

# CALIFORNIA ADAPTATION PLANNING GUIDE



## DEFINING LOCAL & REGIONAL IMPACTS



# CALIFORNIA ADAPTATION PLANNING GUIDE

## PREPARED BY:

California Emergency Management Agency  
3650 Schriever Avenue  
Mather, CA 95655  
[www.calema.ca.gov](http://www.calema.ca.gov)

California Natural Resources Agency  
1416 Ninth Street, Suite 1311  
Sacramento, CA 95814  
[resources.ca.gov](http://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

PAGE INTENTIONALLY LEFT BLANK



**Cal E.M.A.**  
CALIFORNIA EMERGENCY  
MANAGEMENT AGENCY



**"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,

A handwritten signature in blue ink that reads "Ken Alex".

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

A handwritten signature in blue ink that reads "John Laird".

John Laird  
Secretary for Natural Resources Agency

A handwritten signature in blue ink that reads "Mark Ghilarducci".

Mark Ghilarducci  
Secretary  
California Emergency Management Agency

PAGE INTENTIONALLY LEFT BLANK

# ACKNOWLEDGEMENTS

The *Adaptation Planning Guide* (APG) has benefited from the ideas, assessment, feedback, and support from members of the APG Advisory Committee, local governments, regional entities, members of the public, state and local non-governmental organizations, and participants in the APG pilot program.

## 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.	ASSOCIATE 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



# TABLE OF CONTENTS

Executive Summary .....	i
INTRODUCTION .....	1
What is APG: <i>Defining Local &amp; Regional Impacts</i> and how should it be used? .....	2
Direct Climate Impacts.....	5
Secondary Impacts by Sector .....	7
VULNERABILITY STEPS 1-5 BY SECTOR.....	10
Public Health, Socioeconomic, and Equity Impacts .....	12
Ocean and Coastal Resources .....	25
Water Management.....	35
Water Supply .....	46
Forest and Rangeland.....	51
Biodiversity and Habitat .....	56
Agriculture.....	63
Infrastructure .....	68
REFERENCES.....	77

## LIST OF FIGURES

Figure 1. The four California Adaptation Planning Guide (APG) documents. ....	2
Figure 2. The nine steps in adaptation strategy development. ....	4
Figure 3. FEMA 100-Year Flood Hazard Areas.....	37
Figure 4. Illustration of layering of regional and local assets along with exposure to identify infrastructure connections and sensitivity.....	71
Figure 5. Conceptual map of how a jurisdiction can identify impacts on infrastructure on a regional scale.....	71

## LIST OF TABLES

Table 1. Probability based on Global Models .....	10
Table 2. Secondary Impact Associations. ....	11
Table 3: Sea Level Rise Projections using 2000 as the Baseline Year.....	27
Table 4. FIRM Flood Zones .....	40

PAGE INTENTIONALLY LEFT BLANK

# 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: Defining Local & Regional Impacts* focuses on understanding the ways in which climate change can affect a community. These impacts are organized into seven related “sectors.” The discussion of each sector includes the considerations necessary to conduct a vulnerability assessment, the process introduced in *APG: Planning for Adaptive Communities*.

## 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 *APG: Defining Local & Regional Impacts*.

YOU  
ARE  
HERE

## Climate Impacts by Sector

Climate change impacts (temperature, precipitation, sea level rise, ocean acidification, and wind) affect a wide range of community structures, functions, and populations. These impacts are separated into a series of “sectors” that serve as the organizing framework for the community vulnerability assessment.



**Public Health, Socioeconomic, and Equity Impacts:** This sector consists of the public health and socioeconomic impacts of heat events, average temperature change, intense rainstorms, reduced air quality, and wildfires on people, focusing on groups who are most sensitive to these impacts because of both intrinsic factors (e.g., age, race/ethnicity, gender) and extrinsic factors (e.g., financial resources, knowