTPAs which would like to incorporate climate risks into their regional plans.

[2] http://www.dot.ca.gov/hq/tpp/offices/orip/.

Figure 1.1 Map of California MPOs and RTPAs



Source: Caltrans, 2012.

1.3 Data Sources and State-Level Guidance

Although there is currently no requirement at the federal or state level for including climate adaptation into the regional transportation planning process, the consideration of climate change is important in practicing good planning. This document refers to three levels of documentation that are used as data sources endorsed by the State of California and best practices information.

- **Federal Highways Administration (FHWA) and Federal-Level Guidance.** In general, activities to plan, design, and construct highways to adapt to current and future climate change and extreme weather events are eligible for reimbursement under the federal-aid program and for funding under the Federal Lands program. However, program funds are limited and their use for adaptation purposes should be considered as a cost-effective means to extend and preserve the useful life of federal-aid and Federal Lands highway facilities. This section provides high-level summary documentation that MPOs and RTPAs should be aware of at the federal level.
- **Caltrans and State-Level Guidance.** The State of California addresses adaptation to climate change through its California Climate Adaptation Strategy and Adaptation Planning Guide (APG). The APG provides a decision-making framework intended for use by local and regional stakeholders to aid in the interpretation of climate science and to develop a systematic approach to reducing risks caused, or exacerbated, by climate change. The State's third major assessment on climate change explores local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts. Background data and the latest information can be found on the Climate Change portal: http://www.climatechange.ca.gov/adaptation/.
- **The Cal-Adapt On-line Tool.** The California Natural Resources Agency and the California Energy Commission have released Cal-Adapt, a web-based tool which enables city and county planners, government agencies, and the public to identify potential climate change risks in specific areas throughout California. At the time of writing, this is the pre-eminent statewide tool for climate analysis in California.

Details for the key documents referenced can be found in Table 1.1.

Table 1.1 Key Documents, Data and Sources Used for this Guide

	Title	Summary	Author	Date	Category
1	Eligibility of Activities To Adapt To Climate Change and Extreme Weather Events Under the Federal-Aid and Federal Lands Highway Program	On September 24, 2012 the Office of Planning Environment and Realty, the Office of Infrastructure, and Federal Lands Highway released a guidance memorandum to clarify the eligibility of activities to adapt to climate change and extreme weather events for use of federal-aid and Federal Lands funds. Adaptation involves adjusting the way the transportation community plans, designs, constructs, operates and maintains transportation infrastructure to address the impacts of climate change and extreme weather events. This document provides important information for any project pursuing adaptation strategies.	FHWA	9/24/2012	FHWA and Caltrans Guidance
2	Guidance on Incorporating Sea-Level Rise for use in the Planning and Development of Project Initiation Documents	This guidance is intended for use by Caltrans Planning staff and Project Development Teams to determine whether and how to incorporate sea-level rise concerns into the programming and design of Caltrans projects. Because of the evolving nature of climate change science and modeling, this guidance is subject to revision as additional information becomes available. Although MPO and RTPA planners will not likely need to refer to these documents in the planning process, they will need to consider them at the project level.	Caltrans	5/16/2011	FHWA and Caltrans Guidance
3	2010 Regional Transportation Plan Guidelines	The guidelines reflect recent revisions to address the planning requirements of Senate Bill (SB) 375 (SB 375, Steinberg, Statutes of 2008) and other planning practices. SB 375 targets regional greenhouse gas emission reductions from passenger vehicles and light duty trucks through changes in land use and transportation development patterns. To achieve these changes, the law encourages MPOs to think differently about how communities are designed. As a result, MPOs in partnership with local governments are now required to develop a sustainable communities strategy as part of the transportation planning process for inclusion in the RTP. The 2010 CTC RTP Guidelines provide only general guidance on climate adaptation in *Section 6.30 Adaptation of the Regional Transportation System to Climate Change*.	CTC	4/7/2010	FHWA and Caltrans Guidance
4	State Of California Extreme Heat Adaptation Interim Guidance Document	This guidance provides an overview of current climate projections for increased temperature and extreme heat conditions for California, describes the health effects of extreme heat, and presents recommendations for state and local planners, local governments, emergency response, and public health and health care professionals and institutions.	CEC	8/31/2012	State-Level Guidance
5	California Climate Adaptation Planning Guide (APG)	The APG consists of the Planning Guide overview document and three companion documents for use in various combinations on an as-needed basis. In *Planning for Adaptive Communities*, the basis for climate change adaptation planning is presented. The document introduces a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development. Three companion pieces: *Defining Local and Regional Impacts, Understanding Regional Characteristics* and *Identifying Adaptation Strategies* give more in-depth understanding of how climate change can affect a community, how the impact of climate change varies across the State and explores potential adaptation strategies that	CNRA	7/2012	State-Level Guidance

	Title	Summary	Author	Date	Category
		communities can use to meet adaptation varying needs.			
6	Climate Change and Sea-level rise Scenarios for California Vulnerability and Adaptation Assessment	This white paper provides an evaluation of physical elements of climate change and sea-level rise that are contained in the California Climate Change Vulnerability and Adaptation Assessment. The analyses use six global climate models, each run under the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios B1 and A2 scenarios. From the global climate models and associated downscaled output, these scenarios contain a range of warming, continued interannual and decadal variation of precipitation with incremental changes by the middle and end of 21st century, substantial loss of mountain snow pack, and a range of sea-level rise along the California coast.	CEC	7/2012	State-Level Guidance
7	Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future	Caltrans is working with other state agencies to determine specific sea-level rise values to incorporate into future planning and design documents. As new guidance becomes available from the State, it will be important to incorporate that information into future planning assessments and update Caltrans guidance, as appropriate. Tide gages show that global sea level has risen about 7 inches during the 20th century, and recent satellite data shows that the rate of sea-level rise is accelerating. Sea-level rise poses enormous risks to the valuable infrastructure, development, and wetlands that line much of the 1,600 mile shoreline of California, Oregon, and Washington. As those states seek to incorporate projections of sea-level rise into coastal planning, they asked the National Research Council to make independent projections of sea-level rise along their coasts for the years 2030, 2050, and 2100, taking into account regional factors that affect sea level.	National Research Council	2012	State-Level Guidance
8	Reports on the Third Assessment from the California Climate Change Center	The State's third major assessment on climate change explores local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts. More than 30 peer-reviewed papers on energy, water, agriculture, public health, coastal, transportation, and ecological resource sectors are available.	Various	2012	State-Level Guidance
9	Cal-Adapt	This is a web-based interactive visualization tool for conveying the risks of climate change. At the most basic level, the tool can educating the general public and policy-makers with very little or no knowledge of climate change science who are visiting the site to learn about the effects of climate change on their hometown or other locations of interest. MPOs and RTPAs may be able to quickly enter the site to see impacts on their areas of interest. This guide also uses the more technical data and information for their application to specific transportation impacts.	CEC	2012	On-line Tool

Source: Compiled by Cambridge Systematics, Inc., 2012.

1.4 State-of-the-Practice and California Best Practices Review

Because this field is moving rapidly, the project team conducted a state-of-the-practice review of the latest activity conducted by state DOTs and MPOs nationally in this arena. Research papers, reports, and guidance documents were reviewed to gather additional information on agency planning practices, implementation, and potential applicability to California MPOs/RTPAs.

A set of interviews was also conducted with six California MPOs/RTPAs to understand the current status on integrating climate adaptation into the regional transportation planning process.

This national state-of-the-practice research can be found in Appendix B.

1.5 How to Use this Guide

This guide was developed to complement the broader planning and investment processes that MPOs and RTPAs already manage. The project team recognizes the varying capacities and resources among MPOs and RTPAs and provides methods that can be used by organizations seeking to conduct a more sketch-level assessment of the risk and vulnerability of their regional assets to climate impacts, or in-depth analysis that incorporates separate stakeholder processes and geospatial analyses.

The project team has divided the guide's audience into two primary user groups: a **Basic User** and an **Advanced User**. In practice, there is a wide range of capacities and resources to be found among California's MPOs and RTPAs, stretching from basic to advanced. MPOs and RTPAs are encouraged to consider the guidance for both user groups and to tailor a hybrid approach that best suits their needs at the time—perhaps evolving toward a more advanced approach over time.

- The **Basic User** is an MPO or RTPA conducting climate impact assessments and/or climate vulnerability and risk assessments for the very first time. They are often agencies with limited resources and limited GIS capability.
- The **Advanced User** is an MPO or RTPA that has experience with climate impact assessments, has strong interagency partnerships with universities, natural resources agencies or public works departments and have more staff resources and technical tools to dedicate to the effort.

The three sections of the guide are as follows. Each is highlighted as most suitable for Basic User, Advanced Users, or both.

- **Part I. Background Information. For Basic and Advanced Users.** The guide starts by providing background information to help MPOs and RTPAs to better understand the political context, the climate science, and the practical implications to the systems they manage.

- **Part II. A Basic Approach for Incorporating Adaptation in Regional Transportation Planning. For Basic Users.** This part of the guide is well suited for MPOs and RTPAs that are thinking about including climate adaptation in their regional transportation plans for the first time. It gives MPOs and RTPAs with limited time and resources an opportunity to examine these issues within their own planning process. The goal is to step through the issues at a qualitative, sketch-planning level, and to explore the issues that are most relevant for the region. The outcome would be to include a high-level description of the basic climate impacts and their effects on the transportation system as a subsection in the RTP.
- **Part III. An Advanced Approach for Incorporating Adaptation in Regional Transportation Planning. For Advanced Users.** This part of the guide is for regions that would like to fully integrate climate adaptation planning into their RTPs. This section is comprised of a step-by-step methodology, providing separate modules corresponding to steps in the planning process. The modular approach allows MPOs and RTPAs to focus more or less on any particular module given their own interest, and provides recommendations for delving into a more detailed process. This approach assumes MPOs and RTPAs will have the capacity to identify a geospatial dataset through existing resources such as Cal-Adapt or local asset and climate GIS layers.

Additionally, there are several ***Sidebars***, which are highlighted one- or two-paragraph boxes placed throughout the guide. These provide simplified explanations or applied examples to help MPOs and RTPAs to better understand the suggested process.

1.6 GUIDE OUTLINE

This guide for California MPOs and RTPAs will provide a documented set of modules and is organized into the four main parts:

- **Part I: Background Information.** This set of three sections provides the rationale for why California MPOs and RTPAs should incorporate climate change into the regional transportation planning case.
  - **Section 2.0. Making the Case for California MPOs and RTPAs to Prepare for Climate Change.** Provides a background piece on the importance of integrating climate change adaptation into regional transportation planning efforts.
  - **Section 3.0. Climate Change Science and Impacts.** Details current relevant data sources and most recent climate information from statewide guidance.

  - **Section 4.0. Climate Change and Transportation Infrastructure.** Examines the types of infrastructure that may be affected from a range of climate scenarios. Discusses how to incorporate adaptation in the regional transportation planning process.

- **Part II. A Basic Approach for Incorporating Adaptation in Regional Transportation Planning.** This set of two sections is well suited for MPOs and RTPAs that are thinking about including climate adaptation in their regional transportation plans for the first time. It gives MPOs and RTPAs with limited time and resources an opportunity to examine these issues within their own planning process.

  - **Section 5.0. A Basic Approach: Identifying Impacts and Exploring Adaptation Options.** Examines California-specific climate impacts that could affect MPOs and RTPAs, refers to data from the California Adaptation Planning guide and offers language that every MPO and RTPA could use for their upcoming RTPs.

  - **Section 6.0. Where Has This Been Done? California-Specific Data and Examples.** Provides some California-specific examples of RTPs considering climate impacts and examples of projects that have taken place due to extreme weather or for hazard mitigation.

- **Part III. An Advanced Approach for Incorporating Adaptation in Regional Transportation Planning.** This set of seven sections suggests a methodology for incorporating climate adaptation into the RTP process, providing separate modules for moving through the process.

  - **Section 7.0. An Advanced Approach: Applying the Five-Step Climate Change Assessment and Adaptation Modules.** Provides an introduction to the methodology for incorporating climate adaptation into the RTP process.

  - **Section 8.0. Module 1: Set Mission, Goals and Objectives.** Provides a step-by-step method to initiate a process for RTP integration.

  - **Section 9.0. Module 2a: Assemble Asset Inventory and Screen Criticality.** Provides a step-by-step method to determine which assets in the region are critical and should be assessed.

  - **Section 10.0. Module 2b: Select and Apply Climate Information.** Provides a step-by-step method to work through complex and multifaceted climate variables, and how they apply to the transportation system.

  - **Section 11.0. Module 3: Conduct Vulnerability and Risk Assessment.** Provides a step-by-step method to evaluate the vulnerability and risk of key assets identified in Module 2a.

- **Section 12.0. Module 4: Develop Adaptation Strategies.** Provides a step-by-step method to prioritize key assets and lay out a set of strategies to incorporate climate adaptation in project selection.
- **Section 13.0. Module 5: Monitor and Evaluate Plan.** Provides a step-by-step method to continually assess the plan and embed it into the new cycle of RTP planning on a four- or five-year basis.

Appendices include the following:

- **Appendix A, References and Sources**;
- **Appendix B, State-of-the-Practice Climate Change Adaptation Activities for California MPOs and RTPAs**; and
- **Appendix C, California Regional Climate Data from CNRA**.

2.0 Making the Case for California MPOs and RTPAs to Prepare for Climate Change

2.1 What is Climate Change Adaptation and Why is it Important?

As the climate changes, the strategies that California regions must employ include both climate adaptation and mitigation (i.e., reduction of GHG emissions). According to the 2009 California Climate Adaptation Strategy, adaptation refers to "efforts that 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."

Why is Transportation Adaptation Important?

The potential for significant impacts to the community suggest that transportation adaptation is an important consideration for transportation planning. Emergency management is dependent upon the ability of emergency professionals having access to the most vulnerable people and buildings. The 1906 earthquake in San Francisco destroyed water mains, preventing firefighters from being able to put out fires all over the City. The City of San Francisco adapted to this experience by increasing redundancy of the water infrastructure system. The failure of a key route could have long-term economic impacts on a region. There are many examples of routes being affected by historical climate, and there is a real possibility for an increased number of extreme weather events.

No matter how much we reduce our GHG emissions, some changes in climate are unavoidable. Conducting proactive adaptation planning at the local, state, and national levels can limit the damage caused by climate change and reduce the long-term costs of responding to increasing intensity and growing numbers of climate-related impacts in the upcoming years.

The 2007 "Stern Review on The Economics of Climate Change" documented that benefits of strong, early action on climate change considerably outweigh the costs. That study found that one percent of global gross domestic product (GDP) per annum is required to be invested in order to avoid the worst effects of climate change, and that failure to do so could risk global GDP being up to 20 percent lower than it otherwise might be (Stern, 2007).

It is estimated that in California, damages across sectors could results in "tens of billions of dollars per year in direct costs" and "expose trillions of dollars of assets to collateral risk" (Roland-Holst and Kahrl, 2008). Temperature extremes could increase the risk of damage to highways and railroad tracks and a faster deterioration or failure of transportation infrastructure. At one extreme, more frequent precipitation changes are likely to affect the flooding of tunnels, coastal highways, airport runways, and railways, as well as more frequent landslides. At the other extreme, they could increase the chance of drought and wildfires that could require more frequent repair and maintenance. For transportation in California, sea-level rise is a particularly critical climate stressor. A study by the Pacific Institute estimates that a 1.4-meter, projected sea-level rise places coastal property at risk in the order of $100 billion (Heberger et al., 2009). A substantial amount of ground transportation infrastructure, including 2,500 miles of roads and railroads, is projected to be at a growing risk from storm-related coastal flooding due to accelerated sea-level rise (Heberger et al., 2009).

2.2 Reasons for California MPOs and RTPAs to be Proactive

Climate factors are likely to affect decisions in every phase of the transportation management process: from long-range planning and investment; through project design and construction; to management and operations of the infrastructure; and system evaluation. California MPOs and RTPAs will have to face increasing uncertainty in the upcoming years – uncertainty from climate change predictions, uncertainty in the ways that climate will affect the activities of their operations, and uncertainty in the performance of their assets. Thus, it is important to start thinking and planning for climate change adaptation.

- **Planning for the future can benefit the present.** MPOs and RTPAs may find that projected climate change impacts are more extreme versions of climate variability and extreme climate events they are facing today. Planning for these events, such as sea-level rise combined with storm surge, may require a better understanding of the role of transportation to emergency response and evacuation. If alternate routes to highways in low-lying coastal areas are mapped out, they can provide a blueprint for emergency planning and evacuation.
- **Proactive planning can be more effective and less costly than responding reactively to climate change impacts as they happen.** Taking proactive steps can save money. For instance, more frequent and intensive flooding could require the reinforcement or armoring of infrastructure and port facilities, resulting in investments in maintenance that extend service life and can require less total cost over the infrastructure lifetime.
- **Thinking strategically can reduce future risks.** MPOs and RTPAs can create opportunities for modifying present-day policies and practices that can ensure resiliency to climate change. For example, zoning that concentrates development in an area at risk to future sea-level rise and coastal flooding can be altered before that area is built out. Some MPOs have already begun to adopt more flexible, scenario-based approaches in developing their long-

range transportation investment plans. Scenario planning could be adapted to take potential climate changes into account in the development of future regional transportation plans. Planners can include climate change scenarios in projections of current development patterns and supporting transportation infrastructure on maps by showing current elevations and expected sea-level rise. This overlay could illustrate the increased risks of allowing uncontrolled development in vulnerable coastal areas and the desirability of managed growth policies and protection of critical infrastructure.

- **Thinking strategically can increase future benefits.** Being proactive can create opportunities to capitalize on some benefits to climate change for MPOs/RTPAs. Warmer winter temperatures can lead to cost savings from reduced winter road maintenance requirements and a longer construction season, for example.

2.3 How Climate Change Adaptation Can Be Considered in Regional Transportation Planning

Climate Adaptation in Regional Planning

The long-range planning process provides an opportunity incorporate climate change considerations into existing decision-making frameworks. For example, the Boston Region MPO is conducting hazard mapping to identify areas where transportation infrastructure may be vulnerable to natural hazards and to inform the security evaluation of proposed transportation projects.

The MPO has an interactive web tool (www.bostonmpo.org/hazards) that maps the transportation network, natural flood zones, bridge condition, emergency routes, and emergency support facilities. The tool links to the MPO's database of Transportation Improvement Program (TIP) projects, and can be used to determine whether proposed projects are located in areas exposed to flooding, storm surge, or sea level rise.

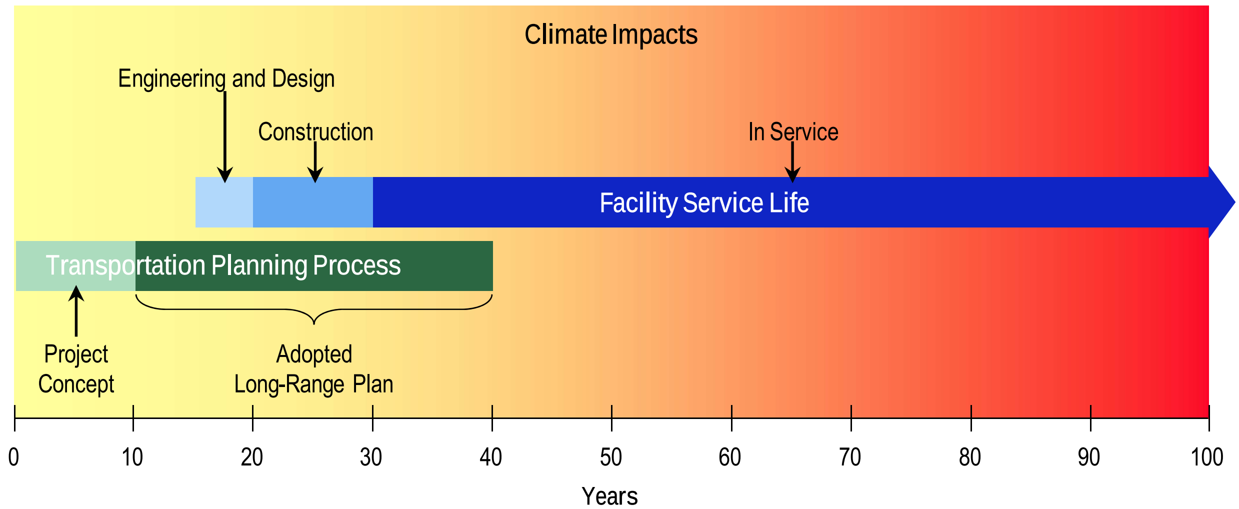
Source: FHWA, 2012.

The uncertainties inherent in projecting long-term climate changes – coupled with the long service life of most transportation infrastructure – present a complex challenge for transportation decision making. Because today's transportation network likely will be in place for decades to come, investment and design decisions made today need to consider potential changes in climate conditions years in the future: 30, 50, and sometimes 100 years or more from now, shown in Figure 2.1.

The prioritization process for transportation investments needs to consider not only the potential intensity of climate impacts, but the condition and vulnerability of existing facilities and the relative importance of those facilities to overall system performance. By weighing all of these factors, transportation managers can direct resources to the most necessary and cost-effective actions.

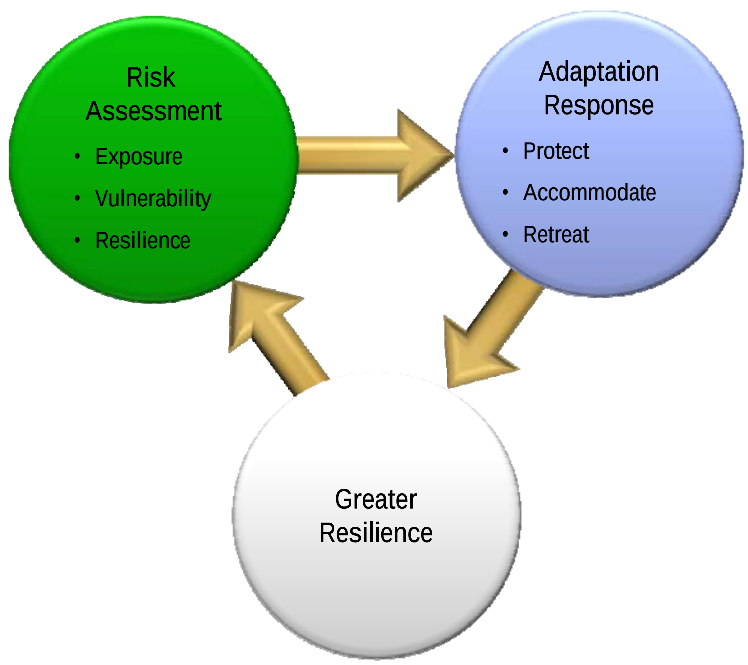
Effective adaptation requires an ongoing, iterative process of risk and vulnerability assessment, adaptation action, performance assessment, monitoring, and continuing adaptation, shown in Figure 2.2. This process requires a range of technical skills, quality data sources, and institutional collaboration to bring together the scientific, engineering, and planning resources necessary to make good decisions. Climate impacts assessment and adaptation planning is not a stand-alone process. In order for climate impacts assessment and adaptation to be pursued effectively, they must be integrated into the ongoing transportation decision-making process.

Figure 2.1 Relationship of Transportation Planning Timeframe and Infrastructure Service Life to Increasing Climate Change Impacts



Source: CCSP, 2008b.

Figure 2.2 Risk Assessment Process to Support Transportation Decisions



Source: CCSP, 2008b.

When designing new infrastructure, there will be a need to switch from designing with standards developed for historic climate trends to designing for future (and uncertain) climate projections – many elements of transportation infrastructure are sufficiently long-lived that it may not be prudent to plan and design based on historic averages. Other possible changes to the design phase include the need for a broader systems approach and risk management procedures to incorporate climate change into decision-making and defining appropriate design characteristics (Meyer, 2008). This long-range perspective needs to be balanced with monitoring for near-term changes that may require more immediate design adjustments. For example in the flooding of San Pedro Creek and coastal erosion at Pacific/Linda Mar State Beach has been a recurring problem for the City of Pacifica[3]. In the 1990s, the city worked with a number of stakeholders to work toward a managed retreat strategy to reduce flooding, erosion threats and restored wetland habitat to buffer the system against future sea-level rise. This wetland project invested substantially more upfront in flood protection including removing fill, relocating infrastructure and restoring beach. This provided long-term payback, including protection before flooding increased further with the potential to affect Highway 1 (Kershner, 2010).

In addition to the direct effects on transportation infrastructure and services, climate change will catalyze changes in the environmental, demographic, and economic conditions within which transportation agencies conduct their work. In the long run, these broader changes may have very significant secondary impacts on the transportation sector that will need to be examined as part of the planning process. For example, changes in population centers induced by shifts in weather conditions will affect travel demand. As regions of agricultural production shift, freight flows may likewise change. The effect on roads and highways from the secondary impacts of sea-level rise in the San Francisco Bay Area is one example. Some cities such as Berkeley and Albany have shorelines along I-80 that are not directly subject to flooding due to the existing roadway elevation; however, erosion from rising sea levels can undermine existing protective structures that can increase the overall cost of highway maintenance (SFBCDC, 2009).

[3] http://www.cakex.org/case-studies/2834.

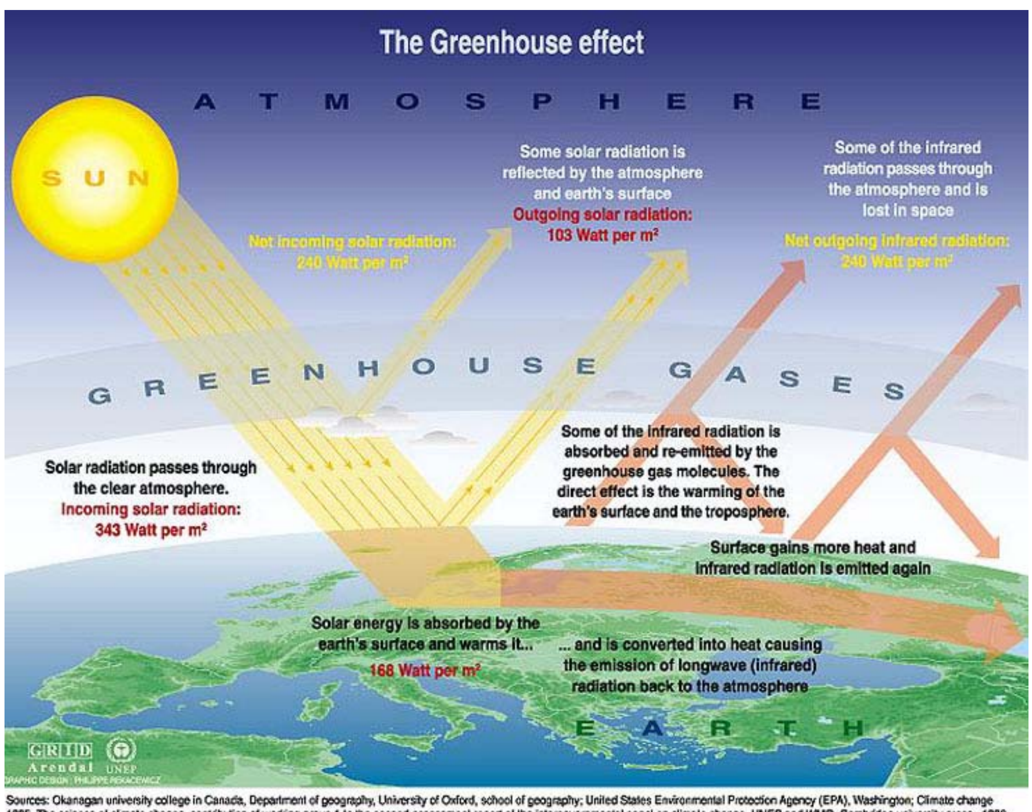
3.0 Climate Change Science and Impacts

3.1 A Brief Overview of Climate Change

The greenhouse effect is the warming of the Earth's surface and lower atmosphere due to the presence of GHG, such as carbon dioxide, methane, and water vapor. These GHG let the sun's energy through to the ground, but impede the passage of energy from the Earth back into space (Le Treut, 2007).

Most of the energy emitted from the sun, solar radiation, travels down through the Earth's atmosphere and is absorbed by the Earth's surface; a small proportion is reflected straight back into space by clouds and by the Earth's surface. The absorption of solar radiation causes the Earth's surface and lower atmosphere to warm up.

Figure 3.1 The Greenhouse Gas Effect

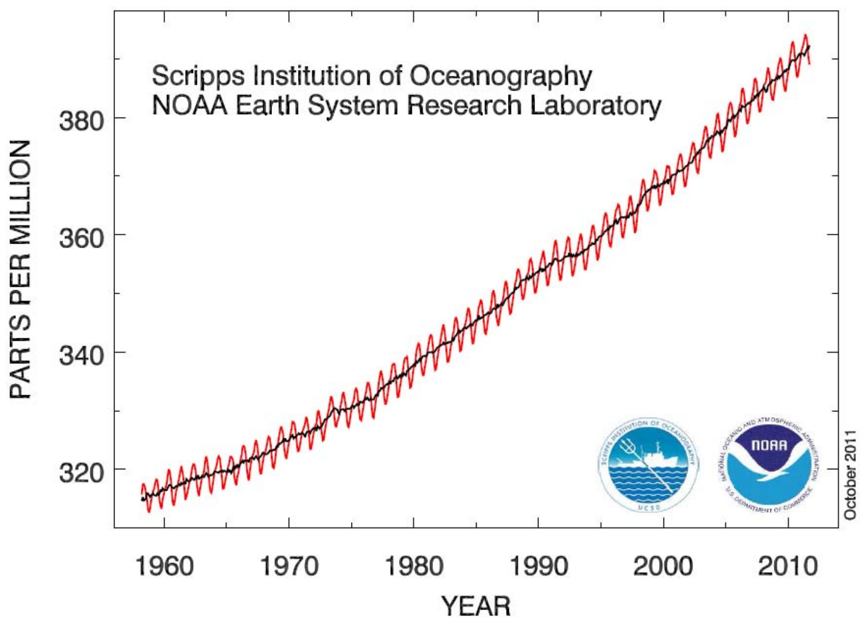


Source: IPCC, 2007.

The warmed Earth emits infrared radiation, which is readily absorbed by GHG in the atmosphere, such as water vapor, carbon dioxide, and methane. Absorption of infrared radiation causes the atmosphere to warm and emit its own infrared radiation. The Earth's surface and lower atmosphere warm until they reach a temperature where the heat radiation emitted back into space, plus the directly reflected solar radiation, balance the absorbed energy coming in from the sun. As a result, the surface temperature of the Earth is around 59°F on average, 90°F warmer than it would be if there was no atmosphere. This is called the natural greenhouse effect.

If the concentration of GHG is increased, then there will be more absorption of infrared radiation. The Earth's surface and the lower atmosphere will warm further until a balance of incoming and outgoing radiation is reached again. This extra warming is called the *enhanced greenhouse effect*. Figure 3.2 shows the observed increase in global carbon dioxide concentrations over the past 50 years. Its concentration has been building up in the Earth's atmosphere since the beginning of the industrial era in the mid-1700s, primarily due to the burning of fossil fuels (coal, oil, and natural gas) and the clearing of forests. Human activities have also increased the emissions of other GHG, such as methane, nitrous oxide, and halocarbons (Forster et al., 2007).

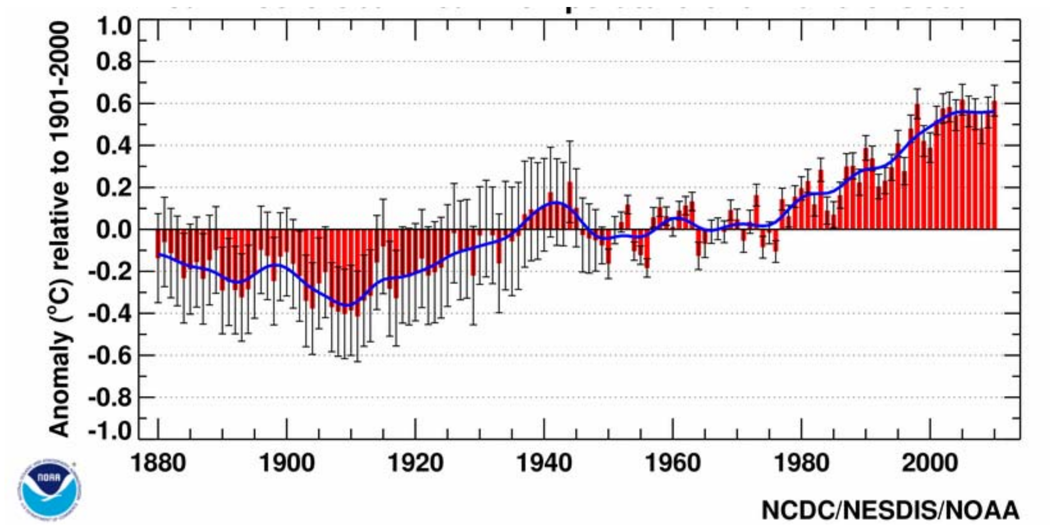
Figure 3.2 Atmospheric Carbon Dioxide at Mauna Loa Observatory



Source: National Oceanic and Atmospheric Administration (NOAA), 2010.

Figure 3.3 shows that the observed global mean temperature over land and ocean has also increased over the same time period. The year 2010 tied with 2005 as the warmest year since records began in 1880. The annual global combined land and ocean surface temperature was 1.12°F above the 20th century average. The 2010 combined land and ocean surface temperature in the Northern Hemisphere was also the warmest on record, while the combined land and ocean surface temperature in the Southern Hemisphere was the sixth warmest such period on record. Warming trends over the 20th century are documented for nearly all locations that have sufficient data except the North Atlantic Ocean near Greenland and Iceland, and the Southeast United States.

Figure 3.3 Observed Global Mean Temperature over Land and Ocean



Source: NOAA, 2010.

The magnitude of the enhanced greenhouse effect is influenced by various complex interactions in the earth-ocean-atmosphere system. Many processes and feedbacks must be accounted for in order to realistically project climate changes resulting from particular GHG emission scenarios. These complications are the source of much of the debate which has occurred about the likely magnitude and timing of climate changes due to the enhanced GHG effect.

3.2 Projected Statewide Consequences of Climate Change

Future projections of climate change for California have been synthesized by the 2009 California Climate Change Scenarios Assessment (Cayan et al., 2009), which examined changes in average temperatures, precipitation patterns, sea-level rise, and extreme events.

Temperature

California should expect overall hotter conditions by the end of the century. All model projections suggest increased temperatures, with the level of emissions representing the biggest uncertainty: temperature levels will rise more quickly and be higher by the end of this century with higher emissions. Based on Cayan et al. (2012), the projections suggest the following:

- Summer average temperatures will increase more quickly than winter average temperatures.
- Average inland areas are likely to increase more quickly than coastal regions.
- Extreme heat events will become more common, last longer, and cover larger areas.
- Temperature changes over the next 30 to 40 years are already largely determined by past emissions. By 2050, temperatures are projected to increase by an additional 1.8 to 5.4°F, regardless of future emissions.
- After 2050, temperature projections diverge for different emission scenarios. By 2100, the models project temperature increases between 3.6 to 9°F.

Precipitation

Projected changes in precipitation are less clear cut than for temperature. The seasonal pattern of cool and wet winters and hot and dry summers, typical of a Mediterranean climate, is likely to continue. However, the amount of precipitation is likely to change, but where and how much rain and snowfall differs with both model and emission scenario. Based on Cayan et al. (2012), the projections suggest the following

- The majority of models suggest drier conditions by mid-century (5 to 8 percent less rainfall) with drier conditions persisting through the end of the century (9 to 12 percent less annual rainfall);
- More precipitation will fall as rain rather than as snow, with important implications for water resources;
- Higher temperatures hasten snowmelt and increase evaporation, which will make for a generally drier climate; and
- Rainfall and meltwater will run off earlier in the year.

Sea-Level Rise

Sea level has been measured at the Presidio tide gauge in San Francisco since 1854, which has recorded a rise in relative sea level of 7.6 inches per century in the last 100 years (NRC, 2012). Rates of relative sea-level rise vary along the coast in relation to vertical land movement: the observed rise per century is 8.0 inches in San Diego, 3.3 inches in Los Angeles, and 2.7 inches in Port San Luis; and is falling in Crescent City at a rate of 2.9 inches per century (NRC 2012, Table 4.6). Present sea-level rise projections suggest that global sea levels in the 21st century can be expected to be much higher, which will result in higher rates of relative sea-level rise. These projections are summarized in the *State of California Sea-Level Rise Interim Guidance Document* (OPC, 2010); and have been incorporated into the *Caltrans Guidance on Incorporating Sea-Level Rise* (Caltrans 2011):

- Up to 2050, the models show strong agreement and there is little variation between emission scenarios. After 2050 the projected global sea level varies by emission scenario.
- By 2050, the models show strong agreement for global sea-level rise with an average of 14 inches and a range of 10 to 17 inches higher than the sea level in 2000.

Table 3.1 Sea-Level Rise Projections

Year	Emissions	Average of Models (Inches)	Range of Models (Inches)
2070	Low	23	17-27
	Medium	24	18-29
	High	27	20-32
2100	Low	40	31-50
	Medium	47	37-60
	High	55	43-69

Source: OPC, 2010, presented in OPC, 2011.

The recent sea-level rise publication from the NRC titled *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* (NRC 2012) revises some of the projections included in the OPC report and Caltrans guidance. Caltrans is working with other state agencies to determine specific sea-level rise values to incorporate into future planning and design documents. As new state guidance becomes available it will be important to incorporate that information into future planning assessments and update Caltrans guidance, as appropriate.

Extreme Events

Gradual changes in average temperature, precipitation and sea level are described above. However, it is likely that the State will face a growing number of climate change-related extreme events, such as heat waves, wildfires, droughts, and floods (Mastrandrea et al., 2009).

- Significant increases in the frequency and magnitude of both maximum and minimum temperature extremes are possible in many areas. It is projected there will be a tenfold increase in the frequency of extreme temperatures currently estimated to occur once every 100 years, even with moderate emissions. Under higher emissions, these 100-year temperature extremes are projected to occur close to annually in most regions.
- Freezing events are projected to become less frequent even in locations where they are currently an annual event. Over large portions of the State, freezing events may occur once every 10 years or less by the end of the 21st century.

What is the Significance of Changes in Extreme Climate?

The type and frequency of extreme events are expected to change at the global scale and can occur even with small changes in climate means.

Shifts in mean climate conditions can exacerbate extreme conditions resulting in higher, more frequent, and more prolonged heat waves, greater flooding and erosion impacts of coastal storm surges, and shifts in watershed runoff and timing. In planning for adapting transportation infrastructure to the changing climate, trends in extreme events will play a major role in understanding the risk to transportation assets.

Source: Mastrandrea et al., 2009.

- Precipitation projections show more variability between models and emission scenarios. In general, longer dry spells will become more common with occasional intense rainfall events.
- Occasional intense rainfall events will continue to occur, with no significant change in the trend of projected frequency of heavy precipitation events.
- The frequency of large coastal storms and heavy precipitation events does not appear to change significantly over the 21st century. However, storms will still impact the coast more severely due to higher sea levels that can result in higher storm surges, more extensive inland flooding, and increased erosion.

3.3 Climate Change Projections and Scenario Modeling

What is the Difference between a Climate Projection and a Prediction?

Due to the inherent uncertainty in the evolution of global economic and technologic factors future climate scenarios represent projections, rather than predictions, of future climate conditions. Projections consider a range of plausible pathways in global resource use (emissions), differences in global climate models, and varying estimates of climate sensitivity to emission concentrations. This range represents the distribution of uncertainty in the many tools used to project future climate conditions. The range and timing of climate change impacts under a variety of possible future conditions provides a spectrum of climate change risk which serves as the basis for adaptation planning.

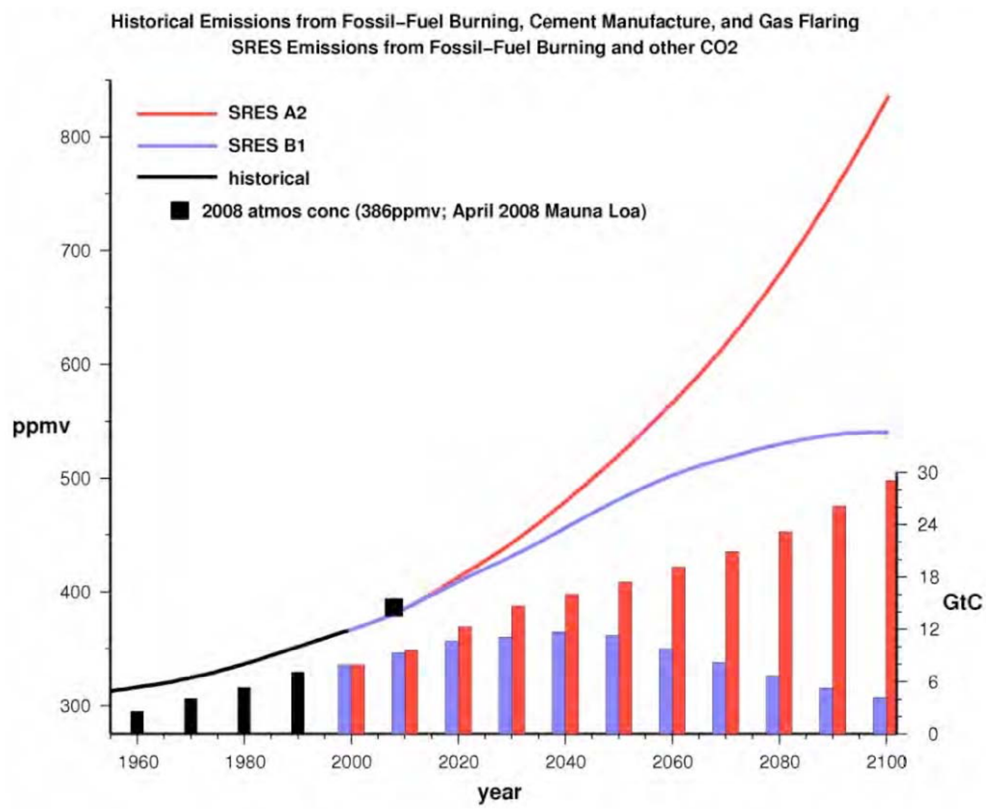
Predicting human-induced changes in climate over the next 100 years requires:

- A prediction of global GHG emissions for the next century.
- A global carbon cycle model to convert these emissions into changes in carbon dioxide concentrations (and similar models for calculating concentrations of other GHG and aerosols).
- A general circulation model (GCM), which uses the GHG and aerosol concentration information to project future climate variations.
- Downscaling of the GCM results to a regional level through a procedure which takes account of the influence of topography on local climate. This can be done either statistically or with a higher resolution regional climate model (RCM).

Global GHG Emission Scenarios

The Intergovernmental Panel on Climate Change (IPCC) has developed different scenarios of change in GHG and sulfate aerosol emissions for use in global climate modeling efforts in its Special Report on Emission Scenarios (Nakicenovic and Swart, 2000). These scenarios are grouped in four categories, or storylines, based on different assumptions about demographic, social, economic, technological, and environmental change. All the scenarios are considered equally probable. The emission scenarios presently used in the 2009 California Climate Change Scenarios Assessment (Cayan et al., 2009) (Figure 3.4) are presented below.

Figure 3.4 Global Atmospheric Carbon Dioxide Concentration and Carbon Emissions



Source: Cayan et al., 2009.

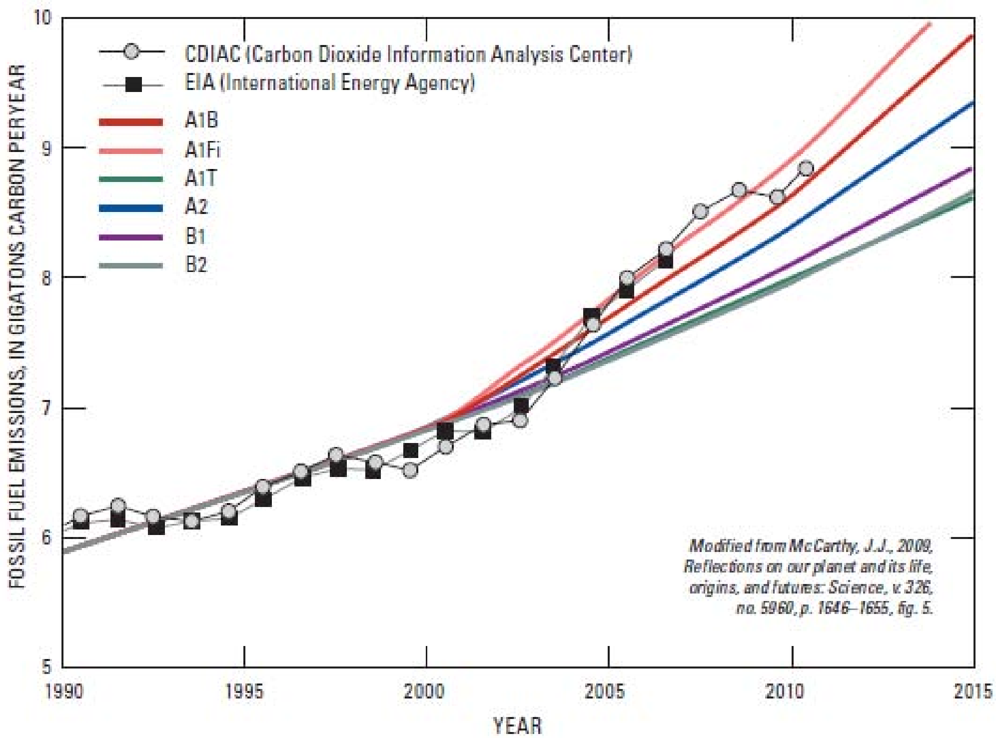
Note: The global carbon emissions (gigatonnes of carbon, GtC) are shown by bars. The atmospheric carbon dioxide (CO_2) concentration (parts per million, volume, or ppmv) is shown by lines. The bars represent the historical period (black), SRES B1 (blue), and SRES A2 (red) emissions scenarios. The black square represents the present day (2008) atmospheric concentration (386 ppmv).

What are Climate Scenarios and How are They Used in my Region?

Different scenarios have been developed to estimate the potential level of emissions each country will produce in the future. The emissions scenarios most commonly used by California state agencies are A2 (medium-high emissions) and B1 (low emissions) scenarios. Each scenario corresponds to a projection of possible emissions levels based on population growth, economic development, technology deployment and other factors. Ultimately, the effect on climate change depends on the amount and the rate of accumulation of heat-trapping gases in the atmosphere that these scenarios suggest, along with atmospheric sensitivity to those emissions levels.

Of the two scenarios extensively evaluated in climate change analyses in California, the A2 scenario is the more realistic choice for decision-makers to use for climate adaptation planning. Generally, the B1 scenario might be most appropriately viewed as a version of a "best case" or "policy" scenario for emissions, while A2 is more of a status quo scenario incorporating incremental improvements. Measured carbon emissions compared to the hypothetical IPCC scenarios is shown in Figure 3.5.

Figure 3.5 Observed Global Mean Temperature over Land and Ocean



Source: Flint, L. E., and A. L. Flint, 2012.

A2

This emission scenario represents a differentiated world in which economic growth is uneven and the income gap remains large between now-industrialized and developing parts of the world; and people, ideas, and capital are less mobile so that technology diffuses more slowly. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other scenarios. The emissions lie near the high end of the range of GHG emissions scenarios.

B1

This emissions scenario presents a future with a high level of environmental and social consciousness, combined with a globally coherent approach to more sustainable development. The B1 scenario assumes global population growth peaks by mid-century and then declines, a rapid economic shift towards service and information economies, and the introduction of clean and resource-efficient technologies. The emissions at the low end of the range of GHG emissions scenarios.

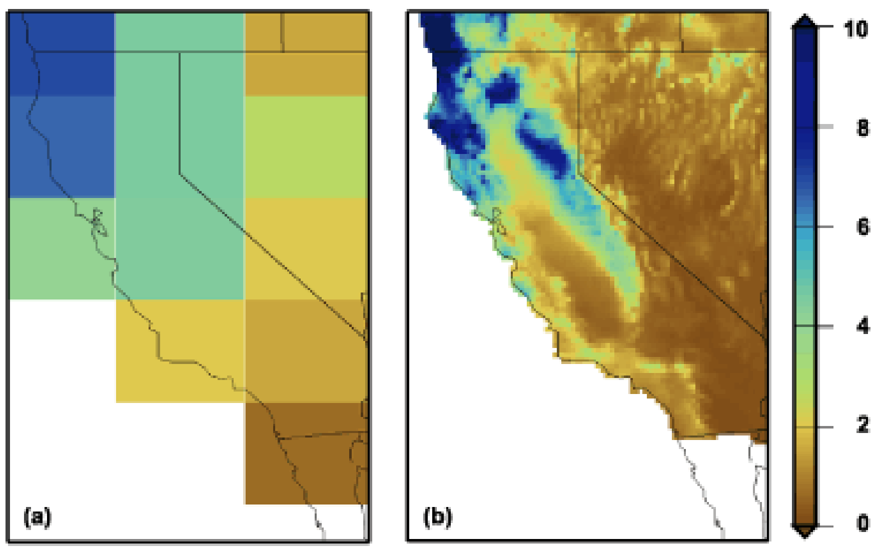
General Circulation Models

General circulation models (GCMs) are used for predicting climate change. They model how the atmosphere, oceans, land surface, and ice interact to create weather and climate over long periods of time (decades and centuries) over the whole globe. GCMs subdivide the Earth's surface, atmosphere, and oceans into a 3D grid of thousands of cells. Standard physical equations for the transfer of heat, water, and momentum are solved for each grid cell to predict temperature, precipitation, and winds. Many relevant processes are well represented at the scale of these grid cells, such as the large-scale westerly flow of moisture from the Pacific Ocean. Many GCMs have been developed around the world; the most recent IPCC assessment report made use of projections from 24 different GCMs.

What is a General Circulation Model (GCM) and What is the Purpose of Downscaling?

- ***General circulation models** – Scientific models, also referred to as global circulation models, model how the atmosphere, oceans, land surface, and ice interact to create weather patterns and climate over long periods. Climate models are complex and require significant computing power to generate future climate change projections. Climate modeling at the global scale requires large grids to reduce computational complexity.*
- ***Downscaling –** Increasing the resolution of a large grid to a small grid based on climatic and topographic gradients. The grid size produced by global modeling is too large to apply model outputs to the State of California, so downscaling is required to produce more accurate (higher resolution) numbers for local regions. Downscaling is like pixels on a television, where a global model is an older television and downscaling is like a new HD television, represented in Figure 3.6.*

Figure 3.6 Illustration on "Downscaling" in Climate Modeling



Source: http://www.accessscience.com/loadBinary.aspx?filename=YB061910FG0020.gif.

In view of the uncertainty of the global climate's responses to increasing GHG emissions and other radiative forcings[4] and the variability amongst models in representing and calculating key processes, it is important to consider results from several GCMs rather than to rely on just a few. For the 2009 California

[4] The term "radiative forcing" has been used in the IPCC Assessments with a specific technical meaning to denote an externally imposed perturbation in the radiative energy budget of the Earth's climate system, which may lead to changes in climate parameters.

Climate Change Scenarios Assessment (Cayan et al., 2009), a subset of available GCMs were selected based on their representation of historic seasonal precipitation and temperature, the variability of annual precipitation, and El Niño/Southern Oscillation (ENSO).

Downscaling

GCMs are designed to represent climate change processes at the global scale. Models can show differences in the rate of climate change at different locations, but only on the continental scale. The size of the GCM grid cells, and thus the spatial resolution of the climate projections, is limited by the computing power necessary to solve the equations for all of the grid cells at hourly (or shorter) time steps for runs which may span 100 years or more. Thus, the climate models at the time of the latest IPCC report in 2007 produced output at spatial scales of roughly 120 to 180 miles.

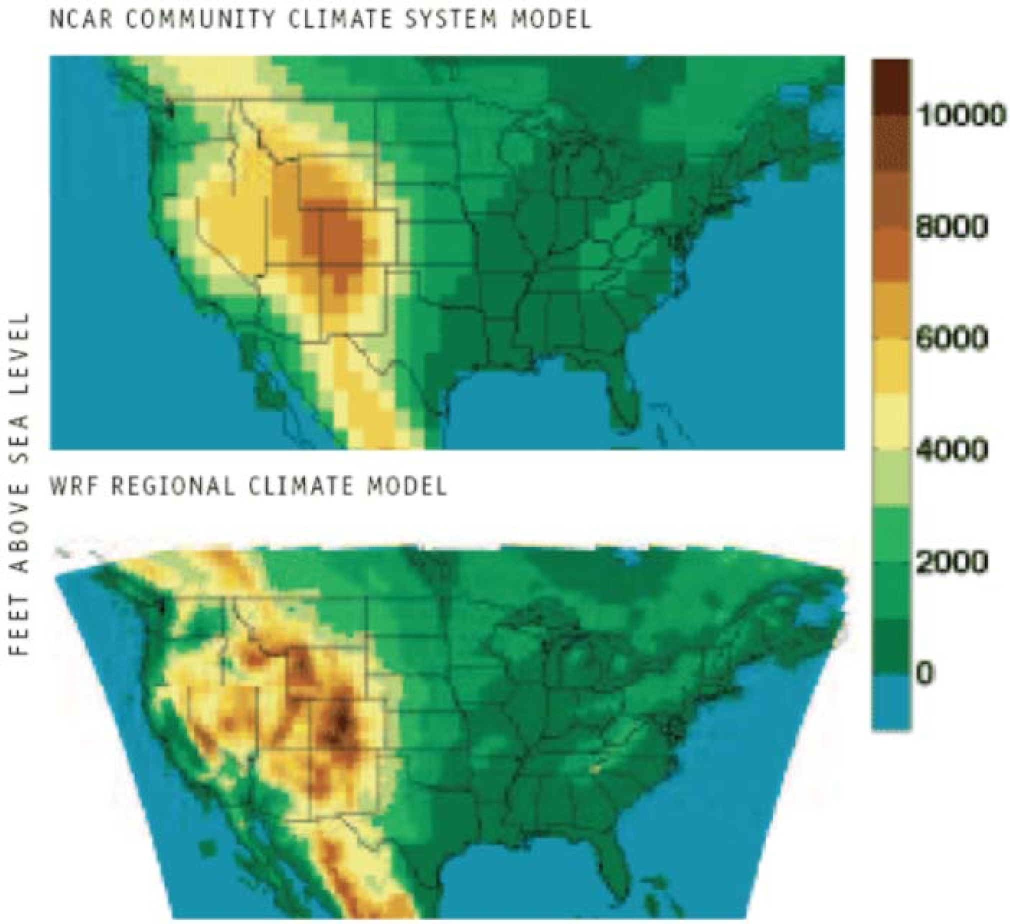
Particularly in mountainous regions, such as the California coastal ranges and the Sierra Nevada, this scale is too coarse to capture the many important effects of topography on climate, as seen in Figure 3.7.

For example, because mountain ranges are averaged with adjacent valleys, the Sierra Nevada, as represented in the GCMs, tops out at around 6,000 feet. The scale of GCM output is also too coarse to use as input for many models predicting environmental impacts, such as basin-scale hydrologic and water system models, or wildlife habitat models. Therefore, techniques to reduce the spatial scale of the GCM output (that is, downscaling) are needed for most user applications.

- **Statistical downscaling.** Statistical relationships between the regional circulation and aspects of the local climate (e.g., temperature, precipitation, wind) are used to apply GCM results to a particular place.
- A **regional climate model** (RCM) uses output from a general circulation model, but simulates processes at much higher resolution over the particular region. A RCM is very much like a GCM, except that it uses much finer resolution and covers a limited area. So a regional model may have a 10-mile grid spacing over specific regions, compared with 120 to 180 miles for a GCM.

When making use of downscaled climate projections, as with the underlying GCM output, a range of projections should be considered rather than one or two. In the case of statistical downscaling, several GCM projections are typically downscaled using the same method. Likewise with RCM downscaling, it is important to consider projections produced by multiple RCM-GCM combinations.

Figure 3.7 Spatial Resolution and Representation of Topography of a Typical GCM and a Typical RCM



Source: National Center for Atmospheric Research (NCAR), 2007.

Abrupt Climate Change

Abrupt climate change is defined as a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems (CCSP, 2008). Some scientists have referred to our current state as leading to a climate "tipping point", or a point when climate changes from a stable state to another stable state that disrupts the natural system.

Four types of abrupt change in the geologic record stand out as being so rapid and large in their impact that, if they were to recur, they would pose clear risks to society in terms of our ability to adapt:

1. Rapid change in glaciers, ice sheets, and hence sea level;
2. Widespread and sustained changes to the hydrologic cycle, including drought and flooding;

3. Abrupt change in ocean circulation patterns, such as the Atlantic Meridional Overturning Circulation; and
4. Rapid release to the atmosphere of methane trapped in permafrost and in ocean sediments.

One proposed reason for the observed abrupt climate change phenomena is that feedback loops within the climate system both enhance small perturbations and cause a variety of stable states (Riall, 2004). These processes that lead to abrupt climate change are poorly understood and are not accounted for in the GCM or RCM projections of climate change.

4.0 Climate Change and Transportation Infrastructure

Long treated as a minor component of climate action planning, climate change adaptation has risen to the forefront in recent years and the literature on its relation to transportation planning is growing rapidly. At the national level, *America's Climate Choices* calls for a national strategy on adaptation – including making the transportation network less vulnerable to climate change (NRC, 2010). In June 2011, U.S. Secretary of Transportation Ray LaHood announced a policy statement on climate change adaptation, stating that the U.S. Department of Transportation (DOT) "shall integrate consideration of climate change impacts and adaptation into the planning, operations, policies and programs of DOT" and encourages "state, regional and local transportation agencies to consider climate change impacts in their decision-making" (LaHood, 2011).

4.1 Addressing Impacts to Transportation

A growing number of transportation agencies have begun incorporating climate change considerations into their planning and design. A survey of state DOTs, conducted for the Federal Highway Administration (FHWA) in 2008, found that 13 state DOTs had some kind of action or activity underway regarding adaptation, 15 had discussions on the issue taking place, and another 24 had no action or activity related to adaptation at all (FHWA, 2008).

For instance, Executive Order S-03-05 requires state agencies in California to plan for sea-level rise, shifting precipitation, and extreme weather events; and is developing a statewide information strategy to support infrastructure vulnerability assessment. As part of this effort, California has formed the Coastal and Ocean Climate Action Team, often referred to as CO-CAT, whose task it is to ensure the State's ability to adapt to climate change impacts on coastal resources (Caltrans, 2011).

Alaska, which is already experiencing climate impacts, has set up a state-level Adaptation Advisory Group, which includes a Public Infrastructure Technical Working Group, and the State Department of Transportation and Public Facilities is actively involved in community relocation and seeking enhanced data collection and collaboration across agencies (Ritter, 2009).

Most state DOTs, as well as the FHWA, regard development of an infrastructure inventory and vulnerability assessment as one of the first steps that will be needed in developing a comprehensive approach to adaptation. For example, Oregon has already taken strategic planning steps in that direction, documenting existing knowledge about climate change impacts and summarizing data that can lead to the development of a full vulnerability assessment of transportation infrastructure (Oregon CCIG, 2008).

The Gulf Coast Study Phase I, a joint U.S. DOT and U.S. Geological Survey (USGS) report, conducted under the auspices of the interagency U.S. Climate Change Science Program, investigated the potential impacts of climate change by 2050 and 2100 on transportation infrastructure in the north central Gulf Coast. That study integrated environmental trend data, climate model outputs based on a range of climate scenarios, and transportation infrastructure data to identify areas of risk to climate impacts in the region. The study also developed a framework for risk assessment and explored adaptation options to address the potential risks of climate change (CCSP, 2008b).

For Phase II of the study of the Gulf Coast, U.S. DOT performed an in-depth assessment of transportation assets across all modes for a single Gulf Cost MPO to: 1) identify critical assets; 2) assess climate impacts on those assets; 3) assess vulnerability; and 4) perform detailed engineering assessments of vulnerable infrastructure, including a review and analysis of adaptation options. The results of this MPO-specific research and analysis informed the development of risk management tools, templates, and architectures for the planning agency in the study region to use in deciding what infrastructure or transportation programs need protecting, and for prioritizing efforts to protect, accommodate, or relocate assets.

In 2008, the Transportation Research Board (TRB) published Special Report 290, *Potential Impacts of Climate Change on U.S. Transportation* (NRC, 2008). In this report, adaptation to climate change within the transportation sector falls into three categories of actions: operational changes, design changes, and other actions.

Climate variability and extreme events, such as storms and precipitation of increased intensity, will require changing operational responses from transportation providers. While U.S. transportation providers already address the impacts of weather on transportation system operations in a diverse range of climatic conditions, existing planning does not take into account long-term changes in climate. Operational changes may include adjusting maintenance (both in the timing and type of maintenance); improved monitoring of conditions (both climatic and infrastructure conditions), incorporating climate scenario modeling into infrastructure planning, modifying procedures for emergency management, and altering construction schedules.

In general, operational changes will apply to procedural planning at varying degrees of adjustment. For example, greater use of technology such as climate scenario modeling can enable infrastructure providers to monitor climate changes and receive advance warning of potential failures due to changing conditions (such as water levels and currents, wave action, winds, and temperatures), exceeding what the infrastructure was designed to withstand.

While transportation planning efforts do take weather conditions into account in the design of infrastructure, there is less examination of whether current design standards are sufficient to accommodate climate change.

For example, the drainage capacity of road infrastructure often incorporates consideration of a 100-year storm event. However, climate projections indicate that current 100-year storm events are likely to occur more frequently (such as every 50 or perhaps even every 20 years) by the end of the current century. In this case, design standards for drainage would need to be updated to consider these changing conditions. Examples of design strategies include improving materials or developing new materials, or upgrading current systems with improvements in design, and enhancing protection.

Similarly, the Federal Emergency Management Agency (FEMA) maps are often used to support development decisions, including the siting of roadways. Because FEMA maps do not reflect projected climate change impacts, including effects of climate change on floodplain designations, roads may be established in areas that are highly vulnerable to flooding in the future.

In addition to operational and design changes, other types of adaptation options are available for transportation infrastructure. Transportation planning and land use controls, especially concerning new construction and development, can integrate projected climate changes into the planning process. For example, development can be restricted or prohibited in zones most at risk from storm surges, flooding, and sea-level rise. In addition, long-range planning and promoting cross-agency collaboration are two examples of other potential adaptation actions for transportation planning.

4.2 Potential Climate Impacts on the California Transportation System and Strategies for Adaptation

As described in Section 3.2, projected climate impacts that will affect California include sea-level rise, increases in intense precipitation events, and temperature – specifically the increase in higher heat days. Each of these key climate impacts will affect a variety of transportation assets ranging from roadways, to railways, to airports and bridges. The focus for regional transportation planners will be to be aware of the potential climate impacts on their regions and their effects on the infrastructure in the MPO or RTPA region. This section will first describe the typical climate impacts in California and their effects on infrastructure. For every climate impact, there are a range of adaptation strategies that can be deployed either through planning, design or operational methods. A listing of these strategies is summarized in Table 4.1.

Table 4.1 Potential Climate Change Impacts to California Transportation Infrastructure and Adaptation Strategies

Climate Impact and Potential Infrastructure Impact	Potential Transportation Impacts	Planning Strategy	Design Strategy	Operations/Maintenance Response
Sea-Level Rise				
Coastal Erosion	• Roadway Washout • Damage to roadway substructure • Route closures • Travel delays	• Identify segments of roadway vulnerable to erosion • Address vulnerability in transportation plans	• Strengthening, heightening, and construction of new seawalls and dikes • Combination of hard engineering (man-made structures) and soft engineering measures (use of ecological principles and practices) to protect coast infrastructure • Relocation of highly impacted or vulnerable infrastructure • Relocation of infrastructure	• Repair damage as needed by emergency contract or permanent restoration project • Increased monitoring of infrastructure and conditions in coastal areas vulnerable to erosion • Repair/replace/restore impacted infrastructure, as needed • Increased erosion control • Prepare for weather related delays and traffic disruptions • Prepare to provide alternative route information
Coastal and inland tidal zone road flooding	• Flooding of roadways • Roadway damage • Road closures • Travel delays • Disruption of transit services	• Identify segments of roadway vulnerable to storm surge and sea-level rise • Address vulnerability in transportation plans • Support land use policies that discourage development on shoreline • Plan and design more redundancy into the system	• Increase base elevation of infrastructure • Change to more resilient building materials • Larger or addition of drainage canals near coastal routes • Relocation of sections of road • Strengthening, heightening and construction of new seawalls and dikes	• Repair damage as needed by emergency contract or permanent restoration project • Increased monitoring of infrastructure conditions during high tide and storm events • Ensure drainage systems are adequate to accommodate flood conditions • Ensure bridge openings/culverts are clear for appropriate flood management • During extreme precipitation events, continually monitor drainage systems • Prepare for weather related delays and traffic disruptions • Prepare to provide alternative route information • Implement emergency operations response procedures

Climate Impact and Potential Infrastructure Impact	Potential Transportation Impacts	Planning Strategy	Design Strategy	Operations/Maintenance Response
Bridge Scour	• Compromised integrity of bridge structures • Bridge failure resulting in closure • Reduced bridge capacity	• Identify locations of bridges in locations vulnerable to sea-level rise and bridge scour • Address vulnerabilities in transportation plans	• Protection of bridge piers and abutments with riprap • Retrofit/replace/relocate existing bridges for new scour conditions	• Repair damage as needed by emergency contract or permanent restoration project • Increased monitoring for bridge pier and abutment scour
Railway Flooding	• Rail and railway roadbed damage • Disruption of rail traffic – closure or delay	• Identify segments of railway vulnerable to sea-level rise • Address vulnerability in rail plans	• Increase base elevation of infrastructure • Strengthen, heighten, and construct new seawalls and dikes • Combination of hard engineering (man-made structures) and soft engineering measures (use of ecological principles and practices) to protect coast infrastructure • Relocate sections of track	• Increased monitoring of infrastructure conditions • Ensure drainage systems are adequate to accommodate flood conditions • Ensure bridge openings/culverts are clear for appropriate flood management
Increase in Intense Precipitation Events				
Flooding of Roadways	• Route closures • Travel delays • Increased safety risks • Increased need for emergency response services • Rapid deterioration of infrastructure	• Identify roadway segments impacted by past intense precipitation events • Address vulnerabilities in transportation plans • Integrate improved flood protection into transportation plans • Identify alternatives to vulnerable routes • Restrict development in floodplains • Perform increased risk assessment for new roads	• Protect critical evacuation routes • Upgrade bridge deck and road drainage systems (increase the standard drainage capacity for new infrastructure) • Increase culvert capacity • Increase/provide new water retention/detention storage systems • New asphalt/concrete mixtures able to withstand flood conditions	• Repair damage as needed by emergency contract or permanent restoration project • Increased monitoring of infrastructure conditions • Pavement grooving and sloping • Prepare for service delays • Ensure bridge openings/culverts are clear for appropriate flood management • During extreme precipitation events, continually monitor drainage systems • Increase capacity and maintenance at pump plant facilities • Minimize repair backlogs • Prepare to provide alternative route information • Implement emergency operations response procedures

Climate Impact and Potential Infrastructure Impact	Potential Transportation Impacts	Planning Strategy	Design Strategy	Operations/Maintenance Response
Landslides Road Washouts	• Route closures • Travel delays • Increased safety risks	• Identify roadway segments impacted by past intense precipitation events • Address vulnerabilities in transportation plans • Identify alternatives to vulnerable routes • Perform increased risk assessment for new roads	• Protect critical evacuation routes • Incorporate landslide mitigation measures for projects in vulnerable areas • Ensure adequate drainage on roadbed surfaces, and shoulders • Incorporate rockfall protection measures	• Repair damage as needed by emergency contract or permanent restoration project • Increased monitoring of infrastructure conditions • Ensure the roadway is clear of rocks, debris, and downed vegetation • During extreme precipitation events, continually monitor drainage systems • Minimize repair backlogs
Bridge Scour	• Compromised integrity of bridge structures • Bridge failure resulting in closure • Reduced bridge capacity	• Identify locations of bridges in locations vulnerable to sea-level rise and bridge scour • Address vulnerabilities in transportation plans	• Protection of bridge piers and abutments with riprap	• Increased monitoring for bridge pier and abutment scour
Railway Flooding	• Disruption of rail traffic – closure or delay • Rail and railway roadbed damage • Malfunctions of track or signal sensors	• Identify segments of railway vulnerable to sea-level rise • Address vulnerability in rail plans	• Increase base elevation of rail beds • Upgrade rail drainage systems • Increase warning and advisory systems for dispatch centers and crews	• Increased monitoring of infrastructure conditions • Ensure drainage systems are adequate to accommodate flood conditions • Ensure bridge openings/culverts are clear for appropriate flood management
Higher Temperatures – Extreme Heat Events				
Highway Asphalt Rutting Highway Asphalt Buckling Concrete Deterioration/ Blow-ups Limits on Periods of Construction Activity	• Route closures • Travel delays • Limitations on construction periods during summer	• Identify roadway segments impacted by past extreme heat events • Address vulnerabilities in transportation plans	• Development of new heat resistant asphalt/concrete mixtures • Overlay with new rut-resistant asphalt	• Increased monitoring of infrastructure during extreme heat events • Overlay with more rut-resistant asphalt • Increased maintenance to prevent impacts of extreme heat • Shift to evening construction schedule

Climate Impact and Potential Infrastructure Impact	Potential Transportation Impacts	Planning Strategy	Design Strategy	Operations/Maintenance Response
Rail Buckling	• Potential for train derailment • Malfunction of track and signal sensors • Disruption of rail traffic – closure or delay	• Identify segments of railway located in areas most vulnerable to extreme heat events • Address vulnerability in rail plans	• Design for higher maximum temperatures in replacement or new rail infrastructure	• Improved monitoring of rail temperatures, tracks, track sensors and signals during extreme heat events • Increased track maintenance • Lower speeds and shorter trains to shorten braking distance when necessary • Lighter loads to reduce track stress when necessary
Increased Thermal Expansion of Bridges	• Bridge damage • Bridge closures	• Identify bridges impacted by past extreme heat events • Address vulnerabilities in transportation plans	• Ensure bridge joints can accommodate anticipated thermal expansion • Design for higher maximum temperatures in replacement or new construction	• Improved monitoring of bridge joints • Increased ongoing bridge maintenance
Changes to Vegetation/ Biodiversity	• Higher temperatures will increase drought conditions. Landscaped right-of-ways will require more watering • Changing temperature patterns will alter natural biodiversity	• When feasible, work with local municipalities to use reclaimed water vegetation irrigation	• Increased consideration of drought tolerant vegetation • Convert to new "smart" irrigation systems that water only when necessary to conserve water • Design alternatives to water reliant plants, such as decorative hardscape • Use native drought resistant plans • Increase use of inert materials as groundcover to minimize exposure and need for plantings	• Increased vegetation management
Increase in Wildfires and Mudslides	• Route closures and detours • Damaged infrastructure such as guardrails and signs		• Use of heat resistant infrastructure • Incorporate mudslide mitigation measures for projects in vulnerable areas (burned-out)	• Increased monitoring of slope stability in vulnerable areas • Repair damage as needed by emergency contract or permanent restoration project

Source: Climate impacts highlighted based on relevance for California regions, Caltrans, 2012.

Impacts of Sea-Level Rise on the Regional Transportation System

California's vast network of roadways and railways include corridor segments that are located in low-lying coastal areas. Aside from potential inundation of key assets, higher water levels may increase coastal bluff erosion rates, change environmental characteristics that affect material durability (e.g., pH and chloride concentrations), lead to increased groundwater levels, and change sediment movement both along the shore and at estuaries and river mouths.

Coastal transportation corridors (both road and rail) are at risk of service interruption due to inundation and erosion. These coastal corridors are critical for both local commuting as well as a portion of shipping. Coastal erosion and coastal and inland tidal zone road flooding can cause roadway damage and both shorter longer term travel delays.

Sea-level rise also impacts bridges by accelerating scour, the erosion caused by fast-flowing water containing abrasive particles or solids. Sea-level rise can exacerbate the removal of sand, earth, or silt from the bottom of banks of a river and progressively wear away the support soils beneath a foundation support of a bridge, such as a spread footing. These foundations support the bridge and, if the support soil is removed, the bridge will fail (collapse) under its own weight.

Regional transportation planners will need to address the effects of sea-level rise. At the planning and project level, they will have to work with Caltrans to incorporate it in project development. Caltrans recently developed a project screening process to plan for the impact of different potential sea levels based on a facility's importance for statewide travel, community safety, and other factors.[5]

Impacts of Increased Precipitation on the Regional Transportation System

Expected changes in precipitation, both for averages as well as extremes, will produce a range of new impacts in California. The frequency, intensity and duration of intense precipitation events contribute to design specifications for transportation infrastructure, and projected changes may necessitate the update of design specifications for roadways, rail beds and stormwater drainage around road and rail tracks.[6]

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[5] California Department of Transportation, Climate Change Working Group, Guidance on Incorporating Sea Level Rise: May 19, 2011.

[6] National Research Council of the National Academies (NRC), *Potential Impacts of Climate Change on U.S. Transportation*, Transportation Research Board Special Report 290, Washington, D.C., 2008.

More intense precipitation may cause an increased incidence of flooding along coastal roadways and rail lines. Low-lying bridge and tunnel entrances for rail and rail transit will also be more susceptible to flooding, and thousands of culverts and other drainage infrastructure could be undersized—designed for today's precipitation instead of tomorrow's.[7]

The cycle of landslides closely follows the rainfall intensity in the winter months. Repeated periods of high-intensity rainfall often result in landslides throughout the State, resulting in, among other things, closures of roads, rail lines, and other transportation systems. For example, the recurrence of the La Conchita landslide roughly every 10 years is caused by winter storms that, in the last failure, completely closed Highway 101 and the parallel rail corridor for a week (CNRA 2012).

Changing precipitation could result in erosion and subsidence of transportation infrastructure like rail beds, causing the interruption or disruption of traffic. The changing precipitation (for instance, changes from frozen to liquid precipitation) could change runoff patterns, increasing the risk of floods, landslides, slope failures, and consequent damage to roadways and rail beds, especially rural areas in the winter and spring months.[8]

Impacts of Changing Temperature on the Regional Transportation System

California should expect overall hotter conditions by the end of the century. All model projections suggest increased temperatures, with the level of emissions representing the biggest uncertainty: temperature levels will rise more quickly and be higher by the end of this century with higher emissions.

Changes in temperature may damage materials used in roads and other transportation infrastructure. The increase in average temperature will also have a cumulative impact on the material properties of infrastructure systems. Individual days of extreme temperatures can also produce failures. Typical construction materials degrade in extreme heat, cold, and moisture. An increase in the intensity of these elements will result in more rapid degradation of an already aged infrastructure.

Changing temperature may affect increased freeze-thaw conditions, creating frost heaves and potholes on road and bridge surfaces and compromising rail beds. Longer periods of extreme heat can cause deformation of asphalt and rails, increasing the chance of derailments, or at a minimum, requiring speed

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[7] Ibid.

[8] Ibid.

restrictions.[9] Buckled rails and heat kinks result from overheated rails that expand and cannot be contained by the ties and other track structures.

Higher heat can increase the cost to cool equipment, which may even have to be redesigned to adequately withstand increased temperatures. Increased extreme heat can also cause overhead catenary wires to sag and lead to overheated vehicles and failed air conditioning systems within the vehicle itself.[10]

High heat can also pose challenges for customer service and worker safety; passengers waiting on platforms in hot weather, or construction and maintenance crews can be affected by an increasing intensity or frequency of extreme heat days.[11]

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[9] National Research Council of the National Academies (NRC), *Potential Impacts of Climate Change on U.S. Transportation*, Transportation Research Board Special Report 290, Washington, D.C., 2008.

[10] Ibid.

[11] Ibid.

PART II. A BASIC APPROACH FOR INCORPORATING ADAPTATION IN REGIONAL TRANSPORTATION PLANNING

5.0 A Basic Approach: Identifying Impacts and Exploring Adaptation Options

5.1 Using the California Adaptation Planning Guide to Understand Local Impacts

The basic approach lays out a qualitative means of evaluating the climate impacts and exploring adaptation options relevant for your MPO or RTPA jurisdiction.

The first step in considering the impacts of climate change within the framework of the regional transportation plan is to understand what impacts are specific to your region.

In July 2012, the State of California produced the Adaptation Planning Guide (APG), which designates 11 climate regions within California based on rough climatic similarity. While conditions are still diverse within each region, the range of climate characteristics is narrower than at the statewide level. Designating regions, thus, allows for greater depth and more detailed guidance to be presented. Some MPO and RTPA boundaries may fall across designated climate regions.

Table 5.1 maps the climate regions by county, and describes the top three potential climate impacts in each region. Appendix C discusses potential impacts in greater detail and provides socioeconomic and demographic information to support the local understanding of the magnitude of impacts. Appendix C also provides a region-by-region evaluation of relevant climate impacts, and how they might affect the infrastructure and assets within a region.

Figure 5.1 shows the climate regions designated in the APG.

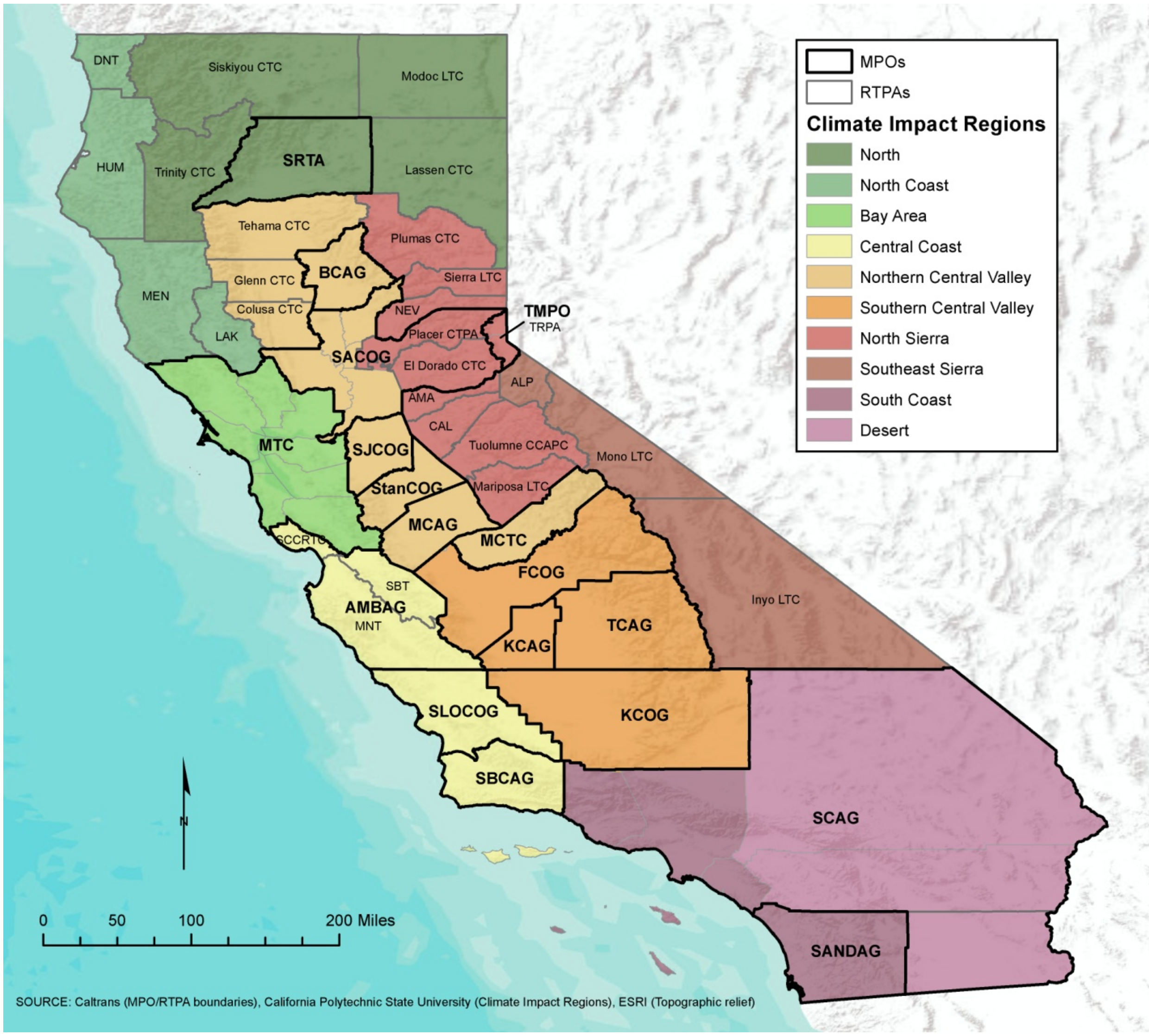
Table 5.1 Potential Impacts by Climate Region by County

Climate Region	County	Potential Climate Impacts
North Coast	Del Norte, Humboldt, Lake, and Mendocino	• Sea-level rise • Threats to sensitive species • Reduced agricultural productivity
North	Lassen, Modoc, Shasta, Siskiyou, and Trinity	• Increased wildfire • Reduced snowpack • Ecosystem shifts
Bay Area	Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma	• Coastal inundation and erosion • Public health – heat and air pollution • Reduced agricultural productivity
Northern Central Valley	Butte, Colusa, Glenn, Madera, Merced, Sacramento, San Joaquin, Stanislaus, Sutter, Tehama, Yolo, and Yuba	• Reduced agricultural productivity • Increased wildfire • Public health – heat
Bay-Delta Region	Contra Costa, Sacramento, San Joaquin, Solano, and Yolo	• Flooding • Reduced agricultural productivity • Public health – heat and air pollution
Southern Central Valley	Fresno, Kern, Kings, and Tulare	• Reduced agricultural productivity • Public health – heat • Reduced water supply
Central Coast	Monterey, San Benito, San Luis Obispo, Santa Barbara, and Santa Cruz	• Reduced agricultural productivity • Coastal flooding • Biodiversity threats
North Sierra	Amador, Calavera, El Dorado, Mariposa, Nevada, Placer, Plumas, Sierra, and Tuolumne	• Economic impacts – tourism decline • Ecosystem change • Increased wildfire
Southeast Sierra	Alpine, Inyo, and Mono	• Economic impacts – tourism decline • Substantially reduced snowpack • Flooding
South Coast	Los Angeles, Orange, San Diego, and Ventura	• Sea-level rise • Reduced water supply • Public health – heat and air pollution
Desert	Imperial, Riverside, and San Bernardino	• Water supply • Public health and social vulnerability • Biodiversity threats

Source: APG Understanding Regional Characteristics, July 2012.

Note: The Central Valley was split into north and south based on hydrologic boundaries; this results in the Northern Central Valley region containing all counties draining to the Sacramento-San Joaquin Delta. The Sierra Nevada area was split based on ecosystem differences, as well as variation in projected climate impacts. The Bay-Delta is the only region that shares all its counties with other regions. The designation of the Bay-Delta as a region recognizes that this area is distinct due to its elevation profile and flood vulnerability.

Figure 5.1 Climate Impact Regions for MPOs and RTPAs



Note: The MPO and RTPA names and acronyms in the figure as follows: Del Norte County Transportation Commission (DNT); Humboldt County Association of Governments (HUM); Siskiyou County Transportation Commission (Siskiyou CTC); Modoc County Transportation Commission (Modoc LTC); Trinity County Transportation Commission (Trinity CTC); Shasta Regional Transportation Agency (SRTA); Lassen County Transportation Commission (Lassen CTC); Tehama County Transportation Commission (Tehama CTC); Plumas County Transportation Commission (Plumas CTC); Mendocino Council of Governments (MEN); Glenn County Transportation Commission (Glenn CTC); Sierra County Transportation Commission (Sierra LTC); Sacramento Area Council of Governments (SACOG); Butte County Association of Governments (BCAG); Lake County/City Area Planning Council (LAK); Nevada County Transportation Commission (NEV); Colusa County Transportation Commission (Colusa CTC); Placer County Transportation Planning Agency (Place CTPA); Tahoe Regional Planning Agency (TRPA); El Dorado County Transportation Commission (El Dorado CTC); Alpine County Transportation Commission (ALP); Metropolitan Transportation Commission (MTC); Mono County Transportation Commission (Mono LTC); Amador County Transportation Commission (AMA); Calaveras County Council of Governments (CAL); Tuolumne County/Cities Area Planning Council (Tuolomne CCAPC); San Joaquin Council of Governments (SJCOG); Stanislaus Council of Governments (StanCOG); Mariposa County Transportation Commission (Mariposa LTC); Merced County Association of Governments (MCAG); Madera County Transportation Commission (MCTC); Fresno Council of Governments (FCOG) Council of Fresno County Governments (COFCG); Inyo County Transportation Commission (Inyo LTC); Santa Cruz County Regional Transportation Commission (SCCRTC); Council of San Benito County Governments (SBT); Transportation Agency For Monterey County (MNT); Association of Monterey Bay Area Governments (AMBAG); Tulare County Association of Governments (TCAG); Kings County Association of Governments (KCAG); Kern County Council of Governments (KCOG); San Luis Obispo Council of Governments (SLOCOG); Santa Barbara County Association of Governments (SBCAG); Southern California Association of Governments (SCAG); San Diego Association of Governments (SANDAG).

Source: Caltrans (MPO/RTPA Boundaries), California Polytechnic State University (Climate Impact Regions) and ESRI, 2012.

A summary of major infrastructure and other regional facilities can help in defining which assets are most vulnerable or at risk, and also which ones are most critical to the regional transportation system. It can also begin to outline what economic functions need to be supported by the region's transportation network. As such, the regional evaluations include a range of infrastructure, including transportation, electricity, water, wastewater, and natural gas, and involves systems critical for the provision of services. Other resources addressed include wastewater treatment plants and power plants. Also included are state and federal parks that may be affected by climate change but also serve as a resource in devising adaptation strategies, particularly for sensitive species.

5.2 Basic Climate Impacts on the Regional Transportation System

Based on the data developed from the Adaptation Planning guide, as well as the impacts to transportation summarized in Chapter 4.0 of this guide, the climate impacts that are likely to take place and have an effect on the transportation systems in California include sea-level rise, increased extreme precipitation events, and increased extreme heat events. These three climate stressors have the most significant potential to impact California's transportation network and should be considered, at a minimum qualitatively, during the RTP process.

Regional transportation planners have a role in planning for existing and future transportation projects in the face of a changing climate. This includes evaluating today's already complex transportation network and the projections for major interconnectivity projects up to 2035 and beyond. Transportation affected by a changing climate includes roadways, railways, airports, marine ports, and shipping routes. It also includes the structures that support these routes, including bridges, culverts, tunnels and tracks.

Transportation infrastructure can be affected by climate change through direct disruption of service due to fire, inundation, or landslide; changes in efficiency and maintenance requirements; and increased demand. Disruption of transportation systems has the potential to be detrimental to the economic vitality of the communities relying on them for delivery of goods and services.

5.3 What Can Every MPO or RTPA Do?

To date, there is no requirement at the federal or state level for including climate adaptation into the regional transportation planning process. However, the proactive consideration of climate change in the process is an aspect of good planning. Even without extensive data or capacity and resources capabilities, any MPO or RTPA can conduct a basic assessment of how climate impacts put the region's most critical transportation assets at risk. For these identified risks, this guide provides a short list of possible adaptation strategies on key infrastructure suggested by Caltrans, shown in Table 4.1. Adaptation strategies that can be addressed in an RTP include hazard mitigation strategies, maintenance and operational strategies, engineering solutions, and planning for alternative routes, for example.

A basic evaluation can comprise the following three steps:

- **Step 1. Find Your Climate Region and Assess the Effects**. This step includes the review of Appendix C of this guide and reading the four-page summary of climate impacts localized for your region. If more extreme heat and sea-level rise are anticipated in your RTP horizon year, for example, you will want to consider the effects of those stressors on your transportation system.
- **Step 2. Think about Your Top Five Transportation Assets and How They Might be Affected by Climate Change.** This step narrows down the universe of possibilities to the five key assets that might be affected by climate change. If there is a major highway on the coast, or a railway that is already susceptible to frequent flooding, these could be critical assets to consider. If you have access to GIS, it may be useful for you to obtain transportation and climate data layers in order to consider the potential spatial interactions between them. If you do not have access to GIS, you may want to think about transportation facilities already impacted by extreme weather and consider how these impacts could change, given the projections for your climate region.
- **Step 3. Develop a Short List of Adaptation Strategies for Further Study and Inclusion into the Regional Transportation Plan.** This step involves convening a half-day workshop or session involving planners, engineers and other relevant stakeholders to examine the list of critical assets, consider potential climate-related risks, and develop a set of possible adaptation strategies for each. A starting point could be Table 4.1 in this guide, which outlines potential climate impacts and various planning, design and operational adaptation strategies that could be employed. It is also possible that the action resulting from this evaluation would be further study into the key assets for future consideration or during project selection. The results of this workshop or session would be a qualitative summary of the vulnerability and risk due to climate change, and short-term and/or long-term strategies to consider in the regional transportation planning process.

6.0 Where Has this Been Done? California-Specific Examples

6.1 Current RTPs Considering Climate Impacts

Although MPOs in California are all required to consider the reduction of greenhouse gas emissions in their RTPs, there is no requirement to date to incorporating climate change in adaptation planning. Despite this, there has been some discussion as part of the RTP process for the four large MPOs in California, and burgeoning activity alongside the RTP process through university activity, nascent discussion, or hazard mitigation for a handful of smaller MPOs/RTPAs.

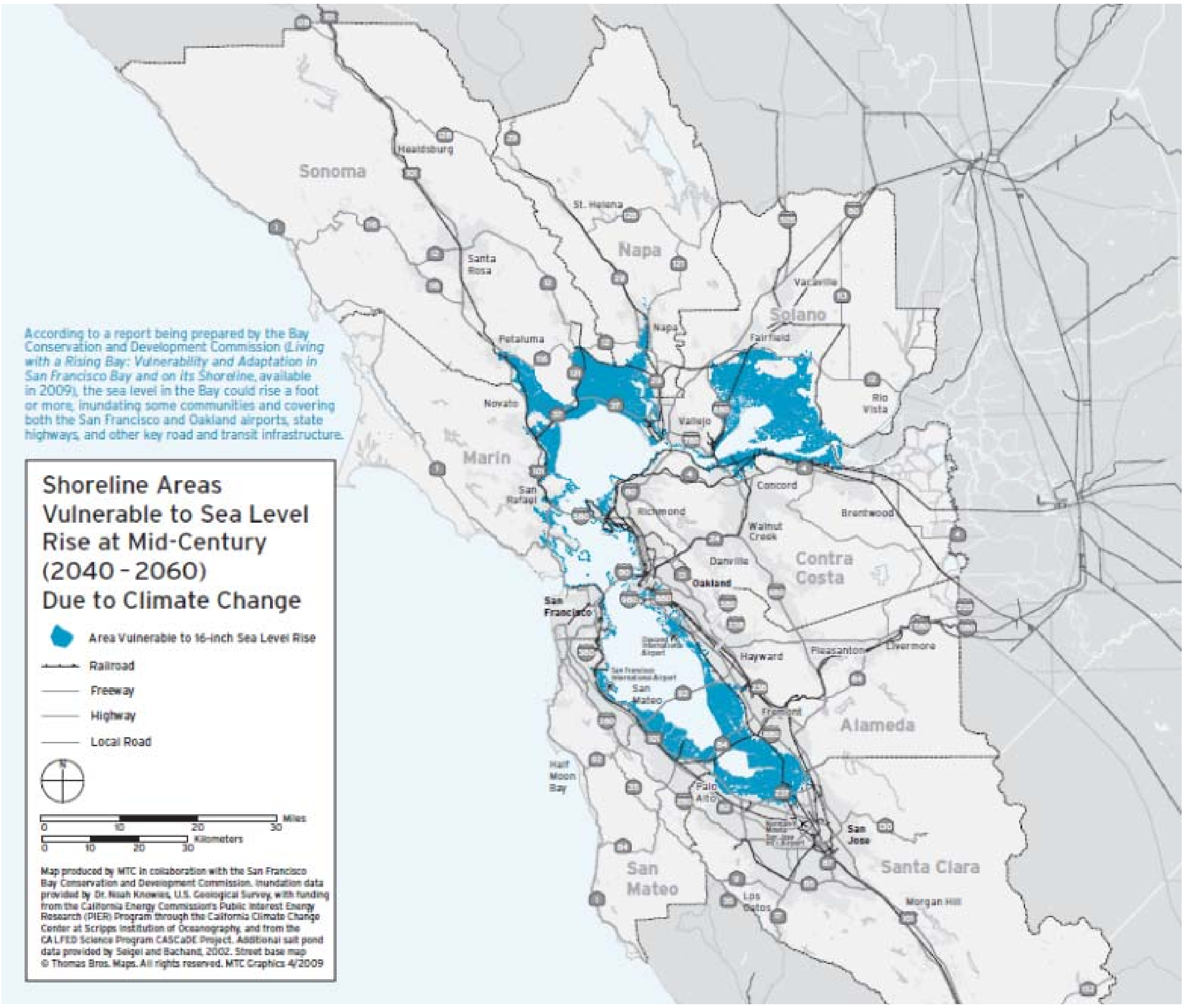
RTP Integration at the Four Large MPOs

For background, this section summarizes the most up-to-date discussion (as of writing) on climate impacts and adaptation from the four largest MPOs in California – the Metropolitan Transportation Commission (MTC), the Sacramento Area Council of Governments (SACOG), the Southern California Association of Governments (SCAG) and the San Diego Association of Governments (SANDAG). Although this guide is focused on smaller MPOs and RTPAs, the activities taking place at the four large MPOs help establish the current state-of-the-practice in California.

Metropolitan Transportation Commission (MTC)

On April 22, 2009, the MTC adopted the *Transportation 2035 Plan for the San Francisco Bay Area*, which specifies how some $218 billion in anticipated federal, state and local transportation funds will be spent in the nine-county Bay Area during the next 25 years. *Transportation 2035* only briefly mentions climate impacts by noting how the Bay Area will experience a greater number of extreme-heat days, increased wildfire risk, a shrinking Sierra snowpack that would threaten the State's water supply, and a rise in sea level (which would threaten the transportation infrastructure concentrated near the shoreline of the Bay). However, it does provide reference to a parallel study on sea-level rise, *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project,* completed in November 2011, and references a preliminary assessment for that study shown in Figure 6.1.

Figure 6.1 Sea-Level Rise and Shoreline Vulnerability on Shoreline Areas from MTC's Transportation 2035 Plan



Source: MTC Transportation 2035 Plan for the San Francisco Bay Area, April 2009, page 49.

Specific findings and further discussion will be included in the current One Bay Area Plan, the RTP process planned for adoption in spring 2013.

Sacramento Area Council of Governments (SACOG)

On April 19 2012, SACOG adopted the Metropolitan Transportation Plan/ Sustainable Communities Strategy (MTP/SCS), the Sacramento region's long-range plan for transportation. Since the prior MTP, California adopted Senate Bill 375, which requires a Sustainable Communities Strategy. The SACOG MTS/SCS includes a short section describing the causes and effects of climate change. It includes discussion on what factors lead to climate change; how it impacts human health, the environment, and economy; and what components of the MTP/SCS can help to minimize the effects climate change will have on the region. The impacts from climate change are focused on five areas: public health, water resources, agriculture, forests and landscape, and rising sea levels. The discussion is brief and high-level, focusing on the broader impacts rather than any specific assessment of risk or vulnerability on the regional transportation infrastructure.

Southern California Association of Governments (SCAG)

On April 4, 2012, the Regional Council of the Southern California Association of Governments (SCAG) adopted the 2012-2035 Regional Transportation Plan/ Sustainable Communities Strategy (RTP/SCS): *Towards a Sustainable Future*. This RTP includes a section on adaptation, specifically citing the 2009 California Adaptation Strategy Report and its projection that southern California will be expected to manage extremes of precipitation and temperature, increased storm frequency and intensity, and sea-level rise. The specific impacts called out in *Towards a Sustainable Future* include the following:

- Longer and hotter heat waves;
- Increased urban heat island impacts, such as heat-related illness and higher cooling demand and costs;
- More damaging storms and storm surges;
- Greater river flooding;
- Increased frequency and intensity of combined sewer overflows;
- More intense and extended duration of droughts;
- Longer water supply shortages; and
- Declines in local ecosystem services, such as species loss or the loss of specific ecosystem types (e.g., forests or coastal wetlands).

As in the SACOG MTP/SCS, the discussion of climate adaptation is brief and high-level, focusing on the broader impacts rather than any specific assessment of risk or vulnerability on the regional transportation infrastructure.

San Diego Association of Governments (SANDAG)

On October 28, 2011, SANDAG adopted the 2050 Regional Transportation Plan (RTP) and Sustainable Communities Strategy (SCS). The 2050 RTP lays out a plan for investing an estimated $214 billion in local, state, and federal transportation funds expected to come into the region over the next 40 years.

SANDAG's RTP identifies the transportation sector as a key contributor to GHG emissions but also notes that the region is affected by the impacts of climate change. It lists potential impacts as more frequent and intense heat waves, more frequent and intense wildfires, degraded air quality, fresh water shortages, rising sea levels and greater storm surges, the loss of native plant and animal species, and a higher demand for electricity during peak periods.

SANDAG also notes that there are some climate impacts that could lead to increased and more frequent maintenance costs, premature deterioration, or even the failure of transportation infrastructure in the region. A brief note about adaptation includes discussing existing fortifications that may need enhancement as sea levels rise and storm surges intensify.

Finally, SANDAG does note that there are tools and methodologies for evaluating and adapting to such climate change impacts but they are still in the early stages of development and will require ongoing monitoring. In the RTP/SCS, SANDAG compiles a list of 31 action items that will be use to implement the SCS by year 2050. One of the action items acknowledges climate adaptation: "To the extent possible, address climate adaptation issues in the design of new projects, and when improvements are made to existing infrastructure." The action is proposed for SANDAG, Caltrans and local jurisdictions.

Promising Examples from Other MPOs/RTPAs

Outside of the four large MPOs, other MPOs and RTPAs are beginning to take note of climate adaptation and exploring ways to incorporate it in planning processes in coordination with local county hazard mitigation planning processes, through research conducted at a local university, or exploration through existing extreme weather effects already impacting regional transportation assets. Summaries from interviews with six leading MPOs/RTPAs can be found in Appendix B. This section also provides some examples of nascent climate adaptation activity that will likely evolve in the upcoming RTP cycles.

- The **Association of Monterey Bay Area Governments (AMBAG)** has recently embarked on an effort to analyze potential environmental impacts and benefits of beach nourishment with opportunistic sand placements. Coastal impacts associated with sea-level rise are widespread and diverse. Impacts of concern for the Monterey Bay region include: increased coastal erosion, coastal inundation, storm and wave damage, and salt water intrusion. To lessen the effects, the Southern Monterey Bay Coastal Sediment Management Plan, developed in 2008, was the first coastal regional sediment management plan completed in California.

  The plan compiled the best existing information on coastal processes, erosion rates and geomorphology. It identified sources of sediment that could be used in nourishment projects to reduce erosion hazards and evaluated the traditional costs and benefits of various scales of nourishment projects, including the potential recreational benefits. The plan also evaluated some of the regulatory and permitting frameworks involved in managing sediment within southern Monterey Bay.

- The **Fresno Council of Governments (FCOG)** staff took part in a regional climate change adaptation assessment conducted by the Local Government

Commission (LGC) to develop recommendations for Fresno County. A workshop and technical report convened and completed in 2010 described the effects of climate change on the regional transportation system including the main transportation routes in the Valley at greatest risk, given their location downstream of reservoirs or adjacent to the County's rivers.

The report noted that increasingly severe extreme heat events can cause damage to existing roadways and railways (e.g., by increases in so-called "blowups" – sudden faulting of concrete slabs). It also described how wildfires in the past had led to closures of important evacuation routes (e.g., Highway 168 in the Big Creek Wildland fire in 1994), and that there is a risk of increased fires in the future due to climate change. Major themes included the need for emergency response and repair.

- The **Humboldt County Association of Governments (HCAOG)** is prepared to incorporate climate change in the upcoming RTP with discussions already forming around climate change mitigation and a high likelihood that climate adaptation will also emerge as a key issue.

  The County is already looking for ways to protect coastal communities on Humboldt Bay threatened by rising sea levels and aging dikes. In October 2012, the Humboldt County Board of Supervisors approved an application for a Coastal Conservancy grant to allow the nonprofit Coastal Ecosystems Institute of Northern California to adapt planning and technical studies associated with sea-level rise in Humboldt Bay.

- The **Santa Barbara County Association of Governments (SBCAG)** has experienced a movement of various stakeholders building local capacity for considering climate change adaptation. For example, the University of Santa Barbara's Ocean and Coastal Policy Center published *Developing Adaptive Policy to Climate Disturbance in Santa Barbara County* in 2009. The Center also formed a committee to focus on wetland recovery in the Goleta Slough near the airport. The adaptation study was driven by the desire to identify specific facilities at risk in the Goleta Slough.

- The **Shasta County Regional Transportation Planning Agency (SCRTPA)** supported Shasta County in completing a local hazard mitigation plan in 2011, called the Shasta County Multijurisdictional Hazard Mitigation Plan. SCRTPA was well aware that information developed for the local hazard mitigation plan was a starting point for understanding impacts that could be exacerbated by climate change.

  The purpose of hazard mitigation is to implement and sustain actions that reduce vulnerability and risk from hazards, or reduce the severity of the effects of hazards on people and property. Concepts such as risk, vulnerability, and resiliency are common to both hazard mitigation, as well as climate adaptation.

6.2 Adaptation Projects Elevated Due to Extreme Weather Events

The impetus for planning for climate adaptation can be instigated by major extreme weather events or natural disasters that have the potential to become more frequent and/or more severe with climate change.

For example, the Confusion Hill Bypass in Mendocino County is an example of how a project can be accelerated due to extreme weather events. The Confusion Hill Bridges are a pair of high bridges carrying two lanes of U.S. Highway 101 over the South Fork Eel River in Mendocino County in northern California. The old route weaved through a river canyon that was closed yearly due to landslides. Between 1997 and 2006, landslides would become an annual occurrence, with earth and rocks covering the road and bringing traffic and business to a halt. Caltrans spent more than $33 million in the nine-year period clearing debris and repairing the road under Confusion Hill. Because of the high costs of maintaining the old section and potential safety issues that perpetually posed a risk to travelers, Caltrans and the County secured $65 million in emergency relief funding from the FHWA and constructed the Bypass, completed in 2009.

Another example is the proposal by Caltrans to move three miles of Highway 1 in Big Sur as far as 475 feet inland in order to protect against expected cliff erosion underneath the current stretch of highway. In 2011, a landslide closed Highway 1 near Big Sur in Monterey County, a major regional and recreation route, forcing motorists to make a long inland detour using U.S. Highway 101. The two-month closure prompted Caltrans to review this stretch of roadway to consider the most relocation as a form of adaptation; in this case, an extreme and costly adaptation option.

These examples reflect how existing extreme weather events already pose hazards to the regional transportation system. Using these examples as extreme possibilities can help provide insight into the types of impacts that climate change may intensify.

PART III. AN ADVANCED APPROACH FOR INCORPORATING ADAPTATION IN REGIONAL TRANSPORTATION PLANNING

7.0 An Advanced Approach: Applying the Five-Step Climate Change Assessment and Adaptation Modules

The remainder of this report outlines a five-step process for California MPOs/RTPAs to incorporate climate change assessment and adaptation into their RTPs. To meet this objective, this report suggests a set of modules shown in Figure 7.1, modified but aligned with the FHWA Climate Change Vulnerability Conceptual Risk Assessment Model.[12]

Figure 7.1 Climate Change Assessment and Adaptation Modules

Source: Cambridge Systematics, Inc., 2012.

[12] http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/vulnerability_assessment_pilots/conceptual_model62410.cfm.

The five modules are as follows:

- **Module 1:** Set Mission, Goals and Objectives
- **Module 2a:** Assemble Asset Inventory and Screen Criticality
- **Module 2b:** Apply Climate Information
- **Module 3:** Conduct Vulnerability and Risk Assessment
- **Module 4:** Develop Adaptation Strategies
- **Module 5:** Monitor and Evaluate Plan

The modules are meant to be flexible and can be applied with anywhere from minimal data and resources, to extensive data and advanced technical capacity. This flexibility allows MPOs and RTPAs to utilize this document in a way that best serves their needs. It can be used for a first time preliminary assessment of adaptation issues for the RTP or as a means to formally integrate climate adaptation into the RTP process.

Caltrans provides many statewide transportation asset layers as geospatial resources in the GIS Data Library.[13] MPOs or RTPAs interested in utilizing this assessment process with GIS data layers can download individual layers through the Caltrans GIS Data Library. Alternatively, resources such as Cal-Adapt can be used for planning level assessment as a complementary data set to transportation layers. Smaller or agencies with limited resources will find it helpful to walk through each module in a more qualitative fashion or simply to use Part II of this guide for Basic Users. An agency with more staff and mapping resources may want to start with the Caltrans GIS Data Library information but layer on additional local and regional GIS layers to apply a more rigorous climate assessment to its facilities.

[13] http://www.dot.ca.gov/hq/tsip/gis/datalibrary/gisdatalibrary.html.

8.0 Module 1: Set Mission, Goals, and Objectives

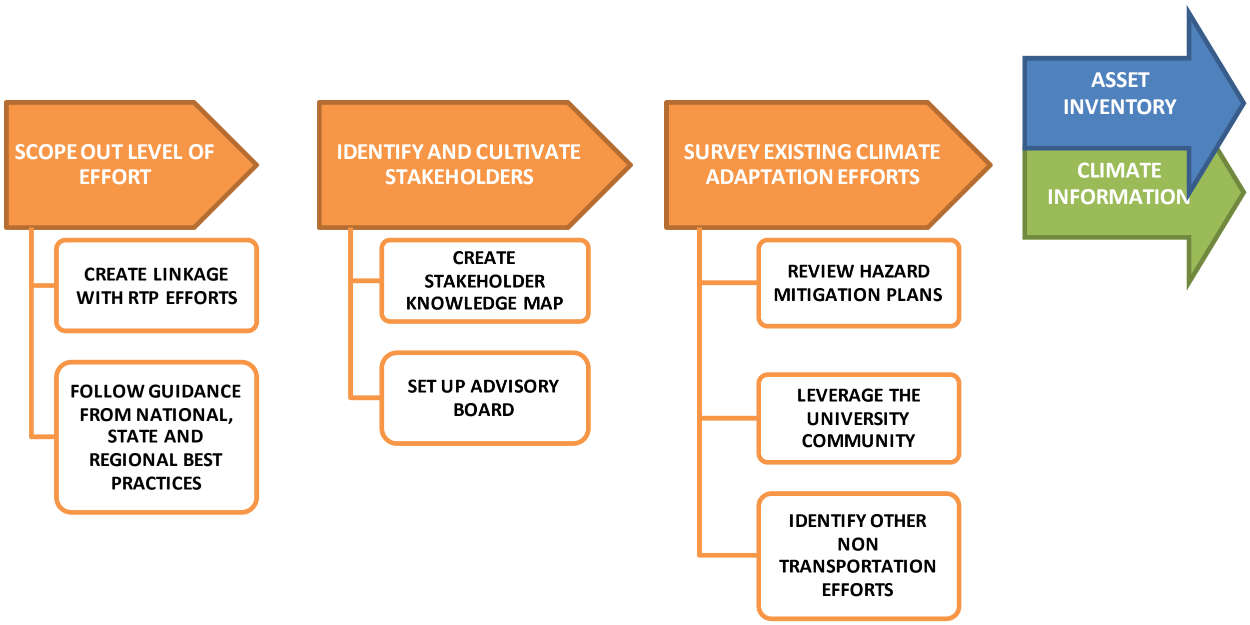
8.1 The Reason for Setting Mission, Goals, and Objectives

Incorporating climate change adaptation is a new topic in transportation planning. It must compete with a litany of requirements already embedded in the RTP guidelines, so MPOs/RTPAs will have to be clear about the goals and objectives of conducting a climate change risk assessment and adaptation strategy. For many California MPOs/RTPAs, the goal may be to develop a high-level scenario assessment with existing data and base the assessment mainly on extrapolations from current hazard mitigation planning. At some agencies, such as at Humboldt County Association of Governments, for which the climate projections reveal extreme impacts of sea-level rise on its coastal roads, planners are already exploring detailed adaptation strategies in parallel with the RTP process.

The purpose of Module 1 is to lay out the overall effort associated with incorporating climate adaptation into the RTP process and to collect and garner as much existing data, support, and technical expertise to leverage efforts already taking place in the region.

Figure 8.1 provides a step-by-step guide for setting the mission, goals and objectives of the effort and is described in greater detail throughout the text.

Figure 8.1 Setting Mission, Goals, and Objectives



Source: Cambridge Systematics, Inc., 2012.

8.2 Initiating the Process for RTP Integration

Currently, there is no federal or state requirement to incorporate adaptation into the RTP. In the already complex and multifaceted, long-range transportation planning on which California MPOs and RTPAs regularly embark, considering climate adaptation should support existing planning processes rather than take place outside of the RTP cycle. Within this context, MPOs/RTPAs would ideally do the following every time an RTP is up for development or revision:

- Identify relevant climate stressors (sea-level rise, temperature changes, snow melt, precipitation changes, flooding, extreme weather events) and assess their impacts and relative risks to the regional transportation system infrastructure and services;
- Conduct an asset inventory and vulnerability assessment of existing infrastructure;
- Prioritize segments and facilities for adaptation action;
- Identify appropriate and cost-effective adaptation strategies; and
- Incorporate climate impact considerations into future long-range transportation planning and investment decisions either through project prioritization or acknowledgment of these impacts and a commitment to ongoing study.

The start of the effort should include scoping out the level of effort, identifying and cultivating stakeholders, surveying existing efforts in the region, and engaging stakeholders in preliminary discussions.

Scope out the Level of Effort

Create Linkages with RTP Efforts

The recommended application of this climate assessment and adaptation procedure is to link the climate adaptation assessment with the RTP efforts. Because RTPs are required to be for a minimum of 20 years, most RTPs have a horizon year of 20 or 25 years. The climate scenarios should be performed for the matching RTP horizon year (or a close as possible given available resources), as well for a much longer-term future year that incorporates the life spans of the most durable infrastructure investments in the region, often bridges. Although at the time of writing, there has been no formal incorporation of climate adaptation in project prioritization, some regions outside of California, such as Oahu MPO and Chattanooga-Hamilton County Regional Planning Agency, have begun to consider these issues parallel to their long-range transportation planning efforts. Larger MPOs in California such as the Metropolitan Transportation Commission (MTC) and San Diego Association of Governments (SANDAG) have also conducted more extensive analyses on sea-level rise specifically, but outside of the formal RTP process.

Follow Guidance from National, State, and Regional Best Practices

There are many sources of guidance from the national, state, and regional levels that a MPO/RTPA must consider before initiating a climate assessment and adaptation strategy. Currently, there is no national recommendation for incorporating climate adaptation into long-range transportation planning, although the FHWA has developed a variety of tools and resources to help regional agencies to take action. For those state and regional agencies working at the forefront of adaptation planning, FHWA has provided pilot project funding for the development of assessments. FHWA provided funds for five projects completed in 2011, and another round of pilot projects is set to begin in early 2013.

At the state level, Caltrans produced *Guidance on Incorporating Sea-Level Rise* (2011) for its planning staff to help determine if sea-level rise should be addressed in a particular project and if so, how to incorporate it. It guides planners and project managers through a two-step process: the first step is to determine if the project will be affected by sea-level rise; the second step balances sea-level rise impacts with consequences to the transportation system to determine if adaptation measures should be included in the project. This guidance document is intended to be updated as research on this emerging topic of climate change adaptation is released. California Executive Order S-13-08, signed in 2008, mandates that state agencies planning projects in vulnerable areas consider various sea-level rise scenarios for the years 2050 and 2100. This provides guidance specific to California as well.

The 2010 CTC RTP Guidelines provide only general guidance on climate adaptation in *Section 6.30 Adaptation of the Regional Transportation System to Climate Change*. Specifically, the document suggests the following best practices:

> *Notwithstanding a lack of reliable information on the future impacts of sea-level rise, precipitation changes, or extreme heat events, MPOs and RTPAs should begin to address climate change in their long-range transportation plans. There are numerous ways planning agencies can begin preparing for climate change adaptation on the transportation infrastructure including preliminary mapping of infrastructure that is vulnerable to changes in precipitation, heat, and sea-level rise. It is also recommended that design and planning standards be re-evaluated to accommodate potential changes. It is important to ensure that planned infrastructure is engineered and built in locations that can withstand future climate change impacts (CTC 2010).*

Because climate information, projections and the science are constantly evolving, it is important to incorporate the most up-to-date guidance available before the planning process, and to stay up-to-date with new information available.

Developing Stakeholders in a Preliminary Climate Study

In the Arizona DOT's Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona (2012), the project team used a "knowledge mapping" approach to determine the process flow of the planning, project development, and asset management activities within the agency. To achieve this, the project team reviewed agency organizational charts, and identified departments that could play important roles in addressing climate adaptation, including management staff, technical staff, and "cross-cutting" departments, who would work across disciplines to provide data to either the management or technical staff. The project team then considered the potential climate impacts that could affect Arizona DOT's operations, and assigned roles related to these impacts to the departments identified through the organizational chart exercise. After that, focus groups were conducted with members of these identified departments to clarify their roles, collect feedback, and determine if the "knowledge mapping" exercise" was thorough and accurate.

Source: ADOT (2012).

Identify and Cultivate Stakeholders

Create Stakeholder Knowledge Map

Because climate change adaptation is an interdisciplinary responsibility, many individuals and departments within the MPO/RTPA and externally will be identified for carrying out plans, risk assessments and adaptation actions.

At the beginning of the RTP process, the lead coordinator should identify stakeholders both inside of the MPO/RTPA, as well as at the cities, counties, and at Caltrans, who might be involved in performing the planning assessment, engaging with operational or design practices, or providing monitoring and feedback in response to climate impacts. Generally, there are three categories of stakeholders who should be involved.

- **Management/Board of the RTP Process.** This includes individuals supporting the overall effort to include climate adaptation within the RTP, providing opportunities for cross-agency planning for a potential change in practice or new opportunity to integrate climate adaptation into the planning and implementation processes.
- **Technical Staff at the MPO/RTPA.** This includes individuals who have direct planning, operations or design responsibilities that would consider climate adaptation in their practices. These individuals would have a direct role in preparing for or responding to climate impacts.
- **Cross-Cutting Agencies.** Individuals in these departments would likely work across disciplines providing data or input to management and technical staff. There is a wide variety of expertise that could be included in this category, including individuals in emergency response and natural hazards planning, economic development, public works engineering, regional entities including air districts and county agencies, regional science organizations or universities and local nongovernmental organizations.

MPOs/RTPAs have an expansive role that spans planning, design and operations functions. It is appropriate to coordinate with city agencies, public works, or state agencies to determine a transportation asset or facility's resiliency and develop relevant adaptation options.

Set Up Advisory Board

The MPO/RTPA would ideally select candidates from the stakeholders listed in the previous section to set up an advisory board. This board can convene in multiple ways depending on the regional make-up, including as a task force, a committee, or a series of expert workshops. Depending on the level of effort pursued, the duration of the policy development period, and the availability of staff, an advisory board can be used for a quick sketch-level assessment or to formulate a longer term strategy or assessment process incorporated into the formal RTP. It is very likely that this board would comprise many stakeholders from outside the MPO/RTPA as it will be important to account for local and regional activities from different sectors as well as at different geographic scales. In addition to determining potential impacts to transportation infrastructure in the region, a critical task of the advisory board will be assessing how well existing policies and programs respond to projected climate changes.

Survey Existing Climate Adaptation Efforts

Review Hazard Mitigation Plans

Although very few MPOs/RTPAs have ventured into climate vulnerability and risk assessment, many work with their counties to develop hazard mitigation plans and conduct local hazard mitigation activities. Using existing hazard plans can offer lessons for adaptation strategy development: natural hazard impacts are one area that may be affected by climate change and climate change has the potential to alter the type, frequency and severity of already existing natural hazards.

The purpose of hazard mitigation is to reduce potential losses from future disasters. The intent of mitigation planning, therefore, is to maintain a process that leads to hazard mitigation actions. For those communities with existing Local Hazard Mitigation Plans, they must be updated at least once every five years in order to continue to be eligible for FEMA hazard mitigation project grant funding.

Because hazard planning relies on historic event probabilities to predict future needs, the process does not provide a complete assessment of potential future climate impacts, and thus must be supplemented with climate change adaptation planning.

Leverage the University Community

Universities often have the best local knowledge of the literature and data pertaining to climate change impacts. Because climate information is downscaled from global climate models to state or regional projections, the resolution is less accurate the smaller the geographic region. For specific impacts, researchers at local universities often have the most appropriate and specific assessment of local climate change. For instance Fresno COG refers to Fresno State for local climate knowledge and SBCAG has a more precise understanding of sea-level rise impacts from research developed at the University of California Santa Barbara.

Cultivating University Partnerships

Fresno State University (FSU) has served as a valuable resource on climate information for Fresno County. In 2010, FSU organized climate change adaptation workshops attended by local leaders and technical experts to address climate impacts that Fresno County will likely experience. From that workshop came a suite of strategies to help the County adapt to the specific projected effects. The recommendations for increasing the area's resilience addressed a broad range of topics, including socioeconomic systems, such as emergency preparedness and infrastructure, as well as species and ecosystems.

Source: ClimateWise, 2011, Integrated Strategies for a Vibrant and Sustainable Fresno County.

Identify Other Non Transportation Efforts

Regional climate adaptation planning has advanced quickly in other fields besides transportation planning. Many existing local and regional plans incorporate climate impacts and adaptation planning in sectors such as water, utilities, agriculture, public health and waste management and have already developed strategies that are effective for certain types of infrastructure and services. Developing adaptation policy through the RTP process can leverage existing policies from other non transportation efforts through the periodic plan update process.

Some cities and regions have a stand-alone climate adaptation plan that provides a comprehensive adaptation strategy for a jurisdiction that integrates the many distinct areas of adaptation policy, with a section on transportation and land use impacts. Alternatively, individual adaptation policies for specific infrastructure could be developed, expanded and then integrated directly into the larger plan, policy, or program most appropriate for implementation.

Examples of plans or policies that can be used to implement adaptation strategies include the general plan, area and specific plans, local hazard mitigation plans, transit plans, climate action plans, urban water management plans, parks master plans and downtown plans. Examples of standards and ordinances that can be used to implement adaptation strategies include the stormwater management program, zoning code, capital improvement plan, building code, fire code, tree ordinance or floodplain ordinance (FEMA APG, 2012).

9.0 Module 2a: Assemble Asset Inventory and Screen Criticality

9.1 The Importance of Knowing Your Assets

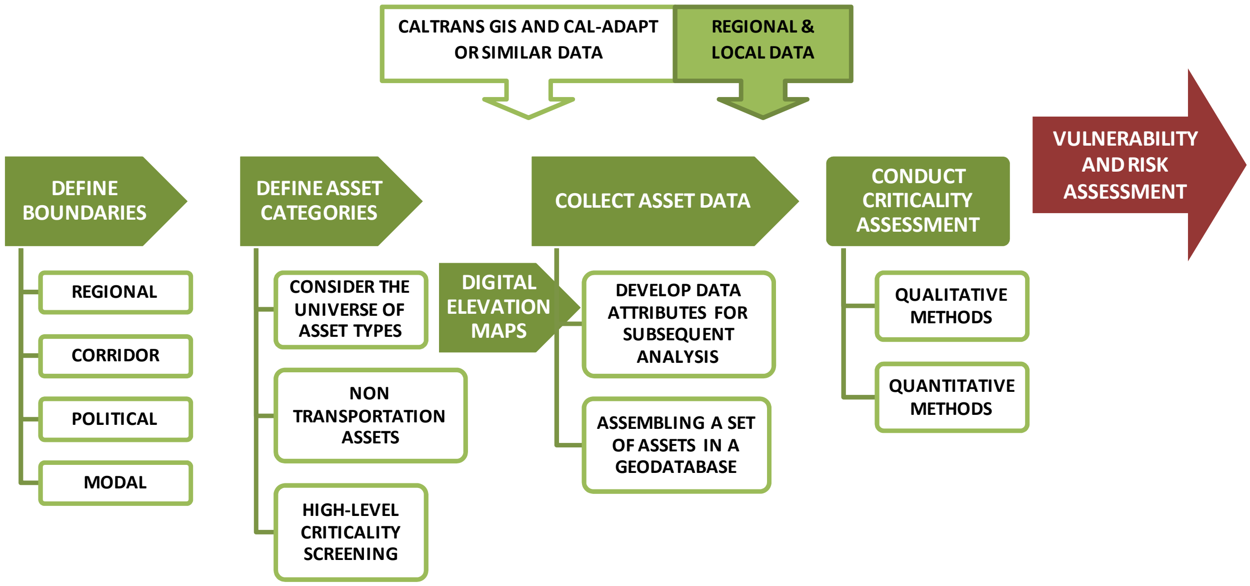
Adaptation planning focuses on the ability of assets and operations to perform effectively and withstand harm and deterioration in the face of future chronic or acute extreme weather events. Module 2a provides guidance to help MPOs and RTPAs of various sizes and capacities in the assembly and formatting of data to support vulnerability and risk assessments at the system level, and, if appropriate, to identify specific vulnerable assets for detailed design, engineering, and operational evaluation.

At its most basic level, a climate change vulnerability and risk assessment requires two categories of information: estimations of potential future climate conditions and multidimensional information on the transportation infrastructure and facilities anticipated to be in service during the assessment timeframe (this will include a substantial selection of current assets, as well as programmed or planned projects). Although climate data is typically generated by scientists and technical experts, the compilation of data on transportation assets is within the collective purview of a variety of federal, state, regional, subregional, and local entities charged with system funding, ownership, operations, and planning.

Developing a comprehensive inventory of assets, especially for a systemwide, multimodal assessment of vulnerability and risk, can be a challenging endeavor – in many cases, data insufficiency will necessitate the use of assumptions, rules of thumb, and/or alternative assessment approaches. The point of the asset inventory exercise is not to develop a perfect data set (an impossible task) but rather to ensure that the best (most appropriate, relevant, and reasonably-obtainable) data is leveraged for subsequent tasks.

Figure 9.1 provides a step-by-step guide for conducting an asset inventory and is described in greater detail throughout the text.

Figure 9.1 Conducting an Asset Inventory



Source: Cambridge Systematics, Inc., 2012.

9.2 Conducting an Asset Inventory

Ideally, the asset inventory will bring together multiple categories of data in a Geographic Information System (GIS) to support the vulnerability identification, risk assessment, and adaptation planning tasks that follow. In order to develop a plausible picture of infrastructure vulnerability, reliable data on the location, extent, elevation, and physical and operational characteristics of assets should be obtained. Risk assessment, and ultimately adaption planning, additionally incorporate attributes that express how critical a given asset is to an agency, the greater transportation system, and the broader region. These data also help to construct a better understanding of the potential consequences of climate-related asset failure.

Determine the Boundaries of Your Study Area(s)

Although seemingly the most basic consideration, the selection of study area boundaries may have significant impacts on both the granularity of the inventory – including how many asset types are included – and the resources required to carry out the subsequent vulnerability and risk assessment tasks. Further, depending on assets inventoried, broader geographic scales could yield data mismatches or incompatibilities (if, for example, two municipalities maintain differing data fields for a similar asset type).

Although there are no strict requirements, generally boundaries can be defined using the following guidelines:

- **Regional.** Including the entire MPO or RTPA geography may provide the most comprehensive geographic coverage, but may necessitate sacrifices in the quantity, type, and scale of data used to populate the inventory. For example, lower roadway functional classifications, such as local access roads, might be omitted or suppressed in order to shift resources to more critical roadways, such as freeways and other principal arterials.
- **Corridor.** Corridors can be oriented to the transportation system (representing a thick backbone of roadway or multimodal infrastructure, for instance), or emphasize economic, social, or natural features. A corridor can begin and terminate within a single region, or run through multiple regions. The choice of corridor boundaries will depend on the objectives of the overall assessment and, again, on the desired scale of the analysis.
- **Political Unit.** At the level of the county or municipality, the granularity of data may be finer and more directly relevant to study objectives (bicycle and pedestrian oriented infrastructure, for example, become more readily accessible at reduced scales). However, smaller geographic analyses may trade a more comprehensive perspective (of network dependencies, for example) for the ability to focus more closely on a more narrow physical area.
- **Modal.** If the study objectives focus on a single or small subset of modes, it may be appropriate to constrain the study boundary only to geographies relevant to that mode or modes. A study focused on general aviation airports, for example, may lead to a study area comprised of several geographic "islands" – although expanding the study to assess airport access would require the addition of a selection of roadway layers.

The choice of asset types to be included will have a significant impact on the resources required for the assessment (with the exception of the "Modal" method, of course). A very extensive geography may be manageable if a limited, standardized selection of assets is included (Interstates, for instance), whereas a small geography richly layered with modal infrastructure and other asset types may be very labor intensive.

Define Asset Categories

Consider the Universe of Asset Types

Although the types and overall quantity of assets eventually included in the asset inventory will likely comprise only a small selection of the overall universe (within the study boundaries), it is good practice to devote some time up front to defining that universe. This step can lead to the identification of synergies or opportunities that involve little marginal effort ("if we're collecting this, why not that as well?"); and also help prevent obvious omissions. For highly differentiated assets, like roadways, this exercise is one of identification (the asset type itself (e.g., roadways)) and expansion (e.g., which functional classifications, funding sources, or ownership). Some basic categories of potential transportation infrastructure and assets are included in Table 9.1, although this list is not all-inclusive.

Table 9.1 Sample Transportation Asset Data Categories

Surface Modes	Maritime	Aviation	Other
• Roadways (no local) – All functional classifications – State, county, and local roadways – Toll roads • Rails – Intercity – Commuter/regional rail – Freight rail (all classes) • Transit – Heavy and light rail – Bus Rapid Transit – Bus routes (applies to roadways) • Nonmotorized – Sidewalks, trails, paths – Bikeways • Structures (stationary and moveable) • Roadway bridges • Rail bridges • Bike/pedestrian bridges • Tunnels • Culverts	• Ferries – Passenger/water taxis – Freight • Ports – Container, bulk, break bulk, liquid bulk, roll-on roll-off etc. – Cruise ports – Barge facilities • Marinas	• Airports – Commercial – General aviation – Freight/logistics – Military – Sea plane launches • Heliports	• Pipelines • Fueling infrastructure • Logistics hubs

Source: Cambridge Systematics, Inc., 2012.

Each asset type is, in reality, an intricate aggregation of components of varying importance that combine to make the asset functional, or to optimize speeds, capacity, safety, and other factors important to the traveling public and to businesses. A commuter rail system, for instance, requires a network of tracks in order to provide basic mobility, but additionally may be reliant on stations/ terminals, yards, catenary/third rail, switches and signals, bridges, and a host of complementary drainage, utility, and communications infrastructure. Save for the most constrained assessments, many of these components might be omitted from the inventory – especially if expertise to evaluate a given component's vulnerability is not obtainable – but this should be a carefully considered decision.

Non Transportation Assets

A robust assessment of climate change vulnerability and risk in the transportation sector is a substantial undertaking, both in terms of the time, resources, and technical capacity required. In some cases, it may make sense to involve non transportation partners in the process or even as an agency co-leader. Bringing in additional, even multiple, sectors can help distribute the resource burden and better leverage the accompanying climate data to provide more value at (potentially) marginal additional cost. Possible non transportation sectors might include the natural environment, the built environment, agriculture, energy, utilities, stormwater/wastewater, emergency management, and economic development, among others.

As noted subsequently ("Conduct Criticality Assessment"), non transportation data is often crucial to developing a full understanding of the importance of transportation infrastructure. Access to jobs, for example, might be of fundamental importance to a region (or parks, fresh food, hospitals, and a host of other regional destinations). Depending on the priorities of the region conducting the assessment, a host of non transportation data might be relevant – and therefore a priority to collect.

High-Level Criticality Screening

As mentioned previously, the more infrastructure and asset types included in the inventory, the greater the effort required for subsequent vulnerability, risk assessment, and adaptation tasks. Even for assessment efforts endowed with substantial time and resources, it is generally wise to remove some types of assets from consideration in order to ensure that adequate emphasis is placed on a constrained group of assets. Approaches to choosing a manageable selection of assets for inventorying are multifold, but potential methods might include:

- **Select "core" assets.** Especially for studies performed in conjunction with a regional or local modal agency (such as a toll road authority or transit agency), choose only assets directly under the ownership or control of the co-sponsor. For agencies with a wider range of assets, such as roadway authorities, "core" assets may mean those which carry significantly greater volumes of drivers or passengers, or assets of higher functional classifications. For multimodal studies, this might require selection of only the top one or two tiers of assets for each mode (e.g., Class 1 freight rail, principal arterials, commercial airports with greater than 50,000 enplanements, etc.).

- **Data sufficiency.** Although few data sets are completely robust, some sets do not provide sufficient information for useful assessment. Where these data sets can be identified prior to the inventory process, consider eliminating them.
- **Minimal climate vulnerability.** Some assets are highly unlikely to be vulnerable to certain future climate hazards. Buried pipelines (which are sometimes considered through the lens of transportation) are an example of an asset class that is not likely to be directly impacted by most climate stressors. For assessments that limit the climate hazards considered – sea-level rise only, for instance – assets that are obviously out of harm's way (far inland or at a significant elevation) may be omitted.

Collect Asset Data

Once the study boundaries are set and the list of assets has been established, data collection can commence. Especially for inventories with many asset categories slated for collection, it may be advantageous to develop a data collection plan. For most purposes, a multitab spreadsheet can facilitate this exercise, listing, for example, the asset type, potential sources (Source A, Source B …), collection responsibility, and desired attributes – a framework for which is set out in the following section. A spreadsheet can also serve to record the current status of the collection effort for each asset type, as well as the file names for GIS or nonspatial database files, which can be a useful component of the project documentation. An example, used for the compilation of the MTC's "Adapting to Rising Tides" report, an FHWA pilot study, is shown in Table 9.2.

In some cases, multiple information sources for a single asset might be identified. Although these sources sometimes can exist side-by-side or, in the best scenario, directly complement one another, generally it is good practice to designate a primary data set which takes precedence in the instance of conflicting information. Obviously, if one data set is known to be more accurate or reliable than another, accuracy should take precedence. Without specific knowledge about accuracy, richer data sets, containing data on the characteristics of usage such as volumes or ridership, for example, are generally preferred, except in the instance where that data is proprietary (and therefore could not be viewed by other parties or stakeholders).

Inventorying Assets in the San Francisco Bay Area

An asset inventory was developed as part of MTC's Rising Tides project. Because MTC faced a few challenges during the data collection process –data was not readily available nor in an accessible format – MTC took an alternative approach to the one that t was laid out in the FHWA conceptual model. This approach was iterative in nature rather than sequential, as the FHWA model describes. First, GIS and spatial data, along with metadata, were collected for the larger subregion. Next, data related to functionality and asset characteristics were collected to help select representative assets. Finally, detailed stressor data were collected.

Source: MTC. (2011.)

Table 9.2 MTC's "Potential Transportation Asset Types and Data Sources"

FHWA Suggested Example Transportation Asset Categories	Transportation Asset Types Considered for the Subregion	Potential Data Type/Availability	Potential Data Source
Key road segments	Highways and State Routes	TeleAtlas Road Network	Caltrans and MTC
	Tunnels and tubes	Reports, some GIS	Caltrans
Signals and traffic control centers	Signals and traffic control centers	GIS	MTC, cities and Alameda County
Evacuation routes	Lifeline routes, Emergency routes for Oakland and other local jurisdictions	Report, some GIS	Caltrans, MTC, cities
Back-up power, communication, fueling, and other emergency operations systems	Emergency operations systems, communication	Addresses	Caltrans, MTC
Intelligent Transportation Systems (ITS), signs	ITS	ITS Elements in GIS for State Highway	Caltrans, sings not readily available as a dataset
Port and airport assets		Not considered as part of the pilot project	

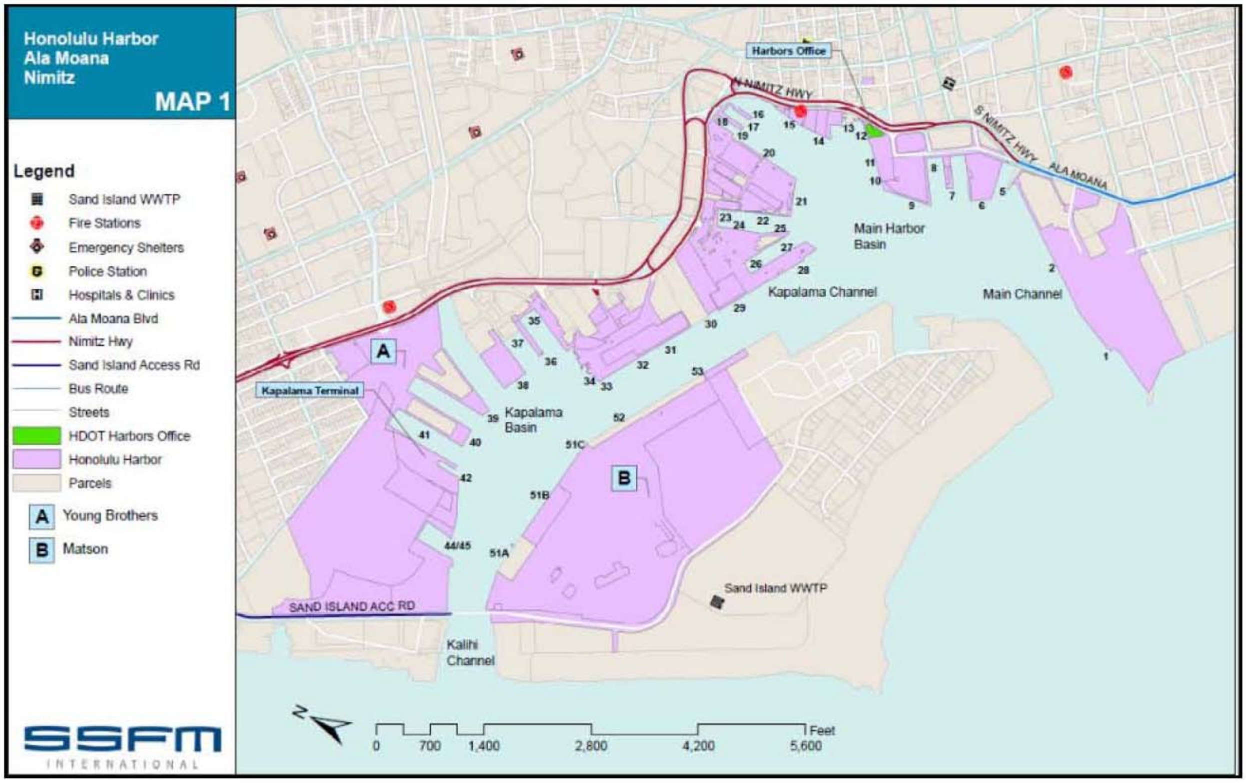
Source: MTC, 2011, Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011, extracted from Appendix A.

Desirable Data Attributes for Subsequent Analysis

An "attribute," in this context, is a component or characteristic of a given asset (or acting on/affecting this asset) that supports the determination of how critical, vulnerable, resilient, and/or adaptable that asset, or the greater network, might be to the effects of climate change. Although the list of potentially desirable asset attributes will be specific to each region and/or agency – and, in any case would be too exhaustive to include in this overview – potential broad attribute categories are included below, along with possible examples.

Location and Extent. At the most basic level, knowledge of the location of a given asset supports identification of possible exposure to geospatial climate hazards, such as inland flooding and sea-level rise. Location may be expressed as a latitude/longitude "point," especially for smaller assets (signs or signals, for example); as a "line," showing, for instance, the extent or spatial path traveled by a roadway or rail line; or, as a two-dimensional shape, called a "polygon," that represents the geographically-specific area of a facility, such as the boundaries of a harbor or airport. Figure 9.2 shows the point, line and polygon assets assembled for the Honolulu Harbor for the Oahu MPO.

Figure 9.2 Point, Line, and Polygon Assets Assembled in GIS for Honolulu Harbor



Source: SSFM International, 2011, *Transportation Asset Climate Change Risk Assessment*, prepared for Oahu MPO.

Relative Elevation. The relative elevation of an asset, which can be paired with points, lines, or polygons, is critical to a robust evaluation of vulnerability to inundation, but is not always embedded in transportation asset data. Therefore, these data are more likely to be derived from separate elevation layers (see Section 3.2.2).

Physical and Operational Characteristics. The determination of asset vulnerability (sometimes referred to as "sensitivity") is dependent on more than just potential exposure. Sensitivity is also a function of how susceptible an asset is to potential climate hazards, both physically and operationally. For a high level assessment, data relevant to sensitivity determinations might include basic structure type, condition, or material data, for which potential impact thresholds have been established (e.g., 95°F for rail bucking). This picture can be enriched further by including data on existing impacts, such as damage or disruption of service, due to extreme weather events. Although it is not possible to establish a consistent correlation between the incidence of a given climate hazard and specific impacts to infrastructure, together these data offer valuable clues to how assets or operations may be affected if those stressors grow more severe and/or more frequent over time.

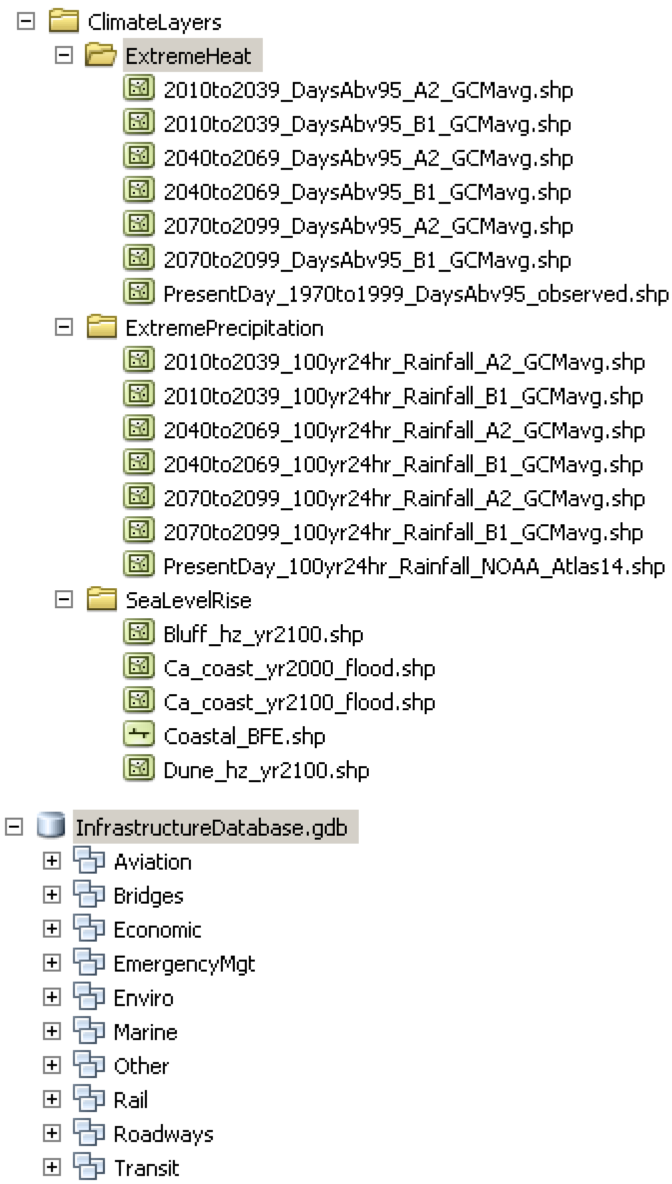
Attributes of Criticality and Consequence. Once assets are identified as potentially vulnerable, a major component in determining the risk posed by climate hazards is a consideration of the potential consequences of damage, deterioration, or disruption. The data agencies can employ to develop a measure of possible consequences is often fundamental to the identification of critical assets as well. For instance, the volume of freight moved via a particular asset could be used to distinguish the most critical elements of the system, but also serve as one potential measure of consequence should the asset be rendered unusable. Data within this broad category might include impacts on:

- **Mobility and Accessibility.** Considers trips, ridership, and/or volumes, along with freight movement, as well as the ability to reach critical destinations (such as jobs/employment or emergency facilities). Data on the distribution of impacts on special populations – such as transit dependent or economically disadvantaged communities – can be used to provide a more granular picture of consequences.
- **Economy.** Considers the direct costs of restoring service with the potential for revenue losses from tolls and fares. Agencies may also include broader economic repercussions – such as jobs affected, lost work days, or losses in overall economic activity – if there is a basis for estimating them.
- **Safety and Public Health.** Considers potential health and life safety impacts to system users, agency employees, or the broader public. This data may also incorporate evacuation routes or emergency detours.
- **Environment.** Considers the impacts to mitigation sites and natural systems as a result of system failures.
- **Reputation.** Considers the loss of confidence by system users, businesses, and elected officials.
- **Redundancy.** While not a consequence itself, data on redundancies helps determine how important a specific asset is on a system level. Redundancy considers the availability and capacity of alternative routes between origins and destinations, both within and across modes.

Assembling a Set of Assets in a Geodatabase

As an aid to regional asset inventory efforts, MPOs and RTPAs may want to go to the Caltrans GIS Data Library to assemble a set of assets in a geodatabase to conduct spatially explicit assessments of critical transportation infrastructure that may be vulnerable to the effects of climate change. This is a foundational data set comprised of state and federal GIS files with key databases joined to spatial features. An example of such a geodatabase is shown in Figure 9.3.

Figure 9.3 Transportation Layers Assembled as a Geodatabase



Source: Cambridge Systematics, Inc., 2012.

Notes:

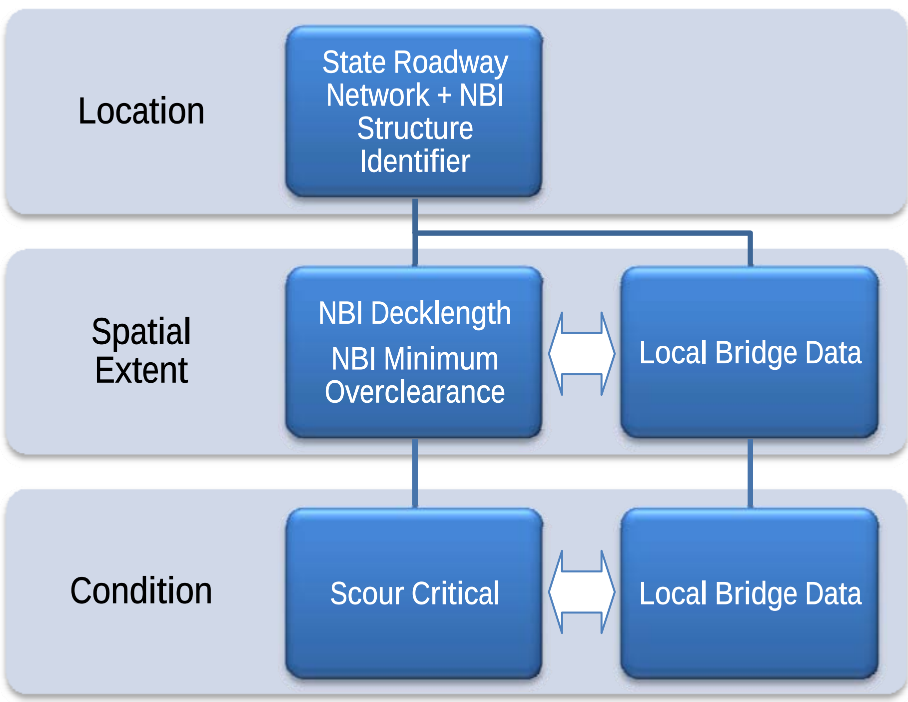
Projection Info for Climate Layers Extreme Heat and Extreme Precipitation shapefiles: geographic, wgs84 (GCS_WGS_1984).

Projection Info for Sea Level Rise shapefiles: California Albers Teale Projection, nad83 (NAD_1983_California_Teale_Albers).

Projection Info for Infrastructure Database layers: geographic, nad 83 (GCS_North_American_1983).

It is anticipated that, while an asset geodatabase populated with state and federal data would be useful to regional assessment, MPOs and RTPAs will want to enhance this information by adding regionally and locally specific layers. This can be accomplished in several ways, including the construction of a separate, free standing geodatabase or "nesting" of regional layers into the statewide database. Figure 9.4 shows an example of this "nesting" method for bridge layers from the National Bridge Inventory (NBI) as well as local bridge data. This approach is preferred, because it allows for the direct integration of complementary layers – including the use of existing feature classes (e.g., Roadways or Bridges). Advanced users with access to on-line mapping licenses (e.g., ESRI FlexViewer), can consider converting the final geodatabase product in order to display and disseminate the data on-line to a select group of subregional stakeholders or the public at large.

Figure 9.4 Abbreviated Approach to Nesting Data for a Vulnerability Assessment, Example for Bridges
State/Federal Data on Left, Regional/Local Data on Right)



Source: Cambridge Systematics, Inc., 2012.

The regional layers should be assembled and organized into feature datasets by asset category. These categories relate to a broad transportation mode or infrastructure type. Within each feature dataset are one or more feature classes, representing independent systems or assets that are thematically similar (or, as is often the case, overlapping datasets from multiple sources).

Develop Digital Elevation Maps

Digital elevation maps provide a critical geospatial dimension lacking in most embedded asset data – that of relative elevation. A roadway layer, for example, typically contains the extent and path of the road and, with the benefit of a width or "lanes" field, some measure of width. However, the elevation of the roadway above a parallel drainage ditch is rarely known.

By incorporating a separate elevation layer into the GIS, most assets will assume the topography of the terrain beneath them. In many areas, high resolution[14] laser (LiDAR) generated elevation data is obtainable, either through the U.S. Geological Survey[15] (USGS) or the NOAA Digital Coast web site.[16] Many large cities and urbanized areas have commissioned their own high resolution digital maps. Lower resolution (7.5-minute) maps are available nationwide through the USGS National Map, last updated in 1992.[17]

An important caveat to the use of most LiDAR data is that manmade structures are generally removed during processing. Although this has little or no effect on roadways or rail, for instance, bridges and skyways are removed, leading to a depiction of inundation for every structure crossing an existing waterway. If possible, these structures should be left in during processing, although this requires significant foresight and processing often takes years to complete. Some structures will have full or partial relative elevation information included in the data. Bridge deck clearances over navigable waterways or other rights-of-way (road or rail) are usually available through NBI datasets, for example – although this field is likely to be null for large culverts and bridges crossing non-navigable waterways. In this case, the status of the bridge approaches may offer clues as to whether the bridge will be rendered unusable during a flood event, but this technique generally cannot be applied systematically (i.e., each bridge would require visual examination by the assessment team).

Climate Assessment in Just Two Days

OahuMPO conducted a two-day workshop in March 2011 to discuss the climate impacts projected to affect Hawaii. Climate scientists, planners, and engineers at the city, state, and Federal levels attended this event, which focused on sea-level rise, flooding, and increased storm frequency and intensity. Through this process, participants identified five specific areas as the most vulnerable transportation assets/locations on Oahu.

Source: OahuMPO (2011).

[14] Less than 1 meter horizontal and 10 centimeters vertically is typical.

[15] http://lidar.cr.usgs.gov/.

[16] http://www.csc.noaa.gov/digitalcoast/.

[17] http://nationalmap.gov/.

Conduct Criticality Assessment

Some of the more prominent climate change vulnerability and risk assessment frameworks, such as the FHWA's Conceptual Model, ask the assessment team to define the relative criticality of various types and tiers of assets. The recent FHWA pilot projects, initiated in order to test, validate, and refine the Model, demonstrate that a broad range of techniques can be used to establish asset criticality, from the very qualitative to the very quantitative.

Qualitative Methods

Especially for assessments with smaller study areas or a limited selection of assets, or for assessment teams with limited technical resources, a qualitative assessment might suffice. This step may simply involve an extension of the "High Level Criticality Screening" described previously, wherein a stakeholder process is used to establish a dialogue on priorities. These regional priorities are then translated into a limited selection of assets for assessment. This technique was recently adopted by OahuMPO (an FHWA pilot) to establish a very constrained list of assets for assessment with limited resources.

Using Transportation Models for Climate Adaptation Assessments

The multi-agency New Jersey project funded as part of FHWA's 2010-2011 Climate Change Vulnerability Assessment Pilot Program used spatial analysis to determine how critical each asset is to achieving the mission and goals of the New Jersey multi-agency coalition. Because transportation infrastructure serves to connect system users with their destinations, a destination-based approach was used. The project team analyzed data related to jobs and population density at the Traffic Analysis Zone (TAZ) level to determine which destinations were critical. These data were used to place highway assets into three levels of "criticality",: "extreme", "high", and "low and medium". The "extreme" assets were those that were the most critical and would cause major problems if they were to fail. The other categories decrease respectively in their level of criticality. Maps displaying these assets according to their criticality levels were then generated.

Source: NJTPA et al. (April 2012).

Quantitative Methods

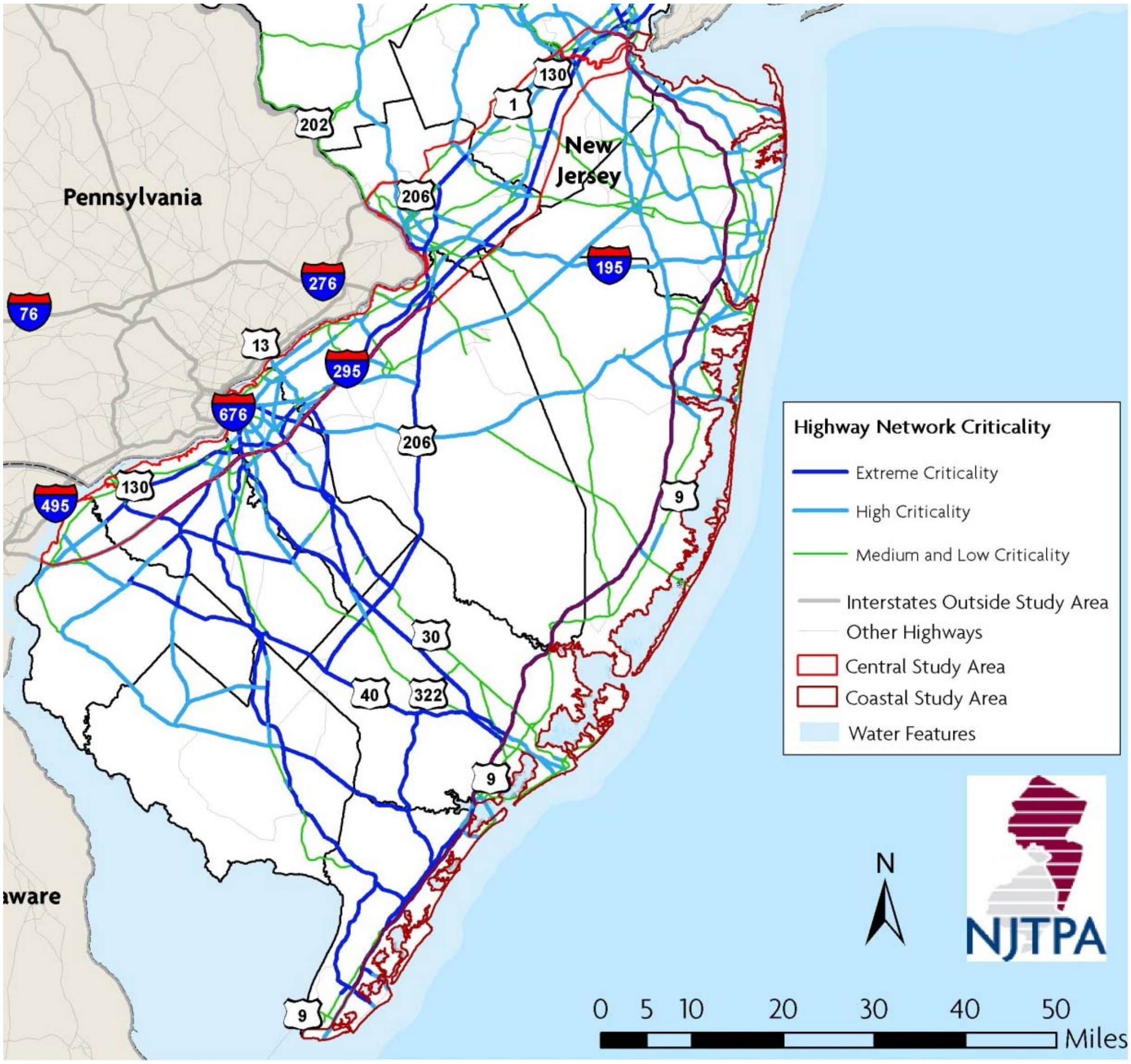
Assessments of greater scope may require the introduction of quantitative elements in order to protect against unintended omissions and potential errors in judgment relating to the relative importance of one asset type or class versus another.

The most basic quantitative technique is to establish a simple numerical scale for rating criticality. Ratings may be conducted collaboratively as a group (linking to the stakeholder process essential to qualitative criticality assessments) or separately and then added or averaged. Washington DOT used a 10-point scale to determine criticality for each major asset as part of its FHWA pilot project, although the rankings are qualified as being subjective and useful primarily as a device in differentiating the rankings.

The North Jersey Transportation Planning Authority's FHWA pilot project included a wide range of roadway assets in the assessment, and therefore adopted a GIS-based approach to tiering assets by criticality. The assessment team developed a destination-based criticality approach, which used jobs and population density for each Traffic Analysis Zone (TAZ) as proxies for critical destinations. To account for the magnitude of the connections made by a given asset, volume or ridership data was also factored in (AADT). Originally, the team intended to use redundancy (or the lack thereof) as another factor to adjust relative criticality, but no systematic data suitable for GIS analysis was available.

Subsequently, a GIS was employed to quantitatively allocate all network roads into tiers of criticality. This process is replicable using any attribute data that can be allocated into a geospatial unit, and is explained in full in the technical appendix. It is important to note that this approach was developed to provide agencies with a robust platform to support decision-making, but it is not intended to substitute for the judgment and discretion of agency officials or public stakeholders. It is recommended that a validation or "truth testing" process succeed the technical analysis to ensure that regional and local priorities are properly reflected. Figure 9.5 shows the network criticality map produced for the NJTPA pilot project.

Figure 9.5 NJTPA Network Criticality Map



Source: Cambridge Systematics, Inc., 2011, *Climate Change Vulnerability and Risk Assessment for New Jersey's Transportation Infrastructure (Draft Final),* prepared for North Jersey Transportation Planning Authority and New Jersey Department of Transportation.

10.0 Module 2b: Select and Apply Climate Information

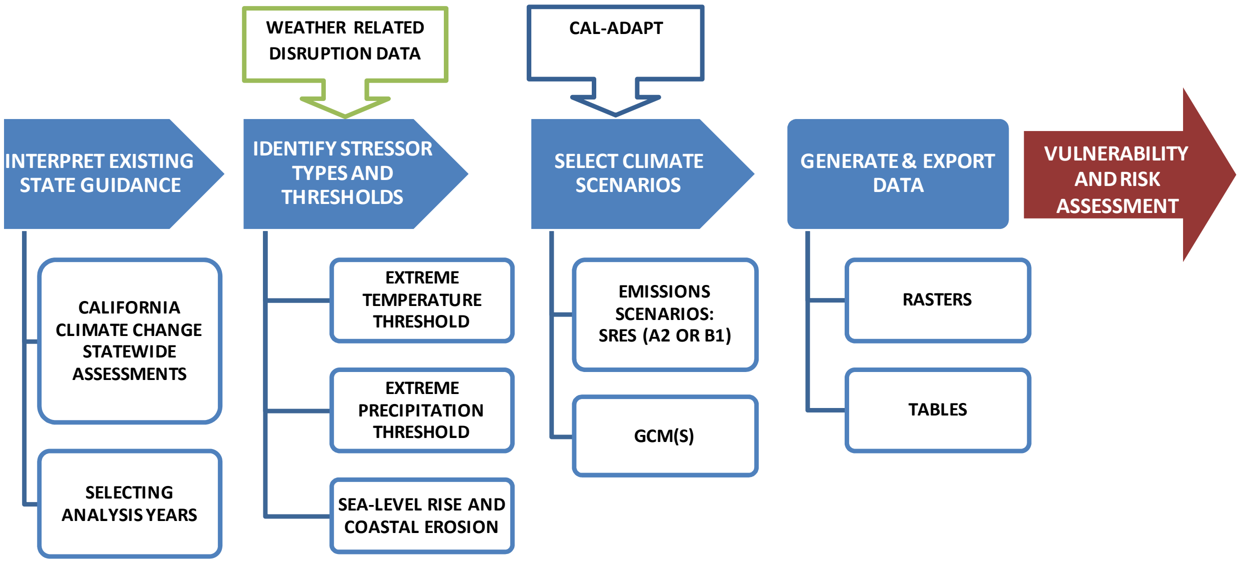
10.1 The Value of Selecting and Applying Relevant Climate Information

The changing global climate influences local factors such as temperature, sea level and the hydrologic cycle, which have significant implications for many sectors including transportation infrastructure. Understanding the magnitude and timing of changes in local climate is essential to evaluating transportation asset vulnerability. Module 2b, intended to be carried out concurrently with Module 2a, is meant to select the appropriate climate data from state projections and localize them to understand the effect at the regional-scale. This section provides an introduction to climate data (including how it is derived) and the modules steps through how to assess and select climate stressor data in preparation for Module 3.

The process of selecting climate change data laid out in this module is intended to be coupled with asset inventory data collected in Module 2a to enable performance of a vulnerability and risk assessment for transportation assets in Module 3. Together, the modules support the subsequent step by enabling the user to overlay transportation assets with climate projections. The steps taken to extract and apply climate information will be informed by the key stressors expected to impact the MPO or RTPA under consideration. The following outlines the process of selecting and applying climate information to inform the vulnerability and adaptation analyses.

Figure 10.1 provides a step-by-step guide for selecting and applying climate information and is described in greater detail throughout the text.

Figure 10.1 Selecting and Applying Climate Information



Source: Cambridge Systematics, Inc., 2012.

10.2 Climate Data Sources

The climate data referenced in this guide can be accessed and viewed from several online sources that have been developed by a wide array of agencies and research organizations. The following sources can be used to obtain climate data to inform the transportation vulnerability analysis:

Cal-Adapt Web Portal (http://cal-adapt.org/)

A product of the PIER program, Cal-Adapt presents climate visualization tools and monthly and annual geographic grid data for numerous climate stressors including temperature, precipitation, and snowpack for multiple GCMs and emissions scenarios. The downscaled grid data is presented at a 12km x 12km resolution. The data available on Cal-Adapt was supplied by the Scripps Institution of Oceanography (Scripps), Santa Clara University, the Pacific Institute, the USGS, and UC Merced.

Coupled Model Intercomparison Project Phase 3 (CMIP3) Archive (http://gdo-dcp.ucllnl.org)

The CMIP3 archive presents compiled data from a joint effort between the US Department of the Interior's Bureau of Reclamation, Lawrence Livermore National Laboratory, Santa Clara University, Scripps, Climate Central, and the USGS. This archive includes downscaled geographic grid data for temperature and precipitation for a number of GCMs and emissions scenarios as well as daily hydrologic projections of precipitation and other climate stressors derived from the downscaled GCM data. The downscaled grid data is presented at a 12km x 12km resolution.

Pacific Institute GIS Data (http://www.pacinst.org/reports/sea_level_rise/)

The Pacific Institute has published a dataset representing coastal flood inundation and erosion hazards resulting from a 100-year event under present conditions and 2100 conditions under sea level rise driven by the A2 emissions scenario. This dataset was presented by the Pacific Institute for the project *Impacts of Sea Level Rise on the California Coast* (Pacific Institute, 2009). At this point in time, this resource from the Pacific Institute is the latest data available for the State.

It is important to note that the data presented by these sources is continually evolving and being updated as our understanding of climate mechanics and future climate conditions is revised and improved. Any application of climate information should cite the source of the data and the date on which it was accessed.

10.3 Applying Climate Information

Interpreting Existing State Guidance

Several climate change studies have been conducted in California to improve our understanding of the expected degree and consequences of climate change and to provide resource management agencies with guidance on planning for future climate conditions. Through the Public Interest Energy Research (PIER) program administered by the California Energy Commission (CEC), California has established the California Climate Change Center (CCCC). The CCCC conducts research on climate change in California and has contributed several studies on evaluating and planning for trends in increased temperature, sea level, and impacts to hydrologic resources.

California Climate Change Statewide Assessments

Since 2006, the scientific and resource management communities in California have conducted three statewide assessments of climate change and resource consequences in California. For the third assessment, climate change projections for California were synthesized in the 2012 *Climate Change and Sea-Level Rise Scenarios for California Vulnerability and Adaptation Assessment* (Cayan et al., 2012), which examined changes in average temperatures, precipitation patterns, sea-level rise, and extreme events. The primary findings of this report are summarized in Chapter 3.2 of this guide.

Selecting Analysis Years

The process is initiated by selecting the relevant time horizons for analyzing a given transportation asset or system. Analysis years can be selected based on transportation planning cycles, the longevity of a selected category of assets (for example, bridges), or based on other criteria important to the region. The climate data accompanying this report has been provided for the following periods:

- **Present conditions.** Climate information for present conditions refers to data reflecting the current status of a given climate stressor. Data for present conditions will be used as the baseline to which future time horizons are compared and the magnitude of change will be ascertained. Typically, present conditions stressor levels are calculated as historic average over multiple years (i.e., 1970-1999).
- **Future conditions.** Future climate projections are often averaged over multiple years to reduce the spread of year-to-year variability and reflect the general trend of expected changes. Typically, projection periods are divided into equal intervals for climate trend averaging such as decadal averages or 30-year averages. As such, the climate conditions for future analysis years should represent an average of the climate trend over a period of several years around the time period selected.

Identify Stressor Types and Thresholds

In this context, the term "climate stressors" refers to climate conditions that pose potential hazards to transportation assets, many of which are projected to increase in frequency or severity in the future. Examples of climate stressors include temperature, precipitation, and sea-level rise. Geospatial climate datasets can be used to aid in characterizing the magnitude of change in these stressors, enabling an analysis of the vulnerability of critical transportation assets to these changes. Potential stressor impacts on transportation assets may include:

- **Temperature.** A primary variable affecting transportation asset vulnerability is the average number of high heat days occurring within a given year. For example, exposure to high temperatures can degrade the material strength of binding materials in asphalt and may leave roads vulnerable to damage. Quantifying the number of heat days in a given region under existing and future conditions will aid in identifying the regions and assets most likely to be impacted by rising temperatures.
- **Precipitation.** Design of drainage capacity for transportation assets relies on knowledge of return periods for rainfall and streamflow conditions established over years of historical measured data. Climate projections indicate that extreme precipitation events are likely to increase in frequency and severity, which may alter the expected return period of a given rainfall depth or streamflow peak. Knowledge of expected changes in precipitation, and associated hydrologic variables including snowpack, runoff, and baseflow, will be critical for evaluating the vulnerability of drainage systems for various transportation assets.
- **Sea-Level Rise**. Impacts to transportation assets from extreme tide levels, exacerbated by net increases in sea level, include the increased frequency, extent, and depth of inundation. Sea-level rise is also expected to increase the

risk of coastal erosion, the effects of which may be further intensified by coastal storms. Understanding projected levels of inundation and patterns of erosion will be necessary for characterizing infrastructure vulnerability in coastal areas.

When selecting a climate stressor or set of stressors it is important to identify thresholds that relate to transportation asset vulnerability. As noted previously, climate stressors include temperature, precipitation, and sea-level rise. Thresholds indicate points at which the risk of damage, deterioration, or disruption of infrastructure caused by a given stressor becomes a significant concern (such as temperatures exceeding 95°F for railroad track kinking). The thresholds focused on in this document include average annual extreme temperature days, the future magnitude of the 24-hour, 100-year (one-percent chance) precipitation event, and the inland inundation extents and erosion hazard zones under a 100-year coastal flood event with sea-level rise. There are many climate stressors, and potentially multiple thresholds for each stressor, that may impact a given asset or asset class.

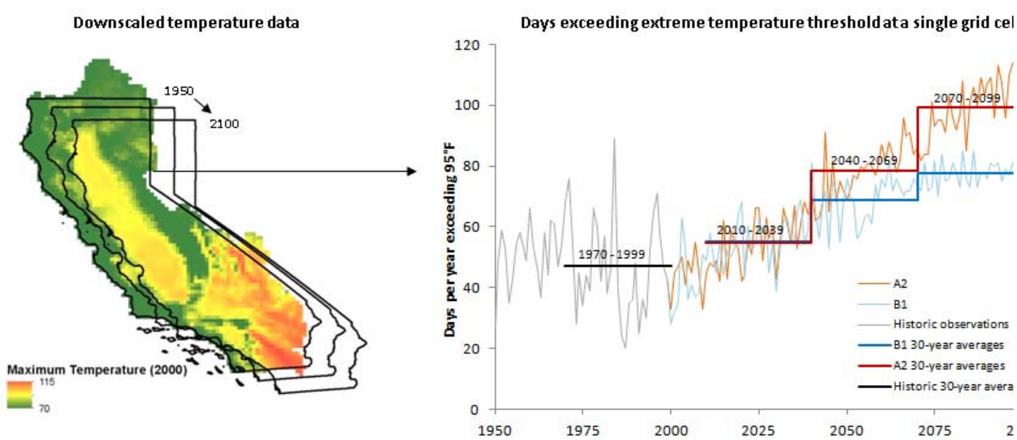
Extreme Temperature Threshold

For the purposes of this document, the extreme temperature threshold is defined as a day in which the maximum air temperature exceeds 95°F. The extreme temperature threshold will vary regionally according to present day conditions. Although precisely and directly correlating non-spatial climate variables such as extreme temperatures is impossible, we can assume infrastructure vulnerability will increase as climate variables exceed critical thresholds more frequently and/or occur with greater intensity. For instance, failure or degradation to pavement can occur well before or well beyond this 95°F threshold condition, and it is highly dependent on other circumstances such as maintenance and upkeep of the asset. Another example is the kinking of railroad track, for example, which may occur at temperatures exceeding 95°F – but does not always and will not affect every type or segment of track equally. The number of days exceeding 95°F in a given year was selected based on interviews conducted with engineers from various state transportation departments and transit agencies as a useful rule of thumb threshold for climate assessment.

Interpreting and Using Extreme Temperature Data

As an example of evaluating extreme temperature data Figure 10.2 contains geospatial and tabular data representing the geographic distribution of days per year exceeding 95°F under present conditions (30-year annual average from 1970 to 1999), and three future periods: 2010 to 2039, 2040 to 2069, and 2070 to 2099. The graphic includes data for both A2 and B1 emissions scenarios, and represents an average of data from six GCMs. This information was computed using daily temperature data from downscaled GCM output downloaded from the CMIP3 public archive (http://gdo-dcp.ucllnl.org/). Extreme temperature information can be viewed in a similar layout on the Cal-Adapt website (http://cal-adapt.org/). For the geospatial map data shown in the figure, the annual number of days exceeding the extreme temperature threshold was tabulated and averaged for the 30-year periods representing present and future conditions. The procedure depicted in Figure 10.2 was repeated for each grid cell to generate a map of extreme heat days for future conditions.

Figure 10.2 Geospatial Layers Created on Temperature Data



Source: ESA PWA, 2012.

Note: The data used to generate this figure was retrieved from the CMIP3 archive on 8/9/2011. A technical summary of the data sources and computational methods applied for generating the climate data can be requested separately through Caltrans.

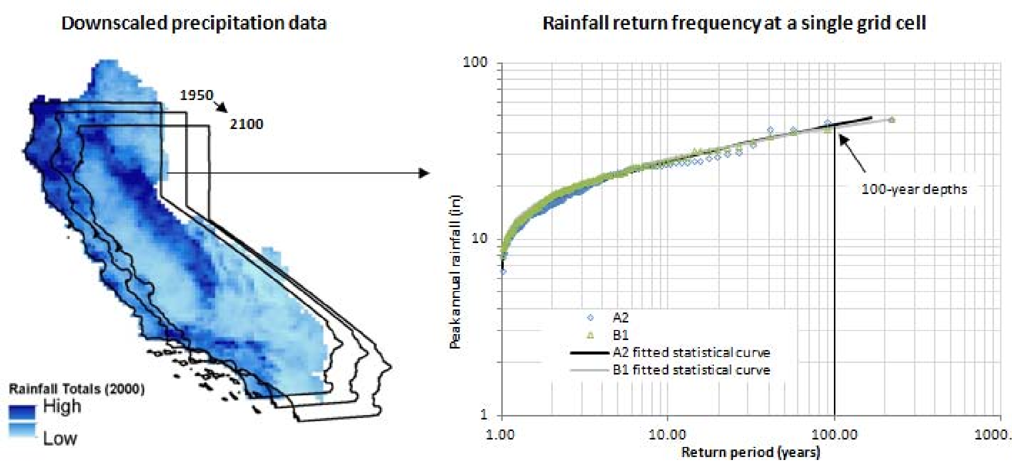
Extreme Precipitation Threshold

A useful indicator for evaluating impacts to transportation infrastructure from projected changes in precipitation is the return frequency of today's 100-year (one-percent chance) rainfall event. Design guidance for transportation drainage often mandates or advises providing adequate capacity to manage the 100-year storm. Under the influence of climate change, the absolute amount of rainfall correlated with today's 100-year event may recur with greater frequency in the future. Evaluating the range of potential rainfall totals corresponding to the projected 100-year rainfall event can be useful for understanding the degree of change in precipitation that will need to be accommodated in the drainage design for a region being analyzed and will aid in considering adaptation strategies in the face of anticipated changes.

Interpreting and Using Extreme Precipitation Data

Additional processing will be required to evaluate rainfall return frequency using available climate data. As an example of evaluating the projected trends in extreme precipitation conditions, Figure 10.3 shows 100-year rainfall depths spatially distributed over California for present conditions (30-year annual average from 1970 to 1999) and three future timeframes (2010 to 2039, 2040 to 2069, and 2070 to 2099) under A2 and B1 emissions scenarios. Present conditions 100-year rainfall depths were downloaded from the NOAA Atlas 14 database (http://hdsc.nws.noaa.gov/hdsc/pfds/). For future conditions, the extreme precipitation data was derived from geospatial grids of projected daily rainfall totals from 1950 to 2100 downloaded from the CMIP3 public archive (http://gdo-dcp.ucllnl.org/). The 100-year rainfall was estimated by fitting a return frequency curve to the downscaled rainfall data as shown in the graphic below. The procedure depicted in Figure 10.3 was repeated for each grid cell to generate a map of 100-year rainfall depths for future conditions.

Figure 10.3 Geospatial Layers Created on Precipitation Data



Source: ESA PWA, 2012.

Note: The data used to generate this figure was retrieved from the CMIP3 archive on 8/9/2011. A technical summary of the data sources and computational methods applied for generating the climate data can be requested separately through Caltrans.

Sea-Level Rise and Coastal Erosion

As the century progresses, the extent and severity of sea-level rise, coastal flooding, and shoreline erosion are expected to increasingly affect transportation infrastructure. As part of a study on infrastructure vulnerability along the California coast, PWA (2009) conducted technical analyses with the ultimate goal of mapping the inundation extents for a 100-year coastal flood event and potential coastal dune and cliff erosion incurred by sea-level rise. This analysis was conducted to support a study from the California Climate Change Center (CCCC) conducted by the Pacific Institute (2009). The data developed for this study included current conditions 100-year flood extents at year 2000, and projected inundation extents with 1.4 meters (4.6 feet) of sea-level rise under A2 emissions, which was the only scenario analyzed for that study. Additionally, this study included estimates of cliff and dune erosion by 2100 under A2 emissions. Geospatial data layers generated for the study by the Pacific Institute for current and projected inundation extents for the full California coast and areas vulnerable to dune and cliff erosion from Santa Barbara to the northern state boundary are available from the Pacific Institute's GIS data page (http://www.pacinst.org/reports/sea_level_rise/data/index.htm).

Interpreting and Using Sea-Level Rise Data

The data available from the Pacific Institute includes four geospatial layers that reflect present and future conditions inundation extents along the full length of the California coastline, and vulnerability zones for dune and cliff erosion from Santa Barbara to the northern State boundary. The Pacific Institute created or modified these layers for a study, titled The Impacts of Sea-Level Rise on the California Coast (Heberger et al., 2009). In brief, the layers were constructed as follows:

- ***Current conditions 100-year flood inundation (year 2000) –*** *100-year flood elevations were aggregated for the full California coastline using published data from the FEMA's digital flood insurance rate maps (DFIRM), and gaps were filled in using local information and engineering judgment. These elevations were projected against topographic data to create flood hazard extents for the 100-year coastal flood.*
- ***Projected 100-year flood inundation under 1.4 meters of sea-level rise (year 2100)*** *– Total water levels for the 100-year flood elevations for future conditions were estimated based on GCM output of water levels and wave heights modified using local information on wave refraction and transformation.*
- ***Dune erosion hazard zone –*** *The dune erosion hazard zone was estimated using the total water levels projected for 2100, and historic erosion rates published by the USGS. The encroachment of the hazard zone by year 2100 is a function of sea-level rise, long-term historic shoreline change rates, and erosion from the 100-year storm event.*
- ***Cliff erosion hazard zones –*** *The extent of cliff erosion hazards was estimated using historic cliff erosion rates and the relative increase in time that total water levels exceed the backshore elevation due to sea-level rise.*

Source: Heberger et al., 2009.

Note: A technical summary of the data sources and computational methods applied for generating the climate data can be requested separately through Caltrans.

Select Climate Scenarios

Due to the uncertainty inherent in climate projections, it is advisable to consider a range of emissions scenarios and GCMs. Two emissions scenarios—A2 (medium-high) and B1 (low)—have been widely applied in statewide analyses of climate impacts in California. These scenarios provide the range of climate scenarios which MPOs and RTPAs should consider when evaluating the range of potential climate conditions. Of the two scenarios evaluated by California for statewide climate assessments and used in this guide, the A2 scenario is the more realistic choice for decision-makers to use for climate adaptation planning. According to the 2009 California Climate Adaptation Strategy, "the world has followed a 'business as usual' emissions pathway, which most closely resembles the A2 scenario."

A2 versus B1: Which Scenario Should I Use?

Two GHG emissions scenarios – referenced as A2 and B1 – were created by the Intergovernmental Panel on Climate Change (IPCC) and used in this guide. These are both scenarios evaluated by California for statewide climate assessments. Each scenario leads to a projection of possible emissions levels based on population growth rate, economic development, and other factors. Ultimately, the effect on climate change depends on the amount and the rate of accumulation of heat-trapping gases in the atmosphere that these scenarios suggest.

Of the two options provided, the A2 scenario is the more realistic choice for decision-makers to use for climate adaptation planning. Generally, the B1 scenario might be most appropriately viewed as a version of a "best case" or "policy" scenario for emissions, while A2 is more of a status quo scenario incorporating incremental improvements.

Emissions Scenarios

The A2 (medium-high) and B1 (low) emissions scenarios reflect potential reasonable range of climate conditions (Cayan et al., 2012). Climate data for individual stressors and analysis years are provided for both the A2 and B1 emissions scenarios. It is preferred for planners to use the A2 scenario from an impacts and adaptation point of view, as it is the more aggressive of the two probable scenarios.

Projecting potential climate trends and extremes requires first establishing future scenarios of population, economic, and technological conditions that will influence future climate patterns. Due to the high level of uncertainty in the evolution of these factors, a series of qualitative storylines describing the evolution of possible trajectories of heat-trapping GHG emissions were developed by the International Panel on Climate Change (IPCC)[18] to guide climate change modeling efforts (IPCC, 2007). The IPCC's (2000) special report on emissions scenarios (SRES) provides six scenario groups of plausible global emissions pathways, with no assigned probabilities of occurrence. Two of these scenarios, A2 and B1 are often selected to represent, respectively, medium-high and relatively low emissions projections (Cayan et al., 2012). These emissions scenarios represent the world as follows:

[18] Unless otherwise stated, all references to the IPCC report on emission scenarios refer to the Fourth Assessment Report (AR4).

- **A2.** Medium-high emissions resulting from continuous population growth coupled with internationally uneven economic and technological growth. Under this scenario, emissions increase through the 21st century and by 2100 atmospheric carbon dioxide (CO_2) levels are approximately three-times greater than pre-industrial levels.
- **B1.** Lower emissions than A2, resulting from a population that peaks mid-century and declines thereafter, with improving economic conditions and technological advancements leading to more efficient utilization of resources. Under this scenario, emissions peak mid-century and then decline, leading to a net atmospheric CO2 concentration approximately double that of pre-industrial levels.

Since the introduction of these emissions scenarios, the climate science, as well as global climate conditions, has rapidly evolved. Since these emissions scenarios were introduced in 2000, actual global GHG emissions have exceeded 35 of the 40 emissions scenarios considered for the SRES (Le Quéré et al., 2009). New formulations of potential emissions scenarios are currently under development for the IPCC's 5th assessment report (AR5). Rather than representing socioeconomic conditions leading to different levels of GHG emissions, the new scenarios are based on alternative futures of atmospheric concentrations of GHG and aerosols referred to as Representative Concentration Pathways (RCPs). For the AR5, emissions scenarios informed by the RCPs will, for the first time, incorporate approaches to climate change mitigation in addition to scenarios constructed without mitigation policy measures in place. Future analyses in climate change projections will apply these new emissions scenarios and will replace and update projections developed under the current scenario framework.

As the science of climate change progresses and scientific understanding of emissions pathways and climate dynamics improve, it will be important to keep pace with developments in climate projections and update planning documents accordingly.

General Circulation Models and Downscaling

Another source of variability in projecting climate stressors is the general circulation model (GCM), or range of GCMs, employed. To identify the GCMs that best suited to predicting climate phenomena in the State of California, Cayan et al. (2012) selected six models from the IPCC Fourth Assessment Report based on data availability and on historic skill in representing climate patterns in California, including seasonal precipitation and temperature, annual variability of precipitation, and the El Niño/Southern Oscillation (ENSO) phenomenon. The six models selected for the assessment were:

1. The NCAR Parallel Climate Model (PCM);
2. The NOAA Geophysical Fluids Dynamics Laboratory (GFDL) model, Version 2.1;
3. The NCAR Community Climate System Model (CCSM);

4. The Max Plank Institute 5th generation ECHAM model (ECHAM5/MPI-OM);
5. The medium-resolution model from the Center for Climate System Research of the University of Tokyo and collaborators (MIROC 3.2); and
6. The French Centre National de Recherches Météorologiques (CNRM) models.

Due to the spread of climate projections over the various models, data is often averaged over multiple GCMs to avoid biasing towards any one model.

Data for a series of climate stressors downscaled to the 12-kilometer (7.5-mile) scale has been archived and made available for public use[19]. This data has been widely applied for evaluating climate trends in California.

Generate and Export Data

Once the process of selecting the relevant analysis years, identifying the applicable emissions scenarios and GCMs, and selecting the appropriate climate stressors/thresholds has been completed, climate data accessed from the previously described archives can be used to inform the transportation asset vulnerability analysis. Geospatial data can be used to construct maps and tables of present and estimated future climate conditions.

10.4 Case Study Example: Extreme Temperature Thresholds for SCAG Region

To evaluate extreme heat day risk to transportation infrastructure in the Southern California Association of Governments (SCAG) region over the course of the 21st century, the following variables have been identified:

- **Analysis years.** Present Conditions (1970 to 1999); and Future conditions (2010 to 2039, 2040 to 2069, and 2070 to 2099).
- **Emissions Scenarios and GCMs.** A2 and B1 emissions scenarios (given), Average of six evaluated GCMs by the State of California (given).
- **Climate Stressor and Threshold.** Extreme heat days/95°F or above.

Geospatial temperature grids downloaded from the CMIP3 archive are used to produce a table of values for the grid cell coincident with the City of Riverside Table 10.1 and Figure 10.4. Downscaled temperature grids are used to produce maps of estimated extreme heat days under the A2 and B1 emissions scenarios as shown in Figure 10.5 and Figure 10.6, respectively.

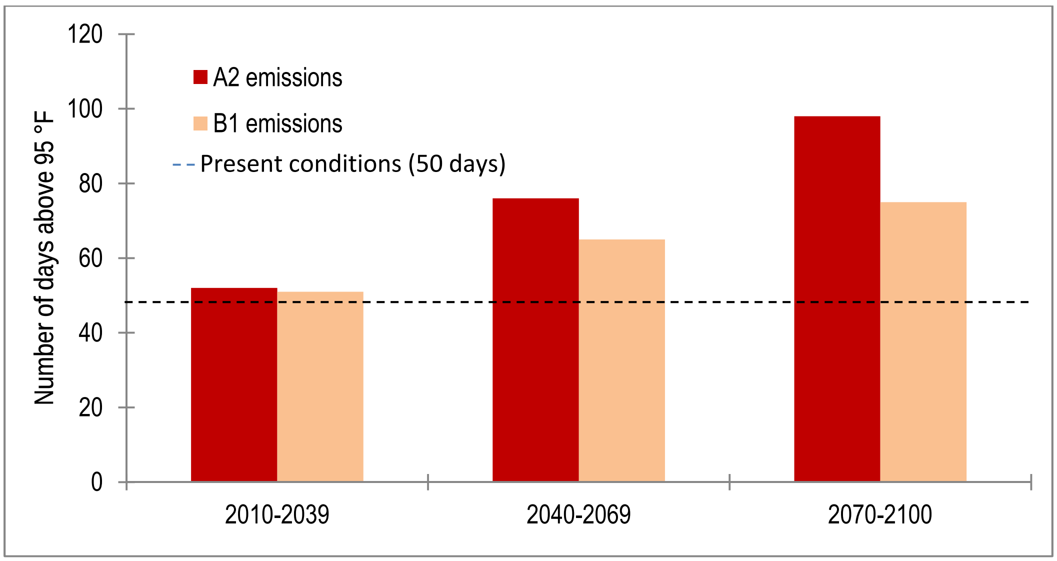
[19] The data used in this report was collected on August 9, 2011, from the CMIP3 archive hosted at: http://gdo-dcp.ucllnl.org

Table 10.1 Total Present and Future Extreme Heat Days in Riverside, California, for A2 and B1 Average GCM Conditions

Analysis Year		Emissions Scenario, GCM	Days per Year Exceeding 95°F
Present Conditions	1970-1999	–	50
Future Conditions	2010-2039	A2, average	52
	2040-2069		76
	2070-2099		98
Future Conditions	2010-2039	B1, average	51
	2040-2069		65
	2070-2099		75

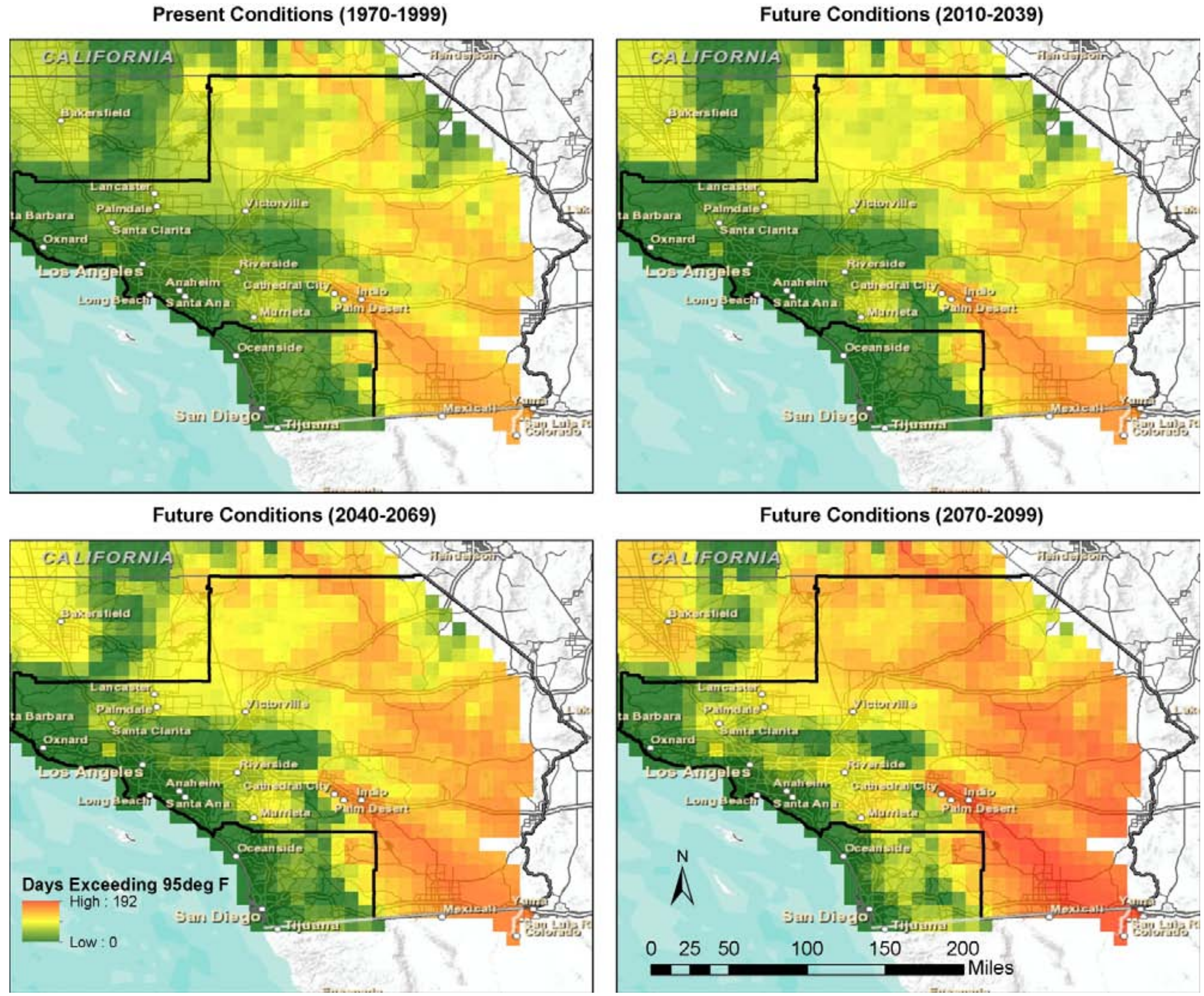
Source: ESA PWA, 2012.

Figure 10.4 Total Present and Future Average Annual Extreme Heat Days in Riverside, California, for A2 and B1 (Average of GCMs)



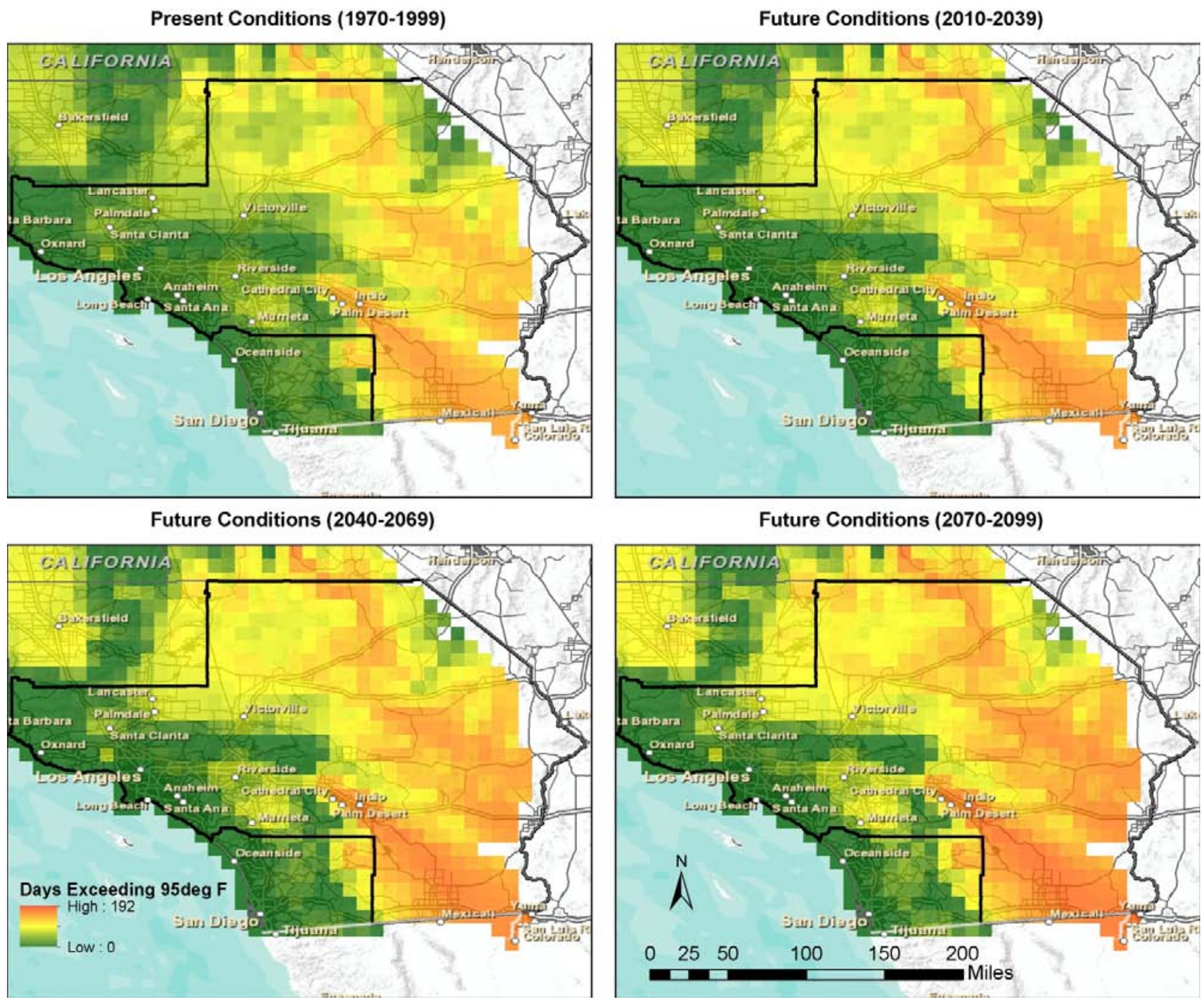
Source: ESA PWA, 2012.

Figure 10.5 Map of Present and Future Annual Extreme Heat Days under A2 Average GCM Conditions for the SCAG Region



Source: ESRI On-line Background Layers (Roads, Terrain, Places), ESA PWA, 2012.

Figure 10.6 Map of Present and Annual Future Extreme Heat Days under B1 Average GCM Conditions for the SCAG Region



Source: ESRI On-line Background Layers (Roads, Terrain, Places), ESA PWA, 2012.

11.0 Module 3: Conduct Vulnerability and Risk Assessment

11.1 The Value of Understanding Your Vulnerabilities and Risks

Module 3 provides guidance to help MPOs and RTPAs of various sizes and capacities in performing a basic vulnerability and risk assessment of critical transportation assets. Together, the recommended steps help agencies derive a measure of integrated risk for transportation assets potentially impacted by climate change. If these risks exceed the agency's tolerance for risk, then the associated infrastructure should be prioritized for adaptation. The expected outcome of this exercise is a shortlist of priority transportation assets which are both critical and potentially vulnerable (to climate hazards) for consideration in the subsequent Module 4, "Develop Adaptation Strategies."

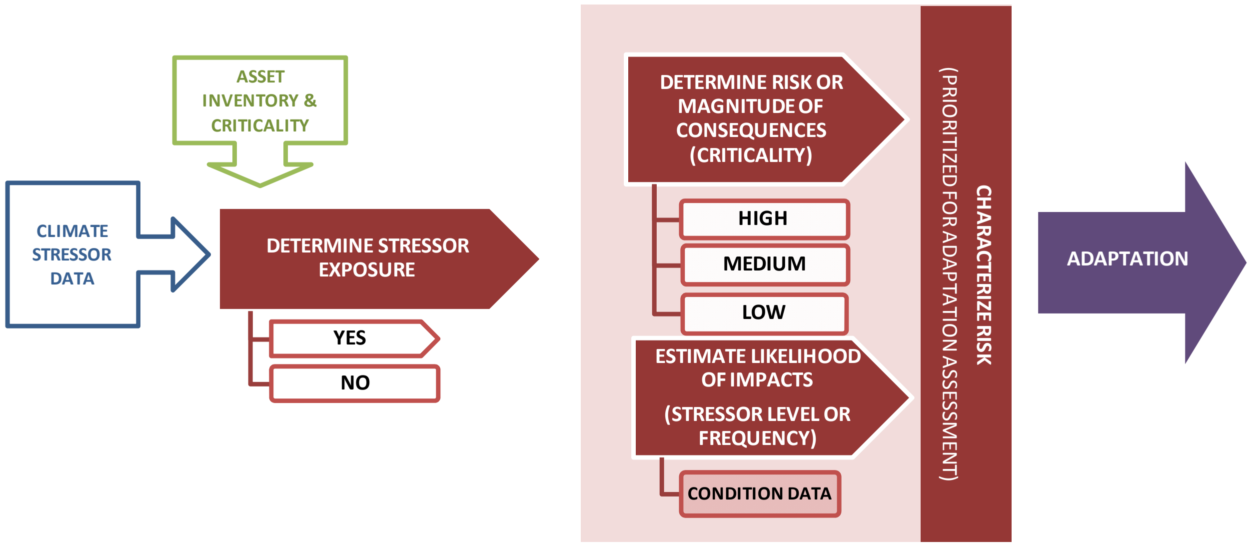
This module is formulated to leverage the information developed during the two previous modules (Module 2a and Module 2b). At its most basic level, a climate change vulnerability and risk assessment requires two categories of information:

1. Multidimensional information on the transportation infrastructure and facilities anticipated to be in service during the assessment timeframe. (This will include a substantial selection of current assets, as well as programmed or planned projects.)
2. Estimations of potential future climate conditions.

The approach suggested by this module describes a sketch-level assessment – performed with systems data (such as data layers downloaded from the Caltrans GIS Data Library) and using rules of thumb to consider vulnerability and risk – in order to rapidly screen down the selection of assets that are advanced to the subsequent adaptation module. Module 4 integrates an approach for more robust, specific, and temporally-oriented risk assessments leading to the generation and prioritization of adaptation strategies, but is likely too time and data intensive for application to all critical assets.

Figure 11.1 provides a step-by-step illustration of the primary elements of the vulnerability and risk assessment.

Figure 11.1 Conducting a Vulnerability and Risk Assessment



Source: Cambridge Systematics, Inc., 2012.

11.2 Conducting a Vulnerability and Risk Assessment

Determine Stressor Exposure

Determining potential stressor exposure is the foundation of the vulnerability assessment. If an asset is not exposed to the effects of a given climate stressor, it cannot be impacted by it, and that stressor/asset combination need not be considered further. For example, it can be fairly assumed that far inland assets are not – and will not be – exposed to storm surge/coastal flooding events. In this case, pursuing an assessment of this asset and stressor combination would be a poor, and unfruitful, use of analytical resources.

The first task in determining exposure is selecting the appropriate climate scenario from Module 2b. For each climate stressor, there is a "low" and a "high" projection. In the near future, the difference between these two scenarios is often negligible, but as the time horizon extends toward 2100, the range of estimates increases. Occasionally, even the expected direction of the trend may differ (for example, precipitation may increase under one scenario, and fall under another). The issue of uncertainty in the degree and direction of stressor change is unavoidable – and challenging – but should not derail the assessment. It may help to consider these projections as the bookends of the range of reasonable climate futures.

In selecting the preferred scenario (or scenarios), an agency's tolerance for risk should be a key factor. Risk tolerance may be uniform across the entire multimodal transportation system, or may be partitioned by asset or asset types.

A Risk Assessment for Five Key Assets in Chattanooga

As part of the Chattanooga-Hamilton County Regional Planning Agency's (CHCRPA) climate adaptation workshop, participants selected three assets for a vulnerability, risk assessment, and adaptation strategy exercise. For one example, the Chickamauga Lock and Dam, the group determined that this asset could be vulnerable to three climate stressors: extreme participation, extreme temperature, and tornadoes. During the workshop, participants collaboratively created a risk assessment and adaptation matrix for this asset (and the two others) that identified potential impacts, consequences, frequencies, and adaptation strategies. Additionally, the group created a list of adaptation strategies that can be applied to a range of regional transportation assets.

Source: Cambridge Systematics, Inc., December 2012.

An extremely critical asset may warrant a higher standard of risk management than an asset that carries little volume, has a high degree of redundancy, and/or does not provide exclusive access to highly important destinations. Where a standard scenario already exists as a legacy of previous vulnerability assessments, the agency may wish to leverage that work, even if it was performed for a different sector.

Another approach to the challenge of managing uncertainty is to conduct the assessment using multiple scenarios. This process, while more resource intensive, allows for the testing and comparison of outcomes stemming from differing scenarios. With a better understanding of the range of potential impacts, consequences, and frequencies/likelihoods, decision-makers may feel more comfortable formulating strategies that balance risk mitigation and resources. The right approach will differ based on the circumstances of each agency.

With the stressor scenario(s) chosen, two basic tests can be employed to determine stressor exposure, although techniques for applying these tests are open to significant discretion:

1. **Geospatial.** Exposure can be determined geospatially if the stressor under consideration is itself geospatial (can be drawn on a map). Such stressors include sea-level rise, storm surge, and inland flooding, although both temperature and rainfall projections vary by location and can be represented on a map as well. Since assets too are physical, and are presented with a high degree of spatial precision in many Caltrans GIS Data Library layers and on other maps (such as floodplain maps), assets and stressors can be overlaid to determine areas of physical coincidence. This technique, when performed in a GIS, is called an "intersection." Intersections can be two-dimensional or, preferably, three dimensional where LiDAR or other topographical data is available. Where elevations of transportation or flood hazard infrastructure are known, they can be integrated into the GIS to further enhance the accuracy of the intersection analysis.

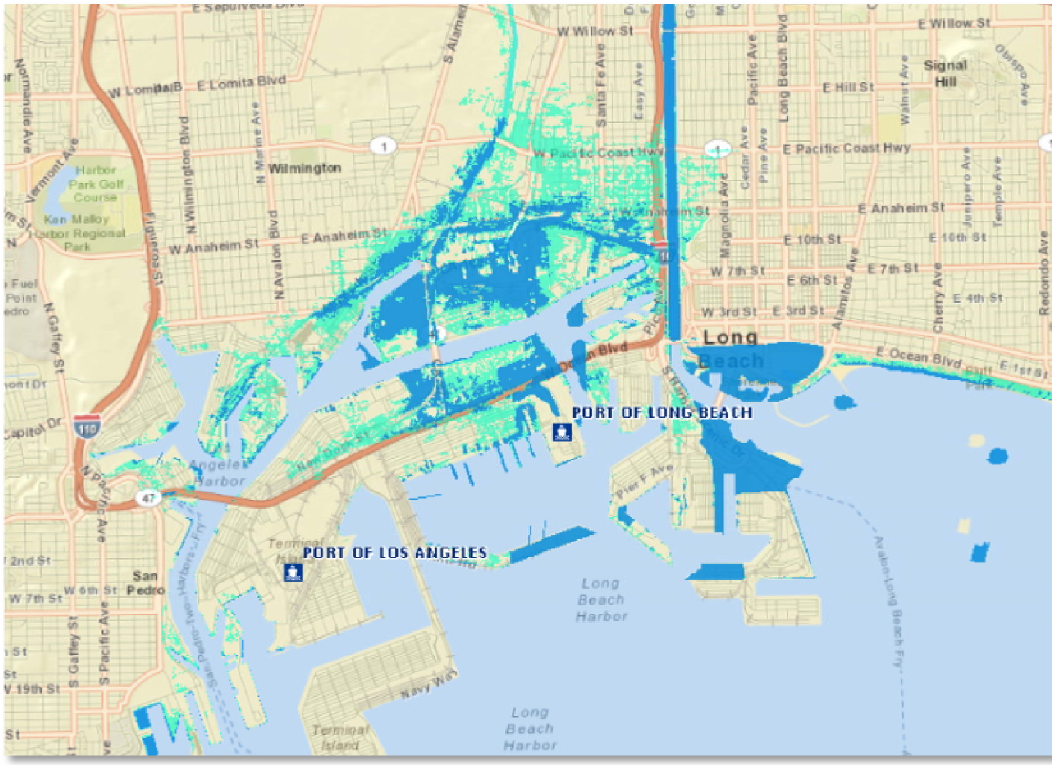
   A buffer zone (an extension of the actual mapped boundaries of stressors and assets) can be applied to increase the results of the intersection analysis. This may be warranted when agencies are concerned about underestimation of exposure, either due to data insufficiency, a perceived under-representation of stressor coverage, or a lower appetite for risk than mapped data can support. For example, if an agency is concerned about the future effects of inland flooding, but does not have the resources to generate revised floodplain maps (which require, at a minimum, information on projected rainfall intensity, runoff coefficients, and concentration areas), a solution may be to expand the floodplain boundary in GIS by a given percentage or distance. While not a rigorous method, this approach could highlight critical assets proximate (but not yet in) current floodplains that it may be prudent to consider – without the costs of conducting hydrological analysis.

Figure 11.2 illustrates the combination of data layers for climate and transportation information using sea level rise as an example.

Using data from the California GIS Data Library layers on ports and roads, coupled with climate layers from the Pacific Institute, one can make a high level assessment of the risk and vulnerability of ports infrastructure. In year 2000, approximately 6 square miles of Los Angeles County are inundated by flooding in a 100-year storm event. In 2100, approximately 11 square miles of Los Angeles County are projected to be inundated, and inundation spreads further inland. Figure 11.2 shows inundation at two major ports – the Port of Long Beach and the Port of Los Angeles. At this time, the two ports are currently evaluating the risk in their own separate climate adaptation studies. If more localized assessment is of interest in the area around the Ports, the processes described in this guide allows planners/data users to add on climate layers and transportation assets at a finer grained level for a more granular assessment approach.

2. **Thresholds.** Exposure can be determined based on established thresholds or rules of thumb. This test is more appropriately applied to stressors that are not conducive to precise geospatial representation (such as extreme temperatures). The key factor is an estimate of the climate stressor threshold that, when exceeded, may pose a hazard to infrastructure. For example, a common threshold for temperature, found throughout the literature of weather-related transportation vulnerability and cited by both engineers and materials researchers, is 95°F. Temperatures of 95°F or greater may cause rutting of some asphalts, kinking of rail tracks, and abnormal expansion of structures and structural elements. Although exceeding this threshold does not necessarily, or even often, result in these impacts, 95°F is a key point at which these impacts become realistic enough to generate concern from infrastructure managers.

Figure 11.2 Example: Sea-Level Rise in the Ports of LA and Long Beach



Year 2000 100-year Storm Inundation

Year 2100 100-year Storm Inundation

Source: Cambridge Systematics, Inc., 2012. Basemap from ESRI. Sea level rise information from Pacific Institute (http://www.pacinst.org/reports/sea_level_rise/), the most updated resource for California to date.

Notes: Projection Info for Sea Level Rise shapefiles: California Albers Teale Projection, nad83 (NAD_1983_California_Teale_Albers).

Projection Info for InfrastructureDatabase layers: geographic, nad 83 (GCS_North_American_1983).

Thresholds can be selected using various techniques available to every region, including:

a. *Empirical knowledge*. Engineers, maintenance personnel, or other qualified professionals often know which thresholds are applicable based on observed asset vulnerabilities. Especially for infrastructure anticipated to remain in service out to the analysis year(s), this technique may produce the most relevant thresholds.

b. *Standards and specifications*. Modern infrastructure design is predicated on a host of engineering standards and materials specifications established through rigorous study and testing. Standards and specifications are oriented to the specific roles and functions of infrastructure (such as expected volumes, for example) and many directly address the specific stresses of climate. The Caltrans Standard Specifications and Highway Design Manual are primary resources, to be supplemented with applicable national (e.g., AASHTO) and local specifications or guidelines.

c. *Prior research*. Several published or forthcoming resources address vulnerability thresholds for transportation infrastructure, including *Climate Change Adaptation and the Highway System* (NCHRP, forthcoming) and the FHWA Climate Change Pilot reports (2011, various authors).

d. *Informed hypotheses*. The objective of the exposure exercise is to rapidly identify the basic potential for significant impacts, and then move qualifying assets into the risk assessment phase for further study. The creation of a nonstandard exposure threshold, either in the absence of other guidance or to correspond with specific climate or transportation attribute data, is acceptable as long as doing so supports this objective. Hypothesized or proxy thresholds, especially those generated collaboratively by qualified professionals, can add value to the assessment process.

The thresholds test supports the application of rules of thumb concerning the susceptibility of assets or asset types to climate *events* of a given severity or frequency in order to estimate the potential for climate *impacts*. Climate impacts are, in effect, the intermediaries between stressors and the expected consequences of extreme climate events, describing what might actually happen to the asset. For instance, extreme rainfall is a stressor, whereas flooding is the related impact from which consequences may stem directly (some impacts may be 3rd or even 4th order effects of stressors). If it is known, or even estimated, that the one-percent chance rainfall is the threshold that leads to a specific impact of concern (e.g., flooding), then it may be assumed that the asset is both exposed and susceptible if the threshold is exceeded.

Consider a sample asset/stressor pairing, a scour critical bridge and extreme rainfall. The rainfall event itself may not detrimental to the bridge, but intense rainfall may concentrate as runoff, engorge a nearby river or stream, increase the flow rate, and thereby promote scour – the climate impact. The same scenario could also lead to inundation of the bridge's approaches – another climate impact. Some climate impact pathways will be simpler – high ambient temperatures can lead to extreme surface temperatures, which, depending on the surface, leads to rutting or detrimental expansion. This is where condition information can be factored in at a systems level, if applicable, to help establish susceptibility.

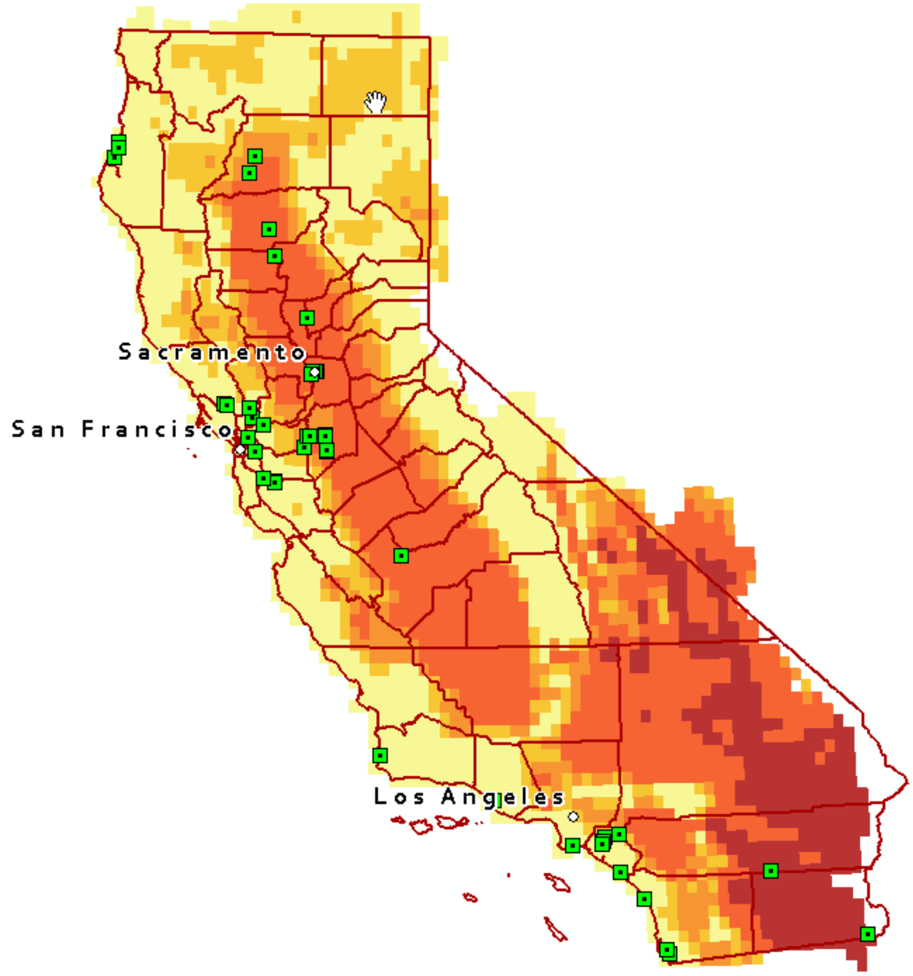
In many instances, it will be preferable to combine the geospatial and threshold tests. Flooding, for example, is geospatial, but mapped floodplains or hazard areas typically correspond to a threshold event – for example the 100-year (one-percent chance) flood. In turn, some transportation infrastructure, such as culverts, is typically sized for specific design events – again, often the one-percent chance runoff event (or, for higher importance facilities, more common events). Similarly, coastal flooding hazards are also commonly linked to specific storm surge events.

Although the potential likelihood of impacts is considered in depth later in this module, it may be appropriate to consider this as part of the exposure analysis as well (as a sort of pre-screening). Flooding event thresholds, for example, already explicitly consider statistically-derived estimates of probability (e.g., the 100-year recurrence event is considered to have a one-percent average annual occurrence probability). For extreme temperatures, almost every region in California experiences a 95°F day at least occasionally, but an isolated 95°F event may not constitute a significant threat. Instead, a certain frequency of this event (e.g., x days annually) may constitute a more relevant threshold.

Both types of exposure tests are supported by the data collected in 2a (Asset Inventory) and 2b (Climate Stressors) for some stressor/asset combinations. Module 2a contains guidance on collecting data on the location and associated attributes of a variety of multimodal infrastructure, while Module 2b contains guidance on sourcing projections for commonly recognized extreme weather thresholds.

Figure 11.3 shows how climate and transportation layers combine to provide a threshold analysis of the number of railroad bridges exposed in areas where there are high heat days. In this example, there are numerous railroad bridges in the State highlighted in green. Some of these railroad bridges fall in a temperature zone that will have a large number of days above 95 degrees in 2100. Since this is the threshold where rail bridges may be affected, this information may provide insights to transportation planners and engineers on whether adaptation strategies should be employed.

Figure 11.3 Example: Railroad Bridges in Various Temperature Zones



Source: Cambridge Systematics, Inc., 2012.

Note: Projection Info for Climate Layers Extreme Heat and Extreme Precipitation shapefiles: geographic, wgs84 (GCS_WGS_1984).

Projection Info for Infrastructure Database layers: geographic, nad 83 (GCS_North_American_1983).

Determine Risk

As explained previously, the risk assessment approach recommended in this module is intended to facilitate the generation of a list of priority transportation assets for assessment in the subsequent module. As with most calculations of risk, this approach cross-references the potential magnitude of consequences with the likelihood of impacts for individual assets or asset classes. With perfect information on both factors, this could be expressed mathematically as [(cost of consequence)*(probability of occurrence)]. If the consequence of a specific climate impact were determined to be $1 million, and its probability to be 50 percent, then the risk could be precisely quantified as $500,000. However, this standard of precision is infeasible and unproductive in this application; the uncertainties are too great and the resources required would make a system level assessment impossible. Instead, the technique described below is oriented toward a rapid, sketch-level assessment of assets at risk, a selection of which can be considered with greater rigor in the following module (Module 4).

Estimate the Potential Magnitude of Consequences

The groundwork for this task will have been performed in Module 2a, where asset criticality is determined. That designation (e.g., low, medium, high; 1-5, etc.) is carried into this exercise as a reasonable estimate of the potential magnitude of consequences from stressor exposure. For example, if an asset is highly critical, meaning that its contribution to mobility, accessibility, economy, safety, etc. is significant, then the potential consequence of disruption, deterioration, or damage is also high. By making this connection, the assessor is spared the potentially painstaking task of attempting to estimate the range of actual consequences – which involves a consideration of the complex interaction of stressor and structure characteristics.[20]

Since potential consequence and criticality are coincident, it should be straightforward to create groupings of magnitudes (such as "high," "medium," and "low"). This can be accomplished in GIS (by selecting critical attributes, such as volumes, for examples) or, for studies that are smaller in scope, by compiling previously generated lists of critical assets. If a large number of assets are designated as high consequence/highly critical, the "likelihood of impacts" exercise explained subsequently may help screen the selection down to a manageable set. Otherwise, it may be necessary to further segment the top "potential consequence" tier to reduce the pool of assets for further assessment (in GIS, this may be accomplished by distributing critical attributes by quintiles instead of quartiles, for example).

Estimate the Likelihood of Impacts

Estimating the likelihood of impacts can be one of the most challenging aspects of the assessment. Stressor frequency or annual probability become more uncertain as the assessment timeframe extends into the future, and the potential susceptibility of a given asset to that stressor is similarly difficult to anticipate – especially when asset deterioration and renewal cycles are considered. This approach recommends deferring these difficulties to the significantly smaller selection of assets to be advanced to the following module. Instead, because the "magnitude of consequences" estimate has already established that this exercise

[20] For studies that have already limited the pool of assets for assessment (whether through constrained geography or policy decisions), it may be appropriate to incorporate more rigorous assessment techniques from Module 4, as needed.

will consider only potential, not actual, risk the estimate of likelihood can be performed solely for the climate stressor.

Determining stressor likelihood varies widely in degree of difficulty, although, as with other uncertainties treated in this module, the preference is for a quick, sketch level methodology rather than a rigorous but time consuming approach. There are three primary perspectives for considering stressor likelihood, average annual frequency of occurrence (frequency), average annual exceedance probability (probability), and average recurrence interval, which express the same phenomenon using different terminology.

- **Average annual frequency of occurrence.** Events that are described by the number of days (or other time periods) meeting or exceeding threshold values, such as days ≤95°F temperatures, ≤1" rainfall, or the upper one-percent rainfall event[21], can be considered in terms of their average annual frequencies. These events are often associated with maintenance and operational impacts or asset deterioration, rather than major damage, although with each event there may be a remote, and potentially increasing, likelihood of more significant impacts (for example a high-heat induced concrete blow-up that causes a motorcycle fatality). Historical average annual frequencies can be derived from weather station records collected by the National Weather Service, with detailed information available on-line from the National Climatic Data Center.
- **Average annual exceedance probability (AEP).** When events are described by their annual likelihood of occurrence, they are referred to in terms of their exceedance probabilities. These stressors typically include flood events, runoff volumes, and significant rainfall events. The FEMA floodplains, for example, represent estimated flood coverage areas for (commonly) 1-percent and 0.2-percent chance flooding events (although common convention, the terms 100-year and 500-year to describe floodplains are misleading, instead referring to average recurrence interval).
- **Average recurrence interval (ARI).** The NOAA Atlas 14 provides estimates of rainfall intensity and depth ranges (associated with 90-percent confidence intervals) for a matrix of event durations (in minutes, hours, and days) and average recurrence intervals from 1 to 1,000 years (periods between exceedance events are random). For the "24-hour" rainfall event, for example, the user can view the range (upper and lower bounds of the confidence interval) of absolute rainfall in inches expected to recur every 100 years, on average (e.g., 5.4 inches, with a range of 4.56 to 6.52 inches, for Sacramento). The average recurrence interval can be adjusted through

[21] In this case, the one-percent precipitation event denotes the values that fall into the top one percent of all precipitation events; not to be confused with the one-percent chance rainfall event.

climate stressor downscaling to derive estimates for the future recurrence of a specific event. In other words, if the 10-year, 24-hour event is associated with a specific set of asset impacts, the assessment could consider how often this same threshold event (e.g., 3.44 inches in Sacramento) might be expected to occur in the analysis timeframe.

Table 11.1 ARI to AEP Conversion Table
Common Values

ARI (Years)	AEP (Percentage)
1	63.2
2	39.3
5	18.1
10	9.5
20	4.9
50	2.0
100	1.0

Source: Australian Bureau of Meteorology, 2012.

All three expressions of potential likelihood may be projected for future time periods though climate stressor downscaling techniques, which adjust current values based on potential climate futures. The 100-year ARI may become the 80- to 90 year ARI, for example, or the region may expect to experience an average of 25 days annually ≤95°F, instead of 10. While it is important to consider projections as potential climate futures, instead of predictions, responsible use of estimates can support decision-making in most cases (the possible exception being significant disagreement among projections).

Where specific projections are not readily available or are not reliable, it may still be possible to characterize the trend direction qualitatively, either based on other statewide guidance, such as Reports from the Third Assessment from the California Climate Change Center, or based on the observations of infrastructure managers (again, while not a scientifically rigorous technique, it may serve the needs of some users).

Characterize Risk and Prioritize Assets for Module 4

The final stage of Module 3 is to consider potential consequences and estimated likelihoods in integration. Ideally, the outcome of this exercise will be a manageable selection of assets (or asset types) suitable for advancement to the more detailed and resource intensive approach explained in Module 4.

For many users, the appropriate (and potentially familiar) vehicle for characterizing risk will be the risk matrix, which arrays magnitude of consequences and likelihood of occurrence on perpendicular (x/y) axes. The units of measurement for each axis will vary by user preference, but are often qualitative designations (e.g., "high," "medium," "low") or simple rankings (1 to 5). The selected units should have already been established during the consequences and likelihood steps described previously, but can be refined for better compatibility with the risk assessment.

The risk matrix suggested for this exercise functions as a screening tool for the subsequent Module. The intent is for asset/stressor combinations to be allocated according to their integrated risk characteristics. As shown in the example matrix included below as Figure 11.2, this means that a "high consequence, high likelihood" asset/stressor grouping would attain the highest rating and almost surely be advanced to Module 4. If another "high consequence" asset were paired with a "medium likelihood" stressor, then this asset/stressor combination might not make the cut (the cut-off point is, of course, at the discretion of the agency, but should yield a manageable quantity of assets for further assessment). For assets graduating into Module 4 that are linked with multiple stressors, lower likelihood stressors could be footnoted to support a more integrated adaptation assessment.

Since the potential consequence is synonymous with an asset's criticality category, assets themselves may remain in a single tier (e.g., a "high" consequence asset remains "high" for multiple stressors), or, if an agency judges it to be necessary, a rule of thumb may be developed to facilitate broad differentiation between asset-stressor consequences. For example, an agency may reasonably determine that high heat days do not threaten an asset with the same magnitude of consequence as heavy rainfall events, and discount the consequences of high heat accordingly.

However, it may be more suitable to factor in the relative threats associated with a particular stressor when ranking the likelihood of each. To continue with the previous example, whereas each individual high heat day may lead to few, or relatively minor, marginal consequences, a preponderance of additional extreme temperature events (an increase of 2, 3, or 5 fold, for instance) might have high cumulative consequences related to deterioration or otherwise rare damage and disruption that could start occurring with greater frequency. When designating the ranges that characterize tiers of likelihood, it is not necessary for every stressor to register projections in each tier. To illustrate the concept, the "high" likelihood extreme temperature frequency might be, hypothetically, "over 100 days annually," even if the upper boundary of projections is significantly less. This way, although consequences for a "high" criticality asset would remain high, the likelihood (frequency) of extreme temperature events could not be – meaning that the integrated asset/stressor risk could never be "high/high."

Depending on size of the universe of assets to be assessed, the matrix could be populated by GIS, by committee or working group, or a combination of the two. For a systems-level analysis of multiple asset types and/or modes, a GIS could support a comprehensive screening if data is sufficient. For example, by creating rules for both consequence and likelihood corresponding to asset and stressor attribute tables, respectively, an intersection analysis could efficiently distill asset/stressor combinations into a virtual matrix. Especially for smaller geographies or a more constrained selection of assets, a knowledgeable committee or working group could collaboratively perform the risk assessment on flip charts or white boards – especially with the assistance of a seasoned facilitator. The integration of these methods, using GIS for screening and a workshop for final determinations, for instance, offers the benefits of both approaches. The result, as shown in Figure 11.2 is a limited pool of high consequence/high likelihood potential vulnerabilities for more rigorous assessment and adaptation decision-making in Module 4 (red cell). Other combinations, such as high/medium (orange cells), could be advanced to Module 4 if assessment resources are sufficient.

Figure 11.4 Illustrative Integrated Risk Matrix

		Consequences		
		Low	Medium	High
Likelihood	High		Asset B/ 1" rainfall	Asset A/ 1" rainfall
	Medium	Asset C/ heat	Asset B/ ≥50-year flood	Asset A/ heat
	Low	Asset C/ storm surge event		Asset A/ 500-year flood

12.0 Module 4: Develop Adaptation Strategies

12.1 The Importance of Adaptation Planning for Climate Change

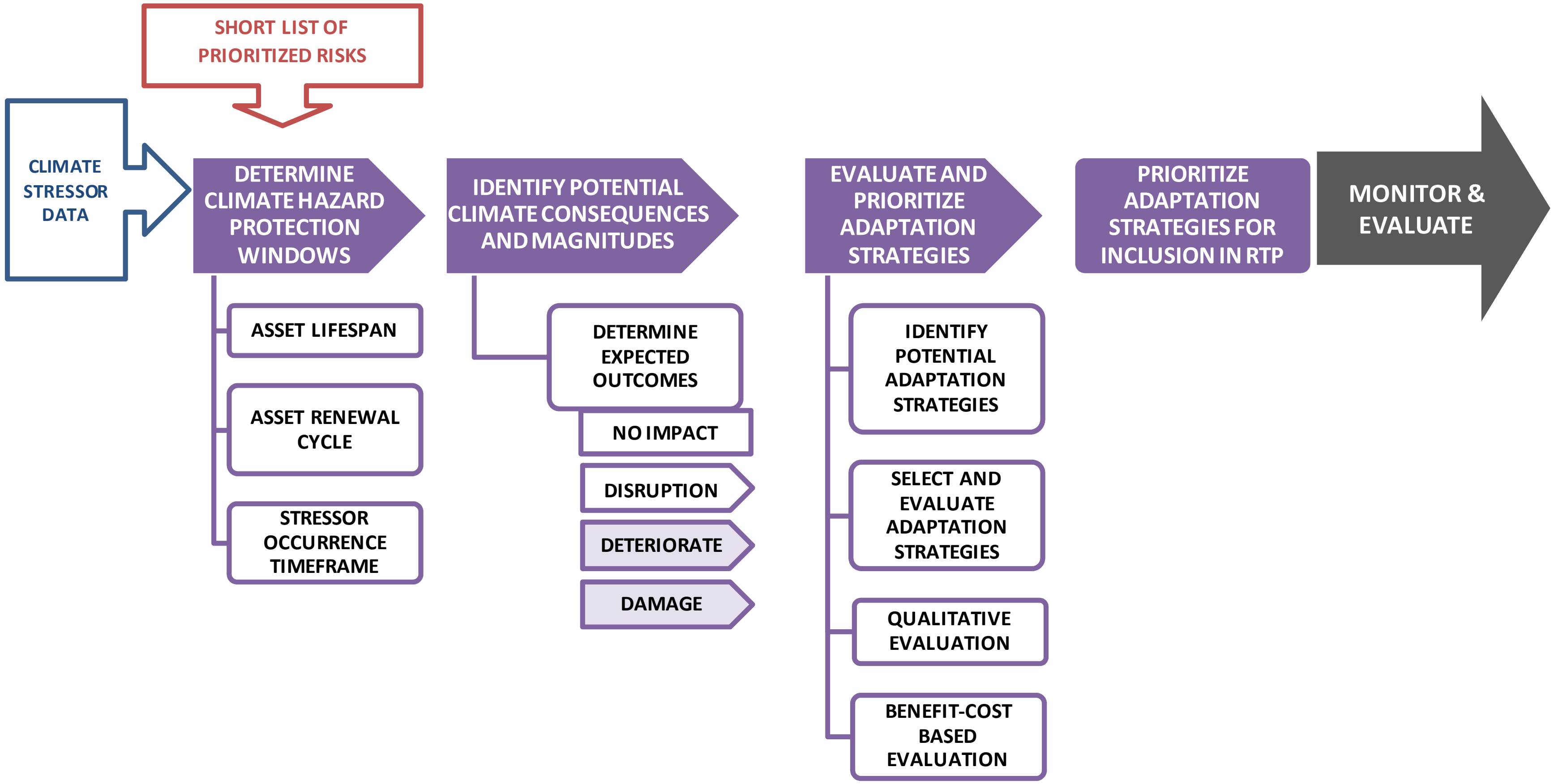
Module 4 supports MPOs and RTPAs in developing and prioritizing cost-effective strategies for adapting critical transportation infrastructure to the potential effects of climate change. This module leverages the rapid assessment performed for Module 3, but encourages greater focus on timing (the coincidence of climate hazards, asset renewal cycles, and asset service life), characterizing the consequences of climate on critical assets, and identifying feasible and effective approaches to mitigating these consequences (adaptation strategies). At the conclusion of this exercise, the region and its transportation operating agencies will:

- Possess an enhanced understanding of when and how climate change could affect its most critical assets;
- Have formulated low risk, high reward strategies to meet the challenges of climate-related threats of particular concern now and in the longer term. The agency may consider these priority strategies for implementation, especially in concert with normal project development and renewal cycles;
- Gain a clearer path toward integrating adaptation into the Long-Range Transportation Plan, the TIP, hazard mitigation plans, and other short- and longer-term transportation planning efforts; and
- Have designated a pool of potentially vulnerable assets for monitoring and periodic reevaluation (Module 5).

By planning for adaptation now, regions place themselves in a position to manage risks proactively, potentially reducing the costs of adaptation (versus reactive retrofitting, for example) and mitigating possible future economic, mobility, reputational, and/or safety losses.

Figure 12.1 provides a step-by-step illustration of the primary elements of the adaptation strategy module.

Figure 12.1 Developing Adaptation Strategies



Source: Cambridge Systematics, Inc., 2012.

12.2 DEVELOPING ADAPTATION STRATEGIES

Determine Climate Hazard Protection Windows

A limited selection of priority asset/stressor groupings are advanced from the rapid assessment described in Module 3 for more rigorous and detailed consideration in Module 4. At this stage, it is understood that the assets themselves are considered critical, often highly critical, and therefore that the potential consequences of exposure to climate stressors could be significant. It is also understood that these assets have a substantial future likelihood, perhaps a high likelihood, of exposure to one or more climate stressors at thresholds that may pose a threat.

However, the rapid assessment's focus is on whether assets and stressors coincide physically, without necessarily[22] considering temporal concurrence (they overlap in space, but do they overlap in time as well?) or changes in the condition or characteristics of assets over time. The Climate Hazard Protection Window concept was developed help capture the role of time in determining exposure. The Window describes the period during which an asset is likely both to be in service and susceptible to the impacts of one or more climate stressors. The Window opens when a climate hazard first poses significant risk to the asset and closes at the projected end of the asset's lifespan (with multiple stressor exposures there may be multiple Windows). Understanding of two key timeframes is therefore necessary to produce a Window (these are described in greater depth, below):

- **Asset Lifespan and Asset Renewal Cycles.** When is the asset due for replacement? What opportunities for adaptation action might coincide with standard asset renewal cycles? Advanced assessments may also explore the interaction between deteriorating asset condition and increased susceptibility to stressors.
- **Stressor Occurrence.** When are stressors likely to begin posing significant risks to assets due increasing severity (such as exceedance of a hazard threshold) or frequency? In some instances, the answer may be "today."

[22] The previous exposure assessment may include time as an element as well. For example, the asset inventory may include future projects from the TIP or LRTP. Hypothetically, where sufficient attribute data is available, even changes in asset condition based on deterioration curves or asset renewal cycles could be incorporated.

Consider, for example, a scour critical[23] bridge is potentially vulnerable to more intense rainfall events leading to increased peak runoff rates, which, hypothetically are expected to increase in likelihood. If the bridge has been replaced, or the scour condition has been otherwise corrected through normal renewal and rehabilitation cycles, by the time rainfall events are likely to exceed hazard thresholds for scour then the issue of exposure might be null. If the asset (or specific asset vulnerability) and the climate hazard are likely to overlap in time, however, then exposure is both physical and temporal and a more detailed assessment of potential consequences may be in order.

The extent of the Window – the duration of potential overlap (between asset and stressor) – may prove instructive in formulating a cost-effective adaptation strategy (or strategies). For example, depending on the region's risk tolerance and resources, a relatively short overlap between stressor incidence and asset replacement could be addressed by slightly advancing the date of replacement/reconstruction, or by implementing maintenance and operational strategies expected to minimize impacts during this higher risk period. Longer overlaps may pose greater challenges, but often can be addressed through a wider variety of strategies (often in synergy), including planning to enhance redundancy, asset management strategies, engineering interventions (such as retrofits), and more. Broad categories of adaptation strategies are set out later in this Module.

Consider Asset Lifespan and Renewal Cycles

Accurate estimates of asset lifespan and renewal cycles can be difficult to obtain in some regions. This data is rarely embedded in systems-level information, such as GIS layers – a primary reason why this screening step is performed for a constrained set of assets. This is in part because the lifespan of assets is typically fluid, depending greatly on changing external conditions (of which climate is one, usage another) and on intermediate treatments (asset management), which can shorten or extend lifespan significantly. Estimates of asset design life may be more readily obtained from asset management databases, where available. Particularly for assets expected to perform over very long time spans – up to a century or more for some bridges – lifespan might be determined by applying common design life rules of thumb to actual construction dates[24]. The managers of these assets should play a key role in formulating these estimates. As with all projections considered in the assessment, estimates of asset lifespan need not be perfect, just feasible based on the best currently available information.

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[23] Subject to the erosion of fill beneath piers and/or abutments, creating structural and safety risks.

[24] See, for example: M. Meyer, 2012, *Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change*. Developed as a working paper for NCHRP 20-83(5).

In some instances, multiple expected life spans might be associated with a single asset, and multiple strategies – or a comprehensive strategy – may need to be employed to mitigate impacts. For example, a given segment of roadway can be divided into a series of components or elements with varying renewal cycles. The surface course (e.g., asphalt) might require replacement every 10 to 15 years depending on usage, the base course every 30 years, and the right-of-way could persist indefinitely. If the stressor of concern is extreme temperatures leading to surface course rutting, then it may be sufficient to monitor the condition and upgrade the asphalt binder (for instance) during normal repaving to increase resiliency – an action of relatively low marginal costs and effort. If the stressor is roadway flooding, it may be necessary to raise the embankment and improve drainage (such as the crown, side swales, and culverts) in conjunction with expected reconstruction cycles – a costly procedure carried out at the most cost-efficient point in time. For severe flooding, if the only viable option is to modify the right-of-way, funds could be sought for land acquisition and the existing segment might be strategically abandoned by performing maintenance only for safety purposes.

Stressor Timeframe(s)

Generally, stressor timeframes are established in Module 2b (Climate Information). However, a modest amount of additional work may be required in order to better align the units of time pertaining to asset lifespan and stressor timeframes. Whereas asset lifespan may be measured in years (when replacements are planned or even budgeted) to decades, climate stressors are often expressed in decadal or 30-year averages. To simplify matters, aligning stressors and assets by decade is recommended, and is an appropriate level of granularity for the assessment (a scale of years, in contrast, is too precise to be realistic, whereas 30-year spans are not sufficiently precise to base decision-making on). For example, if an asset were due for replacement in 2025, this could be reflected by assigning it to the 2020 to 2029 decade. Similarly, for a stressor projection representing a 30-year average, the associated value could be distributed evenly over a series of decades (e.g., 2020 to 2050). Especially if the following 30-year span shows a notable increase, it may be appropriate to anecdotally indicate an upward trend, without representing an increase in values.

Applying the Climate Hazard Protection Windows will likely result in the removal (or downgrade) of some asset/stressor combinations from further consideration if the timing of hazards diminishes the prospect of exposure. For asset/stressor combinations that remain, the Window will serve as a useful framework for the time-sensitive consideration of adaptation strategies.

Identify Potential Climate Consequences and Magnitudes

With potential exposure to climate impacts established for a limited selection of assets, an assessment of consequences can commence. The previous module considered the magnitude of potential consequences as a means by which to help screen the universe of transportation infrastructure down to a manageable number of high risk assets. The consequences assessment recommended in Module 4 involves the creation of a pathway to expected consequences. The exposure assessment constitutes the first segment of the pathway – starting with the stressor of concern and proceeding to potential climate impacts based on asset susceptibility. For example, extreme rainfall → increased stream flows → bridge scour, especially for bridges that already suffer from a scour condition (are scour critical). Since susceptibility was previously established through rules of thumb, agencies may wish to adjust impact susceptibilities based on actual asset characteristics, including condition (or expected condition), if applicable. This may be accomplished in a variety of ways, including consultation with infrastructure managers, but should balance confidence in the results with the time required to make the determination. To illustrate a potential susceptibility adjustment, if the Module 3 assessment identifies a bridge impacted by a flooding event, a closer look in Module 4 might indicate that the deck would be spared overtopping, but that the approaches would likely be inundated, for instance, or that erosion might affect the abutments.

The next step in the pathway is to consider what consequence exposure is likely to have on a given asset. The objective of this exercise – as with all preceding exercises – is to leverage professional knowledge (especially concerning current consequences of similar impacts) and existing assessment techniques to establish the range of reasonable consequences. To continue with the previous example, if a bridge's approaches are expected to be inundated by the one-percent chance (or future one-percent chance) flood event, would the event cause temporary disruption, lead to advanced deterioration, and/or damage the structure?

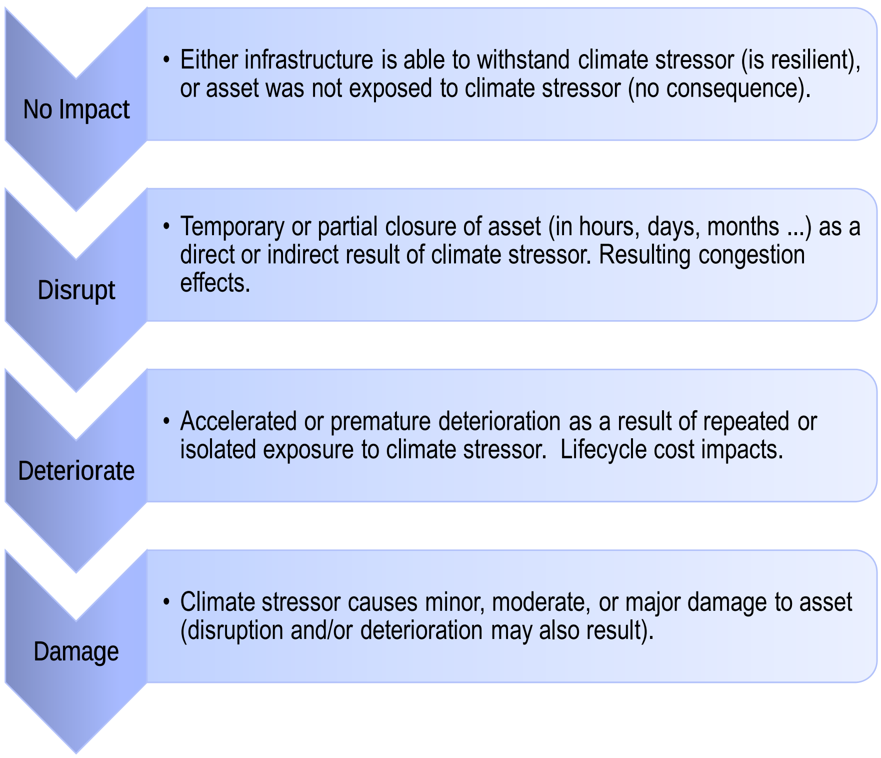
Consequences can be considered through a variety of lenses. Three broad categories of consequences cover most eventualities, at least pertaining to the asset itself (other consequences, like loss of life, could be considered as well, but may be even more challenging to assess). Some impacts may have multiple possible consequences, while some may not have any notable consequences at all:

- **No Impact.** Although most "no impact" asset/stressor combinations will have been screened out by this point, closer examination could show that impacts are actually highly unlikely. When a "no impact" finding is made, the asset/stressor combination need not undergo further assessment.
- **Disruption.** Operations may be disrupted or impeded, either temporarily or partially (as with lane closures), by climate impacts. Slower travel speeds, poorer levels of service, and lower capacity are all examples of partial disruptions.

- **Deterioration.** Climate impacts may lead to effects on infrastructure that, while not rising to the level of damage, nonetheless cause premature or accelerated wear to the facility. Deterioration can apply to the entire asset or to specific materials or structural components. For example, standing water (which would most likely also lead to disruption, could have adverse impacts on roadway base. Repeated incidents might lead to a need to reconstruct that roadway section well before standard deterioration curves would suggest.

- **Damage.** Damage runs the gamut from very minor – really a continuum from deterioration – to the catastrophic. Damage necessitates repair in order to return the asset to safe, efficient operation, which can draw critical resources away from other programs. Damage is often, but not always, coupled with commensurate disruptions.

Figure 12.2 Vulnerability Spectrum/Consequences of Impact



Source: Cambridge Systematics, Inc., 2012.

Each potential consequence will have an associated magnitude – the "cost," or range of costs, of the event in terms of direct dollars, economic losses, reduced mobility, etc. Ideally, at least some of these costs should be related to the criteria considered during the criticality assessment, although there is room for consideration of additional factors. If, for example, the facility was designated highly critical for its economic contributions (say access to jobs, or movement of freight), then these factors should be included in the calculation of loss.

The magnitude of consequences needs to be measured in some fashion. The preferred measure of magnitude may be very qualitative or fairly quantitative, or combine qualitative and quantitative measures. A uniform unit (for example "dollars of direct and indirect losses") is not necessary, and can complicate the analysis (an exception, for regions conducting benefit-cost analyses, is described below). Nor is it necessary, or always realistic, to develop precise estimates of magnitude; ranges or orders of magnitude will suffice for most assessment efforts. The right measure and level of precision will be a matter of preference and measurement resources. For example, disruption to a facility may be measured in time (minutes, hours, days – or, when coupled with damage, potentially months or even years), by detour costs (AADT * detour length * travel time and/or vehicle costs), by congestion effects on the greater system, or using another metric important to the region.

Regions with a constrained list of top tier assets may opt to employ the climate-risk adjusted benefit-cost analysis technique developed for *Climate Change Adaptation and the Highway System* (NCHRP, forthcoming). In this application, full range of consequences is monetized, and becomes, in effect the "benefit" side of the equation – as risks that were expected to affect the asset but are mitigated by adaptation activities (the marginal resources expended in the cause of adaptation become the "cost" side of the equation).

The final step of the consequences pathway is to pair the expected magnitudes of consequence with the likelihood of occurrence. The basis for the consideration of likelihood was established in Module 3, which accounted for expected stressor occurrence at threshold levels to which infrastructure is vulnerable, according to rules of thumb. Revisiting likelihood permits the adjustment of these rules of thumb for determining susceptibility, if needed. Starting with the likelihood of stressor occurrence (from Module 2b), this exercise suggests assessing the likelihood of the range of correlated consequences. For example, the assessment team might have identified "major damage/disruption" and "moderate damage/disruption" as expected consequences of a one-percent chance flood event. By employing knowledge of past consequences, professional knowledge about the asset, and estimates of future condition, "major damage/disruption" might be deemed "highly unlikely/very rare," for instance, whereas "moderate damage/disruption" might be considered more probable. This stage can also be conducted prior to the measurement of consequences as a means of screening out consequences of extremely low probability.

This process yields a screened list of risks that are priorities for adaptation. Although mathematical representation is rarely possible, and not necessarily desirable, the concept is best illustrated as a function of [(stressor likelihood * impact likelihood) * magnitude of impact]. To populate this equation with some hypothetical values, perhaps the stressor likelihood is 50 percent (in a given time period – year, decade, even century). For each occurrence of the stressor, the likelihood of "major damage" is thought to be 1 percent, and the likelihood of "moderate damage" is 50 percent (the matrix of impacts and likelihoods could continue to other permutations). The consequence of "major damage" is estimated to be $10 million; whereas, moderate damage is $1 million. Therefore, the risk of major damage is $50,000 (0.5 percent likelihood * $10 million) and the risk of moderate damage is $250,000 (25 percent * $1 million). The determination will rarely be so clean or so precise, but distinctions are more likely to be apparent in orders of magnitude, allowing regions to create tiers of risk to be addressed with adaptation strategies in the following section.

Evaluate and Prioritize Adaptation Strategies

Identify Potential Adaptation Strategies

Now that risks are better understood, regions can consider opportunities for risk mitigation[25]. Risk mitigation is a process of identifying contextually appropriate adaptation actions, assessing the expected effectiveness (in terms of risk reduction) and implementation feasibility (including cost) of each, and then prioritizing the actions that most cost-effectively address the most significant risks for inclusion in the RTP or other planning and programming processes. It is recommended that the tiers of risk generated in the previous section be addressed in sequence to ensure adequate attention – starting with the greatest risks and moving to lesser risks as time allows.

The first stage involves identifying the range of strategies for consideration. Planners and infrastructure professionals would generate many of these options independently, but, in order to ensure that the full range of options is considered, a quick scan of existing literature is recommended. Sources of particular note include The *Gulf Coast Study* Phase 1 (2008) and Phase 2 (forthcoming), *Climate Change Adaptation and the Highway System* (forthcoming), and the FHWA climate change first round pilots (2011).

Although a number of schemes for categorizing strategies exist, a simple framework is suggested here, including three broad categories: Planning strategies, Design/Engineering strategies, and Operational/Maintenance strategies.

- **Planning.** This covers a host of strategies that stress preparedness and (mostly) longer-term strategic actions, often facilitated through the RTP or other established planning processes (such as hazard mitigation or emergency evacuation plans). Strategies within this category might include the creation of redundant routes or capacity improvements, strategic abandonment and disinvestment, the creation of emergency protocols for rapid implementation (such as detours), or asset management programs.

[25] In the context of climate change, the term "mitigation" often refers to the reduction of greenhouse gas emissions (as in SB 375). In this document, mitigation refers to the reduction of risk through adaptation strategies.

Actions identified in the planning process are often implemented through design/engineering or operations/maintenance programs, but are more proactive (less reactive) if formulated as part of planning processes.

- **Design/Engineering.** This is a broad category that includes strategies that consider how an asset is built or replaced, renewed, or reconstructed. This might involve upgrading materials and specifications categorically or across the board to enhance resiliency (the grade of asphalt binder or the diameter of a culvert, for example). Many of these strategies respond to design and engineering considerations specific to each asset – the type and integrity of the structure, the grade or quality of materials, the elevation or alignment of the facility (location engineering), and even the design capacity of the asset. Strategies within this category could also include the treatment programs (such as preventative maintenance) employed in the course of asset management activities. Design and engineering strategies can be implemented to manage identified risks, or as an evaluation step during project development to address potential climate hazards.
- **Operations/Maintenance.** These strategies address problems as they are developing or occurring. Strategies could include ITS and traffic operations to reduce the effects of disruptions, proactive closures to reduce the risk of stranded travelers and associated safety impacts, or streamlined emergency evacuations (better timing, greater capacity of routes). These strategies also include monitoring, patrolling, and responding to maintenance or life safety situations during emergencies. Emergency maintenance is crucial to reducing the effects of extreme weather during events and (especially) in their immediate aftermath. Maintenance could include the rapid repair of damage or the mitigation of threats that persist in the aftermath of events, such a debris, downed power lines, and standing flood waters. These activities would typically occur anyway, but are generally reactive in nature – addressing a problem that has already occurred. By addressing these strategies in planning or preparedness protocols, they could potentially be deployed more proactively and with greater effectiveness.

Examples of these strategies that are specific to California are outlined in Table 4.1 in Chapter 4.0 of this guide. Where a risk is identified but there is too little information for decision-making, the appropriate action may be to monitor and reevaluate the risk in the course of subsequent RTP updates.

Select and Evaluate Adaptation Strategies

For each priority risk, one or more applicable strategies may be selected for evaluation. Some strategies may be implemented together or in phases – a portfolio approach – whereas, others may be mutually exclusive. The preferred selection of strategies will be:

- Sensitive to the timing of impacts, addressing identified risks before they exceed risk tolerances.

- Implementable in the proper timeframe (implementation feasibility). This means that they are feasible in terms of cost, political will, regulations, and technical capabilities, among other factors. This factor will strongly favor strategies that can be mainstreamed – implemented in accordance with normal asset replacement or renewal cycles.
- Effective at mitigating risks, significantly reducing the consequences of potential climate events.

How to Develop a Risk Matrix

One case study mentioned in NCHRP 20-83(5) is the New York City Climate Change Adaptation (NYCCCA) report, which creates a framework for understanding potential climate change risks and devises an approach to addressing these risks. This project included a Prioritization Matrix, which is a sketch-level approach to measuring benefits and costs. It includes general costs used to implement a strategy and prevent potential negative impacts. One dimension of the matrix includes funding levels, and the other includes urgency. Both are measured on a low/medium/high scale, and the resulting matrix shows the overlap of the two dimensions.

Source: NCHRP, April 2011.

The desired result will be a single strategy or portfolio of strategies for each asset that significantly reduces risks in a feasible, cost-effective manner.

The evaluation of strategies can be performed at varying levels of complexity, ranging from a fairly qualitative assessment to a comparative benefit-cost analysis – or any level of complexity in between. As with all steps of the assessment, the most important factor is the assessment team's capacity to perform the work efficiently and conscientiously, without chasing unrealistic degrees of precision.

Qualitative Evaluation

For agencies that need to rapidly evaluate multiple adaptation strategies for multiple assets, a qualitative approach is likely warranted. Although "qualitative" describes a continuum of approaches, and may incorporate some quantitative information, generally a qualitative evaluation will involve the development of a composite ranking of implementation feasibility and effectiveness of each strategy, for each time period analyzed. An example result might be expressed as "high" implementation feasibility "medium" effectiveness for a given decade within the Climate Hazard Protection Window. These rankings are likely to change by evaluation period, especially as the severity or frequency of climate hazards increase, or asset condition changes (either deterioration or improvement). This qualitative approach could be significantly enriched, either by adding specific rating elements to the evaluation dimensions (e.g., using a rating checklist that breaks out these elements) or by considering engineering level data (cost estimates, drainage calculations, etc.), if available.

Each asset may be affected by multiple impacts, and each impact may be associated with multiple consequences and likelihoods of occurrence – potentially yielding multiple magnitudes of risk that shift over time. Therefore, when prioritizing adaptation strategies, whether for a single asset or an array of critical assets, it is necessary to consider a given strategy's implementation feasibility and effectiveness in the context of the risk it addresses.

This process is thematically similar to the very quantitative and much more time consuming Benefit/Cost Analysis (BCA) process set out in the following section. Implementation feasibility is a broader means of expressing marginal cost (an accounting of what it would take to implement the strategy above and beyond resources already or likely to be dedicated), and effectiveness modifies the risk proposition – potentially reducing the magnitude of the consequence, the likelihood of occurrence, or both. Although not as precise (a debatable attribute) as a benefit-cost ratio, a qualitative determination that a given strategy addresses a high magnitude risk with a high degree of effectiveness and high implementation feasibility (or, otherwise stated, low implementation barriers), is nonetheless useful in comparing the merits of adaptation strategies – a prerequisite for ranking them by priority.

Benefit-Cost Based Evaluation

The *Climate Change Adaptation and the Highway System* (NCHRP 20-83(5)) guidebook presents a climate risk adjusted Benefit-Cost Analysis (BCA) methodology as a means for "evaluating the cost-effectiveness of adaptation strategies in meeting expected impacts, and the opportunity costs of not applying the strategies." This approach is sufficiently flexible for use in the California context, especially for agencies already employing BCA for project selection. Due to its greater resource requirements, especially staff time and capacity, the methodology is likely better applied to alternatives for a single asset or small selection of transportation assets.

The framework structure incorporates several steps, which allow the user to develop a benefit-cost ratio for a given strategy or strategies, weighted by the likelihood of asset failure (a combination of the climate event probability and the likelihood that the asset will withstand the event). In summary, the steps include:

1. **Identify the most vulnerable infrastructure.** This step encapsulates the asset selection process that unfolds in Module 3 and Module 4 of this document. NCHRP 20-83(5) includes a "diagnostic framework" that can also be employed for this purpose.
2. **Estimate future operations and maintenance costs.** This step requires the estimation of average annual operations and maintenance costs for two scenarios: one with and one without adaptation.
3. **Estimate the agency costs of asset failure.** This step requires estimation of the costs of asset failure. The definition of failure is intentionally vague, and should be determined based on context.

4. **Estimate the user costs of asset failure.** User costs are additional burdens placed on passenger and goods movement due to asset failure. These costs may include additional vehicle miles traveled, delay, congestion, etc.

5. **Estimate likelihood of asset failure.** This step guides the user to the generation of year-by-year compound probabilities of failure, a function of the climate event likelihood and the likelihood that the asset will withstand the event. Probabilities are generated for both the adaptation and non-adaptation scenarios.

Unlike the approaches to determining the likelihood of asset failure recommended in this document, the NCHRP 20-83(5) methodology mandates a high degree of precision – the approach is intended for use in a spreadsheet format. To avoid an unrealistically precise failure probability, probabilities pertaining to the climate event and the asset's ability to withstand the event could be toggled to generate a range of likelihoods (resulting in a range of B/C ratios) or to determine the "tipping point" for taking action.

6. **Calculate agency benefits of the strategy.** In this step, the agency benefits of adaptation are calculated based on the inputs from Steps 2, 3, and 5.

7. **Calculate user benefits of the strategy.** In this step, the user benefits of adaptation are calculated based on the inputs from Steps 4 and 5. User benefits will increase over time as traffic volumes increase.

8. **Evaluate results.** The guidebook suggests three options for expressing the benefits:

    a. Calculate a benefit/cost ratio. The suggested applications of the B/C ratio include determining whether a given adaptation strategy is cost effective, comparing multiple adaptation strategies (ranked by ratio), or comparing an adaptation action against another type of project (such as capacity expansion).

    b. Determine a minimum benefit/cost ratio, above which a potential strategy becomes cost effective.

    c. Conduct a sensitivity analysis based on the probability and timing of an event occurring. Toggling or creating multiple probability assumptions can help agencies establish the tipping point for cost-effective strategies, as suggested above.

Specifics for this approach, including formulae and an accompanying spreadsheet template, are available by downloading the NCHRP 20-83(5) report and guidebook.[26]

[26] http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2631 is the link to NCHRP 20-83(5). Spreadsheet template and final guide is planned for spring 2013, and has not been posted at the time of this guide's completion.

Prioritize Adaptation Strategies for Inclusion in RTP

The penultimate stage in the assessment process is the prioritization of adaptation strategies for integration into the RTP, hazard mitigation plans, or even short-term implementation where applicable. At this point, the dimensions critical to prioritization will be known for all assets/strategies that have undergone full assessment: the magnitude of risk, effectiveness (in mitigating risks) and implementation feasibility – or, alternatively, the B/C ratio – preferably for the duration of the Climate Hazard Protection Window. These scorings can be ranked or, perhaps more suitably, grouped into tiers of priority, by time period. For example, "high," "medium," and "low" priorities for short-, mid-, and long-term implementation. It is anticipated that many of these priorities will correspond to established asset renewal cycles, helping agencies cost-effectively promote adaptation in the course of preserving or improving their assets (a practice referred to as "mainstreaming").

Although this document aims to provide efficient, workable approaches for each element of the assessment, it is particularly important at this stage to employ these approaches to the extent that they support decision-making, but not to be constrained by them. Agencies are encouraged to apply (or adapt) their own project planning and prioritization processes, and to integrate other methods and factors to the assessment as they see fit, such as the consideration of complementary benefits to other aspects of transportation or environmental performance. Agencies will also profit by working collaboratively in making these determinations, especially by leveraging the skills and knowledge of infrastructure managers and by working constructively with their constituents and with other agencies to increase the effectiveness and buy-in of their decision-making.

This leads to the incorporation of adaptation into formal plans and processes – the final, and perhaps most important outcome of the assessment. Ultimately, climate adaptation projects must take their places alongside safety, congestion mitigation, accessibility, and environmental projects, for example, which are themselves crucial to fulfilling the agency's mission and the region's goals. It is anticipated that an early, unflinching consideration of climate change, coupled with timely and cost-effective adaptation action, will strengthen the ability of transportation agencies to fulfill their fundamental mandates, now and for decades to come.

13.0 Module 5: Monitor and Evaluate

13.1 The Value of Monitoring and Evaluating the Planning Process and the Plan

To a greater extent than in other sectors, the economic impacts of climate change on the transportation sector are closely tied to the continual cycles of infrastructure renewal and reconstruction. Most transportation infrastructure decisions play out over many decades, and the affected infrastructure often extends long beyond intended design lifetimes.

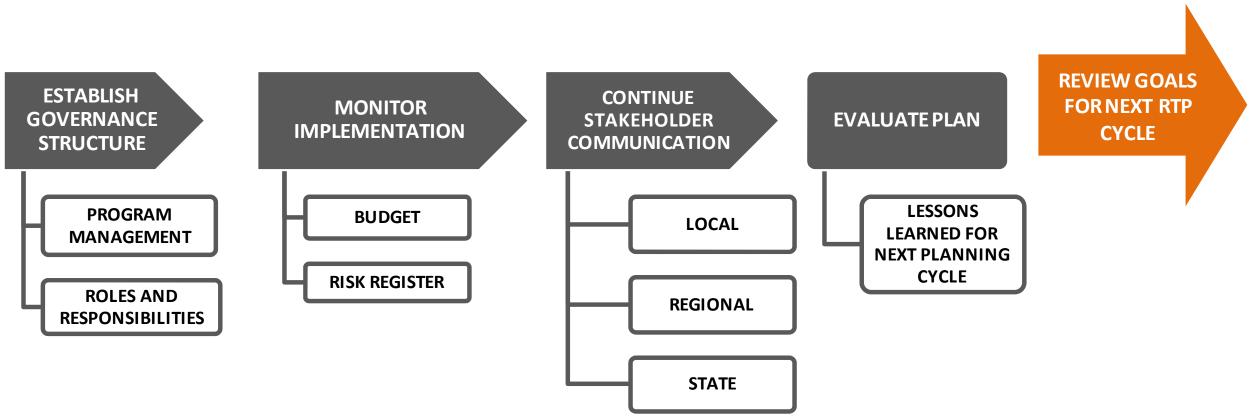
The prioritization process for transportation investments needs to consider not only the potential intensity of climate impacts but the condition and vulnerability of existing facilities and the relative importance of those facilities to overall system performance. By weighing all of these factors, transportation planners can direct resources to the most necessary and cost-effective actions.

Effective adaptation requires an ongoing, iterative process of understanding transportation infrastructure resiliency, conducting a vulnerability and risk assessment, and then selecting adaptation actions. This is a cycle that then feeds into performance assessment, monitoring, and continuing adaptation. This process requires a range of technical skills, quality data sources, and institutional collaboration to bring together the scientific, engineering, and planning resources necessary to make good decisions. Climate impacts assessment and adaptation planning is not a stand-alone process though. In order for climate impacts assessment and adaptation to be pursued effectively, they must be integrated into the ongoing transportation decision-making process. This long-term perspective needs to be balanced with monitoring for near-term changes that may require more immediate design adjustments.

Thus the plan will continue to change. Monitoring strategy effectiveness and scientific advancements is only valuable if the findings are used to adjust adaptation strategies when necessary. Periodic review through the cycle of the RTP process is critical to achieving implementation results. Given the uncertainty inherent in climate projections and impact assessment, an adaptive approach is critical to long-term policy effectiveness and efficient use of resources.

Figure 13.1 provides a step-by-step illustration of the primary elements of the plan monitoring and evaluation module.

Figure 13.1 Process for Monitoring and Evaluating the Plan



Source: Cambridge Systematics, Inc., 2012.

13.2 Monitoring and Evaluation

Like other elements within the RTP, climate adaptation plans and activities should be monitored and refreshed on a periodic basis. This element of the RTP should not only track the adaptation strategies selected but also the scientific updates as well as the tools and technology available to develop climate impact projections. Linking climate adaptation to the RTP/SCS guarantees a venue whereby adaptation options as well as findings from ongoing research on climate change and the tools available to address it will be revisited over time. This will allow MPOs/RTPAs to stay informed of the research and best practices on risk assessment and appropriate adaptation options.

Establish Governance Structure

To ensure that climate adaptation moves from plan to implementation, the MPO/RTPA will have to work with a variety of other agencies to ensure that the adaptation strategies called out in the plan are executed. The MPO/RTPA will have to convert the climate adaptation strategies from the RTP into a work program with a lead department or staff member responsible for implementation. The work program should outline roles and responsibilities with phasing and timelines associated with certain actions.

Defining specific individuals, departments, agencies and organizations can help assure that a strategy is implemented rather than included in a general guidance document. The governance structure can provide a forum for sharing the progress of implementing adaptation strategies over time.

Because adaptation policies often address projected impacts far into the future with sometimes unobservable benefits in the short run, this work program will rely on sustained support and strong leadership. The governance structure will have to involve the coordination of many departments and this work program, much like the RTP documentation, will need to be continually refreshed.

Monitor Implementation

Although at this point, monitoring implementation of adaptation strategies is not always in the hands of the MPO/RTPA, the MPO/RTPA can assist with two key areas: supporting the budget and developing a risk register.

One of the most challenging aspects to implementation of adaptation strategies is identifying and pursuing the funding for it. The RTP process is designed to identify needs and shortfalls over a long-term future time horizon, but as projects emerge, they will have an associated estimated cost that includes the material cost of the strategy, staff time, administrative support, associated outreach, and long-term monitoring. Although the adaptation strategy may be a part of a regional transportation plan, it may not be viewed as critical when compared against all of the other needs in the region. There are a variety of ways in which adaptation strategies can be funded, including government grants, general funds, taxes and fees (including impact fees), bonds, and more. The RTP process is meant to support the identification of costs and of potential funding required.

An MPO/RTPA can also assist with the development of a risk register for the project. This is a project management tool to track project risk probabilities, estimate impact and develop alternative methods to deal with diversions from the original goal or strategy. Each adaptation strategy will have a different set of implementation challenges, and the MPO/RTPA can adopt a risk register along with the implementation agency to track the progress over time.

Continue Stakeholder Communication

Although it is unlikely that the advisory board will continue to be in existence after the development of the climate adaptation component of the RTP, the MPO/RTPA will benefit from longer-term periodic updates with stakeholders, even if through an e-mail listserve or informal correspondence. This builds support for their participation in future RTP cycles and provides a forum for open communication.

Evaluate Plan

Before the next planning cycle begins, the MPO/RTPA will find it worthwhile to catalog the lessons learned from the development of the climate assessment and adaptation plan for incorporation into the next planning cycle.

13.3 Next Step: Review Goals for Future RTP

At the end of the process, the cycle begins again with Module 1, with the timing aligned with the next round of RTP updates, which occurs every four to five years. When resources and/or funding permit, climate adaptation planning can occur at more frequent intervals or on a case-by-case basis for selected infrastructure or strategies.

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B. State-of-the-Practice Climate Change Activities for California MPOs and RTPAs

State-of-the-Practice Climate Change Adaptation Activities for California MPOs and RTPAs

appendix b

report

prepared for

California Department of Transportation

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January 16, 2012

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appendix b report

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prepared for

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prepared by

Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607

date

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Table of Contents

1.0 State-of-the-Practice Adaptation Planning

In recent years, new ways of approaching climate change adaptation are being developed at every level. This chapter reviews several key conceptual frameworks for how climate change adaptation can be incorporated in transportation planning, as well as a list of approaches and case studies conducted at the statewide, and then MPO and regional levels.

1.1 Climate Change Conceptual Planning Frameworks

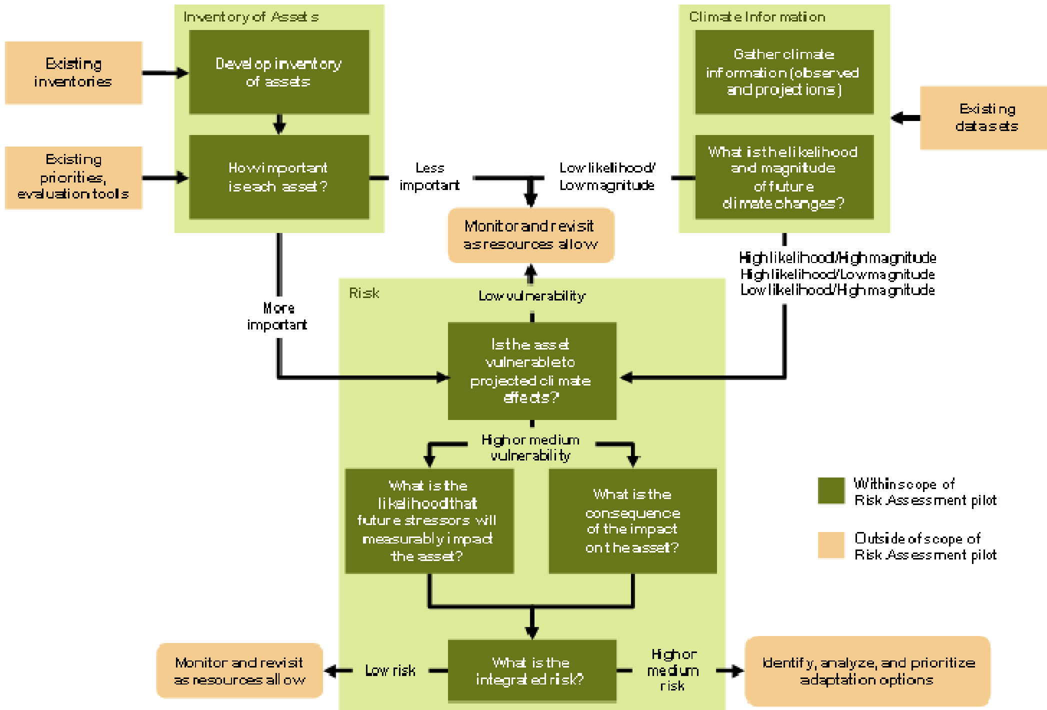
Several conceptual frameworks have emerged in recent years on how to think about climate change and transportation.

Federal Highways Administration Conceptual Risk Assessment Model and Pilot Vulnerability/Risk Assessment Projects

FHWA's *Sustainable Transport and Climate Change Team* developed a conceptual Risk Assessment Model (FHWA, "Assessing Vulnerability…") to assist transportation planners, asset managers, and system operators in identifying infrastructure at the greatest risk for exposure to climate change stressors and determine which threats carry the most significant consequences. The model, shown in Figure 1, includes three primary steps. The first two steps should be executed concurrently and then integrated for the performance of the third step.

1. Build an inventory of relevant assets and determine which are critical to system performance;
2. Gather information on potential future climate scenarios, including the possible magnitude and likelihood of the changes; and
3. Starting with the most critical assets and severe climate stressors, assess the potential vulnerability and resilience of the asset.

Figure 1. FHWA Pilot Climate Change Conceptual Risk Assessment Model



FHWA selected five pilots to implement and provide feedback on the conceptual risk assessment model:

- Metropolitan Transportation Commission in the San Francisco Bay Area;
- New Jersey DOT and North Jersey Transportation Planning Authority;
- Virginia DOT;
- Washington State DOT; and
- Oahu Metropolitan Planning Organization.

The pilot programs, which began early in 2011, are in progress at the time of writing, but will be completed for delivery to FHWA at end of November 2011. Representatives from the pilot agencies have met twice to exchange results and discuss challenges in workshops held in New Jersey and Washington State, and also participate in frequent conference calls to discuss progress. Feedback and lessons learned will be incorporated into a revised version of the conceptual model.

New York Panel on Climate Change Adaptation Assessment

In 2010, the New York Panel on Climate Change (NPCC) designed a framework for climate change adaptation assessment that can be used in any urban area, with region-specific adjustments related to climate risk information, critical infrastructure, and protection levels. The Adaption Assessment Guidebook includes an eight step process to inventory at-risk infrastructure and develop adaptation strategies to address risks (Figure 2). These steps are designed to be incorporated into risk management, maintenance and operations, and capital planning processes of agencies.

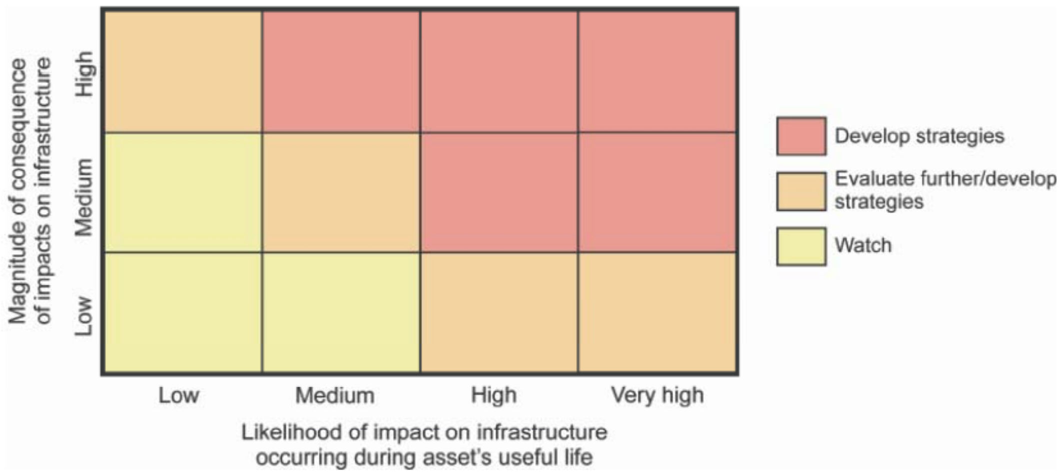
1. Identify current and future climate hazards
2. Conduct inventory of infrastructure and assets
3. Characterize risk of climate change on infrastructure
4. Develop initial adaptation strategies
5. Identify opportunities for coordination
6. Link strategies to capital and rehabilitation cycles
7. Prepare and implement adaptation plans
8. Monitor and reassess

Figure 2. Adaptation Assessment Steps Developed by NPCC

Source: NPCC Climate Change Adaptation: Building a Risk Management Response.

NPCC also provides a Risk Matrix (RM), a tool to help categorize and prioritize the risk assessment findings by facility, based on the probability of the climate hazard, likelihood of impact, and magnitude of consequence (see Figure 3).

Figure 3. Risk Matrix Used by New York City



Source: NPCC Climate Change Adaptation: Building a Risk Management Response.

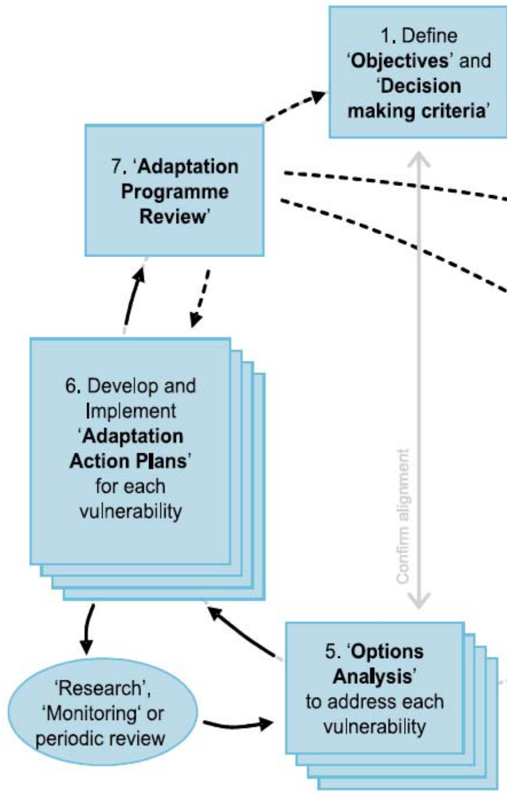
United Kingdom Highways Agency Adaptation Strategy Model

To date, the most fully-developed adaptation framework is that described in The United Kingdom Highway Agency's Climate Change Adaptation Strategy. The framework is a seven-step process for developing a climate change program. It provides a method for prioritizing risk and identifies staff members responsible for different climate change adaptation program development efforts.

The Adaptation Framework provides a platform for decision makers to examine their individual business areas, including standards, specifications, maintenance, and the development and operation of the Highway Agency network. It provides a systematic process to identify the activities that will be affected by a changing climate, determine associated risks (and opportunities), and identify preferred options to address and manage them.

The Highways Agency's Adaptation Framework Model (HAAFM) provides a seven-stage process that identifies activities which will be affected by a changing climate; determines the associated risks and opportunities; and identifies preferred options to address them.

Figure 4. UK Highways Agency Adaptation Framework Model



Source: Climate Change Adaptation Strategy and Framework, Rev B, November 2009.

1.2 Efforts in California

2009 California Climate Change Adaptation Strategy

The California Natural Resources Agency (CNRA), with the help of other state agencies, wrote *The California Climate Change Adaptation Strategy* (2009) in response to Executive Order S-13-2008, which directed California's agencies to develop an approach for statewide climate adaptation planning. This report presents climate change adaptation strategies for seven sectors including transportation. In addition to work done by state agencies involved in the sector-specific working groups, stakeholder input contributed to this strategy. The final product includes a number of preliminary recommendations that relate to both near- and long-term actions. Some are specific to individual sectors and some are more global in nature, such as the recommendation for planning agencies to include climate change impact assessments as part of their plans.

The strategy identifies and describes which types of climate change events are most likely to affect transportation. For example, flooding and sea level rise are two major climate change events that could affect transportation assets and operations. *The Impacts of Sea Level Rise on the California Coast* (Heberger et al., 2009*)* predicted that 2,500 miles of roads and rail will be affected by the year 2100. Flooding can damage infrastructure such as tunnels, highways along the coast, runways, and railways. Three airports in the San Francisco Bay area – San Francisco, Oakland, and San Jose – are all near sea level and based on projections, will need to be relocated and protected from climate change events in order to remain functional. Damage to sea ports from sea level rise will have negative economic effects as California's seaports handle 40% of the country's shipping volume. Moving the ports or implementing other protective measures will be costly as well.

Caltrans Guidance on Incorporating Sea Level Rise

Caltrans produced *Guidance on Incorporating Sea Level Rise* (2011) for its planning staff to help determine if sea level rise should be addressed in a particular project and if so, how to incorporate it. It guides planners and project managers through a two-step process: the first step is to determine if the project will be affected by sea level rise; the second step balances sea level rise impacts with consequences to the transportation system to determine if adaptation measures should be included in the project. This guidance document is intended to be updated as research on this emerging topic of climate change adaptation is released.

Highlights of the guidance include a table of screening criteria that can be used to determine whether or not adaptive measures are needed and the amount of additional funding needed to mitigate the risks. After consideration of all criteria, the project manager would determine whether or not a project needs to incorporate sea level rise. If so, one should determine the expected magnitude of the impact and how to address impact by assessing alternatives.

This document is especially relevant to transportation planning agencies in California because research has shown that future projected sea level rise presents a major threat to transportation infrastructure. EO S-13-08, signed in 2008, mandates that state agencies planning projects in vulnerable areas consider various sea level rise scenarios for the years 2050 and 2100. This provides guidance specific to California as well.

The Impacts of Sea Level Rise on the California Coast

Sea level has risen over the past 100 years and projections indicate that it will continue to rise. *The Impacts of Sea Level Rise on the California Coast* (Heberger et al., 2009) projects what will happen if no actions are taken to address sea level rise, with a focus on population, infrastructure and property. The State of California created the climate change scenario for this report based on International Panel on Climate Change (IPCC) scenarios that assumed medium to high levels of greenhouse gas (GHG) emissions; the IPCC's worst case scenario for sea level rise was not selected. The overarching finding is that the coast will be affected dramatically by sea level rise.

Flooding and erosion will affect the transportation infrastructure greatly. It is projected that the state will lose 41 square miles of California's coast by 2100. The study noted specific facilities at risk. Under current conditions, 1,900 miles of roadways are at risk of flooding (given a 100-year event). In the event of a 1.4-meter sea level rise, 3,500 miles of roadways are at risk. Railways and ports are also at risk, which can have major economic consequences, particularly in the San Francisco Bay Area that depends largely upon manufacturing, freight transportation, and warehouse/distribution services. Many California airports are also vulnerable to flooding. While erosion may affect fewer total miles of roadways and railways, the more concentrated damage from erosion can be worse than flooding effects and more permanent.

The study concludes with a number of recommendations ranging from the inclusion of climate change in planning developments and communities, limiting development in certain areas, and working to prepare communities for emergencies. Additional research is also recommended. Finally, the study recommends that local and regional planning agencies undertake local studies to determine specifically what the affects of climate change might be in their communities and how to prepare for them.

1.3 Other State-Level Efforts

New Jersey DOT and North Jersey Transportation Planning Authority

The NJDOT/NJTPA project is assessing potential climate impacts from sea level rise/storm surge, extreme temperatures and temperature ranges, extreme precipitation and average precipitation levels, drought, and inland flooding in 2050 and 2100. The project team is led by NJTPA, but includes New Jersey DOT, the state's other two MPOs, NJ Transit, and the NJ Department of Environmental Protection. Multi-modal assets, including roadways, bridges, rail and bus transit, maritime assets, airports, and wetlands, are being evaluated for two large study corridors (one primarily inland, one primarily coastal).

The study employs a quantitative and qualitative destination-based criticality assessment technique to determine which assets are evaluated for exposure, potential resiliency to climate stressors, and consequences of asset failure to system performance. This effort also includes an adaptation strategies component.

Virginia Department of Transportation

This pilot focuses on incorporating potential sea level rise into priority setting for long-range transportation plans, in partnership with planning agencies for the Hampton Roads area. The primary goal of this project team is the development of scenario analysis tools that help decision makers incorporate climate change into policy development. Virginia's climate scenarios are integrated with economic, technology, maintenance, and regulatory factors to yield five "influential" scenarios, which are then used to prioritize projects, policies, and traffic analysis zones in the long-range transportation plan.

Washington State Department of Transportation

Washington DOT's (WSDOT) study is exclusive to DOT assets (roadways and bridges), and benefits from extensive inter-agency coordination (13 workshops had been conducted at the time of writing). WSDOT employs a qualitative 1-10 criticality ranking system for specific assets, contrasted with a 1-10 scale of impact severity derived through scenario planning to determine potential vulnerability. Vulnerability rankings are then mapped in GIS. WSDOT considered a variety of climate stressors, including sea level rise (western part of the state only), flooding, extreme heat, drought, and invasive species.

1.4 MPO and Regional Efforts

At the regional level, some Metropolitan Planning Organizations (MPOs) have also started to undertake adaptation planning. Climate change adaptation is still relatively new to many MPOs and local governments, but the following examples represent state-of-the-practice approaches.

King County Guidebook on Local Government

This guidebook is a collaborative effort on the part of a number of organizations and agencies in the Seattle area. The guidebook focuses on preparing for climate change effects with the understanding that planning for potential climate events is not a "one size fits all approach". The guidebook's intended audience is local, regional, and state decision-makers and its purpose is to help these decision-makers prepare for climate change. The document also explains reasons for being proactive about preparing for climate change impacts.

Data included in this document are based on a literature review of scientific research as well as local experiences with efforts related to preparing for climate change effects. Additionally, ICLEI – Local Governments for Sustainability provided input based on experiences with its own climate change adaptation program aimed at local and regional governments. The guidebook also includes suggested steps to start one's "climate resiliency" effort.

This source provides great examples of tools available for decision-makers to use, including descriptions of the types of information available on climate change adaptation as well as an extensive list of sources, organized for easy access by category with concise summaries. Summaries of climate change effects of "mega-regions" within the U.S. from a 2000 NOAA study are also helpful in providing a high-level perspective on climate change. Case studies summarizing efforts from various communities throughout the U.S. and internationally also provide guidance for decision-makers.

Oahu Metropolitan Planning Organization

Oahu MPO has identified a limited group of previously identified critical assets, including Honolulu Harbor, the airport, key access roads and bridges, and communities with only a single means of ingress/egress. Oahu MPO has used a series of workshops to perform its assessment, beginning with an initial workshop for engineers and planners, and continuing with a public input workshop, a two-day risk assessment workshop with climate scientists, and concluding with a socioeconomic impacts workshop. Climate impacts of particular concern were flooding, more frequent storm events, and sea level rise.

Metropolitan Transportation Commission (MTC)

MTC's project entitled "Adapting to Sea Level Rise" is constrained to assessing the potential impacts of sea level rise and storm surge. Although MTC is the project lead, the stakeholder group includes numerous municipal and county governments, transportation authorities, services districts, and environmental non-profits, such as ICLEI. The study is multi-modal, including major roadway classifications, bridges, transit assets, freight assets, and bicycle/pedestrian facilities.

Five primary affects pertaining to seal level rise are considered, all pertaining to rising sea levels: 1) More frequent floods, 2) Longer lasting floods, 3) New flooding extents, 4) Overtopping of shoreline protection structures and resulting erosion, and 5) elevated groundwater and salinity intrusion. The study developed basic categories of shoreline characteristics (e.g., "engineered shoreline protection) and created new inundation maps to aid in the assessment of vulnerability and risk. The assessment integrated exposure scenarios with semi-quantitative asset "sensitivity" ratings and an adaptive capacity rating (for system resiliency) to determine overall vulnerability. The risk assessment step integrates qualitative evaluations of the likelihood of a given stressor impacting critical assets with a qualitative prediction of the potential consequence.

Houston-Galveston Area Council

Houston-Galveston Area Council's (H-GAC) formed the Foresight Panel on Environmental Effects to assess possible climate change impacts in the Houston region. In 2008, the Panel produced the Foresight Panel on Environmental Effects Report that highlighted its findings. The report, piggybacking off of data from the FHWA's Gulf Coast Study, outlines projected climate changes for the Houston metro area and their impacts on infrastructure, public facilities, ecosystems, and public health. A GIS-based study of sea level rise and flooding scenarios helped to illustrate vulnerable infrastructure and facilities. A number of adaption recommendations for the region were also offered. For highways, these included using alternative paving products for higher temperatures and consideration of adaptation in long term transportation planning (including exploring adaptation implications of different mode choices).

Preparing for the Changing Climate: a Northeast-Focused Needs Assessment

This effort provides a "snapshot" of an entire region - from Maine to New Jersey – of what actions agencies are taking to prepare for climate change on the local, state, and regional levels. Methods used include interviews and questionnaires administered to over 200 communities.

Responses were received from 34 local governments, six regional governments, and four state governments. The largest concerns among these respondents are related to sea level rise, more precipitation and floodplain changes, and public health. Many communities need technical assistance doing infrastructure vulnerability assessments. Other needs include climate impact assessments, local climate data maps that project sea-level rise, and updated floodplain maps. Additional needs relate to outreach; many expressed a need to help communicate the message that climate change is happening. They wanted to know how to make the climate change actions a priority during financial hard times. Given these financial hard times, resources and staff to dedicate to this topic are difficult so a common approach is to ask all departments to put a "climate lens" on their projects. Alternatively, hiring an outside consultant with climate change expertise would take the pressure of extra tasks off internal staff.

Atlantic Canada Climate Change Adaptation Strategy

In 2008, the New Brunswick Department of the Environment and Natural Resources Canada (NRCan) hosted a workshop on climate change adaptation for the governments in Atlantic Canada. The product that emerged was a regional adaptation strategy with a focus on improving adaptability and resilience in the region, incorporating adaptation into new and existing plans, and creating a regional collaboration framework.

The provincial governments of Atlantic Canada used a workshop format to discuss their priorities and goals with regard to climate change adaptation. Three priorities were central to this event: coastal areas, inland waters, and infrastructure. The following three objectives were the outcome of the workshop:

1. Improve the region's resiliency and adaptability;
2. Incorporate adaptation into new and existing plans; and
3. Create a framework for regional collaboration.

The *Atlantic Canada Climate Change Adaptation Strategy* was created at the workshop. The Atlantic Climate Adaptation Solutions (ACASA), the partnership among governments from the Atlantic provinces of Canada, then applied for and were awarded a grant from NRCan. Work was scheduled to start in early 2010 with a completion date in December 2012. The grant specified that the recipients must address climate change impacts affecting the region, with a focus on

impacts discussed in a research report published by NRCan called *From Impacts to Adaptation: Canada in a Changing Climate*.
Major findings are summarized below:

- Barriers include the challenge of communication between many partners.
- ACASA used the grant to create 25 community adaptation projects across the region which will be used as models for the future.
- Other deliverables were also proposed using grant funding. One example includes the adaptation by-laws for municipalities.
- The Community Toolkit/Workbook was another key deliverable aimed at helping communities by providing information on relevant tools, vulnerability assessment help, and other documents that help with decision-making.
- ACASA received many benefits from this project, including improved models, vulnerability data, and other data such as LiDAR.

2.0 Additional Information Resources

CAKE (Climate Adaptation Knowledge Exchange)

Climate Adaptation Knowledge Exchange (CAKE) is an on-line resource aimed at practitioners in a variety of disciplines that provides information about climate change adaptation. EcoAdapt and Island Press, both nonprofit organizations, manage the web site in an effort to share information and best practices at no cost and create a "community of practice" around climate change adaptation. Highlights include U.S. and international case studies about adaptation efforts and projects. It is possible to narrow a search by keyword to focus on a specific sub-area such as transportation, for example. Additionally, links to helpful tools relevant documents, and upcoming events are posted on CAKE.

Source: http://www.cakex.org/.

Cal-Adapt

Cal-Adapt, launched in June 2001, provides information about the effect of climate change on the local level in California. Developed by University of California's Berkeley's Geospatial Innovation Facility (GIF) with support from the California Energy Commission's Public Interest Energy Research (PIER) Program and Google.org, this tool incorporates scientific research from across California. The site provides interactive maps and other visual representations to help educate users about potential climate change effects. For example, a user can click on a "Local Climate Snapshot" to see the projected temperature changes, snow pack, or other climate events throughout the state. Images include a map that the user can manipulate as well as graphs charting historical and projected changes in a specific area.

Source: http://cal-adapt.org/

San Francisco Bay Conservation and Development Commission Resources for Adaptation Planning

This web site provides a summary of resources on climate change adaptation relevant for California regions. Topics covered include state and regional climate change science and impacts; adaptation planning principles and process; tools, data sources and example adaptation actions; engaging communities and decision-makers; case studies and example adaptation plans; and state and regional adaptation policy and planning efforts.

Source: http://www.bcdc.ca.gov/planning/climate_change/resources.shtml.

Transportation and Climate Change Clearinghouse

Maintained by US DOT, this clearinghouse is touted as a "one-stop source of information on transportation and climate change issues," including both GHG mitigation and adaptation to climate impacts. Relevant resources are listed within two categories, "Climate Change Impacts" and "Adaptation Planning."

Source: http://climate.dot.gov.

Adaptation Clearinghouse™

The Adaptation Clearinghouse was developed by the Georgetown Climate Center to provide information that will help communities adapt to climate change. Although not specific to transportation, this clearinghouse is fully searchable, with filters including a) state or region, b) resource type, c) impacts, d) sectors (including transportation) and e) jurisdiction, as well as text search capability. Each research includes a substantial summary and typically a hot link to the resource. As of January 1, 2013, there were 211 resources available, with 83 pertaining to transportation.

Source: http://www.georgetownclimate.org/adaptation/clearinghouse.

TRID Database

Produced and maintained by the Transportation Research Board of the US National Academies, the TRID database contains more than one million records on research in the field of transportation. The transportation research community's largest collection of resources must be searched by key-word to yield results on climate change adaptation, and may deliver less relevant results. However, it includes a good selection of international work, and may help identify transportation research efforts that support, but are not specifically focused on, adaptation. As on January 1, 2013, a search for "climate change adaptation" returned 229 results.

Source: http://trid.trb.org/

3.0 State-of-the-Practice at MPOs/RTPAs in California

During November 2011, interviews were conducted with six MPOs/RTPAs around California that were considering the incorporation of adaptation into their RTP process. This feedback provided the study with insight into what types of information would be most beneficial to MPOs with limited resources to conduct a full-scale adaptation planning process. The information collected in this round of outreach provided input into shaping the final guide. Table 1 shows the interviewees.

Table 1. Climate Adaptation Outreach Interviewees

Name	Title / Role	Agency
Peter Imhof	Deputy Director, Planning (Management of Planning Division)	Santa Barbara County Association of Governments
Steph Nelson	Associate Planner	Association of Monterey Bay Area Governments
Barbara Steck	Deputy Director	Fresno Council of Governments
Mike Bitner	Principal Planner	
Kathy Chung	Senior Regional Planner	
Kristine Cai	Senior Regional Planner	
Lauren Dawson	Senior Regional Planner	
Marcella Clem	Executive Director	Humboldt County Association of Governments
Dan Wayne	Senior Planner, Project Manager for RTP/SCS	Shasta County Regional Transportation Planning Agency
Kim Anderson	Senior Regional Planner	San Joaquin Council of Governments
Mike Swearingen	Associate Regional Planner	

Source: Interviews conducted by Cambridge Systematics, November 2011.

3.1 Santa Barbara County Association of Governments (SBCAG)

At this time, the Santa Barbara County Association of Governments (SBCAG) considers climate change adaptation a relatively new issue area, and there have been no actions or plans within the MPO to address it.

SBCAG is in the process of beginning the next RTP update but because climate change adaptation is not discussed in the RTP guidelines, there is nothing specifically being done to address it. There is a lot of uncertainty around the impacts of climate change, and SBCAG would not know how decide which climate change impacts should be incorporated into the planning process

This topic is increasingly important as awareness about climate change adaptation grows. A recent roundtable discussion on climate change adaptation took place in Santa Barbara County. The topic is gaining attention, but there is still no formal framework for considering the issue at the MPO level. SBCAG staff do not feel equipped to handle incorporation of climate change adaptation into the organization's RTPs. In the face of many new requirements (e.g., SB 375 and Sustainable Communities Strategy), SBCAG has not focused on adaptation.

Efforts Underway

There is a nascent local information building movement considering climate change adaptation. A couple examples include the document prepared by UCSB's Ocean and Coastal Policy Center "Developing Adaptive Policy to Climate Disturbance in Santa Barbara County" as well as a committee focused on wetland recovery in Goleta Slough near the airport. This adaptation study was driven by the desire to identify facilities at risk in the Goleta Slough.

At the time of the interview, SBCAG had not received any comments from board members regarding climate change adaptation. Some local interest groups talking discussed the issue with South Coast supervisors, however, adaptation has not been discussed during a formal board setting. Regarding the upcoming RTP, SBCAG has recently (August 2011) informed the Board on the RTP/SCS outline and the performance assessment measures. Thus far, the information provided to the Board has only been for background purposes (i.e., the report has not been reviewed).

At the time of the interview, SBCAG was not planning to address climate change except with regards to mitigation; SBCAG's focus will specifically be on the reduction of greenhouse gas emissions in passenger vehicles and light trucks. This is in compliance with the state law.

SBCAG staff report that the California Coastal Commission is requiring an assessment of climate change adaptation (sea level rise) in advance of permitting of projects and local programs that they certify. Thus, climate change adaptation is considered directly by the county. However, this has not affected how SBCAG approaches the RTP.

How Caltrans Can Help MPOs Incorporate Climate Change Adaptation into the Planning Process

SBCAG staff report that in order to integrate the effects of climate change into the planning progress, SBCAG would need more specific information about the expected effects of climate change and guidelines or a framework to better analyze how climate would affect the region and balance these affects against the agency's other priorities. It was suggested that step-by-step instruction designed to lead MPOs through an analysis would be most helpful. Additionally, a state mandate would likely be necessary in order to motivate the agency to incorporate climate change adaptation planning into the RTP.

3.2 Association of Monterey Bay Area Governments (AMBAG)

For the upcoming 2014 Metropolitan Transportation Plan (MTP), AMBAG will maintain its focus on achieving greenhouse gas (GHG) mitigation as per SB 375. Within the policy framework of the AMBAG MTP, environmental factors are considered as key policy drivers within the region. Climate change adaptation, however, is a newer topic that has not been fully considered.

In the context of the upcoming MTP, the main two environmental issues besides GHG mitigation that concern AMBAG are the preservation of potable water supply for urban areas and sea level rise. Sea level rise is relevant in the MTP process, because much of the opportunity for infill development is currently located on the coastal shorelines, and there is concern that sea level rise and coastal flooding may affect development and planning. The issue has been brought up by environmentalists, developers, and elected officials. Sea level rise concerns were expressed during regional blueprint process, but addressing them was beyond the scope of the project. Because resources are limited and as analysis of this issue is not required under SB375, it is unlikely that it will be addressed in the RTP.

Efforts Underway

There have been some informal discussions between planning staff and coastal commission staff. Ongoing regular communication with coastal commission would benefit the region. AMBAG issued an RFP in the last year for a beach nourishment process, which is an ongoing issue in the region with marine sanctuary (conservation versus the use of Monterey Bay for fishing).

How Caltrans Can Advance Climate Change Adaptation Efforts

A suggested process regarding when to consider climate change adaptation strategies when developing a long range transportation plan or during the project implementation process would be useful to AMBAG. Additionally, information on various adaptation strategies would greatly help to inform incorporating adaptation into the planning process.

Information provided in the Caltrans study should address different stakeholders and different perspectives. For instance, public works officials think very differently than about climate change because different time frames concern them for planning and implementation. It would be useful to have further discussion with multiple stakeholders involved in the MTP process and to have targeted information material for different stakeholders.

3.3 FRESNO COUNCIL OF GOVERNMENTS (FCOG)

Efforts Underway

The Fresno Council of Governments is starting their process for the next RTP. Several seminars have been held at the staff level to review guidelines and figure out how to meet the targets set for the SCS. But, at this time, climate change adaptation is not planned for inclusion.

Four years ago for the previous RTP, there was a climate change element in which pricing policies and the pros and cons of instituting these programs were discussed. FCOG included documentation that had to be done due to an Attorney General request on the climate change element. This was written on a voluntary basis. This time the information as related to climate change mitigation will be done through the SCS process.

There have been no specific questions from the Board on climate change or climate change adaptation. FCOG suspects that the coastal areas are probably ramping up on this issue more than MPOs in the Central Valley.

Extreme Events Affecting Existing Roadways

Local governments that face issues such as flooding today may be thinking more about the affects of climate change and how to address them. Because part of Fresno is in the mountains, several state highway and county roads are susceptible to snowmelt, which can cause difficult driving conditions.

On west side of Fresno County flooding and extreme weather events are more often occurring. There is a project partnering to address the issues within Caltrans. As sea level changes and the sedimentation that emerges from that process increases, there are infrastructure effects that need to be considered.

How Caltrans Can Advance Climate Change Adaptation Efforts

It would be useful to develop educational materials to communicate the importance of climate change adaptation issues planners and elected officials would facilitate incorporating climate change adaptation the long range planning. Educational materials would help to inform the board and local city managers about climate change and how it might affect the decision-making process.

Additionally, moving into the RTP update, it could be useful to see how climate change impacts might affect project selection. Guidance on how to incorporate performance measures to guide project selection based on expected climate change affects would be helpful.

3.4 Humboldt County Association of Governments (HCAOG)

The HCAOG RTP was last adopted in 2008, and there was no mention of mitigation or adaptation. In the general plan update process, there have been some discussions on climate change issues, but these issues have not taken front stage. The city of Arcata has adopted a Climate Action Plan.

Efforts Underway

HCAOG is currently planning the new June 2013 update to the RTP and HCAOG will not ignore climate change in the next RTP. Humboldt County has experienced effects of climate change, flooding, inundation, and mudslides. The RTP process will include a stakeholder process to make sure of its inclusion. The RTP will have discussion on climate change mitigation and likely on adaptation as well. In Humboldt County there are many active environmental groups.

How to Help Incorporate Climate Change Adaptation in Planning

In order to assist HCAOG to incorporate climate change adaptation into the RTP, HCAOG would request guidelines, information, and data on climate change adaptation. Additionally, the agency is concerned about coming up with the necessary resources to add this element to the RTP.

Comments from District 1

Although, coastal communities are concerned with coastal storm surges and barricading facilities, the Caltrans Eureka-Arcata Route 101 corridor improvement project does not include a discussion of sea level rise and potential climate change impacts because Caltrans is waiting for policy language and guidance. There is concern with how Caltrans is conforming with Coastal Commission guidance (District 1 has been challenging to deal with). When Caltrans is applying for permits with the coastal development commission – the same standards are used. This is an important issue in trying to permit projects.

Follow Up Suggestions

HCAOG would appreciate a summary of interview findings as part of the project. Also, in the review of case studies and peer work going on in this arena, it would be helpful for Caltrans to share any good examples of how climate change (especially sea level rise) is handled in other RTPs.

3.5 Shasta County Regional Transportation Planning Agency (SCRTPA)

Efforts Underway

Climate change adaptation has not been a priority for Shasta County Regional Transportation Planning Agency (SCRTPA). Climate change adaptation has not yet emerged in Board conversations or through public meetings. In the upcoming update to the RTP/SCS there are no plans to address the issue.

The Shasta County Air Quality Management District is assembling a Climate Action Plan that addresses adaptation. This effort takes a greenhouse gas (GHG) inventory and polls all local agencies for GHG reduction policies, and some of these policies may touch on climate change adaptation.

Additionally, Shasta County recently completed a local hazard mitigation plan, which included information similar to what one might be important in a climate change adaptation planning process.

Effects of Climate Change in Shasta County

Shasta County expects to be affected by changing precipitation and temperatures associated with climate change, but anticipates that these effects will not be as dramatic those felt in other parts of the. Worsening air quality due to forest fires and drought conditions are likely to affect Shasta County. If heat effects and drought conditions are amplified in future years, there will be increasingly worse air quality in the region.

Bridges in the northern part of California will be affected by climate change. Two thirds of the state's bridges are in the northern counties. Shasta County would like to know how climate change might affect the bridge structures in the near or distant future. An inventory of where these bridges are and the expected effects climate change is expected to have on these structures would be helpful. Shasta County does not keep a bridge layer in GIS (note: this is something that Caltrans would likely have) but it may have a note of this in a feature class within the database.

How Caltrans Can Advance Climate Change Adaptation Efforts

SCRTPA would consider RTP guidelines that address climate change adaptation if they are easy to integrate. Climate change adaptation might not be considered one of the core issues in this round of RTP/SCS at this time but it could be taken under consideration.

SCRTPA understands that other MPOs might consider climate change adaptation as a factor within project selection within the RTP's list of projects. For Shasta County, the issue of climate change adaptation would be unlikely to be weighted at all within project priority. However, to the degree climate change might have an impact on new projects, the county would like to include discussion about relevant impacts.

A product that might be helpful for Shasta County would be spatial data layers in GIS format that could help the RTPA take climate change adaptation into consideration. For instance, these could include specific areas of vulnerability based on deviation from historical variance and weather patterns. This would help SCRTPA know the range and extent of what these impacts are. The engineered systems work well within a range of variation – but the effects of climate change may go beyond the engineered ranges. In these cases it would be helpful to know what the impact and timeframe is for these effects, so that SCRTPA can plan more effectively.

Future Coordination of Efforts

The region that includes Shasta County and the surrounding RTPAs are considered a superregion (i.e., the North State superregion). Data requests going to this superregion for a uniform call for data is the most effective way to submit a request for information. Shasta County administration includes both the public works department and the responsibility for the RTPA.

In order to understand the effects of climate change on infrastructure within Shasta County, it could be useful to interview Shasta County public works and city of Redding engineers to answer questions about engineered ranges for infrastructure. One could start with the public works directors and the traffic and engineering staff. Public works within SCRTPA is a small department – one could go straight to the director to be referred to the right staff.

3.6 San Joaquin Council of Governments (SJCOG)

Efforts Underway

San Joaquin Council of Governments (SJCOG) is just embarking on the process of thinking about how climate change adaptation might be incorporated into regional planning. SJCOG is starting to engage the public on SB 375 and has begun developing criteria for ensuring that the mandates of SB 375 are reflected in Long Range Transportation Plans. SJCOG has not developed comprehensive hazard mitigation plans either, although there has been project specific mitigation to shore up the levee system protecting assets from the Delta, designed to re-secure the area for the next 200 years. Currently, that system is in "jeopardy," and is a top concern of SJCOG.

Thus far, no SJCOG stakeholders or board members have mentioned adaptation as an issue of interest, with mitigation taking a much more prominent role. There have not yet been any public meetings to explain SB 375, and the subregional jurisdictions' main concern seems to be land use control in context of forthcoming requirements for GHG mitigation.

A few jurisdictions, notably Stockton, have progressed further in their thinking about climate change, having created a climate action plan on the ICLEI model. Among the few subregional plans and initiatives that have been completed or are currently underway, the impact of climate change on transportation has received less focus than agricultural/farmland impacts and general GHG reductions.

SJCOG does not expect to consider climate change adaptation comprehensively in the next LRTP update. Instead, specific emphasis will be placed on the vulnerability of the transportation assets near the Delta, and general focus will be placed on SB 375 mandated GHG mitigation.

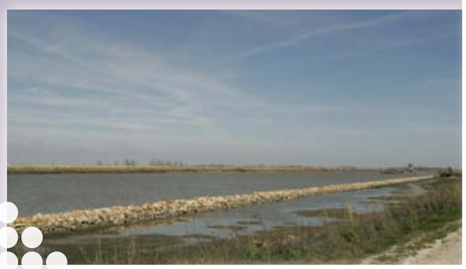
How Caltrans Can Advance Climate Change Adaptation Efforts

SJCOG would benefit from "getting down to basics" first on issues of climate adaptation before incorporating them into the planning process. SJCOG could benefit greatly from a "Climate Change 101" module and training, and is looking to innovators, such a SANDAG, for ideas and guidance.

SJCOG also has a need to better understand what others are doing in this area, which will come from outreach meetings with their jurisdictions. To the extent adaptation is important to their subregions, it will be considered important to COG. Finally, SJCOG will be looking to Caltrans to facilitate knowledge transfer among California's MPOs and to be a conduit to relevant work performed by other states and guidance issued by the federal government.

C. California Regional Climate Data (from CNRA)

CALIFORNIA ADAPTATION PLANNING GUIDE



UNDERSTANDING REGIONAL CHARACTERISTICS

Cal EMA CALIFORNIA EMERGENCY MANAGEMENT AGENCY
CALIFORNIA natural resources AGENCY
FEMA

California Adaptation Planning Guide

Prepared by:
California Emergency Management Agency
3650 Schriever Avenue
Mather, CA 95655
www.calema.ca.gov

California Natural Resources Agency
1416 Ninth Street, Suite 1311
Sacramento, CA 95814
resources.ca.gov

WITH FUNDING SUPPORT FROM:

Federal Emergency Management Agency
1111 Broadway, Suite 1200
Oakland, CA 94607-4052

California Energy Commission
1516 Ninth Street, MS-29
Sacramento, CA 95814-5512

WITH TECHNICAL SUPPORT FROM:

California Polytechnic State University
San Luis Obispo, CA 93407

July 2012

"It's time for courage, it's time for creativity and it's time for boldness to tackle climate change" - Governor Brown, September 2011

September 4, 2012

Dear reader,

We are pleased to present the "Climate Adaptation Planning Guide" prepared by California Emergency Management Agency and the California Natural Resources Agency. The Guide is designed to provide guidance and support for local governments and regional collaboratives to address the unavoidable consequences of climate change.

The State of California is leading the way on climate change adaptation in conjunction with local and regional efforts. Local and regional responses to climate change are identified in state-level planning documents including the California Emergency Management Agency's State Hazard Mitigation Plan, and the California Climate Adaptation Strategy. In addition, we anticipate on-going collaboration and engagement at the regional and local-scale. To that end, the Governor's Office of Planning and Research hosted a one-day conference earlier this year titled "Confronting Climate Change: A Focus on Local Government Impacts, Actions and Resources," and is promoting additional outreach and partnerships.

As climate change impacts your community, it is important for local governments to be prepared to meet this new reality. We hope you find this Planning Guide of value.

Sincerely,

Ken Alex
Senior Policy Advisor to Governor Edmund Brown and
Director of the Office of Planning and Research

John Laird
Secretary for Natural Resources Agency

Mark Ghilarducci
Secretary
California Emergency Management Agency

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California Emergency Management Agency

Mark Ghilarducci	Secretary	
Mike Dayton	Undersecretary	
Christina Curry	Assistant Secretary	Preparedness
Kathy McKeever	Director	Office of Infrastructure Protection
Joanne Brandani	Chief	Critical Infrastructure Protection Division, Hazard Mitigation Planning Division
Ken Worman	Chief	Hazard Mitigation Planning Division
Julie Norris	Senior Emergency Services Coordinator	Hazard Mitigation Planning Division
Karen McCready	Associate Government Program Analyst	Hazard Mitigation Planning Division

California Natural Resource Agency

John Laird	Secretary
Janelle Beland	Undersecretary
Julia Levin	Deputy Secretary for Climate Change
Kurt Malchow	Climate Adaptation Coordinator

California Polytechnic State University – Project development team

Project Management

Adrienne Greve, Ph.D.	Project Director, Co-Principal Investigator, Associate Professor	City and Regional Planning Department
Kenneth C. Topping, FAICP	Co-Principal Investigator, Lecturer	City and Regional Planning Department
Cindy Pilg	Research Support Coordinator	City and Regional Planning Department

Project Faculty and Staff

Michael Boswell, Ph.D., AICP	Co-Principal Investigator, Professor	City and Regional Planning Department
William Siembieda, Ph.D.	Co-Principal Investigator, Professor, Director	City and Regional Planning Department Planning, Design, and Construction Institute
Christopher Dicus, Ph.D.	Professor	Natural Resources Management and Environmental Sciences
Kelly Main, Ph.D.	Assistant Professor	City and Regional Planning Department
Robb Eric S. Moss, Ph.D., P.E.	Associate Professor	Civil and Environmental Engineering Department
Carol Schuldt	GIS Resources Coordinator(Ret.)	Robert E. Kennedy Library

Graduate Research Assistants

Elizabeth Brighton	City and Regional Planning Department
Megan Elovich	City and Regional Planning Department
Michael Germeraad	Civil and Environmental Engineering, City and Regional Planning Department
Brian Provenzale	City and Regional Planning Department
Jean Long	City and Regional Planning Department, Civil and Environmental Engineering
Steve Rogers	City and Regional Planning Department

Consultants

Natalie Macris	Planning Editor
Monica Fiscalini	Copy Editor

Adaptation Planning Guide – Advisory Committee

Will Barrett	American Lung Association in California
Amy Vierra	Ocean Protection Council
Marian Ashe	California Environmental Protection Agency
Andrew Altevogt, PhD.	California Environmental Protection Agency
Abe Doherty	California Ocean Protection Council
Alex Westhoff	Delta Protection Commission
Kristal Davis Fadtke	Sacramento-San Joaquin Delta Conservancy
Chris Keithley	California Department of Forestry and Fire Protection
Guido Franco	California Energy Commission
Janna Franks	California Energy Commission
Joe Gibson	California Special Districts Association, Conejo Recreation and Park District
Elliot Mulberg	California Special Districts Association, Florin Resource Conservation District
Jon Elam	California Special Districts Association, Talpais Community Services District
Cara Martinson	California State Association of Counties
Garth Hopkins	California Department of Transportation
Andrew Schwarz	California Department of Water Resources
John Andrew	California Department of Water Resources
Dave Pegos	California Department of Food and Agriculture
Jay Chamberlin	California Department of Parks and Recreation
Kathy Dervin	California Department of Public Health
Amber Pairis	California Department of Fish and Game
Whitney Albright	California Department of Fish and Game
Kyra Ross	League of California Cities
Kate Meis	Local Government Commission
Scott Clark	Local Government Commission
Ben Rubin	Governor's Office of Planning and Research
Michael McCormick	Governor's Office of Planning and Research
Scott Morgan	Governor's Office of Planning and Research
Steve Goldbeck	San Francisco Bay Conservation and Development Commission
Will Travis	San Francisco Bay Conservation and Development Commission
Eric Oppenheimer	State and Regional Water Quality Control Boards
Linda Zablotny-Hurst	Sierra Club California
Rachel Dinno-Taylor	Trust for Public Lands
Sara Moore	Sonoma State University
Brian Holland	ICLEI - Local Governments for Sustainability
Steve Sanders	Institute for Local Government

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Executive Summary

The *California Adaptation Planning Guide* (APG), a set of four complementary documents, provides guidance to support communities in addressing the unavoidable consequences of climate change. The APG, developed by the California Emergency Management Agency and California Natural Resources Agency, introduces the basis for climate change adaptation planning and details a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development.

The *APG: Understanding Regional Characteristics* provides environmental and socioeconomic information for a series of 11 climate impact regions. The choice to designate regions is due to the statewide diversity in biophysical setting, climate, and jurisdictional characteristics. While conditions may be diverse within each region, the range of conditions will be narrower than at the statewide level. Designating regions allows for greater depth and more detailed information to be presented.

California Adaptation Planning Guide Documents

- *APG: Planning for Adaptive Communities* – This document presents the basis for climate change adaptation planning and introduces a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development. All communities should start with this document.
- *APG: Defining Local & Regional Impacts* – This supplemental document provides a more in-depth understanding of how climate change can affect a community. Seven "impact sectors" are described to support communities conducting a climate vulnerability assessment.
- *APG: Understanding Regional Characteristics* – The impact of climate change varies across the state. This supplemental document identifies climate impact regions, including their environmental and socioeconomic characteristics.
- *APG: Identifying Adaptation Strategies* – This supplemental document explores potential adaptation strategies that communities can use to meet adaptation needs. Adaptation strategies are categorized into the same impact sectors used in the *APG: Defining Local & Regional Impacts* document.

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Climate Impact Regions

The APG is organized into a series of climate impact regions (see Figure 1). The regions allow for greater depth and more detailed guidance to be presented. The regions were designated based on county boundaries in combination with projected climate impacts, existing environmental setting, socioeconomic factors, and regional designations and organizations.

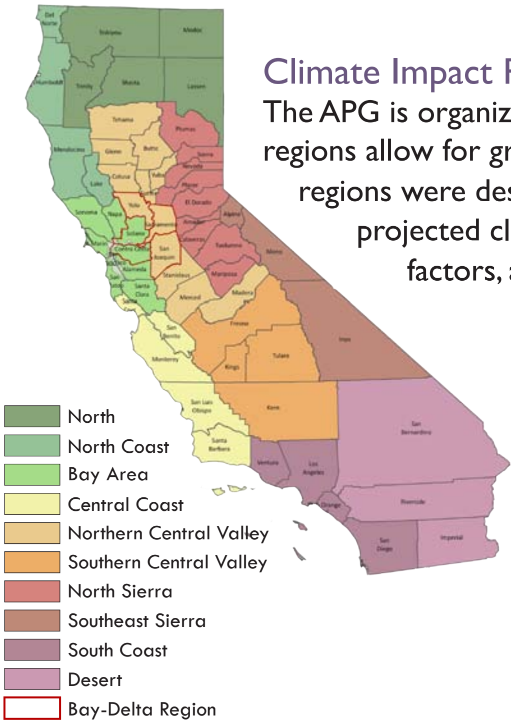


FIgure1. Climate Impact Regions.

The 11 regions presented in this document are listed below, along with a selection of the potential impacts faced by each region.

North Coast

- Sea level rise
- Threats to sensitive species
- Reduced agricultural productivity

North

- Increased wildfire
- Reduced snowpack
- Ecosystem shifts

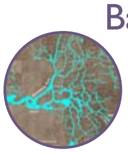
Bay Area

- Coastal inundation and erosion
- Public heath - heat and air pollution
- Reduced agricultural productivity

Northern Central Valley

- Reduced agricultural productivity
- Increased wildfire
- Public health - heat

Bay-Delta Region

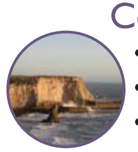


- Flooding
- Reduced agricultural productivity
- Public heath - heat and air pollution

Southern Central Valley

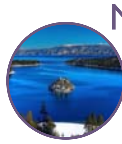
- Reduced agricultural productivity
- Public health - heat
- Reduced water supply

Central Coast



- Reduced agricultural productivity
- Coastal flooding
- Biodiversity threats

North Sierra



- Reduced tourism
- Ecosystem change
- Increased wildfire

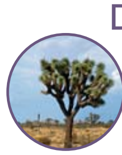
Southeast Sierra

- Economic impacts – tourism decline
- Substantially reduced snowpack
- Flooding

South Coast

- Sea level rise
- Reduced water supply
- Public healsth - heat and air pollution

Desert



- Water supply
- Public health and social vulnerability
- Biodiversity threats

Introduction

The State of California has been taking action to address climate change for over 20 years, focusing on both greenhouse gas emissions reduction and adaptation. The California Adaptation Planning Guide (APG) continues the state's effort by providing guidance and support for communities addressing the unavoidable consequences of climate change.

The APG includes four documents (see Figure 1). *APG: Understanding Regional Characteristics* is one of three documents developed to supplement an overarching planning process document, *APG: Planning for Adaptive Communities*.

- *APG: Planning for Adaptive Communities* – Presents the basis for climate change adaptation planning and introduces a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development.

- *APG: Defining Local & Regional Impacts* – Use this supplemental document to gain a more in-depth understanding of how climate change can impact a community. Seven sectors of impacts are presented to support local communities conducting a climate vulnerability assessment.

YOU ARE HERE

- ***APG: Understanding Regional Characteristics*** – The impact of climate change varies across the state. Use this supplemental document to understand the distinct climate impact regions including their environmental and socioeconomic characteristics.

- *APG: Identifying Adaptation Strategies* – Use this supplemental document to explore potential adaptation strategies that communities can use to meet their adaptation needs. Adaptation strategies are categorized into the same sectors used in the APG: *Defining Local & Regional Impacts* document and include examples from jurisdictions already pursuing adaptation strategies and offer considerations for tailoring strategies to meet local needs.

Figure 1. The four California Adaptation Planning Guide (APG) documents. All APG users should start with the *APG: Planning for Adaptive Communities*. The other three documents support the process presented in the first document by providing additional information and greater detail.

What is the *APG: Understanding Regional Characteristics* document and how should it be used?

The *APG: Understanding Regional Characteristics* is organized into a series of climate impact regions (see Figure 2). The choice to designate regions is due to the statewide diversity in biophysical setting, climate, and jurisdiction characteristics. While conditions may be diverse within each region, the range of conditions will be narrower than at the statewide level. Designating regions allows for greater depth and more detailed information to be presented.

Each region is still diverse. The regional section is meant to summarize some of the key considerations for each region, above and beyond the statewide considerations presented in *APG: Defining Local & Regional Impacts*. If an impact is included in the *APG: Defining Local & Regional Impacts,* it is not included in this document unless there are region-specific details that require assessment for impact evaluation such as a paricularly vulnerable ecosystem unique to the region. As a result, some of the presented information varies between regions based on how well, or not, the information in *APG: Defining Local & Regional Impacts* applies to the region. Each region includes a summary of climate exposure, considerations considered critical for jurisdictions in the region, and regionally-specific resources that may aid communities in the region. Communities can use this document to assess regional context or identify other jurisdictions facing similar climate pressures.

How were the regions defined?

Regions were designated based on county boundaries in combination with projected climate impacts, existing environmental setting, socioeconomic factors, and regional designations. The choice to use counties (e.g. political boundaries) was based on a commitment to make the APG as useful as possible for local governments, including counties. The counties were clustered into regions based on the following factors:

- Projected climate change impacts were evaluated using Cal-Adapt. Cal-Adapt climate impact projections for precipitation, temperature, snowpack, and wildfire risk were used to identify counties that share a similar group of projected impacts.

- Existing regional designations were evaluated because there are some climate-related impacts best addressed at a regional scale. Counties that share a regional designation (e.g., air districts, regional water quality control boards) are more likely to have already established relationships with neighboring jurisdictions that are necessary for regional strategy development and implementation. The regional designations examined include regional water quality control boards, air basins and air districts, California Emergency Management Agency Regions, and metropolitan planning organizations. Figures 3 through 6 overlay the impact regions with these regional designations.

- Habitat was assessed based on bioregion, habitat, and land cover maps developed by the California Department of Forestry and Fire Protection, Fire and Resource Assessment Program (FRAP). These data were included when determining the regions because the potential consequences of a change in climate (e.g., temperature and precipitation) vary based on the preexisting biophysical setting. Figure 7 displays the climate impact regions in comparison to bioregion.

- Socioeconomic characteristics, including the location of major population centers and economic base, were considered. These characteristics were particularly important for counties that have more than one area with distinct suites of projected climate impacts. For example, a county that shares some characteristics with the Northern Sierra and others with the Northern Central Valley was evaluated based on which setting supported the local economy to a greater degree and/or was home to a larger portion of residents.

What are the designated climate impact regions?

Based on the factors described above, 11 regions were identified (see Figure 2). Some of the regions were based on specific factors particularly relevant to the region. For example, the Central Valley was split into north and south based on hydrologic boundaries; this results in the Northern Central Valley region containing all counties draining to the Sacramento-San Joaquin Delta. The Sierra Nevada area was split based on ecosystem differences as well as variation in projected climate impacts. The Bay-Delta is the only region that shares all its counties with other regions. The designation of the Bay-Delta as a region recognizes that this area is distinct due to its elevation profile and flood vulnerability. Additional detail about the characteristics of each region can be found in the following section.

The regions are defined as follows:

- **North:** Lassen, Modoc, Shasta, Siskiyou, and Trinity counties
- **North Coast:** Del Norte, Humboldt, Lake, and Mendocino counties
- **Bay Area:** Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma counties
- **Northern Central Valley:** Butte, Colusa, Glenn, Madera, Merced, Sacramento, San Joaquin, Stanislaus, Sutter, Tehama, Yolo, and Yuba counties
- **Bay-Delta:** Contra Costa, Sacramento, San Joaquin, Solano, and Yolo counties
- **Southern Central Valley:** Fresno, Kern, Kings, and Tulare counties
- **Central Coast:** Monterey, San Benito, San Luis Obispo, Santa Barbara, and Santa Cruz counties
- **North Sierra:** Amador, Calaveras, El Dorado, Mariposa, Nevada, Placer, Plumas, Sierra, and Tuolumne counties
- **Southeast Sierra:** Alpine, Inyo, and Mono counties
- **South Coast:** Los Angeles, Orange, San Diego, and Ventura counties
- **Desert:** Imperial, Riverside, and San Bernardino counties

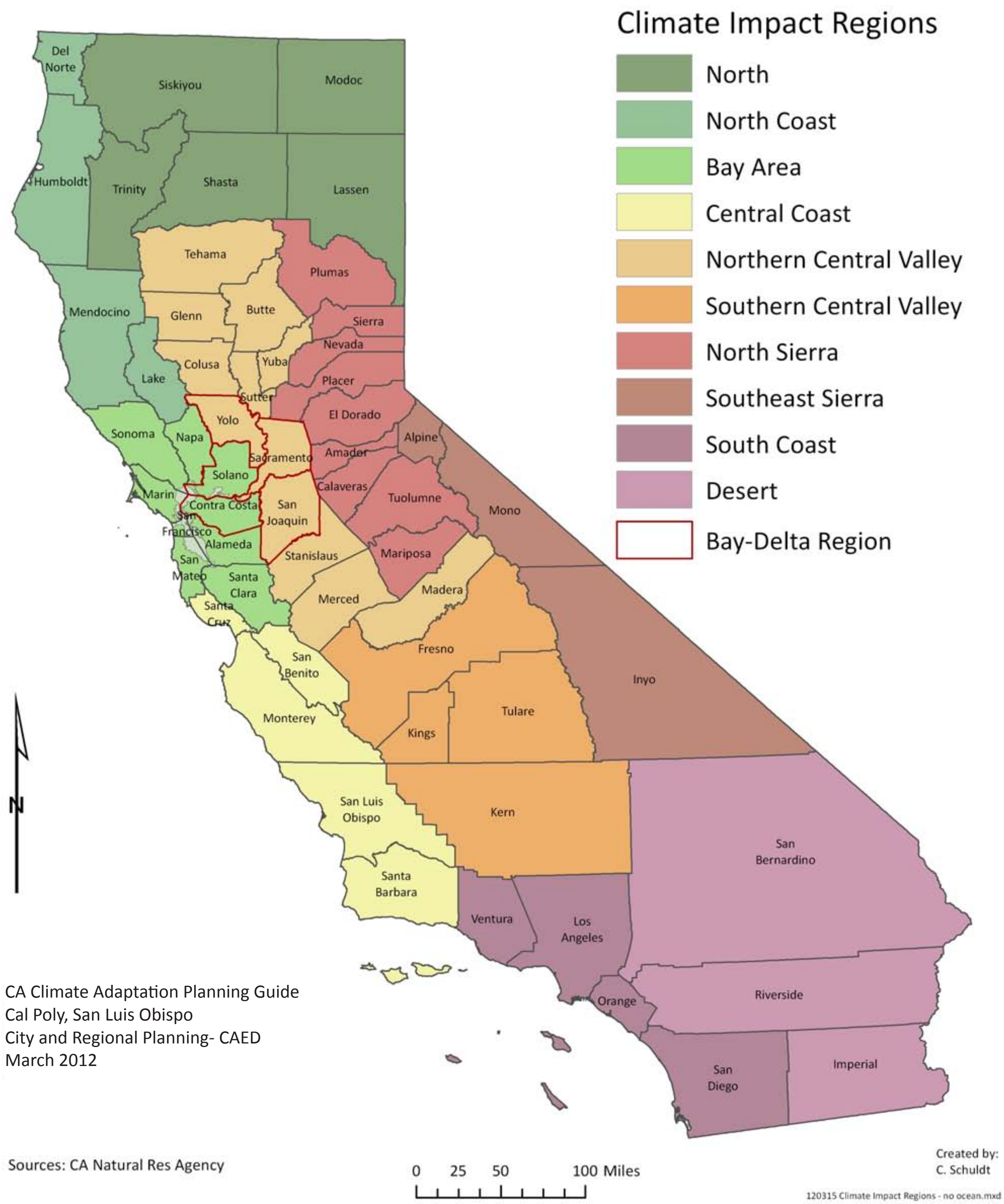


Figure 2. Adaptation Planning Guide Climate Impact Regions

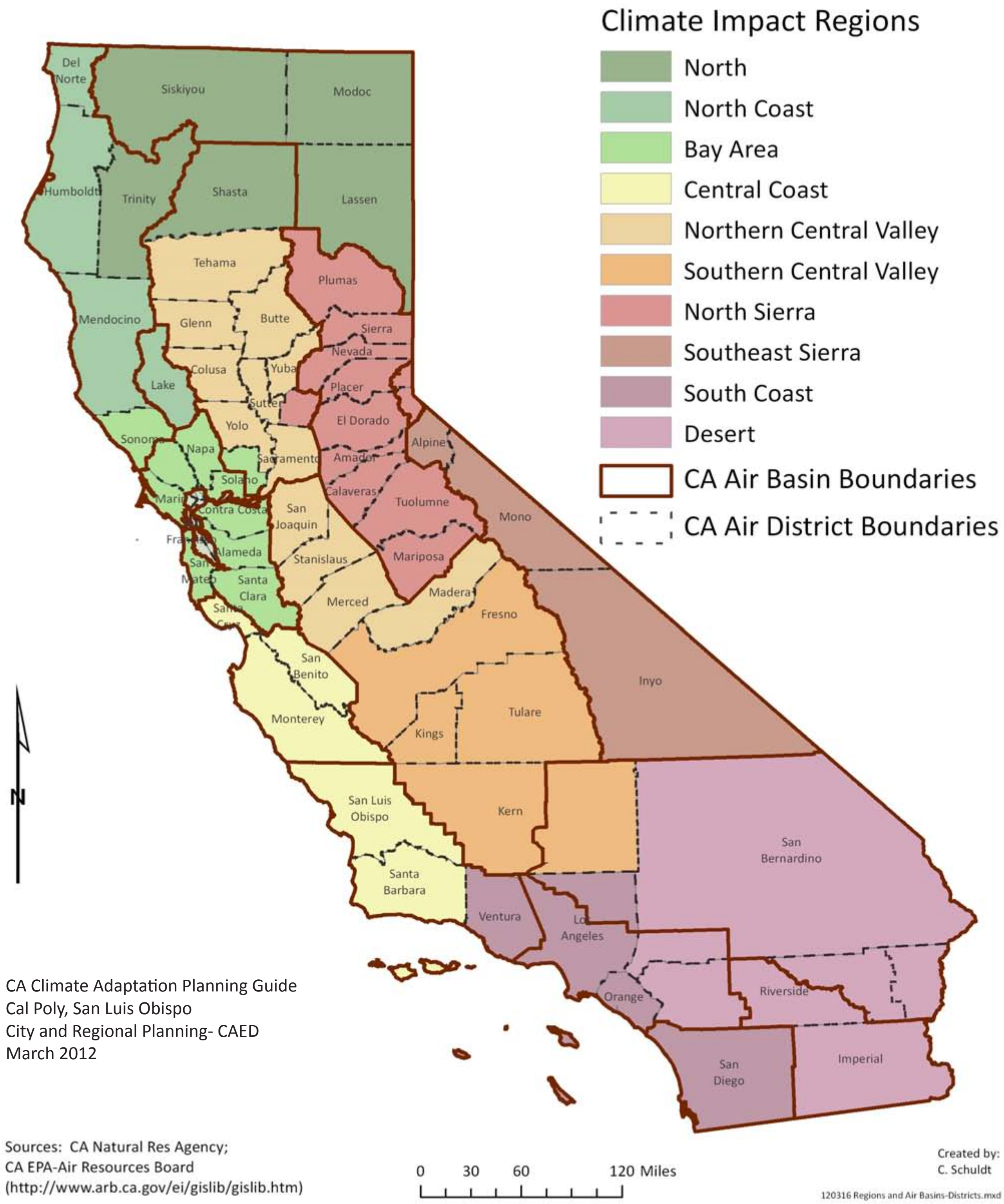


Figure 3. California Air Resources Board Air Basin and Air District Boundaries In Comparison to the Adaptation Planning Guide Climate Impact Regions.

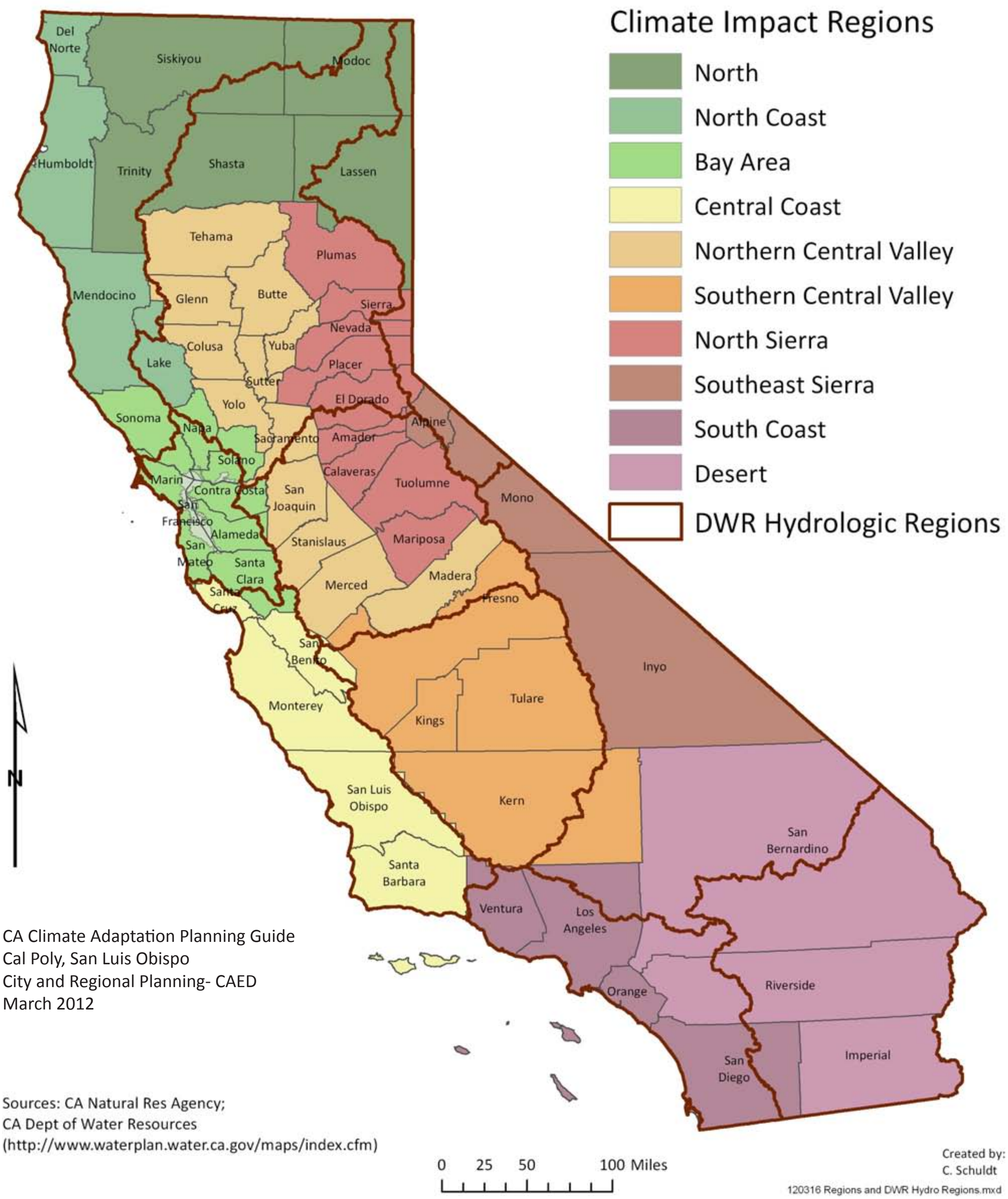


Figure 4. California Department of Water Resources Hydrologic Regions in Comparison to the Adaptation Planning Guide Climate Impact Regions.

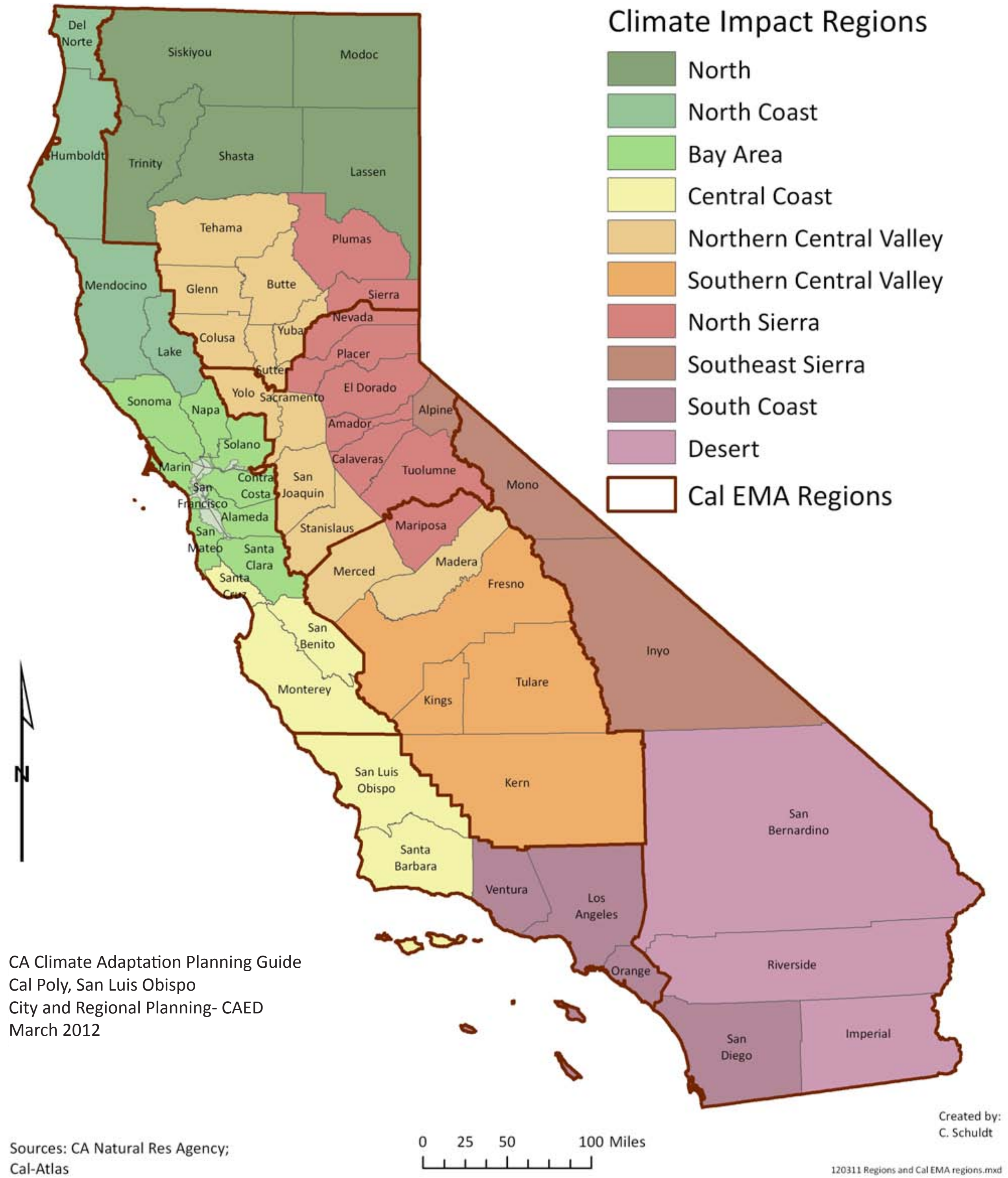


Figure 5. California Emergency Management Agency Regions in Comparison to the Adaptation Planning Guide Climate Impact Regions.

Figure 6. Adaptation Planning Guide Climate Impact Regions in Comparison to the Boundaries of California Councils of Government (COGs), Municipal Planning Organizations (MPOs), and Regional Transportation Planning Agencies.

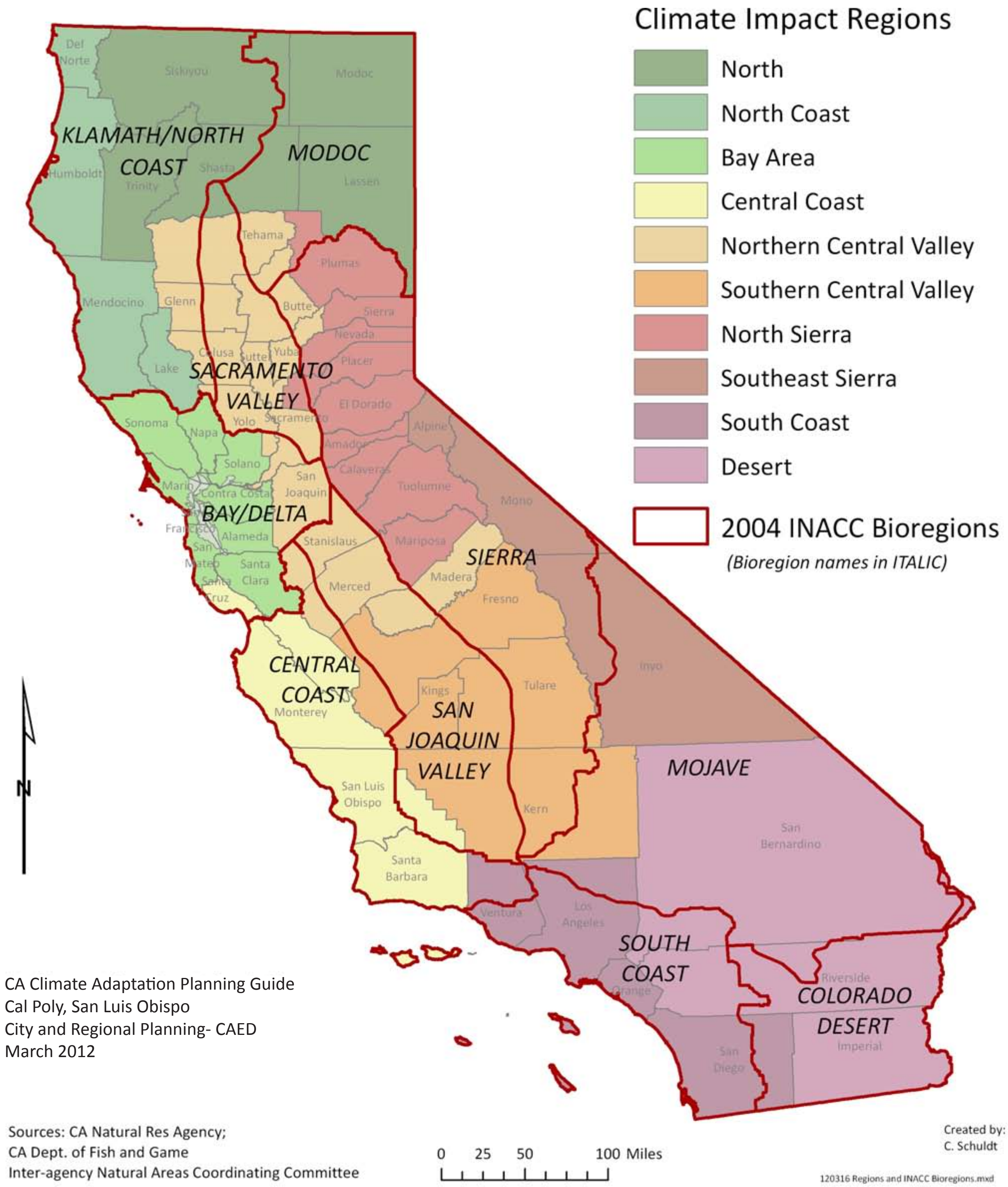


Figure 7. California State Bioregions in Comparison to the Adaptation Planning Guide Climate Impact Regions.

What is included in the regional profiles?

APG: Understanding Regional Characteristics reviews each region in the state, providing detail or specificity above and beyond that presented in *APG: Defining Local & Regional Impacts*. For each region, specific information likely to help communities evaluate vulnerability and formulate adaptation strategies is provided. This information includes the following:

- **Cal-Adapt Projections.** Cal-Adapt projections for the region are summarized. The table provided for each region is intended to generally identify the types of changes projected for the region. Local jurisdictions also should use the web-based Cal-Adapt tool (www.Cal-Adapt.org) to generate projections specific to their locations.

- **Water Sources.** The primary sources of water for the region are identified to allow for general identification of potential vulnerability associated with water supply. Because each jurisdiction acquires rights to its community water supply, individual jurisdictions should assess their supplies. This evaluation will have much greater specificity, allowing for community-based vulnerability assessment.

- **Biophysical Characteristics.** A short summary of major regional features is provided. In regions with ecosystems or special-status species that are particularly vulnerable to climate change, additional discussion of these issues is provided following the listing of basic data.

- **Regional Entities.** A list of air districts, regional organizations, and tribal lands in the region is provided. Some climate change impacts are best addressed on regional scales. Regional organizations, and the local jurisdictions associated with them, may represent potential collaboration partners for devising regional adaptation strategies, from infrastructure continuity to migration corridors for sensitive species.

- **Major Infrastructure and Selected Regional Resources.** A brief summary of major infrastructure and other regional facilities is provided. Infrastructure, including transportation, electricity, water, wastewater, and natural gas, involves linear systems critical for the provision of services. Major infrastructure can link communities in a region and facilitate processes on a state and national level. Other resources addressed include wastewater treatment plants and power plants. Also included are state and federal parks that may be affected by climate change but also serve as a resource in devising adaptation strategies, particularly for sensitive species.

- **Selected Demographic Data**. Selected employment and population data for the region are provided. Certain populations, such as children, the elderly, and people living at or below the poverty level, are more likely to be affected by climate change than others. The table provided for each region lists the population younger than five years old, the population older than 65 years old, and the population at or below the poverty level. Local jurisdictions should complement these data with locally-specific information, such as demographic data (poverty, percent elderly, percent children) that are available on a county basis. Local jurisdictions will need to evaluate these data on a scale appropriate to the jurisdiction.

- **Adaptation Considerations.** The discussion of each region concludes with a summary of issues to consider in developing climate change adaptation policy for jurisdictions within the region. The content included in this section varies from region to region depending on the extent to which the content presented in *APG: Defining Local & Regional Impacts* applies. If regional information is already included in *APG: Defining Local & Regional Impacts*, it has not been included in the regional discussion here.

North Coast Region

TOTAL 2010 POPULATION	
North Coast Region	**315,739**
Del Norte	28,610
Humboldt	134,623
Lake	64,665
Mendocino	87,841

[U.S. Census Bureau, 2010]

Counties: Del Norte, Humboldt, Lake, Mendocino
Five Largest Cities (CDOF, 2011): Eureka (27,283); Arcata (17,318); Ukiah (16,109); Clearlake (15,289); Fortuna (11,977)

The North Coast is a lightly populated, sparsely settled region, with only one city over 20,000 people (Eureka). It represents the northern coast of the state. It is home to the largest timber-producing county in the state (Humboldt) and two wine grape-growing counties (Mendocino and Lake). In addition, the North Coast is home to sandy beaches and several estuaries that support rich biodiversity. Due to varied terrain, it is also home to several microclimates and distinct ecosystems.

Potential climate change impacts to be considered by North Coast communities include the following:

- Reduced snowpack
- Increased wildfires
- Sea level rise and inland flooding
- Threats to sensitive species (e.g. coho salmon)
- Loss in agricultural productivity (e.g. forestry, wine grapes, nursery products, dairy)
- Public health and safety

Cal-Adapt Projections

Table 1. Summary of Cal-Adapt Climate Projections for the North Coast Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 2°F by 2050 and up to 5°F by 2100 July increase in average temperatures: 3°F by 2050 and up to 6°F by 2100 (Modeled average temperatures; high emissions scenario)
Precipitation	Annual precipitation varies by location with a subtle decrease throughout the century in most areas. Areas of heavy rainfall (80 inches or more) are projected to lose 5 to 7 inches by 2050 and 11 to 15 inches by the end of the century. Slightly drier places are projected to see a decrease of around 3 to 4 inches by 2050 and 6 inches of precipitation by 2100. (CCSM3 climate model; high carbon emissions scenario)
Sea Level Rise	By 2100, sea levels may rise up to 55 inches, posing threats to many areas in the region, particularly in bays and estuaries. The increase in acreage vulnerable to 100-year floods due to sea level rise in the region will be 18 percent in both Humboldt and Mendocino counties and 17 percent in Del Norte County.
Heat Wave	Heat wave is defined as five consecutive days over 68°F over most of the coastal areas and as high as 93°F in some inland areas to the south. Little change is expected by 2050 with possibly one to three more heat waves projected in region. By 2100, projected heat waves are more variable. Along much of the coast eight to 15 more heat waves than currently occur are projected. Inland it is variable, but generally lower, between two and eight more waves per year.
Snowpack	March snow levels in the eastern, higher-elevation portion of the region will drop to almost zero by the 2090s, a decrease of 2 to 10 inches from 2010 levels. In areas with more snow, 3 to 5 inches of reduction will occur by 2050. In areas with currently little snow (<3 inches), the snowpack is projected to be near zero by 2050. (CCSM3 climate model; high carbon emissions scenario)
Wildfire Risk	Substantial increase in fire risk is expected throughout the region. Modest increases in area burned are projected for 2050. By 2100, the projected frequency increases dramatically, eight times greater in parts of Del Norte, Humboldt, and Mendocino counties. Lake County and northern Mendocino County are projected to have up to 2.5 times greater wildfire frequency. (GFDL climate model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

The primary supply of water in the North Coast Region (which includes this climate impact region, plus Siskiyou County) is from the Klamath River and Eel River systems, and accounts for about 17 of the approximately 18 million acre-feet available in 2005 (DWR, 2009). The remaining supply is from groundwater (primarily in coastal areas), reuse, and state or federal projects. Water outflow goes primarily to scenic rivers (again nearly 17 million acre-feet), with a small minority going to urban areas, irrigated agriculture, and managed wetlands. Total storage capacity in the region's reservoirs is 3.78 million acre-feet (DWR, 2009).

Biophysical Characteristics

The landscape of the North Coast region consists primarily of the Coast Mountain Ranges, where peaks vary from 2,000 to 5,000 feet. The Klamath River, which originates in Oregon, winds its way through the north end of the state, culminating 45 miles south of Crescent City. The other major river system, the Eel, extends from Lake County to the Pacific Ocean 15 miles south of Eureka (CERES, 2005). Most of this region, part of the larger Klamath/North Coast Bioregion, is covered by forest. It receives more rainfall than any other part of the state (CDFG, 2007). The region supports diverse wildlife in varied ecosystems that include sand coastlines, coastal estuaries, grasslands, coastal shrub, freshwater aquatic ecosystems, riparian areas, pine forests, mixed evergreen forests, and redwood forests (CERES, 2005; CDFG, 2007). These ecosystems support human activities from basic services to industries such as forestry and fishing.

Regional Entities

- Air Districts: Lake, Mendocino, North Coast Unified
- Regional Organizations: Del Norte Local Transportation Commission, Humboldt County Association of Governments, Lake County/City Area Planning Council, Mendocino Council of Governments
- Tribal Lands (U.S. EPA, 2011): Big Lagoon, Big Valley, Blue Lake, Coyote Valley, Elk Valley, Hoopa Valley Indian, Hopland, Laytonville, Manchester (Point Arena), Middletown, Pinoleville, Redwood Valley, Resighini, Robinson, Rohnerville, Round Valley, Sherwood Valley, Smith River, Sulphur Bank (El Em), Table Bluff, Trinidad, Upper Lake, Yurok

Selected Infrastructure and Regional Resources

Table 2. Infrastructure and Resources in the North Coast Region

TYPES	NAMES
Airports	Andy McBeth, Arcata, Dinsmore, Eureka Municipal, Garberville, Jack McNamara Field, Kneeland Field, Little River, Murray Field, Rohnerville, Shelter Cove, Ward Field, Willits Municipal, Ukiah Municipal
National and State Parks	National: Humboldt Bay National Wildlife Reserve, Redwoods National Park State: Azalea S.N.R., Clear Lake S.P., Grizzly Creak Redwoods S.P., Henry A. Merlo S.R.A., Humboldt Lagoons S.P., Humboldt Redwoods S.P., Jug Handle S.P., Mallard Redwoods S.P., Manchester S.P., Montgomery Woods S.P., Navarro River Redwoods S.P., Patrick's Point S.P., Prairie Creek Redwood S.P., Richardson Grove S.P., Russian Gulch S.P., Sinkyone Wilderness S.P., Van Damme Beach S.P.
Ports	Crescent City Harbor, Humboldt Bay Harbor, Noyo Harbor
Power Plants (MWs)*	Humboldt Bay (137).

S.P. = State Park; S.R.A. = State Recreation Area; S.N.R. = State Natural Reserve; MWs = megawatts
*Located within the 100-year flood zone for 1.5-meter sea level rise.

Selected Demographic Data

Table 3. Top Five Employment Sectors in the North Coast Region

EMPLOYMENT SECTOR RANKING					
County	1	2	3	4	5
Del Norte	Government	Health Care	Retail Trade	Lodging & Food Services	Construction
Humboldt	Government	Retail Trade	Health Care	Lodging & Food Services	Construction
Mendocino	Government	Retail Trade	Health Care	Lodging & Food Services	Construction
Lake	Government	Health Care	Retail Trade	Lodging & Food Services	Construction

[CA REAP, 2011]

Table 4. Selected Population Data for the North Coast Region

						POPULATION BELOW POVERTY LEVEL		
	TOTAL 2010 POP.	POP. <5 YEARS	PERCENT < 5 YEARS	POP. ≥65 YEARS	PERCENT ≥65 YEARS	ESTIMATED - ALL AGES	ESTIMATED PERCENT	MARGIN OF ERROR
County	280,490	15,529	5.50%	46,897	16.70%	50,077		
Del Norte	28,610	1,703	6.00%	3,873	13.50%	5,824	23.5	4.6
Humboldt	134,623	7,738	5.70%	17,725	13.20%	23,752	18	2.2
Lake	64,665	3,633	5.60%	11,440	17.70%	13,438	21	3.4
Mendocino	87,841	5,347	6.10%	13,493	15.40%	16,976	19.6	3.3

[US Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

Many of the stressors already affecting the varied ecosystems in this region are exacerbated by climate change. These include water management, forest management, fire regimes, agricultural and urban development, coastal management and development, and public health (CDFG, 2007). Changes in these areas can result in secondary consequences that affect the local economy, public health, and safety.

Water Management

Depending on location, parts of this region are projected to experience between 6 inches and 15 inches less rainfall by 2100 (see Table 1). Reduced rainfall, combined with reductions in snowpack and existing diversions, could result in an altered flow regime in the region. This change would be particularly challenging due to its impact on anadromous fish, such as the coho salmon. Reduced flow, altered timing of flows, and periodic extreme events can result in reduced water quality, habitat destruction, and/or isolation of habitats. Local jurisdictions should carefully assess local aquatic ecosystems for vulnerability to these changes.

Forest Management and Fire Regimes

In 2010, this region was one of the highest timber-producing areas in the state in both volume and value (BOE, 2010). Humboldt and Mendocino counties are two of the highest timber-producing counties in California (BOE, 2010).

Productivity of forestry operations is likely to be affected by climate change due to forest growth rates and wildfire vulnerability. While in the short term increased carbon dioxide concentrations can promote growth, climate change can affect invasive species, pest populations, and seasonal temperature and moisture regimes, which, over the long term, can affect productivity of forestry operations. The northern part of the state is projected to have a greater increase in wildfire risk than other parts of the state. This projected increase is based only on climate (e.g., temperature projections) and does not include an assessment of other factors such as vegetation type or fuel load. In the North Coast region, moderate to large increases in large fires (>200 ha) (Westerling et al., 2009; Westerling and Bryant, 2006) are projected in inland areas. A slight decrease in wildfire risk along the coast is projected due to changes in vegetative composition (Lenihen et al., 2006).

Wildfire threatens not only the forestry industry but also the safety of residents. The projected wildfire frequency is a considerable change from current conditions, meaning communities are less likely to be accustomed to the risks of fire and the measures required to address them. Of particular concern for the elderly and children under the age of five (see Table 4) are eye and respiratory illnesses due to air pollution resulting from wildfires, and exacerbation of asthma, allergies, chronic obstructive pulmonary disease (COPD), and other cardiovascular diseases. Wildfire also threatens safety at the wildland-urban interface. With the increase in wildfire likelihood, more residents are likely to be vulnerable to wildfire in the future, and additional strategies will need to be developed to address this risk. Smoke management, especially the use of prescribed burning as a fuel-reduction tool, should be coordinated with the air districts.

Agriculture

The highest value agricultural product of the northernmost areas of the region (Del Norte and Humboldt counties) is timber (California Farm Bureau Federation, 2012). In addition to timber, other products include milk, nursery products, and wine grapes. The southern two counties (Mendocino and Lake) produce wine grapes, valued at more than double any other crop.

Each of the products from this region will be affected by climate change differently. Forests will experience changed seasonal patterns that may alter moisture and temperature regimes, both of which may affect growth rates. Further threatening timber production is that temperature and precipitation along with management and invasive species (fuel load) will result in increased fire risk in this region (see above).

For wine grapes, the largest crop in the southern part of the region, climate can affect productivity, as well as the quality of the grape for wine production. North Coast communities should collaborate closely with local agricultural organizations to best support and prepare for changes in this economic sector.

Coastal Development

The region is relatively undeveloped on the coast and therefore will generally be resilient as sea level rise occurs. Notable exceptions are the Arcata/Eureka/Fortuna area, which is in a coastal plain subject to flooding, and Crescent City, which is currently susceptible to tsunami. For example, Humboldt County is projected to see an 18 percent increase in coastal inundation by 2100. The earthen levees holding back the sea in many of these areas are at or near capacity. These communities should carefully assess the potential consequences of these impacts.

U.S. Highway 101 is a key transportation route and lifeline for all communities in Humboldt and Del Norte counties. In many areas, the roadbed is located at or below sea level and protected by aging shoreline protective structures (near Humboldt Bay, for example). The highway corridor also crosses major river systems and estuaries, where bridged crossings will be particularly vulnerable to increased erosion of support structures, and eventually, to flooding. State Route 1 performs a similar function in rural Mendocino County. There too, the roadway faces future stress from coastal erosion and may be inundated in lower lying areas.

Sea level rise is expected to affect vulnerable populations along the coast through the immediate effects of flooding and temporary displacement and longer-term effects of permanent displacement and disruption of local tourism. Some populations do not have the resources to prepare for, respond to, and recover from disasters. These populations are vulnerable to temporary and permanent displacement, drowning, and property damage, as well as coastal erosion harming recreational activities, tourism, and the tourism industry.

In addition to causing inundation of built structures and public safety hazards, sea level rise can affect tourism. In 2000, over 7 percent of the region's employment was dependent on coastal resources (NOEP, 2005), with tourism-based activities representing the largest part of this percentage. Preparing for potential impacts of climate change means taking action to preserve the coastal ecosystems that serve as the tourist attraction. From an ecological perspective, the estuaries at the mouth of the Smith River, Humboldt Bay, and the mouth of the Eel River are of particular concern.

Public Health, Socioeconomic, and Equity Impacts

Extreme heat events are less likely to occur in the North Coast region than in other parts of the state. When they do occur, vulnerable populations may be severely affected because of a historic lack of adaptive capacity having to do with historically milder temperatures. For instance, "low air conditioner ownership" is found along the California coast. Humboldt County has "only medium air conditioner ownership (60-65 percent of the population)" (English et al., 2007). Humboldt County has moderately high proportions of populations eligible for energy utility financial assistance programs (47 to 55 percent) (English et al., 2007). Households eligible for these programs are an indicator of potential impacts, as these households may be more at risk of not using cooling appliances, such as air conditioning, due to associated energy costs. Del Norte County has a relatively higher poverty level (more than 23 percent), which suggests residents may not have the material resources needed to prevent, respond, or recover from impacts.

Populations that are isolated in some of the rural areas of this region and may not have the access to care or means necessary to recognize impacts and/or evacuate are at increased risk for injuries and death from burns and smoke inhalation and heat-related illnesses. Mendocino County is one of the state's counties with the highest proportion of elderly living alone (English et al., 2007).

ADDITIONAL RESOURCES

- Sea level rise and biodiversity and ecosystem resources
  - Humboldt Bay is a critical aquatic resource in this region. A collaborative of local and state agencies participated to develop an approach to adaptation titled the Humboldt Bay Initiative: Adaptive Management in a Changing World, http://ca-sgep.ucsd.edu/sites/ca-sgep.ucsd.edu/files/advisors/sschlosser/files/HBI%20StratPlan2009.pdf
- Wildfire resources include the following:
  - California Fire Science Consortium, Northern California Module: http://www.cafiresci.org/home-northern-ca/
  - Northern California Prescribed Fire Council: http://www.norcalrxfirecouncil.org/Home_Page.html
  - NorCal Society of American Foresters: http://norcalsaf.org/
  - California Fire Alliance: http://cafirealliance.org/
  - California FireSafe Council: http://www.firesafecouncil.org/
- California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
  - The Wildlife Action Plan divides the state into regions. The North Coast-Klamath Region overlaps with the North Coast region.

North Region

Counties: Lassen, Modoc, Shasta, Siskiyou, Trinity
Five Largest Cities (CDOF, 2011): Redding (90,250); Susanville (17,554); Shasta Lake (10,125); Anderson (10,125); Yreka (7,775)

TOTAL 2010 POPULATION	
North Region	**280,490**
Lassen	34,895
Modoc	9,686
Shasta	177,223
Siskiyou	44,900
Trinity	13,786

[U.S. Census Bureau, 2010]

The North region is an inland region that is sparsely settled (280,000+ people), with the exception of the city of Redding (90,000+ people). The region is characterized by rugged mountains and thick forests in the west. The mountain ranges result in a series of microclimates and distinct ecosystems. To the east, the Modoc Plateau supports high desert ecosystems and associated species. The prominent features include Mt. Shasta and Shasta Dam. Major economic activities include tourism and timber.

Climate-change impacts that jurisdictions in the North region should consider evaluating include the following:

- Increased wildfire
- Reduced snowpack
- Ecosystem shifts and non-native species
- Flooding
- Economic impact (timber, tourism, grazing)
- Reduced public health due to air pollution (especially for elderly)

Cal-Adapt Projections

Table 5. Summary of Cal-Adapt Climate Projections for the North Region

EFFECT	RANGES
Temperature Change, 1990-2100	January average temperature increase of 0.5°F to 4°F by 2050 and 3°F to 6°F by 2100. July average temperature increase 3°F to 5.5°F by 2050 and 8°F to 10°F by 2100, with larger temperature increases in the mountainous areas in the northeastern portion of the region. (Modeled high temperatures – average of all models; high carbon emissions scenario)
Precipitation	Annual precipitation is projected to decline by approximately an inch by 2050 and 2 inches by 2100 for most of the region. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	Heat wave is defined as five days above a temperature between 89°F and 99°F depending on location. By 2050 there is projected to be two to four more heat waves than 2010. Projected heat wave occurrence in 2100 is variable depending on location, between six and 15 per year.
Snowpack	March snowpack disappears by 2090 for most of the region with the exception of areas near Mt. Shasta. (CCSM3 climate model; high carbon emissions scenario)
Wildfire Risk	Substantial increases in the likelihood of wildfires are projected in most of the region, especially in Shasta and Siskiyou counties where risks may be multiplied 6 to 14 times by the end of the century. (GFDL climate model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

The North region overlaps portions of the Sacramento River, Northern Lahontan, and North Coast hydrologic regions as defined by the California Department of Water Resources (2009). Water supply relies on a mix of imported, regional surface water and groundwater resources for meeting local demand. Overdraft and illegal diversions create challenges for resource management in some areas, contributing to concerns about the preservation of aquatic and riparian habitats (DWR, 2009). Most of Shasta County, the southeastern corner of Siskiyou County, the central portions of Modoc County, and the northwestern area of Lassen County are located in the Sacramento River hydrologic region. In this region there is heavy reliance on groundwater and on the surface water conveyance systems that provide much of the Delta inflow. The easternmost parts of Modoc County and much of Lassen County are located in the North Lahontan hydrologic region (DWR, 2009). The Susan River drains the North Lahontan area and serves as a critical source of water. Trinity County, much of Siskiyou County, and the northwestern portions of Modoc

County are in the North Coast hydrologic region. Trinity Lake, located 40 miles northwest of Redding, is the largest reservoir in the North region, containing a volume of over 2.4 million acre-feet. This and other North Coast sources export water to the Sacramento River region via the Clear Creek Tunnel (DWR, 2009). The abundance of rivers and groundwater basins in the region allows for many of the small communities to rely on local resources to meet water demand.

Biophysical Characteristics

The majority of the region is located between 3,000 and 12,000 feet above sea level. Aquatic and riparian resources within the area include Goose Lake, Clear Lake Reservoir, the Klamath River, the Pit River, Shasta Lake, the Sacramento River, Eagle Lake, and Honey Lake (DWR, 2009). Natural vegetation differs based on location within the region. The southwestern portion of the region is characterized by oak, pine, mixed-conifer, and hardwood-conifer forests accompanied by mixed chaparral and low sage (FRAP, 1998). Areas in Lassen and Modoc counties offer habitat characterized by Joshua trees and juniper woodland, perennial grassland, wetland meadows, and freshwater emergent wetlands (DWR, 2007). The Modoc Plateau and dependent species are declining due to excessive grazing and invasive species.

Regional Entities

- Air Districts: Lassen, Modoc, North Coast Unified, Shasta, Siskiyou
- Regional Organizations: Lassen County Transportation Commission, Modoc County Local Transportation Commission, Shasta County Regional Transportation Planning Association, Trinity County Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Alturas, Big Bend, Cedarville, Fort Bidwell, Karuk, Likely, Lookout, Montgomery Creek, Quartz Valley, Redding, Roaring Creek, Round Valley, Susanville, XL Ranch

Selected Infrastructure and Regional Resources

Table 6. Infrastructure and Resources in the North Region

TYPES	NAMES
Airports	Trinity Center, Weaverville, Hayfork, Hyampom, Ruth, Butte Valley, Happy Camp, Weed, Dunsmuir Municipal-Mott Airport, Montague-Yreka Rohrer Field, Redding Municipal, Fall River Mills, Shingletown, Alturas Municipal, California Pines, Cedarville, Tulelake Municipal
National and State Parks	National: Klamath National Forest, Lassen Volcanic National Park, Modoc National Forest, Shasta National Forest State: Ahjumawi Lava Springs State Park, Castle Crags State Park, Hayden Hill-Silva Flat State Game Refuge, McArthur-Burney Falls Memorial State Park
Passenger Rail	Coast Starlight (Union Pacific Railroad); Lake County Railroad (Modoc Northern Railroad); Central Oregon & Pacific Railroad (Union Pacific); Yreka Western Railroad (Kyle Railways) Humboldt Bay (137).

Selected Demographic Data

Table 7. Top Five Employment Sectors in the North Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Lassen	Government	Retail Trade	Health Care & Social Assistance	Other Services	Lodging & Food Services
Modoc	Government	Farm Employment	Other Services	Retail Trade	Real Estate
Shasta	Government	Health Care & Social Assistance	Retail Trade	Lodging & Food Services	Other Services
Siskiyou	Government	Health Care & Social Assistance	Retail Trade	Lodging & Food Services	Other Services
Trinity	Government	Retail Trade	Lodging & Food Services	Construction	Other Services

[CA REAP, 2011]

Table 8. Selected Population Data for the North Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
County	280,490	15,529	5.50%	46,897	16.70%	50,077		
Lassen	34,895	1,625	4.70%	3,474	10.00%	4,198	16.8	4
Modoc	9,686	545	5.60%	1,905	19.70%	2,061	21.9	4.1
Shasta	177,223	10,268	5.80%	29,967	16.90%	31,766	18.2	2.4
Siskiyou	44,900	2,473	5.50%	8,782	19.60%	9,558	21.5	3
Trinity	13,786	618	4.50%	2,769	20.10%	2,494	18.4	4.4

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

Several aspects of the local economy in this region – including timber harvest, tourism, grazing, and water supply – rely on the local ecosystem. The changes projected for the North region may detrimentally affect these systems as well as threaten public safety and public health.

Ecosystems and Wildfire

Changes in temperature, amount of precipitation, and reduction in snowpack (see Table 5) have potential impacts on water quantity and quality. Siskiyou and Trinity counties are home to rivers and streams that support the current and historic range for endangered coho salmon. Alteration of flow regimes and water quality will affect this species (CDFG, 2007). Changes to aquatic systems affect more than just the species, but also economy and human health. Severe Blue Green Algae (BGA) has already affected the Klamath River; local officials have issued health advisories affecting reservoirs used for fishing and boating activities. Thus, BGA, in addition to posing a health risk, threatens tourism. Moreover, Native American tribes that use the river for ceremonial purposes have been affected (CDPH, 2008).

In the northeast portion of the state (Modoc and Lassen counties), grazing is a major economic activity. Grazing has altered the vegetative pallet of the region by reducing herbaceous vegetation. This change has affected native herbivores and created conditions that provide invasive species a competitive advantage. Riparian areas are also detrimentally affected by livestock grazing (CDFG, 2007).

Climate change can increase forest productivity in the short term, due to increased carbon dioxide and increased temperature. Ultimately, however, reduced water availability, drier conditions, altered pest and invasive species ranges, and increased fire severity and frequency can harm forests. Large increases in wildfire are projected in all parts of the region (Klamath Mountains, Siskiyou Mountains, Southern Cascade Mountains, Modoc Plateau) (Lenihan et al., 2006; Westerling and Bryant, 2006; Westerling et al., 2009).

Wildfire affects not only the local ecosystem and timber industry, but also public health and safety. Of particular concern for the elderly and children under the age of five (see Table 8) are eye and respiratory illnesses due to air pollution resulting from wildfires, and exacerbation of asthma, allergies, chronic obstructive pulmonary disease (COPD), and other cardiovascular diseases. Fires would not only jeopardize safety and property, but also destroy resources for the timber industry and affect the local economy.

Water Resources

In addition to affecting aquatic ecosystems, shorter rainfall events and rapid snowmelt will reduce the region's water supply. Recreation and tourism in the region are likely to suffer due to lower water levels in waterways and reservoirs and declining snowpack in north-central areas of the region. Unstable working conditions in the tourism industry may increase the economic vulnerability of employees in this industry.

Rapid snowmelt events and intense rainfall can result in flooding. Flood events may overwhelm water treatment and wastewater management facilities and risk exposing communities to contaminated water resources. Higher temperatures and early snowmelt may also lengthen the life and impact of vector-borne diseases.

Public Health, Socioeconomic, and Equity Impacts

Households eligible for energy utility financial assistance programs are an indicator of potential impacts. These households may be more at risk of not using cooling appliances, such as air conditioning, due to associated energy costs. Siskiyou and Trinity counties have some of the state's highest proportions of population eligible for energy assistance (56 to 63 percent). Lassen County also has a moderately high proportion of population eligible (47 to 55 percent) (English et al, 2007). Modoc and Siskiyou counties have relatively higher poverty levels (more than 21 percent), which suggests residents may not have the material resources needed to prevent, respond, or recover from impacts.

The second largest employment sector in Modoc County is farming. In Trinity, Siskiyou, and Lassen counties, lodging and food are in the top five employment sectors, indicating that tourism is an important industry. Foothills and mountainous communities of this region may be particularly subject to respiratory problems and heat stress due to a combination of higher ozone levels, higher elevations, and increasing temperatures in these areas (English et al., 2007; Drechsler et al., 2006). In areas such as these, conditions conducive to ozone formation are projected to increase by as much as 25 to 80 percent by 2100 (Drechsler et al., 2006, Karl and Roland-Holst, 2008).

Those most vulnerable to high levels of ozone and particulate matter include people who work or spend a lot of time outdoors, such as employees of the agricultural and the tourism industries. People over the age of 65 have the largest increase in mortality with increased concentrations of ozone (Medina-Ramon and Schwartz, 2008). Trinity, Modoc, Siskiyou and Shasta counties have a relatively high percentage of population older than 65. This population is more vulnerable to heat events and air quality problems.

Modoc County is one of the state's counties with the highest proportion of elderly living alone (English et al., 2007). Populations that are isolated in some of the rural areas of this region and may not have the means necessary to recognize impacts and/or evacuate are at increased risk for injuries and death from burns and smoke inhalation and heat-related illnesses.

ADDITIONAL RESOURCES

- Wildfire resources include the following:
    - California Fire Science Consortium, Northern California Module: http://www.cafiresci.org/home-northern-ca/
    - Northern California Prescribed Fire Council: http://www.norcalrxfirecouncil.org/Home_Page.html
    - NorCal Society of American Foresters: http://norcalsaf.org/
    - Quincy Library Group: http://qlg.org/
    - California Fire Alliance: http://cafirealliance.org/
    - California FireSafe Council: http://www.firesafecouncil.org/
- California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
    - The Wildlife Action Plan divides the state into regions. The North Coast-Klamath and Modoc Plateau Regions overlap with the North region.

BAY AREA REGION

Counties: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, Sonoma
Five Largest Cities (CDOF, 2011): San Jose (958,789); San Francisco (812,820); Oakland (392,932); Fremont (215,711); Santa Rosa (168,856)

TOTAL 2010 POPULATION	
Bay Area Region	**7,150,739**
Alameda	1,510,271
Contra Costa	1,049,025
Marin	252,409
Napa	136,484
San Francisco	805,235
San Mateo	718,451
Santa Clara	1,781,642
Solano	413,344
Sonoma	483,878

[U.S. Census Bureau, 2010]

The Bay Area is a heavily urbanized region (over 7 million people). The predominant feature of this region is San Francisco Bay and the miles of shoreline, both on the Pacific coast and along the bay, extending north to Sonoma County, inland to the Delta, and south to San Jose. The urbanized areas are concentrated primarily around the bay. To the north and south, the region is characterized by low coastal mountains (CDFG, 2007). Sonoma and Napa counties produce wine grapes valued over $850 million in 2010 (California Farm Bureau Federation, 2012). To the east, Solano and Contra Costa counties are on the western edge of the low-lying California Delta.

Communities in the Bay Area should consider evaluating the following climate change impacts:

- Increased temperatures
- Reduced precipitation
- Sea level rise – coastal inundation and erosion
- Public health – heat and air pollution
- Reduced agricultural productivity (e.g., wine grapes)
- Inland flooding
- Reduced tourism

Cal-Adapt Projections

Table 9. Summary of Cal-Adapt Climate Projections for the Bay Area Region

EFFECT	RANGES
Temperature Change, 1990-2100	January: 4°F to 5°F increase in average temperatures July: 5°F to 6°F increase in average temperatures (Modeled high temperatures – average of all models; high carbon emissions scenario)
Precipitation	Precipitation varies widely in this region, with annual totals over 40 inches in northern Sonoma County to roughly 15 inches in the eastern portions of Solano and Contra Costa counties. A moderate decline in annual rainfall, 1 to 3 inches by 2050 and 4 to 5 inches by 2090, is projected throughout the region. (CCSM3 climate model; high carbon emissions scenario)
Sea Level Rise	By 2100, sea levels may rise up to 55 inches, posing considerable threats to coastal areas and particularly to low-lying areas adjacent to San Francisco Bay. The number of acres vulnerable to flooding is expected to increase 20 to 30 percent in most parts of the Bay Area, with some areas projected for increases over 40 percent. Coastal areas are estimated to experience an increase of approximately 15 percent in the acreage vulnerable to flooding.
Heat Wave	Along the coast, particularly to the south, heat wave is defined as five days over 72°F to 77°F; in other areas the threshold is in the mid- to upper 90s. Over most of the region a limited increase in the number of heat waves is expected by 2050 with only the eastern areas expecting more than one or two more per year. By 2100, between six and 10 more heat waves can be expected per year.
Fire Risk	There is little change in projected fire risk in this region, save for the slight increases expected in western Marin County. (GFDL climate model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

Approximately 70 percent of the water used in the region is imported, with another 15 percent supplied via groundwater. The imported water comes from a variety of sources, including the Russian River (4 percent); the Delta (approximately 32 percent, via San Luis Reservoir, North Bay Aqueduct, Contra Costa Canal, South Bay Aqueduct); Lake Berryessa (5 percent); Mokelumne River (25 percent); and Tuolumne River (33 percent). The vast majority of these water sources (e.g., Delta sources, Mokelumne River, Tuolumne River) originate in the Sierra Nevada, meaning that climate change impacts on snowpack may have a dramatic impact on the Bay Area water supply. Total reservoir storage capacity in the Bay Area is 746,000 acre-feet (DWR, 2009).

Biophysical Characteristics

The Bay Area region is located in an area characterized by a Mediterranean climate, with warmer summer temperatures observed in the eastern portions of the region. San Francisco Bay and the associated estuarine ecosystem sit at the center of the region and serve as the outlet for the Sacramento and San Joaquin rivers. This estuary supports rich biodiversity, including many special-status species (CDFG, 2007).

The eastern portions of Contra Costa and Solano counties meet the western edge of the area commonly known as the Delta. This area has subsided and has elevations below sea level.
The topography in the Bay Area region reaches to over 4,000 feet in the Coastal Range and falls to the low-lying areas along the coast and bay. In the west, the dominant vegetation is coniferous forest with a mix of hardwoods. To the east, shrubs and grasses begin to emerge (FRAP, 1998; FRAP, 2003).

Regional Entities

- Air Districts: Bay Area Air Quality Management District
- Regional Organizations: Association of Bay Area Governments, Metropolitan Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Dry Creek, Stewarts Point

Selected Infrastructure and Regional Resources

Table 10. Infrastructure and Resources in the Bay Area Region

TYPES	NAMES
Airports	International: Oakland International, San Francisco International, San Jose International General Aviation: Angwin-Parrett Field, Byron, Concord/Buchanan Field, Cloverdale Municipal, Gnoss Field, Half Moon Bay, Hayward Executive, Healdsburg Municipal, Livermore Municipal, Napa County, Nut Tree Airport, Ocean Ridge, Palo Alto, Petaluma Municipal, Rio Vista Municipal, San Carlos, Sonoma County, Sonoma Valley, South County
National and State Parks	National: Golden Gate National Recreation Area, Gulf of the Farallones National Marine Sanctuary, Muir Woods National Monument, Point Reyes National Seashore, San Francisco Bay National Wildlife Refuge Complex (7 sites) State: Albany State Marine Reserve, Angel Island S.P., Annadel S.P., Ano Nuevo S.P., Armstrong Redwoods Natural Reserve, Big Basin Redwoods S.P., Bothe-Napa Valley S.P., Butano S.P., Castle Rock S.P., China Camp S.P., Eastshore S.P., Emeryville Crescent State Marine Reserve, Henry W. Coe S.P., Kruse Rhododendron Natural Reserve, Mount Diablo S.P., Mount Tamalpais S.P., Pacheco S.P., Portola Redwoods S.P., Robert Louis Stevenson S.P., Robert W. Crown Memorial Beach, Salt Point S.P., Samuel P. Taylor S.P., San Bruno Mountain S.P., Sonoma Coast S.P., Sugarloaf Ridge S.P., Tomales Bay S.P.
Passenger Rail	Altamont Commuter Express, Amtrak, Bay Area Rapid Transit, Caltrain, San Francisco Muni Metro, Santa Clara Valley Transportation Authority
Ports	Bulk and Container: Benicia, Oakland, Pittsburg, Richmond, Redwood City, San Francisco Other: Pillar Point Harbor, Porto Bodega Marina
Power Plants (MWs)*	Duke Energy Oakland (165), Newby Island 2 (6.5), Pittsburg (1310), GWF Power Systems L.P. (22.8), Foster-Wheeler Martinez Cogen L.P. (114), Nove Power Plant (3), American Canyon Power Plant (1.7), Hunters Point (215), United Cogen Inc. (31), Gianera (49.5), Gas Recovery Systems-Fremont (3.75), Solano Cogen (1.45)

S.P. = State Park; MWs = megawatts
*Located within the 100-year flood zone for 1.5-meter sea level rise

Selected Demographic Data

Table 11. Top Five Employment Sectors in the Bay Area Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Alameda	Government	Professional & Technical Services	Health Care	Retail Trade	Manufacturing
Contra Costa	Retail Trade	Health Care	Government	Professional & Technical Services	Finance & Insurance
Marin	Professional & Technical Services	Health Care	Retail Trade	Government	Other Services
Napa	Manufacturing	Government	Lodging & Food Services	Health Care	Retail Trade
San Francisco	Professional & Technical Services	Government	Lodging & Food Services	Finance & Insurance	Health Care
San Mateo	Professional & Technical Services	Retail Trade	Health Care	Finance & Insurance	Government
Santa Clara	Manufacturing	Professional & Technical Services	Government	Retail Trade	Health Care
Solano	Government	Retail Trade	Health Care	Lodging & Food Services	Construction
Sonoma	Government	Health Care	Retail Trade	Professional & Technical Services	Manufacturing

[CA REAP, 2011]

Table 12. Selected Population Data for the Bay Area Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Bay Area	7,150,739	447,811	6.30%	878,229	12.30%	781,399		
Alameda	1,510,271	97,652	6.50%	167,746	11.10%	200,273	13.5	1
Contra Costa	1,049,025	67,018	6.40%	130,438	12.40%	97,544	9.3	0.9
Marin	252,409	13,932	5.50%	42,192	16.70%	22,456	9.2	1.5
Napa	136,484	8,131	6.00%	20,594	15.10%	14,189	10.7	1.8
San Francisco	805,235	35,203	4.40%	109,842	13.60%	100,910	12.8	1.1
San Mateo	718,451	46,360	6.50%	96,262	13.40%	49,908	7	0.9
Santa Clara	1,781,642	124,464	7.00%	196,944	11.10%	186,051	10.6	0.7
Solano	413,344	26,852	6.50%	46,847	11.30%	49,159	12.2	1.4
Sonoma	483,878	28,199	5.8%	67,364	13.9%	60,909	12.8	1.2

Adaptation Considerations

Large urban areas are prone to specific secondary climate-change impacts due to population density and urban settlement patterns. In the Bay Area region, the location of the urbanized area near a bay that serves as the mouth of two major river networks creates the potential for additional impacts. Outside of the urbanized region, ecosystem shifts and impacts on agriculture, specifically wine grapes, may be experienced.

Sea Level Rise

Since much of the urbanized part of the region is near the ocean or bay, sea level rise will significantly affect development and infrastructure. This is likely to be the greatest threat from climate change to the Bay Area. A 1.4-meter rise in sea level will increase the population vulnerable to a 100-year coastal storm from 10,610 to 13,730 (CCCC, 2009).

The San Francisco Bay Conservation and Development Commission (BCDC) evaluated vulnerability to sea level rise in the region and potential adaptation strategies. Key issues identified by BCDC for the region include the following:

- A "55-inch rise in sea level would place an estimated 270,000 people in the Bay Area at risk from flooding, 98 percent more than are currently at risk. The economic value of Bay Area shoreline development (buildings and their contents) at risk from a 55-inch rise in sea level is estimated at $62 billion…" (BCDC, 2011, p. 3).

- Coastal flooding presents a risk to major transportation infrastructure in the region including freeways, rail lines, ports, and airports (especially San Francisco and Oakland).
- "The impacts of climate change are expected to substantially alter the Bay ecosystem by inundating or eroding wetlands and transitional habitats, altering species composition, changing freshwater inflow, and impairing water quality. Changes in salinity from reduced freshwater inflow may adversely affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. The highly developed Bay shoreline constrains the ability of tidal marshes to migrate landward, while the declining sediment supply in the Bay reduces the ability of tidal marshes to grow upward as sea level rises" (BCDC, 2011, p. 5).

With the large number of local and special purpose governments in the region, addressing the sea level rise problem will require regional collaboration involving the California Coastal Commission and San Francisco Bay Conservation and Development Commission. The San Francisco Planning + Urban Research Association (2012) has recommended the following actions for addressing climate change:

- Barrier(s) or tidal barrage(s) to manage tidal flows in and out of San Francisco Bay (at the Golden Gate or in smaller, strategic parts of the bay)
- Coastal armoring with linear protection, such as levees and seawalls, to fix the shoreline in its current place
- Elevated development in which the height of land or existing development is raised and protected with coastal armoring
- Floating development on the surface of the water, or development that may be floated occasionally during a flood, making it largely invulnerable to changing tides
- Floodable development designed to withstand flooding or to retain stormwater
- Living shorelines with wetlands that absorb floods, slow erosion, and provide habitat
- Managed retreat that safely removes settlement from encroaching shorelines, allowing the water to advance unimpeded, and bans new development in areas likely to be inundated

Alameda and San Mateo counties could see significant increases in the number of United States Environmental Protection Agency (U.S. EPA)-regulated sites at risk for sea level rise, including Superfund sites, hazardous waste generators, facilities required to report emissions for the Toxics Release Inventory, facilities regulated under the National Pollutant Discharge Elimination System (NPDES), major dischargers of air pollutants with Title V permits, and brownfield properties (CCCC, 2009).

Sea level rise is also expected to affect vulnerable populations along the coast through the immediate effects of flooding and temporary displacement and longer-term effects of permanent displacement and disruption of local tourism. Of particular concern are populations that do not have the resources to prepare for, respond to, and recover from disasters. Impacts could include temporary and/or permanent displacement, drowning and property damage, and coastal erosion harming recreational activities, tourism, and the tourism industry.

Vulnerable populations living in institutional settings are disproportionately vulnerable during evacuations from disasters. For instance, Solano and Marin counties have a high proportion of elderly living in nursing homes that could be affected (English et al., 2007).

Flooding

The risk of flooding is highest for the inland, low-lying areas in the eastern part of the region. Reduced snowpack and increased number of intense rainfall events in the Northern Sierra are likely to put additional pressure on water infrastructure, including the Delta levees, which are already vulnerable (DWR, 2011). These impacts increase the chance of flooding associated with breached levees or dams (e.g., in the Sacramento-San Joaquin Delta). Flooding and damage to infrastructure can put large populations in adjacent regions at risk (CDPH, 2008), including:

- The elderly and children less than five years of age, who are isolated or dependent on others for evacuation.
- Populations that may lack the resources or knowledge to prepare or respond to disaster due to language or economic status, including having access to transportation, which would allow them to escape flooding, at least temporarily.
- Vulnerable populations living in institutional settings who are particularly vulnerable during evacuations from disasters. For instance, Solano, and Marin counties have a high proportion of elderly living in nursing homes that could be affected (English et al., 2007).

Public Health, Socioeconomic, and Equity Impacts

Some of the state's highest percentages of impervious surfaces are in the urban areas of the San Francisco Bay Area, increasing the potential impacts of heat islands (English et al., 2007). Santa Clara, Alameda, San Francisco, and Contra Costa counties rank fifth, sixth, ninth, and tenth in the absolute numbers of the elderly and children less than five years of age. These two populations are most likely to suffer from heat-related illnesses and heat events (English et. al, 2007). The highest risk of heat-related illness occurred in the usually cooler regions found in coastal counties and not in the Central Valley where the highest actual temperatures were experienced (Gershunov and Cayan, 2008; CDPH, 2008).

Because of a lack of acclimatization, the largest mortality rate percent increases in California are expected in coastal cities such as San Francisco (CNRA, 2009). Lodging and food services are among the top five employment sectors in Napa, San Francisco, and Solano counties, indicating that may be a significant number of employees who work in the tourism industry/outdoors. Sea level rise may impact employees in the tourism industry. Air quality and heat events may impact outdoor workers, including agricultural and dairy workers.

The higher cost of living in some areas of this region (i.e. San Francisco, Silicon Valley, Marin County) means low-income families pay a high percentage of their income on housing and transportation. Increases in food and energy costs may impact low-income residents.

Fire

A slight increase in fire occurrence is projected for the region. This increase is projected to be largest in the northeastern part of the region. Despite moderate increases in fire risk, huge increases in fire damages are projected due to high population in fire-vulnerable areas (Bryant and Westerling, 2009). Along with impacts associated with temporary and/or permanent displacement, long-term impacts on the elderly and children under the age of five are of concern. Eye and respiratory illnesses due to air pollution resulting from wildfires, and exacerbation of asthma, allergies, chronic obstructive pulmonary disease (COPD), and other cardiovascular diseases, are likely to increase.

Agriculture

Alteration of temperature and precipitation regimes changes the seasons as experienced by plants and animals. These changes are expected to affect the wine industry because the wine grape is a crop that requires a fairly narrow range of climate conditions (Todorov, 2011). These changes might affect not only wine grape growers, but also the businesses and residents dependent on this industry. Communities reliant on the wine industry as an employment base, tourist attraction, or local economic base should closely collaborate with vintner associations and other local agricultural organizations to best understand the risk and support grower efforts to adapt. Communities also may need to plan for a future in which wine grapes and associated activities make up a smaller part of their local economy.

ADDITIONAL RESOURCES

- Public Health, Socioeconomic, and Equity Impacts
  - San Francisco's Healthy Development Measurement Tool (www.theHDMT.org) provides health-based rationales, goals, and indicators applicable to other jurisdictions. The San Francisco Public Health Department has also used it to generate a wide range of health-oriented maps, including proximity to farmers markets, noise levels, bike collisions, and truck routes.
  - Issues and Opportunities Papers for the City of Richmond's upcoming general plan update (http://www.cityofrichmondgeneralplan.org/docManager/1000000640/Existing%20Condictions%20Report%20August%202007.pdf) include a baseline assessment built largely from the framework of the Healthy Development Measurement Tool described above.
  - The Oakland Health Profile (2004) includes maps comparing diabetes and childhood asthma hospitalization rates across the city and county (Public Health Law and Policy, How to Create a Healthy General Plan, 2008).
  - The San Jose area has a Health Heat Watch Warning System in place (CDPH, 2008).
- Wildfire Resources
  - California Fire Science Consortium, Central & South Coast Module: http://www.cafiresci.org/home-central-and-southern-ca/
  - California Fire Alliance: http://cafirealliance.org/
  - California FireSafe Council: http://www.firesafecouncil.org/
- Biodiversity and Ecosystems
  - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
  - The Wildlife Action Plan divides the state into regions. The Marine and Central Valley and Bay-Delta Regions overlap with the Bay Area region.

NORTHERN CENTRAL VALLEY REGION

Counties: Butte, Colusa, Glenn, Madera, Merced, Sacramento, San Joaquin, Stanislaus, Sutter, Tehama, Yolo, Yuba
Five Largest Cities (CDOF, 2011): Sacramento (469,566); Stockton (293,515); Modesto (202,290); Elk Grove (154,594); Chico (86,900)

TOTAL 2010 POPULATION	
Northern Central Valley	3,725,950
Butte	220,000
Colusa	21,419
Glenn	28,122
Madera	150,865
Merced	255,793
Sacramento	1,418,788
San Joaquin	685,306
Stanislaus	514,453
Sutter	94,737
Tehama	63,463
Yolo	200,849
Yuba	72,155

[U.S. Census Bureau, 2010]

The Northern Central Valley is a largely agricultural, inland region with over 3.7 million people, with substantial cities, the largest being the state capital, Sacramento (469,000+ people). The central portion of the region is defined by the Delta, with inland marshes intermingled with agriculture, interspersed with cities along transport corridors. The region contains the Port of Stockton, the most inland port for ocean-going vessels, approximately 80 miles from the Golden Gate Bridge. Agriculture is the predominant economic activity. The agricultural operations in this region include rice, dairy, and nut trees (almond and walnut) (California Farm Bureau Federation, 2012). The region's agricultural activity is one of the most productive in the nation.

In the Northern Central Valley region, communities will need to assess vulnerability to the following impacts:

- Temperature increases – particularly nighttime temperature
- Reduced precipitation
- Flooding – increase flows, snowmelt, levee failure in the Delta
- Reduced agricultural productivity (e.g., nut trees, dairy)
- Reduced water supply
- Wildfire in the Sierra foothills
- Public health and heat
- Reduced tourism

Cal-Adapt Projections

Table 13. Summary of Cal-Adapt Climate Projections for Northern Central Valley

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperature of 4°F to 6°F and between 8°F and 12°F by 2100. July increase in average temperature of 6°F to 7°F in 2050 and 12°F to 15°F by 2100. (Modeled high temperatures – average of all models; high carbon emissions scenario)
Precipitation	Annual precipitation is projected to decline by approximately one to two inches by 2050 and three to six inches by 2100. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	Heat wave is defined as five days over 102°F to 105°F, except in the mountainous areas to the east. Two to three more heat waves per year are expected by 2050 with five to eight more by 2100.
Wildfire Risk	By 2085, the north and eastern portions of the region will experience an increase in wildfire risk, more than 4 times current levels in some areas. (GFDL model, high emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

Two rivers, the San Joaquin and Sacramento, run through this region. The rivers originate from snowmelt in the Sierra Nevada and the mountainous regions in the north and flow toward San Francisco Bay, where the flows eventually reach the Pacific Ocean. The confluence of the rivers occurs in the Sacramento-San Joaquin Delta.

Water moves through the region through natural waterways as well as a network of canals and reservoirs. The reservoir and canal systems that hold much of the region's water allow it to be leveraged for energy generation and recreational use (DWR, 2009). The water supply network for the region is highly complex. One third of the regional water supply relies on groundwater pumping, which can increase during drought periods when more water may be pumped to make up for surface water shortfalls. For the remaining majority of the water supply, there is heavy reliance on the surface water conveyance systems that provide the inflow to the Sacramento-San Joaquin Delta (also known as the California Delta or the Bay-Delta.

The Delta serves as a primary water source for the entire state, serving approximately 25 million residents as far south as San Diego and an agricultural industry valued at over $25 billion (San Diego County Water Authority, n.d.). These supplies are delivered through the State Water Project, the Central Valley

Project, and a host of other federal water projects. In the Delta, the system of canals, bordered by levees, also serves to deliver floodwater, support commercial fishing, provide for recreational activities, and maintain ecosystem health. The network of reservoirs within the region also plays a vital role in preventing saltwater intrusion in the California Delta by providing freshwater flushes during the summer and fall (DWR, 2009).

The Northern Central Valley region overlaps three hydrologic regions as defined by the Department of Water Resources: San Joaquin River, Sacramento River, and Sacramento-San Joaquin Delta. Reservoir storage capacity in the Sacramento River and San Joaquin River hydrologic regions is 16.15 and 11.48 million acre-feet, respectively (DWR, 2009).

Biophysical Characteristics

While elevations range from 3,000 to 12,000 feet in the eastern areas of Madera, Butte, Sutter, and Tehama counties, areas located within the primary Delta zone in southern Yolo County and eastern Sacramento and San Joaquin counties are at or below sea level (CDFG, 2007). On average, elevation in the Northern Central Valley region is less than 300 feet above sea level. The region is bordered by the Sierra Nevada to the east and the coastal mountain ranges to the west. The extensive natural vegetation in the region is dominated by grasslands and scrub but also contains hardwood and coniferous forest and woodland (FRAP, 1998). Major rivers include the Sacramento, San Joaquin, Feather, Merced, and Stanislaus. Many of the large lakes in the region are the result of river damming as part of reservoir and water project construction.

Regional Entities

- Air Districts: Butte, Colusa, Feather River, Glenn, San Joaquin Valley Unified, Tehama, Yolo-Solano
- Regional Organizations: Butte County Association of Governments, Tehama County Transportation Commission, Glenn County Transportation Commission, Colusa County Transportation Commission, Sacramento Area Council of Governments, San Joaquin Council of Governments, Stanislaus Council of Governments (StanCOG), Merced County Association of Governments, Madera County Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Berry Creek, Colusa (Cachil Dehe), Cortina, Enterprise, Grindstone Creek, Mooretown, North Fork, Picayune, Rumsey

Selected Infrastructure and Regional Resources

Table 14. Infrastructure and Resources in the Northern Central Valley Region

TYPES	NAMES
Airports	International: Sacramento International Airport General Aviation: Chico Municipal Airport, Oroville Municipal Airport, Paradise Airport, Ranchaero Airport, Richvale Airport, Colusa County Airport, Willows-Glenn County Airport, Haigh Field, Madera Municipal Airport, Chowchilla Airport, Merced Regional Airport, Castle Airport, Gustine Airport, Los Banos Municipal Airport, Sacramento Mather Airport, Sacramento Executive Airport, Stockton Metropolitan Airport, Escalon Airport, Lodi Airport, Tracy Municipal Airport, Modesto City-County Airport, Oakdale Airport, Patterson Airport, Turlock Airpark, Sutter County Airport, Red Bluff Municipal Airport, Corning Municipal Airport, Watts Woodland Airport, UC Davis University Airport, Yolo County Airport, Borges Airport, Yuba County Airport, Brownsville Aero Airport
National and State Parks	National: Lassen National Forest, Lassen Volcanic National Park, Mendocino National Forest, Yosemite National Park State: Bidwell-Sacramento S.P., Great Valley Grasslands S.P., Pacheco S.P., Caswell Memorial S.P., Henry W. Coe S.P., Sutter Buttes S.P.
Ports	Port of Sacramento, Port of Stockton, Rio Vista Harbor
Passenger Rail	Cal-P (Central Pacific), SP West Valley Line (California Northern Railroad), Feather River (Union Pacific), Altamont Commuter Express (Union Pacific Railroad), San Joaquin (Union Pacific Railroad), Sacramento Regional Light Rail System, Central California Traction Company (Union Pacific & BNSF Railway), Modesto & Empire Traction Company (Beard Land & Investment Company), Sierra Northern Railway (Sierra Railroad Company)

S.P. = State Park

Selected Demographic Data

Table 15. Top Five Employment Sectors in the Northern Central Valley Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Butte	Health Care	Government	Retail Trade	Other Services	Lodging & Food Services
Colusa	Government	Farm Employment	Manufacturing	Lodging & Food Services	Wholesale Trade
Glenn	Government	Farm Employment	Retail Trade	Other Services	Lodging & Food Services
Madera	Government	Health Care	Retail Trade	Farm Employment	Manufacturing
Merced	Government	Retail Trade	Manufacturing	Health Care	Farm Employment
Sacramento	Government	Health Care	Retail Trade	Professional & Technical Services	Finance & Insurance
San Joaquin	Government	Health Care	Retail Trade	Manufacturing	Lodging & Food Services
Stanislaus	Government	Retail Trade	Health Care	Manufacturing	Lodging & Food Services
Sutter	Retail Trade	Health Care	Government	Lodging & Food Services	Farm Employment
Tehama	Government	Retail Trade	Farm Employment	Health Care	Manufacturing
Yolo	Government	Retail Trade	Health Care	Professional & Technical Services	Transportation & Warehousing
Yuba	Government	Retail Trade	Farm Employment	Construction	Other Services

[CA REAP, 2011]

Table 16. Selected Population Data for the Northern Central Valley Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Northern Central Valley	3,725,950	276,063	7.40%	414,921	11.10%	679,162		
Butte	220,000	12,409	5.60%	33,817	15.40%	43,392	20.1	2.2
Colusa	21,419	1,841	8.60%	2,495	11.60%	3,161	14.9	3
Glenn	28,122	2,178	7.70%	3,737	13.30%	4,890	17.6	3.6
Madera	150,865	11,983	7.90%	17,262	11.40%	30,912	21.7	3.3
Merced	255,793	22,226	8.70%	23,960	9.40%	58,212	23.1	2.3
Sacramento	1,418,788	101,063	7.10%	158,551	11.20%	234,470	16.7	1.1
San Joaquin	685,306	54,228	7.90%	71,181	10.40%	128,331	19	1.5
Stanislaus	514,453	39,779	7.70%	54,831	10.70%	100,554	19.7	1.5
Sutter	94,737	7,153	7.60%	11,990	12.70%	15,780	16.8	2.7
Tehama	63,463	4,409	6.90%	10,071	15.90%	12,810	20.4	3.3
Yolo	200,849	12,577	6.30%	19,771	9.80%	31,942	16.4	2.3
Yuba	72,155	6,217	8.60%	7,255	10.10%	14,708	20.7	3.5

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

Waterways in the Northern Central Valley region drain to the California Delta. Part 1 of the APG identifies the California Delta as a special sector due to the distinctiveness of the setting and the challenges faced there. The issues, particularly flooding, identified in the section on the California Delta will not be repeated here but should be carefully considered.

Flooding

The eastern part of the Northern Central Valley contains the foothills of the Sierra Nevada mountain range. The mountainous areas of the state are projected to have less precipitation falling as snow and to be subject to rapid melt events. This will result in extreme, high-flow events and flooding in the Central Valley. Communities should evaluate local floodplains and recognize areas where a small increase in flood height would inundate large areas and potentially threaten structures, infrastructure, agricultural fields, and/or public safety. As the rivers of the region flow toward San Francisco Bay, the land decreases in elevation and is protected by levees, many of which are vulnerable, particularly to seismic events. The threat of flooding due to climate-induced increased flows in the California Delta is examined in Part 1 of this document.

Flooding and damage to infrastructure can put large populations at risk (CDPH, 2008), including:

- The elderly and children less than five years of age, who are isolated or dependent on others for evacuation. As an example, Sutter County is one of California's counties with a high proportion of elderly living in nursing homes (English et al., 2007).
- Populations that may lack the resources or knowledge to prepare or respond to disaster due to language or economic status, including having access to transportation, which would allow them to escape flooding, at least temporarily.

Addressing the flood threats in this region may require regional collaboration. This collaboration should include counties, cities, special districts, the California Department of Water Resources (DWR), the California Emergency Management Agency (Cal EMA), the Federal Emergency Management Agency (FEMA), the Central Valley Flood Protection District, and other entities.

Agriculture

The Northern Central Valley is one of the largest agricultural producing regions, not only in California, but in the United States. Between climate change impacts on water availability and seasonal temperature regimes, the health of livestock, and productivity of trees and crops are likely to be affected.

Agriculture in this region is varied, with rice, nuts (almonds, walnuts, pistachios), and dairy being three of the most predominant products. Others include pears, cattle, wine grapes, chicken, sweet potatoes, and plums.

Each crop is likely to react slightly differently to alteration in seasonal temperature regimes and water availability. Rice is projected to experience a moderate loss in productivity (less than 10 percent; CCCC, 2009). In the case of nut trees, it is the reduction in nighttime cooling that may have the most impact (Luedeling et al., 2011). Jurisdictions reliant on almonds, walnuts, pistachios, or other nuts should specifically evaluate projected changes in daily low temperatures and/or loss of nighttime chill hours. It is difficult to specifically project the production impact on crops because this relates to many factors in addition to temperature and precipitation, including pest regimes, availability of imported or groundwater irrigation water, and management practices (Luedeling et al, 2011).

As with crops, climate change impacts on dairy cows depend on a variety of factors. For example, the severity of heat stress, which can influence productivity, is influenced by the following factors (Chase, 2006, p.2):

- The actual temperature and humidity
- The length of the heat stress period
- The degree of night cooling that occurs
- Ventilation and air flow
- The size of the cow
- The level of milk production and dry matter intake prior to the heat stress (higher-producing animals will experience greater effects of heat stress)
- Housing – type, ventilation, overcrowding, etc.
- Water availability
- Coat color (lighter color coats absorb less sunlight)

The impact of climate change on agricultural productivity has the potential to alter a community's economic continuity, including its employment base. Communities should work with farm bureaus and other agricultural organizations to understand the challenges faced and to support these organizations and their members as much as possible. Communities should also consider developing plans that limit the impact of productivity reductions on community operations and the provision of basic services.

Public Health, Socioeconomic, and Equity Impacts

Increased temperatures and more frequent heat waves are expected in the region. Sacramento County ranked eighth in the absolute numbers of the elderly and children less than five years of age. These two populations are most likely to suffer from heat-related illnesses and heat events (English et al., 2007). Impervious surfaces are increasing in the Central Valley, increasing the potential impacts of heat islands (English et al., 2007).

Farm employment or lodging and food services are among the top five employment sectors in several of the counties in this region. Agricultural workers and employees in the tourist industry are more susceptible to heat events. The foothill areas outside of the Sacramento area (e.g., Placerville, Auburn, Grass Valley) show higher ozone levels and increased temperatures. Those most vulnerable to high levels of ozone and particulate matter include people who work or spend a lot of time outdoors, such as residents of this region who are employees of the tourist industry (Lake Tahoe) in the nearby Northern Sierra region. (Medina-Ramon and Schwartz, 2008).

Regardless of their occupation, the poor are less likely to have the adaptive capacity to prevent and address impacts for reasons stated above. For instance, Merced and Madera counties are considered "high poverty" counties (English et al., 2007). Butte, Stanislaus, Tehama, and Yolo all have poverty levels at approximately 20 percent. Households eligible for energy utility financial assistance programs are an indicator of potential impacts. These households may be more at risk of not using cooling appliances, such as air conditioning, due to associated energy costs. A relatively high proportion of Yuba County's population (56 to 63 percent) is eligible for energy assistance. Merced and Madera counties have moderately high proportions of populations eligible (47 to 55 percent) (English et al., 2007).

Water Supply

Shorter rainfall events and rapid snowmelt will reduce the region's water supply by making water more difficult to capture in reservoirs or retain for groundwater recharge. Recreation and tourism in the region are also likely to suffer due to lower water levels in waterways and reservoirs and declining snowpack.

Agriculture will also be impacted due to reduced or altered precipitation. Water supply (for irrigation) can alleviate some of the other climate stresses (altered temperature or precipitation) or, in the case of reduced water supply, exacerbate them. The challenge of climate change is that water supply is projected to be reduced and water that is available will be more costly for users. Employees of water-reliant industries such as agriculture may become more economically vulnerable because of unstable working conditions.

Fire

Fire risk is projected to increase in the foothills lining the eastern edge of the region. The areas northeast of Sacramento, due to population density and fire risk, are projected to have large property loss (Westerling and Bryant, 2006). Jurisdictions should pay careful attention to the wildland-urban interface and enforcement of mitigation measures such as residential vegetation and setbacks.

ADDITIONAL RESOURCES

- Wildfire Resources
  - California Fire Science Consortium, Central & South Coast Module: http://www.cafiresci.org/home-central-and-southern-ca/
  - California Fire Alliance: http://cafirealliance.org/
  - California FireSafe Council: http://www.firesafecouncil.org/
- Biodiversity and Ecosystems
  - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
  - The Wildlife Action Plan divides the state into regions. The Central Valley and Bay-Delta Regions overlap with the Northern Central Valley region.

Bay-Delta Region

Counties: Contra Costa, Sacramento, San Joaquin, Solano, and Yolo
Five Largest Cities (CDOF, 2011): Sacramento (469,566); Stockton (293,515); Elk Grove (154,594); Vallejo (116,508); Fairfield (104, 815)

TOTAL 2010 POPULATION	
Bay-Delta Region	3,638,618
Contra Costa	1,049,025
Sacramento	1,418,788
San Joaquin	685,306
Solano	413,344
Yolo	72,155

[U.S. Census Bureau, 2010]

Among the APG regions, the Bay-Delta region is unique in that it overlaps with two other regions: Bay Area and Northern Central Valley. The Bay-Delta is included as a distinct region because of the distinct challenges faced by the area and the critical importance it plays in statewide water supply. While the Bay-Delta region contains diverse and vulnerable aquatic ecosystems, the discussion of this region focuses specifically on water management..

While the Bay-Delta region contains diverse and vulnerable aquatic ecosystems, the content of this region focuses specifically on water management. The state water system (Central Valley Project and State Water Project) relies on the Delta for water export from the North to the South. In its entirety, the Delta is home to over a half a million people, yet more than 23 million people rely on water that travels through the Delta, and one sixth of all irrigable land in the United States is in the Delta watershed (PPI, 2007). Any community reliant on water that travels through the Delta must understand how climate change alters the vulnerability of this supply. This section is intended to provide an overview of the levee system that protects residents, Bay-Delta agriculture, and the water supply of much of the state.

Prior to the 1850s, the Delta was a vast wetland of channels and islands nourished by semi-annual flooding and sediment deposits. With flood control and land conversion to agriculture, the elevation of large portions of the Delta dropped below sea level. Levees were constructed to protect the agricultural and residential areas, which are now below-sea-level islands. The lower Delta islands are continuously dropping in elevation, below sea level, because of topsoil loss from agricultural activities, increase in temperatures causing organic soils to dry out, and potential wind storm severity. These factors could result in lower island

elevations, increased static levee loading, and higher levee vulnerability.
In the Bay-Delta region, communities will need to assess vulnerability to the following impacts:

- Temperature increases
- Reduced precipitation
- Sea level rise
- Flooding – increased flows in areas below sea level, exacerbated by levee failure
- Reduced agricultural productivity
- Reduced water supply
- Public health – heat & air pollution
- Decline in Biodiversity - erosion of riparian habitats

Cal-Adapt Projections

Table 17. Summary of Cal-Adapt Climate Projections for the Bay-Delta Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 3°F to 4°F by 2050 and 6°F to 7°F by 2100. July increase in average temperatures: 3°F to 5°F by 2050 and 7° to 9°F by 2100 (Modeled high temperatures; average of all models; high carbon emissions scenario)
Precipitation	Precipitation across the region is projected to decline by approximately 3 to 5 inches. The most dramatic decline of 5 inches is projected around Richmond, while most other areas are projected to experience a decline of 4 inches, although Stockton may only experience a 3-inch decline in precipitation. (CCSM3 climate model; high carbon emissions scenario)
Sea Level Rise	The portions of the region close to San Francisco Bay are projected to be increasingly susceptible to 1.4-meter sea level rise. Solano County is anticipated to experience a 13% increase in estimated acreage of land vulnerable to a 100-year flood event. This indicator rises to 40% in Contra Costa County and 59% in Sacramento County. Most flooding is projected to occur in areas around Suisun City, Pittsburg, Benicia, Richmond, and Vallejo.
Heat Wave	Heat wave is defined as five days above 97°F to 100°F. There is projected to be four more heat waves per year by 2050 and eight to ten by 2100.
Wildfire Risk	Portions of western and northern Yolo County, northwestern Solano County, southern Contra Costa County, and eastern San Joaquin and Sacramento counties are projected to experience limited increases in potential area burned by wildfire. There are moderately high increases projected for the far eastern areas of San Joaquin County. (GFDL model, high carbon emissions scenario)

[Public Interest Energy Research (2011). Cal-Adapt. Retrieved from: http://cal-adapt.org]

Water Sources

The largest source of water for the Bay-Delta is the Sacramento River, which is fed by several major tributaries including the Pit River and Feather River, as well as other water bodies within the Sacramento River watershed. In addition to the 21 million acre-feet of water that the Sacramento River discharges to the Bay-Delta, just over 3.9 million acre-feet of water flows into the Delta from the Yolo Bypass, San Joaquin River, and other eastern rivers. Precipitation adds about another 1 million acre-feet. A large amount of water in the Sacramento River watershed is diverted and used before it reaches the Delta.

Groundwater supplies are continually recharged because of flows in the channels and the soft, deep soils of Delta islands. Groundwater levels fluctuate because of droughts, development, delivery of surface waters to the region, and periods of extended wet weather (DWR, 2009, pg. D-14). The water table is relatively shallow and groundwater levels in most basins have declined as a result of agricultural and urban development. For example, the Eastern San Joaquin Subbasin has been in severe overdraft with significant land depressions east of Stockton and Lodi (DWR, 2009, pg. D-14).

Groundwater supplies are threatened by climate change due to seawater intrusion. In the Delta, groundwater supports agriculture. The contamination of groundwater is just one threat to the agriculture in the region.

Biophysical Characteristics

The Bay-Delta region is a floodplain estuary that connects river to ocean and land to water. It was once a large marshland formed by the Sacramento and San Joaquin rivers, but, as people began to settle in the area, the marsh was drained and diked for flood control and land conversion to agriculture. More than 90 percent of the marshland has been converted to farms or urban areas. Structures like dams and levees in the Delta have also been detrimental to the migration of species, such as the Chinook salmon (CDFG, 2007)

Floodplain estuaries are among the most productive ecosystems on the planet, but the Delta has very low levels of primary productivity in the upper surface waters of both the Suisun Marsh and the Delta because of a variety of ecological stressors (CDFG, 2007). Wildlife and plant species have been subject to habitat loss, degradation, and fragmentation because of agriculture and urban land development, which has profoundly affected species' ability to survive. The grizzly bear and gray wolf no longer reside in the Delta, but a population of tule elk has been established in the Suisun Marsh. The Suisun Marsh is an important wintering and nesting area for waterfowl using the Pacific Flyway (DWR, 2009, pg. D-5-6).

The ecosystem functions of the Delta have been significantly affected and irrevocably changed by introduced, non-native, and invasive species. Introduced species now dominate all habitats in the Delta; these species include the aquatic weed *Egeria densa*, the water hyacinth, the Asian clam and the overbite clam, and the striped bass and largemouth bass, which are predatory and outcompete native fish species (DWR, 2009, pg. D-5-6).

Regional Entities

- Air Districts: Bay Area Air Quality Management District
- Regional Organizations: San Francisco Bay Conservation and Development Commission, Association of Bay Area Governments, Sacramento Area Council of Governments, San Joaquin Council of Governments

Selected Infrastructure and Regional Resources

Table 18. Infrastructure and Resources in the Bay-Delta region.

TYPES	NAMES
Airports	International: Sacramento Airport General Aviation: Borges-Clarksbug, Buchanan Field, Byron, Franklin Field, McClellan Airfield, New Jerusalem, Nut Tree, Rancho Murrieta, Rio Vista Municipal, Sacramento Executive, Sacramento Mather, Stockton Metropolitan, Tracy Municipal, University, Yolo County
National and State Parks	State: Bidwell-Sacramento S.P., Caswell Memorial S.P., Mount Diablo S.P., Sutter Buttes S.P.
Passenger Rail	Altamont Commuter Express, Amtrak, Bay Area Rapid Transit, Cal-P (Central Pacific), Southern Pacific West Valley Line, San Joaquin (Union Pacific Railroad), Sacramento Regional Light Rail System
Ports	Benicia, Pittsburg, Richmond, Sacramento, Stockton, Vista Harbor
Power Plants (MWs)*	Foster-Wheeler Martinez Cogen L.P., Nove Power Plant (3), Pittsburg (1310), GWF Power Systems L.P., Solano Cogen (1.45)

S.P. = State Park; MWs = megawatts
*Located within the 100-year flood zone for 1.5-meter sea level rise

Selected Demographic Data

Table 19. Top Five Employment Sectors in the Bay-Delta Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Contra Costa	Retail Trade	Health Care	Government	Professional & Technical Services	Finance & Insurance
Sacramento	Government	Health Care	Retail Trade	Professional & Technical Services	Finance & Insurance
San Joaquin	Government	Health Care	Retail Trade	Manufacturing	Lodging & Food Services
Solano	Government	Retail Trade	Health Care	Lodging & Food Services	Construction
Yolo	Government	Retail Trade	Health Care	Professional & Technical Services	Transportation & Warehousing

[CA REAP, 2011]

Table 20. Selected Population Data for the Bay-Delta Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Delta	3,767,312	261,738	6.95%	426,788	11.33%	541,446		
Contra Costa	1,049,025	67,018	6.40%	130,438	12.40%	97,544	9.3	0.9
Sacramento	1,418,788	101,063	7.10%	158,551	11.20%	234,470	16.7	1.1
San Joaquin	685,306	54,228	7.90%	71,181	10.40%	128,331	19	1.5
Solano	413,344	26,852	6.50%	46,847	11.30%	49,159	12.2	1.4
Yolo	200,849	12,577	6.30%	19,771	9.80%	31,942	16.4	2.3

[US Census, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

The California Delta is critical to the overall function of the state including water supply, biodiversity, and economy. This regional section focuses primarily on threats to water supply, so that reliant communities can assess vulnerability. The immediate threats to communities located in the Delta extend well beyond water supply, however. Flooding, seawater intrusion, and alteration of the Delta ecosystems can threaten a wide variety of regional assets and resources, including the physical safety of residents; the viability of economic activities including agriculture, fisheries, and recreation; the health of community members; and regional biodiversity.

Setting and History

The California Delta is the center of a vast river network that drains the central valley of California, receiving roughly 80 percent of the water in the state (Delta Vision, 2008). The Delta is fed by several rivers, the largest being the Sacramento River and the San Joaquin River, in addition to the Mokelumne, American, and Calaveras rivers. These rivers empty into the low-lying basin of the Delta, which outlets to San Francisco Bay and then the Pacific Ocean.

Before the 1850s, the Delta was nourished by semi-annual flooding and the accompanying sediment deposits, making for vast wetlands of channels and islands. As the sediment supply was curtailed through flood control and the land was converted to agriculture, the elevation of large portions of the Delta dropped below sea level making this area prone to more frequent flooding. Levees were constructed to protect the agricultural and residential areas on what are now below-sea-level islands. The drop in elevation continues, resulting in a need for increased levee height over the roughly 2,000 kilometers of levees that continuously hold back water in the low-lying areas(see Figuire 8).

The state water system (Central Valley Project and State Water Project) relies on the Delta as the conduit for water exported from the north to the south. In its entirety, the Delta is home to over half a million people, yet more than 23 million people rely on water that travels through the Delta, and one sixth of all irrigable land in the United States is in the Delta watershed (PPI, 2007). Conditions in the Delta have been altered dramatically from its pre-developed state. These changes have endangered many native species and created habitat for even more non-native species.

The water supply, economic viability, and environmental resources of the Bay-Delta region are critical to the state.

Climate Change Impacts in the Lower Bay-Delta

Climate change is expected to result in the following impacts in the lower Bay-Delta:

- Higher temperatures and increased storm/wind activity may exacerbate drops in elevation of low-lying areas.
- Changes in the magnitude of precipitation and precipitation/snowmelt runoff intensity may reduce control of the salt water front that is artificially held downstream of water export pumps.
- Sea level rise is not expected to have an appreciable impact on the seismic vulnerability of the lower Delta.

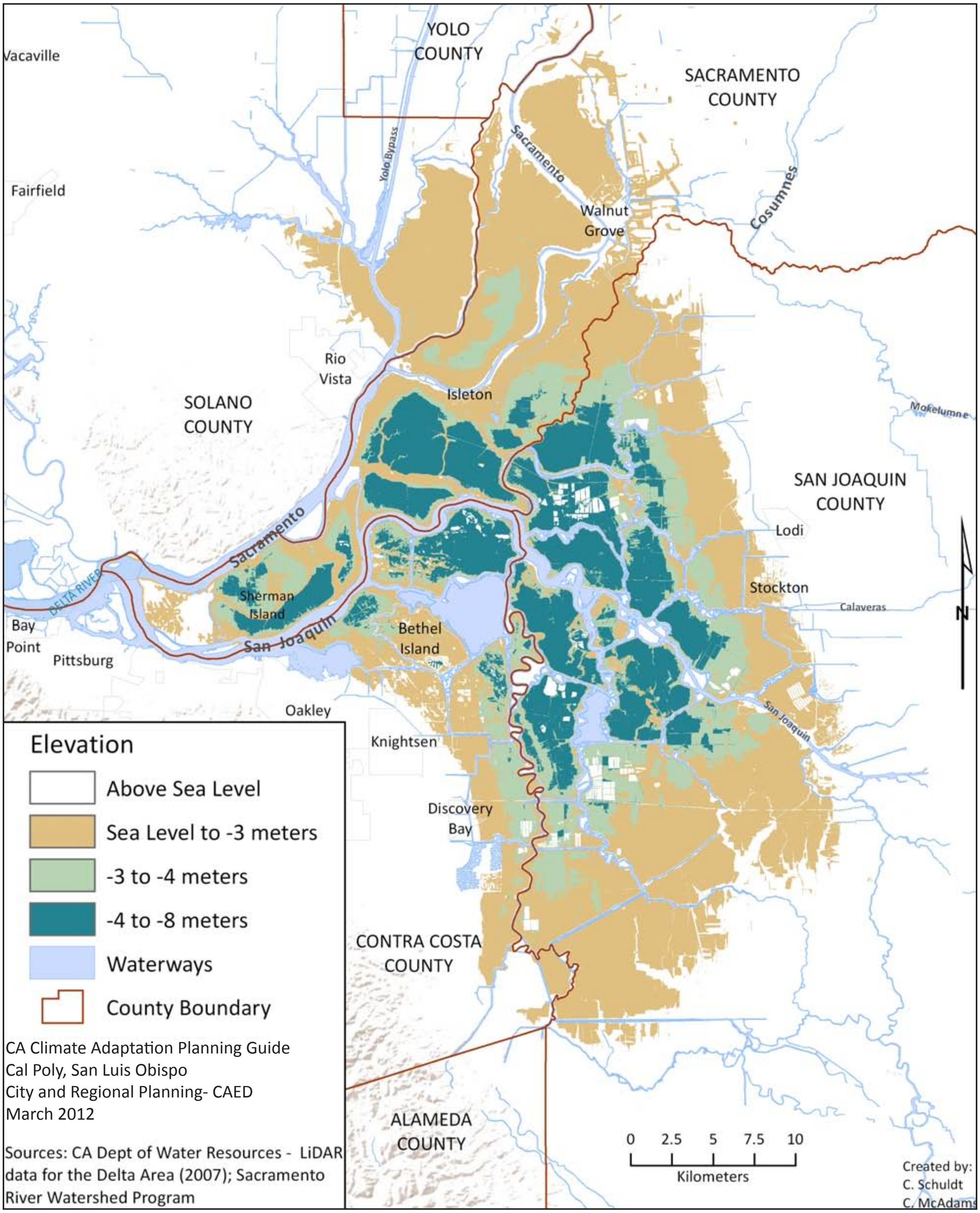


Figure 8. Bay-Delta Region with Elevation

The islands in the lower Bay-Delta are defined as those areas below mean sea level (see Figure 8). These areas hold back water on a continuous basis and crest heights target the peak water conditions due to tidal fluctuations from the sea, peak flows from the rivers, or the combination of the two. Levee failures and subsequent island flooding regularly occur; over 160 failures occurred in the last century (DWR, 2009). Levee failures and flooding occur due to peak water level conditions, but they can also take the form of what are called "sunny day" failures during which there are no adverse loading conditions.

The Delta has yet to experience a substantial earthquake in its current configuration. The seismic behavior of the levees in the Delta is a concern, however, because the levees have not been designed or tested for such loading conditions and may fail via several different mechanisms (e.g., seismic liquefaction of the foundation or embankment soil, co-seismic deformation of the foundation or embankment soil, or post-seismic reconsolidation of the foundation soil). The scenario that threatens disruption of the state's water supply is an earthquake that can result in multiple levee failures, flooding the freshwater into the below sea level islands, and allowing saltwater intrusion to degrade water quality thereby shutting down water exports to the south (DWR, 2009).

Because the levees in the lower Delta currently hold back water on a continuous basis (in some places upwards of 8 meters) incremental increases in sea level or increase in peak-flow heights will not have an appreciable impact on the seismic vulnerability. The concern is earthquake loading of the vulnerable levees, not relatively small increases in the static loading from increased water level heights. This also holds true for any other asset or community in the lower Delta residing below mean sea level. Seismic levee integrity and static levee integrity are not necessarily addressing the same failure mechanisms.

The lower Delta islands are continuously dropping in elevation, below sea level, due to a number of factors. One main factor is the loss of topsoil from agricultural activities. An increase in average temperatures accelerating the drying of peaty organic soils and an increase in wind storm severity could exacerbate this process, resulting in lower island elevations, increased static levee loading, and higher levee vulnerability. Also of concern are the high water conditions and erosion that are associated with winter storms. While they might not cause the widespread failure that may result from a seismic event, storm events have the potential to result in a notable increase in levee failure.

Changes in precipitation can have an influence on maintaining the saltwater front below the intake pumps for the water delivery to the south. Currently the saltwater front is maintained primarily by controlling the release from Shasta Dam, among other flood control structures. Unreliable water supply and timing from the input rivers (Sacramento, Mokolumne, and San Joaquin) due to changes in precipitation and snow melt will make ensuring water quality and water delivery increasingly difficult.

Climate Change Impacts in the Upper Bay-Delta

Climate change is expected to result in the following outcomes in the upper Bay-Delta:

- Increased precipitation and snowmelt peak runoff are likely to increase the static vulnerability of levee.
- Not have an appreciable impact on the seismic vulnerability of the levees.

For communities in the upper Delta that are above mean sea level (behind levees that are not continuously holding back water), increased peak flows due to climate change pose a threat to the static stability of the levees but will not have an appreciable impact on the seismic vulnerability of the levees. The odds of coincidence of higher peak flows with earthquake ground shaking are negligible. However, earthquake ground shaking could damage levees, and if not repaired in time, subsequent peak water levels could result in levee failures. Increase in sea level will affect the static stability of the levees just above current mean sea level and may provide more static push during seismic events, but again the change is insignificant compared to the overall seismic vulnerability of the levees. Again, seismic levee integrity and static levee integrity are not necessarily addressing the same failure mechanisms. The "Water Management" section of *APG: Defining Local & Regional Impacts* provides further discussion of flooding.

Evaluating Climate Change Impacts

An approach to evaluating levee vulnerability to climate change impacts is to divide adaptation needs into chronic ongoing problems and catastrophic impacts. Ongoing problems address small-scale damage and disruption such as property damage, crop loss, or similar effects that can usually be quantified in terms of insurance claims and can be addressed with maintenance. Catastrophic impacts include the shut-down of the state water exports, disruption of regional or state infrastructure (highways, rail lines, telecommunication and power grids, gas and water mains, etc), or other broad multi-jurisdictional or dramatically disabling impacts that often require more substantial fixes.

Addressing impacts requires close collaboration between local jurisdictions and the levee districts and other flood control or levee management entities. For Delta communities these stakeholders are critical members of the climate change adaptation team who can aid in supplying critical data and providing feedback in understanding risk.

Some of the questions that should be considered when evaluating the current state of preparedness are as follows:

- Have the levees protecting the community and associated resources been assessed for integrity?
- Is there a funding mechanism for ongoing maintenance and repair? Is it adequate for current needs?
- Are levee improvements planned in the near future?
- Is there a monitoring system in place to assess levee integrity?
- Is this monitoring used to adjust management practices?
- Is there a local hazard mitigation plan? What are the measures identified for flood mitigation preparation and response?
- Does the urban water management plan include contingency measures in the event of levee breach?

For structures located in or near floodplains or levee-protected areas, questions to consider include the following:

- Are critical business or community resources located in areas that may be subject to flooding?
- Are there neighborhoods that may face increased flood risk due to climate change?
- Are there some members of particularly vulnerable populations (e.g. elderly) that may be less able to evacuate from vulnerable areas?
- Does local land use policy (e.g. general plan, zoning, or specific plans) allow for expansion of designated flood zones?
- Is development planned in areas likely to have increasing flood risk (e.g. near levee toe)

For agricultural productivity, questions to consider include the following:

- Are agricultural facilities and equipment located in areas currently or projected to be at risk for flooding?
- Do local growers have plans for product protection and post-flood recovery?

For public safety, questions to consider include the following:

- Are employees and residents aware of the local flood risk?
- Are employees and residents aware of standard procedures in the event of a flood due to a levee over-topping or failing?
- Are local resources for emergency response and medical care adequately prepared in the event of increased flood risk?

For infrastructure, questions to consider include the following:

- Do vulnerable regions have evacuation routes identified?
- Are there contingency plans in the event of water, wastewater, energy, or communication networks interruption?

ADDITIONAL RESOURCES

- Delta Protection Commission. 2007. DPC Land Use & Resource Management Plan for the Primary Zone of the Delta. Retrieved from http://www.delta.ca.gov/Land%20Use%20and%20Resource%20Management%20Plan%20for%20the%20Prim.htm
- Department of Water Resources. 2011. Delta Risk Management Strategy. Retrieved from http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/

Southern Central Valley Region

Counties: Fresno, Kern, Kings, Tulare
Five Largest Cities (CDOF, 2011): Fresno (500,121); Bakersfield (351,443); Visalia (125,770); Clovis (97,218); Tulare (59,926)

TOTAL 2010 POPULATION	
Southern Central Valley	**2,365,242**
Fresno	930,450
Kern	839,631
Kings	152,982
Tulare	442,179

[U.S. Census Bureau, 2010]

The Southern Central Valley is a largely agricultural, inland region with over 2 million people. Its regional character is defined largely by agriculture, interspersed with cities along primary transport corridors, with Fresno (500,000+ people) prominent in the northern end and Bakersfield (350,000+ people) in the southern end. Agriculture is the predominant economic activity; the region contained the top three agricultural counties in the state in 2010 when evaluated on value, totaling roughly $16 billion California Farm Bureau Federation, 2012). The region also stretches into the foothills of the Sierra Nevada and is known as a prominent tourism access point for Yosemite National Park, Kings Canyon National Park, and Sequoia National Park. Several communities in the region rely on tourism.

Communities in the Southern Central Valley should evaluate vulnerability to the following impacts:

- Temperature increases
- Reduced precipitation
- Reduced water supply
- Reduced agricultural productivity
- Flooding
- Decrease in tourism – Sierra Nevada foothills
- Wildfire risk in the Sierra Nevada foothills

Cal-Adapt Projections

Table 21. Summary of Cal-Adapt Climate Projections for the Southern Central Valley Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 3°F to 4°F by 2050 and 7°F to 10°F by 2100. July increase in average temperatures: 5°F to 6°F in 2050 and 9°F to 11°F by 2100, with larger temperature increases in the mountainous regions to the east. (Modeled high temperatures; average of all models; high carbon emissions scenario)
Precipitation	Low areas are projected to experience declines in annual precipitation of 1 or 2 inches by 2050 and up to 3.5 inches by 2100, while more elevated areas are projected to experiences loses of up to 10 inches. (CCSM3 climate model; high carbon emissions scenario)
Snowpack	Snowpack in the eastern elevated regions is projected to decrease by approximately 9 inches, resulting in pack that is less than 4 inches by March 2090. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	The threshold temperature that defines a heat wave is over 100°F in most of the region. In the mountains, a heat wave is defined by lower termperatures, 70°F to 90°F. By 2050, the number annual heat waves is projected to increase by three to five. An increase of seven to 10 is expected by 2100 in most of the region, with an increase of up to 14 expected in the mountain areas.
Wildfire Risk	The eastern edge of the region is projected to experience an increase in wildfire risk of 4 to 6 times current conditions. (GFDL model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

Most of the Southern Central Valley region is located within the Tulare Lake hydrologic region. The water supply in this region relies primarily on Sierra snowmelt, delivered by natural waterways and canal systems, and groundwater. During parts of the year, water is limited. As a result, the region has developed a careful management system, integrating groundwater and surface water resources to assure year-round supply (DWR, 2009). This management system seeks to avoid groundwater overdraft but has not always succeeded, leading to increased water table depths and associated land subsidence.

Within the region, western areas are subject to more limited resources. Therefore, they rely on imported resources from the Central Valley Project and the State Water Project. These imported sources have increased salt concentrations, which have led to a salt build-up in soils and groundwater.

Agriculture is the largest water user in the region (more than 80 percent), followed by environmental and urban uses. In addition, the extensive network of reservoirs is used for power generation and storage. Reservoir storage capacity in the region totals 2.05 million acre-feet (DWR, 2009).

Biophysical Characteristics

The western portion of the Southern Central Valley is approximately 300 feet above sea level, with the central areas of Fresno and Kings counties lying below an elevation of150 feet. In contrast, the eastern areas of Kern and Tulare counties range from 1800 to 12,000 feet above sea level (CDFG, 2007).

The region features warm, dry summers, with rainfall generally occurring in the winter. Elevations over 5,000 feet receive consistent snowfall. While the western portions of the region are drier than the east, the region contains wetlands, vernal pools, and an extensive network of rivers and associated riparian habitats. Despite having lost the majority of the historic distribution of these habitats, they continue to support an average of 5.5 million waterfowl annually (DWR, 2009). Ecosystems outside urbanized areas accommodate diverse vegetation including irrigated cropland, grassland and a variety of shrub-lands, oak and juniper woodland, and red and white fir forests (DWR, 2011).

Regional Entities

- Air Districts: San Joaquin Valley Unified
- Regional Governments: Fresno Council of Governments, Kings County Association of Governments, Kern Council of Governments, Tulare County Association of Governments
- Tribal Lands (U.S. EPA, 2011): Big Sandy, Cold Springs, Santa Rosa, Tule River

Selected Infrastructure and Regional Resources

Table 22. Infrastructure and Resources in the Southern Central Valley Region

TYPES	NAMES
Airports	International: Fresno Yosemite International Airport, Meadows Field International Airport General Aviation: Fresno Chandler Executive Airport, Firebaugh Airport, Mendota Airport, New Coalinga Municipal Airport, Reedley Municipal Airport, Sierra Sky Park Airport, California City Municipal Airport, Delano Municipal Airport, Kern Valley Airport, Lost Hills Airport, Mojave Airport, Shafter Airport, Taft Airport, Tehachapi Municipal Airport, Wasco Airport, Hanford Municipal Airport, Visalia Municipal Airport, Sequoia Field
National & State Parks	National: Sequoia National Park, Kings Canyon National Park, Red Rock Canyon National Park, Sequoia National Forest, Sierra National Forest State: Red Rock Canyon State Park
Passenger Rail	Altamont Commuter Express, Amtrak, Bay Area Rapid Transit, Cal-P (Central Pacific), SP West Valley Line, San Joaquin (Union Pacific Railroad), Sacramento Regional Light Rail System, San Joaquin Valley Railroad (Rail America)

S.P. = State Park

Selected Demographic Data

Table 23. Top Five Employment Sectors in the Southern Central Valley Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Fresno	Government	Heath Care	Retail Trade	Forestry & Fishing	Manufacturing
Kern	Government	Retail Trade	Health Care	Forestry & Fishing	Construction
Kings	Government	Federal Military	Health Care	Retail Trade	Manufacturing
Tulare	Government	Retail Trade	Farm Employment	Health Care	Manufacturing

[CA REAP, 2011]

Table 24. Selected Population Data for the Southern Central Valley Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Southern Central Valley	2,365,242	205,816	8.70%	222,667	9.40%	555,610		
Fresno	930,450	78,980	8.50%	93,421	10.00%	245,330	26.8	1.3
Kern	839,631	72,885	8.70%	75,437	9.00%	172,531	21.4	1.4
Kings	152,982	12,877	8.40%	12,030	7.90%	29,606	22.5	3
Tulare	442,179	41,074	9.30%	41,779	9.40%	108,143	24.6	2

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

Climate change impacts in the Southern Central Valley region are varied, but not necessarily new. In many cases, climate is projected to exacerbate existing challenges such as limited water supply, agricultural conditions, social vulnerability, and wildfire.

Agriculture

Agriculture in this region is critical to the food supply in California as well as the rest of the country. In 2010, the counties in the Southern Central Valley were ranked first, second, third, and ninth in the state in terms of the economic value of their agricultural production (California Farm Bureau Federation, 2012).

The crops produced are varied and include almonds, milk, cattle, cotton, oranges, and poultry. Each crop type is likely to react differently to alteration in seasonal temperature regimes and changes in water availability. It is difficult to specifically project the production impact on crops because it relates to many factors in addition to temperature and precipitation, including pest regimes, availability of irrigation water, and management practices (Luedeling et al., 2011). The particular aspect of climate change most important to assessing impact also will vary. In the case of nut trees, it is the reduction in nighttime cooling that may have the most impact (Luedeling et al., 2011). Jurisdictions reliant on almonds, walnuts, pistachios, or other nuts should specifically evaluate projected changes in daily low temperatures.

As with crops, climate-change impacts on dairy cows depend on a variety of factors. For example, the severity of heat stress, which can influence productivity, is influenced by the following factors (Chase, 2006, p.2):

- The actual temperature and humidity
- The length of the heat stress period
- The degree of night cooling
- Ventilation and air flow
- The size of the cow
- The level of milk production and dry matter intake prior to the heat stress (higher- producing animals will experience greater effects of heat stress)
- Housing – type, ventilation, overcrowding, etc.
- Water availability
- Coat color (lighter color coats absorb less sunlight)

The impact of climate change on agricultural productivity has the potential to alter a community's economic continuity, including its employment base. Communities should work with farm bureaus and other agricultural organizations to understand the challenges being faced and support these organizations as much as possible. Communities should also consider developing plans that limit the impact of productivity reductions on community operations and the provision of basic services.

Public Health, Socioeconomic, and Equity Impacts

Heat is a contributing factor in the production of ground level ozone, an air pollutant that affects respiratory function. Visalia is a location in the San Joaquin Valley traditionally high in ozone. Using Visalia and Riverside, two areas traditionally high in ozone, Dreschler et al. (2006) projected that the number of days in California with "conditions conducive to ozone" could increase by 25 to 80 percent by 2100, "depending on warming scenarios" (Kahrl and Roland-Holst, pg. 105).

Inland low-lying areas in California, such as the San Joaquin Valley, reported the greatest number of heat-related deaths in the 2006 heat wave. The counties in the Southern Central Valley region have a relatively large number of agricultural workers. Extreme heat and temperature-related declines in air quality are likely to contribute to increased physical strain, respiratory issues, and general health conditions. Agricultural workers will have increased exposure to heat events and will be especially at risk of heat illness due to the combination of outdoor work and jobs demanding physical exertion. In addition, farmworker housing may lack air conditioning. Farm employment is one of the top five industries in Tulare County, and while not registering in the top five employment sectors in the remaining counties, the absolute number of employees involved in agriculture in this region is significant.

Regardless of their occupation, the poor are less likely to have the adaptive capacity to prevent and address impacts. For instance, Fresno County is considered a "high poverty" county (English et. al., 2007). All of the counties in this region exceed poverty levels of greater than 20 percent of their populations. Households eligible for energy utility financial assistance programs are an indicator of potential impacts. These households may be more at risk of not using cooling appliances, such as air conditioning, due to associated energy costs. Kings and Tulare counties have moderately high proportions of populations eligible (47 to 55 percent) (English et al., 2007).

The foothill areas outside of and between Fresno and Bakersfield may experience higher ozone levels and temperatures. Those most vulnerable to high levels of ozone and particulate matter include people who work or spend a lot of time outdoors, such as residents of this region who are employees of the tourist industry (Sequoia, Kings Canyon, and Yosemite national parks) in the nearby North Sierra and Southeast Sierra regions.

Water Supply

Water supply in this region relies primarily on snowmelt from the Sierra. Climate change is projected to result in a dramatic decrease in snowpack. This change will not only limit the availability of water in the warmer summer months, but also may result in flooding during the spring. Precipitation falling as rain rather than snow and/or in intense rainfall events can limit the ability to capture the water in reservoirs or groundwater.

Further threatening local water supply is the vulnerability of the levees protecting the California Delta. The Delta feeds the State Water Project and Central Valley Project, two key water sources for the region. There is the potential for this source to be compromised by catastrophic levee failure (DWR, 2011).

Communities in this region should evaluate their vulnerability to loss of the water supply from the Delta and plan accordingly.

Limited water supply could have drastic impacts on the economic stability of the region. The vast majority of the region's water supply (approximately 80 percent; DWR, 2011) supports agriculture. Loss or reduction of water supply would undermine the economic engine of the region. Communities should carefully plan to bolster water supply, simultaneously working to improve the local efficiency of use.

Surface Water and Flooding

Rapid snowmelt or intense rain affects not only water supply, but also the aquatic systems that rely on the flows and the safety of communities in the Sierra foothills. Aquatic systems (e.g., river, lakes, and wetlands) rely on a seasonal hydrological regime. Climate change will disrupt this regime, forcing species to adapt. Recreation and tourism in the region are also likely to suffer due to lower water levels in waterways and reservoirs and declining snowpack. Employees of these industries may become more economically vulnerable because of unstable working conditions.

The mountainous areas are projected to have less precipitation falling as snow and to be subject to rapid melt events. This will result in extreme, high-flow events and flooding in the valley. Communities should evaluate local floodplains and recognize areas where a small increase in flood height would inundate large areas and potentially threaten structures, infrastructure, agricultural fields, and/or public safety.

Fire

A big increase in large fire occurrence is projected for the eastern portion of the region. Once burned, these areas may be prone to landslide or debris flow. Large property loss should be expected in areas with higher population densities, such as tourist destinations in the foothills to the east of Fresno.

ADDITIONAL RESOURCES

- Wildfire Resources
    - California Fire Science Consortium, Central & South Coast Module: http://www.cafiresci.org/home-central-and-southern-ca/
    - California Fire Alliance: http://cafirealliance.org/
    - California FireSafe Council: http://www.firesafecouncil.org/
- Biodiversity and Ecosystems
    - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html

CENTRAL COAST REGION

Counties: Monterey, San Benito, San Luis Obispo, Santa Barbara, Santa Cruz
Five Largest Cities (CDOF, 2011): Salinas (151,219); Santa Maria (100,062); Santa Barbara (89,253); Santa Cruz (60,800); Watsonville (51,495)

TOTAL 2010 POPULATION	
Central Coast	1,426,240
Monterey	415,057
San Benito	55,269
San Luis Obispo	269,637
Santa Barbara	423,895
Santa Cruz	262,382

[U.S. Census Bureau, 2010]

The Central Coast region is a largely agricultural, intermittently settled region of over 1 million people, with substantial cities, the largest being Salinas (150,000+ people). Its character is defined by features such as coastal mountains, the Big Sur coastline, wooded hillsides, and the Salinas River Valley. Inland valleys have a somewhat different character from the coastal areas, but agriculture and tourism are common themes on both sides of the coastal ranges.

Communities in the Central Coast region may face one or more of the following climate change impacts:

- Increased temperatures
- Reduced precipitation
- Reduced agricultural productivity
- Sea level rise – coastal flooding and infrastructure damage
- Biodiversity threat
- Public health threats
- Reduced tourism

Cal-Adapt Projections

Table 25. Summary of Cal-Adapt Climate Projections for the Central Coast Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 1°F to 2°F in 2050 and 4°F to 5°F by 2100. July increase in average temperatures: 2°F to 3°F by 2050 and 4°F to 7°F by 2100, with larger increases in the mountainous regions to the east. (Modeled high temperatures – average of all models; high carbon emissions scenario)
Precipitation	Low areas are projected to experience declines in annual precipitation of about 2 inches by 2050 and 3 to 4 inches, by 2100 while more elevated areas are projected to experiences loses of approximately 10 inches. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	Heat waves are defined as five days over 79°F to 85°F along the coast and 99°F to 101°F inland. Coastal areas should expect one more heat wave per year by 2050 and four to eight more per year by 2100. Inland, three to four more heat waves are expected to 2050 and eight to ten more per year in 2100.
Snowpack	Snowpack in the eastern elevated regions is projected to decrease by approximately 9 inches, resulting in pack that is less than 4 inches by March 2090. (CCSM3 climate model; high carbon emissions scenario)
Wildfire Risk	The eastern edge of the region is projected to experience an increase in wildfire risk of 4 to 6 times current conditions. (GFDL model, high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

Except for the State Water Project, which derives from Sierra Nevada sources, most of the region's water comes from the region itself. Overall, 66 percent of the region's water comes from groundwater, with the remainder split mostly between federal projects and reuse. Only about 6 percent of the region's total, mostly in San Luis Obispo and Santa Barbara counties, comes from the State Water Project (DWR, 2009). Federal projects (the U.S. Bureau of Reclamation's Santa Maria and Cachuma projects) store floodwater from the Santa Maria River watersheds, using it to replenish groundwater and mitigate saltwater intrusion. The region's water supply in 2005 totaled approximately 1.4 million acre-feet, less than 1 percent of which came from outside regions. Agriculture accounted for the majority of use at about 0.9 million acre-feet, followed by urban use at 0.25 million acre-feet. Total reservoir storage capacity in the region is 1.23 million acre-feet (DWR, 2009).

Biophysical Characteristics

The Central Coast region is characterized by the mountains of the Coast Ranges, which surround the Salinas River valley. The Santa Cruz Mountains, the Santa Lucia Range, and the Diablo Range make up the higher-elevation areas, which reach around 5,800 feet on Junipero Serra Peak.

Redwood forests cover much of Santa Cruz County. Scrub and annual grassland make up most of the coastal vegetation, with annual grasses occupying much of San Benito, San Luis Obispo, Monterey, and Santa Barbara counties. Mixed chaparral is also widespread in the latter three counties along the mountain ranges. Irrigated cropland makes up most of the land along the Salinas River Valley, along with portions of southern Santa Cruz and northern San Benito counties. The coastal areas of this region host a variety of critical habitats, from the near-shore ecosystems along Big Sur to bays such as Monterey to the estuaries, including Elkhorn Slough and Morro Bay.

Regional Entities

- Air Districts: Monterey Bay Unified, San Luis Obispo, Santa Barbara
- Regional Organizations: Association of Monterey Bay Area Governments, San Benito Council of Governments, San Luis Obispo Council of Governments, Santa Barbara County Association of Governments, Santa Cruz County Regional Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Santa Ynez

Selected Infrastructure and Regional Resources

Table 26. Infrastructure and Resources in the Central Coast Region

TYPES	NAMES
Airports	Bonny Doon Village, Hancock Field, Lompoc, Marina Municipal, McChesney Field, Mesa del Rey, Monterey Peninsula, Paso Robles, Salinas Municipal, Santa Barbara Municipal, Santa Ynez, Watsonville Municipal
National and State Parks	National: Channel Islands National Park, Ellicott Slough National Wildlife Reserve, Elkhorn Slough National Estuarine Sanctuary, Los Padres National Forest, Morro Bay National Estuary, Pinnacles National Monument, Salinas River National Wildlife Refuge State: Andrew Molera S.P., Big Basin Redwoods S.P., California Sea Otter State Game Refuge, Castle Rock S.P., Estero Bluffs S.P., Forest of Nisene Marks S.P., Fort Ord Dunes S.P., Fremont Peak S.P., Garrapata S.P., Gaviota S.P., Harmony Headlands S.P., Henry Cowell Redwoods S.P., John Little S.N.R., Julia Pfieffer Burns S.P., Limekiln S.P., Los Osos Oaks S.N.R., Montana de Oro S.P., Morro Bay S.P., Moss Landing State Wildlife Area, Pfeiffer Big Sur S.P., Point Lobos S.N.R., San Simeon S.P., Wilder Ranch S.P.
Passenger Rail	Amtrak
Ports	Monterey Fisherman's Wharf, Moss Landing Harbor District, Santa Cruz Harbor
Power Plants (MWs)*	Marina Landfill (5.4), Southern California Gas/UCSB (.2), Water Street Jail (.18)

S.P. = State Park; S.N.R. = State Natural Reserve; MWs = megawatts

*Located within the 100-year flood zone for 1.5-meter sea level rise, capacity .1 or greater

Selected Demographic Data

Table 27. Top Five Employment Sectors in the Central Coast Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Monterey	Government	Lodging & Food Services	Retail Trade	Health Care	Professional & Technical Services
San Benito	Government	Manufacturing	Retail Trade	Construction	Lodging & Food Services
San Luis Obispo	Government	Retail Trade	Lodging & Food Services	Health Care	Professional & Technical Services
Santa Barbara	Government	Retail Trade	Health Care	Professional & Technical Services	Lodging & Food Services
Santa Cruz	Government	Retail Trade	Health Care	Professional & Technical Services	Construction

[CA REAP, 2011]

Table 28. Selected Population Data for the Central Coast Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Central Coast	1,426,240	92,377	6.50%	174,360	12.20%	219,506		
Monterey	415,057	32,547	7.80%	44,422	10.70%	68,031	17.1	1.7
San Benito	55,269	4,092	7.40%	5,360	9.70%	7,010	12.7	2.6
San Luis Obispo	269,637	13,343	4.90%	41,022	15.20%	36,179	14.3	1.7
Santa Barbara	423,895	27,350	6.50%	54,398	12.80%	72,112	17.7	1.5
Santa Cruz	262,382	15,045	5.70%	29,158	11.10%	36,174	14.2	2

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

The Central Coast region is defined primarily by its coastal setting and a temperate climate that makes it an ideal location for agricultural operations such as berries, lettuce, and wine grapes (California Farm Bureau Federation, 2012). Climate change will affect coastal conditions and temperatures, as well as fire risk and public health and safety.

Sea Level Rise

The region has numerous small communities that depend significantly on tourism. The following areas are likely to see coastal recreation resources such as beaches, wharves, and campgrounds affected by sea level rise: Santa Barbara, Pismo Beach, Morro Bay, Monterey Peninsula, Santa Cruz, and Half Moon Bay. In addition, several large downtowns – including those in Santa Barbara, Monterey, Castroville, and Santa Cruz – lie within areas subject to coastal flooding that will be exacerbated by sea level rise. A 1.4-meter rise in sea level will increase the population vulnerable to a 100-year coastal storm from 26,070 to 38,000. Most of the population at risk is in Monterey and Santa Cruz counties (CCCC, 2009).

Sea level rise is expected to affect vulnerable populations along the coast through the immediate effects of flooding and temporary displacement and longer-term effects of permanent displacement and disruption of local tourism. Impacts could include temporary and/or permanent displacement; drowning and property damage; and coastal erosion harming recreational activities, tourism, and the tourism industry. Of particular concern are populations that do not have the resources to prepare for, respond to, and recover from disasters. Vulnerable populations living in institutional settings are particularly vulnerable during evacuations from disasters. For instance, Santa Cruz County has a high proportion of elderly living in nursing homes that could be affected (English et al., 2007).

Sea level rise also will affect the provision of basic services through disruption of linear infrastructure. Portions of two of the state's major north-south roadways—US 101 and the Pacific Coast Highway (PCH or SR 1)—are located on the coast. Impacts on these roadways could affect regional transportation, access to communities, and access to tourism areas. Weather-related landslides already regularly close SR 1 through Big Sur.

Sea level rise and severe storm surges are a concern for nuclear power plants near the Pacific Ocean, including Diablo Canyon Nuclear Power Plant in San Luis Obispo County. Risks associated with this facility include flooding of containment buildings where highly radioactive spent nuclear fuel is stored and loss of generating capacity owing to severe erosion from the intrusion of seawater and other damages to the facility due to sea level rise. The plant's cooling practices might be affected due to rising ocean temperatures (CDPH, 2008). These impacts could affect those populations who live near the facility or rely on the power produced by the facility.

Finally, communities that depend on groundwater basins within the coastal zone may be affected by saltwater intrusion driven by sea level rise. Of particular concern is the Pajaro Valley, which supplies water for Watsonville and surrounding agricultural areas.

Agriculture

Residential and agricultural development already dramatically impacts some of the endemic species in this region (e.g., through habitat loss). Climate change is projected to further stress these species either through a lack of water (e.g., vernal pools and wetlands) or alteration of habitat conditions (CDFG, 2007). In some cases, species are able to migrate as long as appropriate habitat is available and a pathway to the habitat is unobstructed. In the eastern, warmer, and drier portions of the region, this is a critical consideration for species such as the San Joaquin kit fox (CDFG, 2007).

The ecosystem changes that affect species–including changes in vegetative cover, water availability, seasonal temperature, and precipitation regimes–also affect agricultural. Agriculture plays a significant role in the local economies of the Central Coast region, which produces a large amount of wine grapes, strawberries, lettuce, and vegetable crops (California Farm Bureau Federation, 2012). Climate change has the potential to reduce the productivity of these operations (CAT, 2009). Each crop type has distinct water and temperature needs. As a result, jurisdictions will need to collaborate with agricultural organizations in the region to best support and prepare for impacts.

Fire

A slight increase in large fire occurrence is projected for the region (Westerling and Bryant, 2006), with a large increase in the Monterey Bay Area based on shifting vegetative regimes (Westerling et al., 2009). In addition, a large number of home losses is predicted in Monterey due to large fire occurrence in combination with population density (Bryant and Westerling, 2009). Collaboration with air districts will be required for prescribed burning as a fuel reduction tool. The southern subdistrict of Cal Fire's Coastal District (counties of Santa Cruz, Santa Clara, San Mateo, San Francisco, and Marin) may require extra types of regulations beyond normal California Forest Practice Rules.

Public Health, Socioeconomic, and Equity Impacts

Lodging and food services are among the top five employment sectors in all five counties. Sea level rise may impact the tourism industry and its employees. In addition, workers in these industries who work outside are more susceptible to extreme heat events. Extreme heat events are less likely to occur in the Central Coast region than in California's inland valleys. When they do occur, however, vulnerable populations may be severely affected because of a historic lack of adaptive capacity due to historically milder temperatures.

The higher cost of living in some areas of this region (i.e. San Luis Obispo, Santa Barbara) means low-income families pay a high percentage of their income on housing and transportation. Increases in food and energy costs may impact low-income residents.

ADDITIONAL RESOURCES

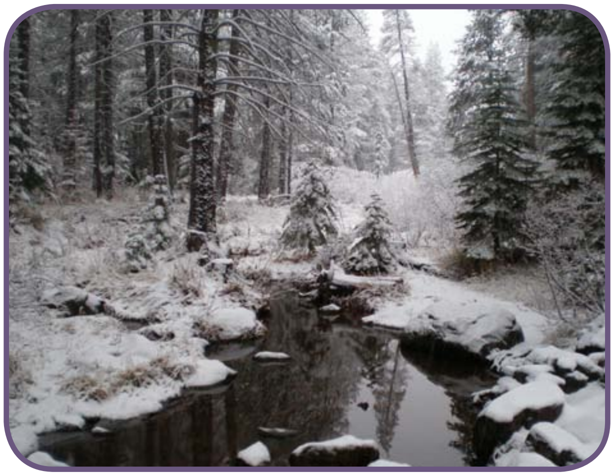
- Sea Level Rise
  - A notable example of regional cooperation is the effort being led by the Center for Ocean Solutions and Monterey Bay National Marine Sanctuary/NOAA to address sea level rise in the Monterey Bay region: http://www.centerforoceansolutions.org/news-events/press-releases/monterey-bay-communities-convened-prepare-climate-change
- Wildfire
  - California Fire Science Consortium, Central & South Coast Module: http://www.cafiresci.org/home-central-and-southern-ca/
  - California Fire Alliance: http://cafirealliance.org/
- California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
  - The Wildlife Action Plan divides the state into regions. The Central Coast Region defined in the Wildlife Action Plan overlaps with the Central Coast region described in this APG.

North Sierra Region

Counties: Amador, Calaveras, El Dorado, Mariposa, Nevada, Placer, Plumas, Sierra, Tuolumne
Five Largest Cities (CDOF, 2011): Roseville (120,593); Rocklin (57,901); Lincoln (43,248); South Lake Tahoe (21,557); Truckee (16,212)

TOTAL 2010 POPULATION	
North Sierra	808,786
Amador	38,091
Calaveras	45,578
El Dorado	181,058
Mariposa	18,251
Nevada	98,764
Placer	348,432
Plumas	20,007
Sierra	3,240
Tuolumne	55,365

[U.S. Census Bureau, 2010]



The North Sierra is a mountainous region that is very sparsely settled (808,000+ people), with a few cities scattered along primary transport routes, the largest being Roseville (118,000+) in the foothills near Folsom Dam. Seventy-two percent of the region's residents reside in El Dorado, Nevada, and Placer counties. The most prominent feature is Lake Tahoe and the surrounding summer and winter resorts. Tourism is a primary economic activity; the region contains six of the top seven counties in the state when tourism revenue is measured as a percentage of total earnings (Sierra Business Council, 2007).

Climate change impacts that should be evaluated by communities located in the North Sierra region include the following:

- Increased temperature
- Decreased precipitation
- Reduced snowpack
- Reduced tourism
- Ecosystem change
- Sensitive species stress
- Increased wildfire

Cal-Adapt Projections

Table 29. Summary of Cal-Adapt Climate Projections for the North Sierra Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 2.5°F to 4°F by 2050 and 6°F to 7°F by 2100. The largest changes are observed in the southern part of the region. July increase in average temperatures: 4°F to 5°F by 2050 and 10°F by the end of the century, with the greatest change in the northern part of the region. (Modeled average temperatures; high emissions scenario)
Precipitation	Precipitation decline is projected throughout the region. The amount of decrease varies from 3 to 5 inches by 2050 and 6 inches to more than 10 inches by 2100, with the larger rainfall reductions projected for the southern portions of the region. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	Heat waves are defined as five consecutive days over 83°F to 97°F depending on location. By 2050, the number of heat waves per year is expected to increase by two. A dramatic increase in annual heat waves is expected by 2100, eight to 10 more per year.
Snowpack	Snowpack levels are projected to decline dramatically in many portions of the region. In southern portions of the region, a decline of nearly 15 inches in snowpack levels – a more than 60 percent drop – is projected by 2090. (CCSM3 climate model; high carbon emissions scenario)
Wildfire Risk	Wildfire risk is projected to increase in a range of 1.1 to 10.5 times throughout the region, with the highest risks expected in the northern and southern parts of the region. (GFDL climate model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

The North Sierra climate region primarily overlaps two Department of Water Resources hydrologic regions: Mountain Counties and North Lahontan. The Sierra Nevada snowpack is the major water source for the entire state of California, but local populations rely on local surface and groundwater resources. For example, South Lake Tahoe's primary water supply comes from underground aquifers through wells, and not from Lake Tahoe. Groundwater aquifers are located in areas such as the upper portions of the substantial Feather River watershed (DWR, 2009). Melting of snowpack provides groundwater recharge throughout the Sierra Nevada and valley aquifers. Reservoirs with the largest capacities, over one million acre-feet, depend on water derived from the Sierra Nevada and include the Don Pedro, Lake Almanor, Lake McClure, New Melones, and Oroville reservoirs (DWR, 2009).

Biophysical Characteristics

The elevation of the counties in the North Sierra region range from under,1000 feet above sea level on the eastern edge of the Central Valley to 14,000 feet above sea level at some of the higher mountain peaks. Major land forms include the canyons in the Sierra Nevada carved by glaciers, such as Yosemite Valley.

Melting snowpack feeds the extensive network of rivers and streams that connect to hundreds of lakes and reservoirs in the region. The major rivers in the Sacramento River hydrologic region include the Feather, Yuba, Bear, and American rivers. The major rivers in the San Joaquin River hydrologic region include the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, Merced, Chowchilla, Fresno, and San Joaquin rivers. Most of the streams and rivers lie on the western slopes because of the pronounced rain shadow effect, leaving desert-like conditions on the other side of the mountain range (DWR, 2009).

With the variation in temperature and elevation, the Sierra Nevada is home to diverse and complex ecosystems. The westernmost edge of the Sierra Nevada along the Central Valley boundary is characterized by woodland and chaparral, where there is high plant biodiversity. The encroachment of human settlements has, however, become a concern at these boundaries. In the lower mountain zone, starting at 3,000 feet, the Ponderosa and Jeffrey pines are characteristic plant forms. With increasing elevation, the mixed conifer zone transitions into an upper mountain zone around 7,000 feet. Generally beginning at 9,500 feet, above the tree line, the alpine zone has limited vegetation because of the harsh climate conditions (UCSNEP, 1996). This region contains more than 3,500 native species of plants, making up more than 50 percent of the plant diversity in California. Vegetation grows along a north-south axis pattern, with the dominant watersheds that flow from east to west contributing to a secondary pattern. Native animal species include the endangered Sierra Nevada red fox, Sierra bighorn sheep, and yellow-legged frog (Sierra Nevada Alliance, 2010).

Regional Entities

- Air Districts: Amador, Calaveras, El Dorado, Mariposa, Northern Sierra, Placer, Tuolumne
- Regional Governments: Amador County Transportation Commission, Calaveras Council of Governments, El Dorado County Transportation Commission, Mariposa County Transportation Commission, Nevada County Transportation Commission, Placer County Transportation Planning Agency, Plumas County Transportation Commission, Sierra County Transportation Commission, Tahoe Metropolitan Planning Organization, Tahoe Regional Planning Agency, Tuolumne County/Cities Area Planning Council
- Tribal Lands (U.S. EPA, 2011): Chicken Ranch, Greenville, Jackson, Sheep Ranch, Shingle Springs, Tuolumne

Selected Infrastructure and Regional Resources

Table 30. Infrastructure and Resources in the North Sierra Region

TYPES	NAMES
Airports	International: Lake Tahoe-Reno Airport General Aviation: Truckee-Tahoe, Nevada County, Auburn Municipal, Georgetown, Placerville, Cameron Airpark, Amador County-Westover Field, Calaveras County, Columbia
National and State Parks	National: Plumas National Forest, El Dorado National Forest, Stanislaus National Forest, Yosemite National Park, Tahoe National Forest, Sequoia National Forest, Kings Canyon National Park State: Burton Creek S.P., Calaveras Big Trees S.P., D.L. Bliss S.P., Donner Memorial S.P., Ed Z'berg Sugar Pine Point S.P., Emerald Bay S.P., Plumas-Eureka S.P., South Yuba River S.P., Tahoe Recreation Area, Washoe Meadows S.P.

S.P. = State Park

Selected Demographic Data

Table 31. Top Five Employment Sectors in the North Sierra Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Amador	Government	Retail Trade	Health Care	Professional & Technical Services	Construction
Calaveras	Government	Construction	Retail Trade	Other Services	Real Estate
El Dorado	Government	Professional & Technical Services	Retail Trade	Finance and Insurance	Real Estate
Mariposa	Lodging & Food Services	Government	Construction	Other Services	Retail Trade
Nevada	Retail Trade	Government	Construction	Health Care	Professional & Technical Services
Placer	Retail Trade	Government	Health Care	Lodging & Food Services	Finance & Insurance
Plumas	Government	Retail Trade	Construction	Lodging & Food Services	Health Care
Sierra	Government	Health Care	Administrative & Waste Services	Professional & Technical Services	Finance & Insurance
Tuolumne	Government	Health Care	Retail Trade	Lodging & Food Services	Construction

[CA REAP, 2011]

Table 32. Selected Population Data for the North Sierra Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
North Sierra	808,786	42,285	5.20%	136,635	16.90%	82,876		
Amador	38,091	1,431	3.80%	7,865	20.60%	4,286	12.8	2.6
Calaveras	45,578	1,992	4.40%	9,565	21.00%	4,996	11.1	2.7
El Dorado	181,058	9,513	5.30%	26,524	14.60%	16,825	9.4	1.6
Mariposa	18,251	775	4.20%	3,821	20.90%	2,665	14.8	3
Nevada	98,764	4,365	4.40%	19,174	19.40%	11,456	11.7	1.8
Placer	348,432	20,851	6.00%	53,562	15.40%	31,489	9.1	0.9
Plumas	20,007	883	4.40%	4,154	20.80%	3,012	15.3	2.7
Sierra	3,240	147	4.50%	676	20.90%	427	13.4	3
Tuolumne	55,365	2,328	4.20%	11,294	20.40%	7,720	15.2	3

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates

Adaptation Considerations

The North Sierra is rich in natural resources. It is the source for the majority of the water used by the state and home to a varied landscape supporting rich biodiversity.

In the past, this region relied on industries such as mining, timber production, and agriculture. Population growth in recent decades has shifted the region's economy to be driven by the provision of services, tourism, and second home development (Sierra Business Council, 2007). Today, the region's economy is primarily tourism-based. Climate change has the potential to disrupt many features that characterize the region, including ecosystem health, snowpack, and the tourist economy.

Ecosystems and Biodiversity

One of the biggest threats to the ecosystems of the North Sierra is development pressure, including ski area development, second home development, and agriculture (including timber). While these pressures are not caused by climate change, they interact with the changes in climate to further stress ecosystems and endemic species. Climate change can cause habitats to shift, creating conditions inhospitable to these species (CDFG, 2007). As a result, plant and animal species tend to migrate either up in elevation or farther north. Development can limit opportunities for migration and also introduce non-native species, which can further damage habitat.

Timber practices have also had ecosystem consequences that are exacerbated by climate change. The timber industry has resulted in forests with trees of similar age, lacking snags and underbrush. These management practices reduce the diversity of the habitat. In addition, logging road construction and fire suppression has also altered these habitats (CDFG, 2007).

The most altered habitat in the Sierra is aquatic and riparian systems. The causes of this change include development and water diversion (CDFG, 2007). Changes in hydrologic flow regime and increased temperature will further stress these systems, which are home to many special- status species.

Snowpack and Flooding

The North Sierra snowpack serves as a reservoir for the rest of the state. The climate-related decrease in snowpack therefore will have dramatic consequences on the lowland area that depends on this water.

In addition, the snowpack decrease may cause the North Sierra region to experience detrimental impacts from flooding, landslide, and loss of economic base (e.g., skiing). These flood events are likely to put additional pressure on water infrastructure and increase the chance of flooding along waterways. Flooding and damage to infrastructure can put large populations at risk (CDPH, 2008). The populations at risk include the elderly and children, who are isolated or dependent on others for evacuation. Populations that lack the resources or knowledge to prepare or respond to disaster due to language barriers or economic status, including having access to transportation, which would allow them to escape, at least temporarily, flooding also may be at risk (English et al., 2007).

More than any other part of the state, the North Sierra region relies on tourism as its economic base. Recreation and tourism are also likely to suffer due to lower water levels in waterways and reservoirs and declining snowpack. Reduced recreational opportunities due to fewer ski days or low water levels will affect the other economic sectors fed by tourism such as hotels, restaurants, and second home development. In addition, employees of these industries may become more economically vulnerable because of unstable working conditions.

Wildfire

Despite the fact that the ecosystems in the North Sierra have evolved with recurring fire, there is a long history of fire suppression in the North Sierra region. Recently, fire has been recognized as a critical part of ecosystem function (CDFG, 2007). The challenge is twofold: (1) a century of built-up fuel due to suppression cannot be remedied quickly, and (2) the number of structures that have been built throughout the region make it difficult to let fires burn.

To this mix, climate change is added. Climate change is projected to result in large increases in wildfire frequency and size. The expected property loss is likely to be highest in areas with higher population densities (Westerling and Bryant, 2006).

Fire can also set in motion a series of other potential impacts. Following fire, an intense rainstorm can result in landslide or large erosion events that can have drastic consequences for the receiving stream, river, or lake.

Public Health, Socioeconomic, and Equity Impacts

The foothill areas outside the Sacramento area (e.g., Placerville, Auburn, Grass Valley) show higher ozone levels and increased temperatures. People over the age of 65 have the largest increase in mortality with increased concentrations of ozone (Medina-Ramon and Schwartz, 2008), and the elderly make up approximately 20 percent of the population in Amador, Calaveras, Mariposa, Nevada, Plumas, Sierra, and Tuolomne counties. In addition, people who work or spend a lot of time outdoors, such as employees of the tourist industry (Lake Tahoe), are vulnerable. In Mariposa, Placer, Plumas, and Tuolomne counties, lodging and food services rank among the top five employment sectors. The combination of diminished snowpack and exposure to higher ozone levels may make these populations particularly vulnerable.

ADDITIONAL RESOURCES

- Wildfire Resources
  - California Fire Science Consortium, Sierra Nevada Module: http://www.cafiresci.org/homepage-sierra-nevada/
  - Northern California Prescribed Fire Council: http://www.norcalrxfirecouncil.org/Home_Page.html
  - NorCal Society of American Foresters: http://norcalsaf.org/
  - Quincy Library Group: http://qlg.org/
  - California Fire Alliance: http://cafirealliance.org/
  - California FireSafe Council: http://www.firesafecouncil.org/
- Biodiversity and Ecosystems
  - Sierra Nevada Ecosystem Project: http://ceres.ca.gov/snep/
  - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
  - The Wildlife Action Plan divides the state into regions. The Sierra Nevada and Cascades Region overlaps with the North Sierra region.
  - Tahoe Regional Planning Agency: http://www.trpa.org/

Southeast Sierra Region

Counties: Alpine, Inyo, Mono
Cities (CDOF, 2011): Mammoth Lakes (8,286); Bishop (3,893)

TOTAL 2010 POPULATION	
Southeast Sierra	33,923
Alpine	1,175
Inyo	18,546
Mono	14,202

[U.S. Census Bureau, 2010]

The Southeast Sierra is a combination mountainous and desert region and is the most sparsely settled (33,000+ people) of all the climate regions. A few small towns scattered along Highway 395 are heavily used for tourism access to Las Vegas and Lake Tahoe to the north as well as the Sierra Nevada to the west. The largest settlement is the ski resort town of Mammoth Lakes (8,200+), where the winter population swells with ski season. Tourism is a major economic activity in this region, with 50 percent or more of new home construction in Alpine and Mono counties being second home development. There are also modest agricultural operations in this region.

Communities located in the Southeast Sierra region should consider evaluating the following climate change impacts:

- Increased temperatures
- Reduced precipitation
- Reduced tourism
- Substantially reduced snowpack
- Flooding

Cal-Adapt Projections

Table 33. Summary of Cal-Adapt Climate Projections for the Southeast Sierra Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 1.5°F to 2.5°F by 2050 and 5°F to 10°F by 2100. July increase in average temperatures: 3°F to 5°F by 2050 and 8°F to 10°F (Modeled high temperatures; average of all models; high carbon emissions scenario)
Precipitation	Potential precipitation decline is between 0 and 4 inches by 2050 and 1 and 15 inches by 2100. The range varies widely depending on location. Some areas receive less than 6 inches annually, with projected reductions bringing totals under 4 inches by 2090. In other areas, total rainfall exceeds 45 inches per year and is projected to decrease by roughly 15 inches by 2090. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	There is a lot of variation in heat wave threshold in this region. To the north a heat wave is five days over temperatures in the 80s. To the south, a heat wave is five days over temperatures as high as 115°F. By 2050, there will be 2 to 3 more heat waves per year, increasing up to over 14 to 16 per year by 2100.
Snowpack	Snowpack levels are projected to decline dramatically by 2090 in some areas, with drops of over 50 percent. (CCSM3 climate model; high carbon emissions scenario)
Wildfire Risk	By 2085, wildfire risk is projected to increase substantially (up to 19.1 times) over current levels in Alpine County and the northern part of Mono County. The rest of Mono County and all of Inyo County is projected to have a wildfire risk between 1.1 to 4.8 times greater than current levels. (GFDL climate model; high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org. Sierra Nevada Alliance, 2010.]

Water Sources

This climate region occupies the southern portion of the North Lahontan hydrologic region and the Mono and Inyo county portions of the South Lahontan hydrologic region. Groundwater meets over 65 percent of urban, agricultural, and environmental water demands in the South Lahontan. Locally developed surface water accounts for 90 percent of water consumption in the region (DWR, 2009). Much of the surface water, however, is not available locally because of water appropriation rights that lay claim to the region's water resources. For example, Inyo County has a joint agreement with the Los Angeles Department of Water and Power for groundwater pumping and surface water management in the Owens Valley. The Owens Valley Basin has an estimated capacity of 30 to 35 million acre-feet (DWR, 2009). Replenishment of the basin comes primarily from percolation of the surrounding mountains' stream flow. Major water bodies include Mono Lake, June Lake, Grant Lake, and Lundy Reservoir (Mono County Community Development Department, Planning Division, 2007).

Biophysical Characteristics

The southeastern part of the Sierra is generally dry and arid, typical of regions affected by the rain shadow along mountain ranges. The Southeast Sierra is the location of the highest point in California–Mount Whitney, at 14,505 feet above sea level–and also the lowest point, at 282 feet below sea level in Death Valley National Park. Both features are in Inyo County. Mono Lake in Mono County supports a distinct ecosystem, while the dry lakebed of Owens Lake in Inyo County is a significant reminder of the critical role of water in the state. Mono Lake is also a prominent stop for migrating birds. Major vegetation in the three counties bordering the desert of Nevada include desert shrub, alkali desert shrub, and bristlecone pines in Inyo County and Jeffrey pine, red firs, and subalpine conifers in Alpine County (FRAP, 1998).

Regional Entities

- Air District: Great Basin Unified
- Regional Organizations: Alpine Local Transportation Commission, Inyo County Transportation Commission, Mono County Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Benton Paiute, Big Pine, Bishop, Bridgeport, Fort Independence, Lone Pine, Washoe (Woodfords Community)

Selected Infrastructure and Regional Resources

Table 34. Infrastructure and Resources in the Southeast Sierra Region

TYPES	NAMES
Airports	Primary: Mammoth Yosemite Airport General Aviation: Eastern Sierra Regional, Independence, Lone Pine, Bryant, Lee Vining
National & State Parks	National: Death Valley National Park, Inyo National Forest State: Grover Hot Springs State Park, Mono Lake Tufa State Park

Selected Demographic Data

Table 35. Top Five Employment Sectors in the Southeast Sierra Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Alpine	Lodging & Food Services	Government	Arts, Entertainment & Recreation	Construction	Other Services
Inyo	Government	Lodging & Food Services	Retail Trade	Other Services	Construction
Mono	Lodging & Food Services	Government	Real Estate	Retail Trade	Construction

[CA REAP, 2011]

Table 36. Selected Population Data for the Southeast Sierra Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
South-east Sierra	33,923	2,034	6.00%	5,078	15.00%	4,261		
Alpine	1,175	71	6.00%	166	14.10%	196	16.9	4
Inyo	18,546	1,070	5.80%	3,535	19.10%	2,535	13.9	2.7
Mono	14,202	893	6.30%	1,377	9.70%	1,530	10.8	2.5

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

The sparsely populated Southeast Sierra region relies heavily on tourism. All three counties in the Southeast Sierra rank in the top seven in the state for tourism revenue as a percentage of total revenue. Second home construction makes up more than half of all home construction in two of the counties.

Similar to the North Sierra, the Southeast Sierra region serves as a source for water for other areas of the state, specifically Los Angeles.

Ecosystems and Biodiversity

This region has an incredibly varied set of ecosystems, from high mountains to arid regions to areas with high rainfall. This diversity means that a large number of endemic species are supported in the region. Climate change–from reduced rainfall to increased temperatures to altered hydrologic regimes–will stress these species. In some areas, there is currently very little rainfall. A small decrease or prolonged drought can detrimentally affect species adapted to this setting (CDFG, 2007).

Species stressed by alteration of their preferred habitat may have the ability to migrate. Migration is easiest for terrestrial species; these species will most often move farther north or to a higher elevation. Any number of factors, such as road construction or development, can inhibit migration.

Snowpack and Flooding

The Southeast Sierra region is home to mountainous areas that have consistent annual snowpack. Aquatic systems rely on this snowpack, as do those downstream jurisdictions that depend on it for water supply. Increased temperatures can result in precipitation falling as rain instead of snow and in rapid snowmelt events. These events can cause flooding and erosion and ultimately result in reduced water supply. Flood events also put additional pressure on water infrastructure. These impacts increase the chance of flooding along waterways. Flooding and damage to infrastructure can put large populations at risk (CDPH, 2008), particularly the elderly and children less than five years of age, who are isolated or dependent on others for evacuation (English et al., 2007).

The loss of snowpack will also have detrimental economic consequences as it is a primary draw for the tourist industry in the region, particular in Mammoth Lakes. Employees of this industry may become more economically vulnerable because of unstable working conditions.

Public Health, Socioeconomic, and Equity Impacts

Inyo County is one of California's counties with the highest proportion of elderly living alone in the state, although the absolute number is relatively smaller than in more urban areas (English et al., 2007). Extreme heat events are less likely to occur in the Southeast Sierra region than in other parts of the state. However, when extreme heat events do occur, vulnerable populations may be severely affected because of a historic lack of adaptive capacity having to do with historically milder temperatures.

ADDITIONAL RESOURCES

- Wildfire Resources
    - California Fire Science Consortium, Sierra Nevada Module: http://www.cafiresci.org/homepage-sierra-nevada/
    - Northern California Prescribed Fire Council: http://www.norcalrxfirecouncil.org/Home_Page.html
    - SoCal Society of American Foresters: http://norcalsaf.org/
    - California Fire Alliance: http://cafirealliance.org/
    - California FireSafe Council: http://www.firesafecouncil.org/
- Biodiversity and Ecosystems
    - Sierra Nevada Ecosystem Project (http://ceres.ca.gov/snep/
    - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
    - The Wildlife Action Plan divides the state into regions. The Sierra Nevada and Cascades and Mojave Desert Regions overlap with the Southeast Sierra region.

South Coast Region

Counties: Los Angeles, Orange, San Diego, Ventura
Five Largest Cities (CDOF, 2011): Los Angeles (3,810,129); San Diego (1,311,882); Long Beach (463,894); Anaheim (341,034); Santa Ana (325,228)

TOTAL 2010 POPULATION	
South Coast	16,747,468
Los Angeles	9,818,605
Orange	3,010,232
San Diego	3,095,313
Ventura	823,318

[U.S. Census Bureau, 2010]

The South Coast (16+ million people) is the most heavily urbanized region in the state. The region consists of sprawling suburban development interspersed with dense urban centers, most notably Los Angeles (3.8+ million people) and San Diego (1.3+ million people). The character of the region is defined by the predominant feature of the Southern California coastline, accompanied by the San Gabriel Mountains and coastal mountains to the south. Corners of the region, such as the high desert community of Lancaster, differ substantially in context. However, the most prominent regional feature is the sprawling coastal metropolis along a coastal plain, interspersed with low-lying hills and a few inland areas such as the San Fernando and San Gabriel valleys.

Communities in the South Coast region should consider evaluating the following climate change impacts:

- Increased temperatures
- Reduced precipitation
- Sea level rise
- Reduced tourism
- Reduced water supply
- Wildfire risk
- Public health - heat and air quality
- Coastal erosion

Cal-Adapt Projections

Table 37. Summary of Cal-Adapt Climate Projections for the South Coast Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 1°F to 2.5°F by 2050 and 5°F to 6°F by 2100 July increase in average temperatures: 3°F to 4°F by 2050 and 5°F to 10°F by 2100 with larger increases projected inland. (Modeled high temperatures; high carbon emissions scenario)
Precipitation	Annual precipitation will vary by area but decline overall throughout the century. Low-lying coastal areas will lose up to 2 inches by 2050 and 3 to 5 inches by 2090, while high elevations will see a drop of 4 to 5 inches by 2050 and 8 to 10 inches by 2090. (CCSM3 climate model; high emissions scenario)
Sea Level Rise	By 2100, sea levels may rise 55 inches, posing threats to many areas in the region including Venice Beach, the Port of Long Beach, the South Coast naval stations, and San Diego Harbor. As a result of sea level rise, 45 percent more land in Los Angeles County, 40 percent more land in San Diego County, 35 percent more land in Ventura County, and 28 percent more land in Orange County will be vulnerable to 100-year floods.
Heat Wave	Along the coast, a heat wave is five days over temperature in the 80s. Inland, the temperature must hit the 90s and 100s for five days. All areas can expect 3 to 5 more heat waves by 2050 and 12 to 14 by 2100 in most areas of the region.
Snowpack	March snowpack in the San Gabriel Mountains will decrease from the 0.7-inch level in 2010 to zero by the end of the century. (CCSM3 climate model; high emissions scenario)
Wildfire Risk	Little change is projected in the already high fire risk in this region, save for slight increases expected in a few coastal mountainous areas such as near Ojai and in Castaic, Fallbrook, and Mission Viejo.

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

The South Coast hydrologic region encompasses Ventura, Los Angeles, Orange, and San Diego counties, as well as the southwestern portion of San Bernardino County and western Riverside County. The region derives its water supply primarily from the State Water Project (SWP) (which draws from the Sierra), the Colorado River, groundwater, and local imports. These sources vary in quantity in a given year, but on average the SWP and groundwater provide more than 1 million acre-feet each, while the Colorado River provides nearly the same. Depending on the water supply in a given year, approximately 5 million acre-feet of water are used. Most of the use is by urban areas at around 4 million acre-feet, followed by agriculture, which uses about 0.5 to 1 million acre-feet annually. Total reservoir storage capacity is about 3 million acre-feet (DWR, 2009).

Biophysical Characteristics

The South Coast region contains several mountain ranges surrounding the coastal basins of the Santa Clara, Los Angeles, and Santa Ana rivers. Elevation ranges from sea level at the coast to around 200 feet for most of the urban areas (State of California, 2005c). The mountain ranges, which peak at about 8,000 feet, are the major physical features of the South Coast counties and include the Sierra Madres, the Transverse Ranges, and the Peninsular Ranges in Ventura, Los Angeles, and San Diego counties, respectively (DWR, 2009). Between the latter two ranges lies the 35mile-by-15-mile Los Angeles Basin, which is almost entirely urbanized. The largest rivers are the Los Angeles, San Diego, San Gabriel, San Luis Rey, Santa Ana, Santa Clara, and Santa Margarita. Due to urbanization, vegetation is constrained to the mountains and consists mostly of scrub and chaparral. Wildlife includes mountain lions, coyotes, raccoons, golden eagles, ospreys, brown pelicans, kangaroo rats, and foxes (grey and kit) (FRAP, 1998). Marine life includes whales, dolphins, and California sea lions.

Regional Entities

- Air Districts: San Diego, South Coast, Ventura
- Regional Governments: Southern California Association of Governments, San Diego Association of Governments, Los Angeles Metropolitan Transportation Authority, Orange County Transportation Authority, Ventura County Transportation Commission
- Tribal Lands (U.S. EPA, 2011): Barona; Campo, Capitan Grande, Cuyapaipe, Inaja-Cosmit, Jamul Indian Village, La Jolla, La Posta, Los Coyotes, Manzanita, Mesa Grande, Pala, Pauma-Yuima, Rincon, San Pasqual, Santa Ysabel, Sycuan, Table Mountain, Viejas

Selected Infrastructure and Regional Resources

Table 38. Infrastructure and Resources in the South Coast Region

TYPES	NAMES
Airports	International: Los Angeles International, San Diego International General Aviation: Bob Hope, Camarillo, El Monte, Fallbrook Community Airpark, John Wayne, Long Beach, Oxnard, Van Nuys, Whiteman
National and State Parks	National: Angeles National Forest, Cabrillo National Monument, Channel Island National Park, Cleveland National Forest, Los Padres National Forest, Santa Monica Mountains National Recreation Area State: Antelope Valley Poppy Reserve, Arthur Ripley Desert Woodland S.P., Anza-Borrego Desert S.P., Border Field S.P., Chino Hills S.P., Crystal Cove S.P., Cuyamaca Rancho S.P., Leo Carillo S.P., Malibu Creek S.P., Palomar Mountain S.P., Placerita Canyon S.P., Point Mugu S.P. Ripley Desert Woodland S.P., Saddleback Butte S.P., Topanga S.P., Torrey Pine State Reserve
Passenger Rail	Amtrak, Los Angeles County Metro Rail, Metrolink, San Diego County Coaster and Sprinter
Ports	Bulk & Container: Port of Hueneme, Port of Long Beach, Port of Los Angeles, Port of San Diego Other: Avalon, Dana Point Harbor, Oceanside Harbor, Redondo Beach Harbor, Two Harbors
Power Plants (MWs)*	El Segundo (1,020), Southeast Resource Recovery (34.6), Harbor Cogen (107), Long Beach Peaker (260), Alamitos Generating Station (2,010), Queen Mary (1), Haynes (1,570), Orange County Sanitation District-Plant No. 2 (18), Huntington Beach (904), Goodrich Cogeneration Center Plant (9.5), Eastside Water Renovation (.5), Mandalay (560), Ormond Beach (1,520)

S.P. = State Park; MW: Megawatt

Selected Demographic Data

Table 39. Top Five Employment Sectors in the South Coast Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Ventura	Government	Retail Trade	Health Care	Manufacturing	Finance & Insurance
Los Angeles	Government	Health Care	Retail Trade	Professional & Technical Services	Manufacturing
Orange	Professional & Technical Services	Retail Trade	Manufacturing	Government	Health Care
San Diego	Government	Professional & Technical Services	Retail Trade	Health Care	Lodging & Food Services

[CA REAP, 2011]

Table 40. Selected Population Data for the South Coast Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	% < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
South Coast	16,747,468	1,096,243	6.50%	1,863,110	11.10%	2,598,624		
Los Angeles	9,818,605	645,793	6.60%	1,065,699	10.90%	1,699,264	17.6	0.4
Orange	3,010,232	191,691	6.40%	349,677	11.60%	363,924	12.2	0.6
San Diego	3,095,313	203,423	6.60%	351,425	11.40%	445,556	14.8	0.7
Ventura	823,318	55,336	6.70%	96,309	11.70%	89,880	11	1.3

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

The South Coast is a highly urbanized region. High population density also creates greater vulnerability to climate-related hazards simply because more people are in harm's way. The concentration of population on the coast has the potential to affect public safety, infrastructure, and the integrity of coastal ecosystems. In addition, the urban setting can also amplify public health risks because increased temperatures are even higher due to the urban heat island.

Sea Level Rise

Sea level rise has the potential to result in far-reaching impacts on the South Coast region. Sea level rise may affect the region's tourism–the largest value tourist industry in the state (NOEP, 2005)–as well as other considerable assets, including international airports and seaports.

A study by the California Department of Boating and Waterways and San Francisco State University (*n.d.*) using three example beaches in the region shows considerable loss of recreational and ecological benefits due to sea level rise. A 1.4-meter rise in sea level will increase the population vulnerable to a 100-year coastal storm from 86,000 to 149,300. Most of the population at risk is in Orange County (CCCC, 2007). Areas near Huntington Beach, Seal Beach, the Port of Long Beach, Marina Del Rey, and Port Hueneme also will be of particular concern in the region due to the significant inland penetration of flood waters exacerbated by sea level rise (cal-adapt.org, PIER, 2011).

Sea level rise is expected to affect vulnerable populations along the coast through the immediate effects of flooding and temporary displacement and longer-term effects of permanent displacement and disruption of local tourism. Of particular concern are populations that do not have the resources to prepare for, respond to, and recover from disasters. Impacts could include temporary and/or permanent displacement; drowning and property damage; and coastal erosion harming recreational activities, tourism, and the tourism industry.

Sea level rise and severe storm surges are a concern for nuclear power plants near the Pacific Ocean, including the San Onofre Nuclear Power Plant in Orange County. Risks associated with this facility include flooding of containment buildings where highly radioactive spent nuclear fuel is stored, loss of generating capacity owing to severe corrosion from the intrusion of seawater, and other damages to the facility due to sea level rise. The plant's cooling practices might be impacted due to rising ocean temperatures. (CDPH, 2008) These impacts could affect populations that live near the facility or rely on the power produced by the facility. Industrial development in the region has left a legacy of brownfields and contaminated waste sites. Some of these will be exposed to coastal flooding due to sea level rise. These sites need to be identified, and priorities for their clean-up may need to be set before contamination spreads.

Wildfire

The South Coast already experiences wildfire. The extent to which climate change is projected to alter existing wildfire risk is variable (Westerling and Bryant, 2006). Wildfire frequency and severity will depend on shifts in vegetation and Santa Ana wind behavior (Miller and Schlegal, 2006; Westerling et al., 2009). Management of fire risk such as prescribed burns may be subject to regulations beyond normal California forest practice. For example, the "High Use" subdistricts of Cal Fire's Southern District (counties of Ventura, Santa Barbara, Los Angeles, San Bernardino, Orange, Riverside, Imperial, San Diego, Monterey, San Luis Obispo, and those portions of Placer and El Dorado counties lying within the authority of the Tahoe Regional Planning Agency) may have additional stipulations with regard to management practice.

Increased temperature and decreased moisture, such as longer drought periods, will increase fire vulnerability in a number of areas. Along with impacts associated with temporary and/or permanent displacement, long-term impacts on the elderly and children under the age of five are of concern. Eye and respiratory illnesses due to air pollution resulting from wildfires, and exacerbation of asthma, allergies, chronic obstructive pulmonary disease (COPD), and other cardiovascular diseases are likely to increase.

Public Health, Socioeconomic, and Equity Impacts

In the highly populated areas within this region, "urban heat islands" will exacerbate the public health impacts that poor air quality and heat waves have upon the more vulnerable populations of this area. The highest percentages of impervious surfaces are in the urban areas of Los Angeles and San Diego counties, increasing the potential impacts of heat islands (English et al., 2007). Southern California's urban centers are warming more rapidly than other parts of the state (English et al., 2007). Los Angeles, San Diego, and Orange counties rank first, second, and third in the state in absolute numbers of the elderly and children less than five years of age. These two populations are most likely to suffer from heat-related illnesses and heat events (English et al., 2007).

Because of the significant and varied population in this region, there is also likely to be a significant population that fits into a number of the socially vulnerable categories lacking adaptive capacity. This increases the vulnerability of these populations.

The higher cost of living in some areas of this region means low-income families pay a high percentage of their income on housing and transportation. Increases in food and energy costs may impact low-income residents.

Water Supply

Two primary sources of water used by the South Coast region are the State Water Project and the Colorado River. In both cases, these water supplies originate in mountain snowpack. Climate change will result in reduced snowpack, which will translate into reduced water supply. Further threatening the regional water supply is the vulnerability of the levees protecting the California Delta, which feeds the State Water Project (DWR, 2011). Jurisdictions in the South Coast must carefully consider the vulnerability of their water supply.

Climate change will reduce water supply and subsequently increase costs. Industries reliant on water may be affected, resulting in reduced revenue and employment base.

ADDITIONAL RESOURCES

- Sea Level Rise
  - In San Diego, the Public Agency Steering Committee, working with ICLEI-Local Governments for Sustainability and The San Diego Foundation, developed the "Sea Level Rise Adaptation Strategy for San Diego Bay." Source: http://www.cakex.org/sites/default/files/documents/San_Diego_Bay_SLR_Adaptation_Strategy_Complete.pdf. This should serve as a key reference for communities in the region.
- Wildfire
  - California Fire Science Consortium, Central & South Coast Module: http://www.cafiresci.org/home-central-and-southern-ca/
  - SoCal Society of American Foresters: http://norcalsaf.org/
  - Southern California Association of Foresters & Fire Wardens: http://scaffw.org/SCAFFW_home.htm
  - California Fire Alliance: http://cafirealliance.org/
    California FireSafe Council: http://www.firesafecouncil.org/
- Public Health, Socioeconomic, and Equity Impacts
  - The Los Angeles County Department of Health Services' Office of Health Assessment and Epidemiology has produced an excellent resource: Premature Deaths from Heart Disease and Stroke in Los Angeles County: A Cities and Communities Health Report (www.lapublichealth.org/epi/docs/CHR_CVH.pdf). Notably, this report provides information on heart disease and stroke, as well as economic hardship, by city or community (spatializing the data to inform built environmental planning decisions). (Public Health Law and Policy, How to Create a Healthy General Plan, 2008)
  - Los Angeles and San Diego counties are two of a few places in California with real-time surveillance data for communicable diseases and outbreaks. (CDPH, 2008)

Desert Region

Counties: Imperial, Riverside, San Bernardino
Five Largest Cities (CDOF, 2011): Riverside (305,779); San Bernardino (211,076); Fontana (198,456); Moreno Valley (195,215); Ranch Cucamonga (168,181)

TOTAL 2010 POPULATION	
Desert	4,399,379
Imperial	174,528
Riverside	2,189,641
San Bernardino	2,035,210

[U.S. Census Bureau, 2010]

The Desert is a heavily urbanized inland region (4.3+ million people) made up of sprawling suburban development in the west near the South Coast region and vast stretches of open, largely federally owned desert land to the east. Prominent cities within the desert portion include Palm Springs (44,500+) and El Centro (42,500+). The region's character is defined largely by the San Gabriel Mountains, San Gorgonio Mountains, San Jacinto Mountains, and smaller inland mountains reaching through the desert to the Colorado River, which borders the region on the east.

Communities in the Desert region should consider evaluating the following climate change impacts:

- Reduced water supply
- Increased temperature
- Reduced precipitation
- Diminished snowpack
- Wildfire risk
- Public health and social vulnerability
- Stress on special-status species

Cal-Adapt Projections

Table 41. Summary of Cal-Adapt Climate Projections for the Desert Region

EFFECT	RANGES
Temperature Change, 1990-2100	January increase in average temperatures: 2°F to 4°F by 2050 and 5°F to 8°F by 2100 July increase in average temperatures: 3°F to 5°F by 2050 and 6°F to 9°F by 2100 (Modeled high temperatures; high carbon emissions scenario)
Precipitation	Generally, annual rainfall will decrease in the most populous areas. Wetter areas like the western part of Riverside and southwestern San Bernardino counties will experience a 2 to 4 inch decline by 2050 and 3.5 to 6 inch decline by the end of the century. Big Bear is expected to lose around 8 inches per year by 2090. Southern Imperial County will have a small decline of about 0.5 inches. The eastern, desert portion of the region will see little to no change in annual rainfall. (CCSM3 climate model; high carbon emissions scenario)
Heat Wave	Heat waves are defined by five consecutive days over temperatures in the 100s over most of the region. Three to five more heat waves will be experienced by 2050, increasing to 12 to 16 in the western parts of the region to more than 18 to 20 in the eastern parts of the region.
Snowpack	March snowpack in the Big Bear area will diminish from the 2.5-inch level of 2010 to 1.4 inches in 2030 and almost zero by 2090. (CCSM3 climate model; high emissions scenario)
Wildfire Risk	Most areas are projected to have the same or slightly increased likelihood of wildfire risk. The major exceptions are the Mecca San Gorgonio and San Jacinto Mountains, where wildfire will be 1.5 and 2.0 times more likely. (GFDL model, high carbon emissions scenario)

[Public Interest Energy Research, 2011. Cal-Adapt. Retrieved from http://cal-adapt.org]

Water Sources

Water for most of the Desert region is supplied primarily from the State Water Project, the Colorado River, and local groundwater. The less-populated eastern part of the region uses approximately 4.5 million acre-feet of water annually. Nearly 4 million acre-feet come from the Colorado River, while almost 0.5 million acre-feet are supplied from the State Water Project and groundwater. Usage is split between agriculture, at nearly 4 million acre-feet, and urban consumption, at approximately 0.5 million acre-feet. Storage capacity in the region's reservoirs totals 0.62 million acre-feet (DWR, 2009).

Note: The State of California measures water supply/usage for the populous western Riverside County and southwestern San Bernardino County as part of the South Coast hydrologic region, which also includes Los Angeles, San Diego, Orange, and Ventura counties. Please see the South Coast region summary for more information.

Biophysical Characteristics

The Mojave and Colorado deserts dominate the geography of the Desert region. These hot, arid lands lie east of the San Bernardino and San Jacinto mountains. The Colorado Desert is low-lying, below 1,000 feet in elevation, and is home to desert scrub, palm oasis, and desert wash. Native birds and animals include muskrats, mule deer, coyotes, bobcats, and the Yuma antelope ground squirrel (State of California, 2005a). The Salton Sea, a saltwater lake and the largest lake in California, is situated in the middle of the Colorado Desert. Both northwest and south of the Salton Sea are large agricultural areas irrigated by the Colorado River. The vast majority of the population inhabits the western edge of the region, particularly along the Santa Ana River, in the valley between the San Gabriel, San Bernardino, San Jacinto, and Santa Ana mountains (State of California, 2005a).

By contrast, most of the Mojave region is uninhabited and is owned and managed by the United States Bureau of Land Management. Plant species include desert wash and scrub, alkali and Joshua tree scrub, and palm oasis. Native and rare animals include bighorn sheep, desert tortoise, prairie falcon, and the Mojave ground squirrel. The natural recreational attractions for the region include the Salton Sea, the Picacho State Park along the Colorado River at the Arizona border, and Joshua Tree National Park (State of California, 2009).

Regional Entities

- Air Districts: Imperial, Mojave Desert, South Coast
- Regional Organizations: Imperial Valley Association of Governments, Riverside County Transportation Commission, San Bernardino Associated Governments, San Bernardino County Transportation Commission, Southern California Association of Governments, Western Riverside Council of Governments
- Tribal Lands (U.S. EPA, 2011): Agua Caliente, Augustine, Cabazon, Cahuila, Chemehuevi, Colorado River, Fort Mojave, Morongo, Pechanga, Quechan, Ramona, San Manuel, Santa Rosa, Soboba, Torres-Martinez, Twenty-Nine Palms

Selected Infrastructure and Regional Resources

Table 42. Infrastructure and Resources in the Desert Region

TYPES	NAMES
Airports	International: Ontario International General Aviation: Big Bear City; Cable (Upland), Cliff Hatfield Memorial (Calipatria), Corona Municipal, Hesperia, Holtville, Imperial County, Needles, Riverside Municipal
National & State Parks	National: Joshua Tree National Park, Mojave National Preserve, San Bernardino National Forest, Salton Sea National Wildlife Refuge State: Anza-Borrego Desert State Park, Chino Hills State Park, Mount San Jacinto State Park, Salton Sea State Park

Selected Demographic Data

Table 43. Top Five Employment Sectors in the Desert Region

EMPLOYMENT SECTOR RANKING					
County	**1**	**2**	**3**	**4**	**5**
Imperial	Government	Retail Trade	Health Care	Lodging & Food Service	Manufacturing
Riverside	Government	Retail Trade	Health Care	Lodging & Food Service	Construction
San Bernardino	Government	Retail Trade	Health Care	Lodging & Food Service	Transportation & Warehousing

[CA REAP, 2011]

Table 44. Selected Population Data for the Desert Region

						POPULATION BELOW POVERTY LEVEL		
	Total 2010 Pop.	Pop. <5 years	Percent < 5 years	Pop. ≥65 years	Percent ≥65 years	Estimated - All Ages	Estimated Percent	Margin of Error
Desert	4,399,379	334,754	7.60%	458,086	10.40%	753,533		
Imperial	174,528	13,526	7.80%	18,152	10.40%	36,666	22.3	2.9
Riverside	2,189,641	162,438	7.40%	258,586	11.80%	354,768	16.4	0.9
San Bernardino	2,035,210	158,790	7.80%	181,348	8.90%	362,099	18.1	1.1

[U.S. Census Bureau, 2010, General Population and Housing Characteristics & Small Area Income and Poverty Estimates]

Adaptation Considerations

The Desert region has a large population along its western edge and smaller populations to the east. The higher population areas are more prone to climate change impacts associated with urban areas (heat and air quality). In the desert areas, climate change will have dramatic impacts on the fragile ecosystems.

Ecosystems and Biodiversity

Many of the species endemic to the inland desert areas of California are adapted to a specific, often narrow, temperature and precipitation range. Changes to the seasonal pattern can stress species, particularly aquatic species. Increased temperature and reduced precipitation can limit the existence and extent of habitats such as intermittent streams or other periodic habitats. For terrestrial species, migration becomes a critical point of assessment. Species such as the desert tortoise have had their habitat fragmented and been stressed by invasive species and pest populations (CDFG, 2007).

There are extensive federal land holdings in the region. Preserving species relies partly on managing these lands (for grazing, solar installation, etc and managing the adjoining lands to accommodate migration corridors.

Water Supply

Similar to the South Coast region, the Desert region relies on water from the Colorado River and the State Water Project. Both of these sources begin with mountain snowpack. Climate change will result in drastically reduced supply from these sources. Declining snowpack in the San Gabriel Mountains, San Gorgonio Mountains, and San Jacinto Mountains will lead to permanently diminished local water supply.

Public Health, Socioeconomic, and Equity Impacts

Riverside and San Bernardino counties rank fourth and seventh in the state in the absolute numbers of the elderly and children less than five years of age. These two populations are most likely to suffer from heat-related illnesses and heat events (English et al., 2007).

Impervious surfaces are increasing in Riverside and San Bernardino counties, increasing the potential impacts of heat islands (English et al., 2007). Foothill and mountainous communities of this region may be particularly subject to respiratory and heat stress due to a combination of higher ozone levels, higher elevations, and increasing temperatures in these areas (English et al., 2007; Drechsler et al., 2006). Those most vulnerable to high levels of ozone and particulate matter include people who work or spend a lot of time outdoors, such as agricultural employees in Imperial County and employees of the tourist industry around Big Bear. As there may be impacts upon tourism from reduced snowpack, floods, and wildfires, employees of this industry may become more economically vulnerable because of unstable working conditions.

Impacts upon safety and emergency response services are of particular concern in this region because of the potential for particularly lengthy and severe heat events. In extreme heat events, roads essential for disaster response could buckle.

Wildfire

The high temperatures that characterize much of the desert landscape in this region limit the production of fuels that result in wildfire. However, short periods of high moisture (intense rainfall events) can increase production of fine fuels. In addition, invasive species, particularly in desert settings, may facilitate fire in areas not historically prone to burn.

ADDITIONAL RESOURCES

- Wildfire
  - California Fire Science Consortium, Mojave and Sonoran Desert Module (http://www.cafiresci.org/home-mojave-desert/)
  - California Fire Alliance (http://cafirealliance.org/)
  - California FireSafe Council (http://www.firesafecouncil.org/)
- Biodiversity and Ecosystems
  - California Department of Fish and Game. 2007. California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento. Retrieved from http://www.dfg.ca.gov/wildlife/wap/report.html
    The Wildlife Action Plan divides the state into regions. The Colorado Desert and Mojave Desert Regions overlap with the Desert region.

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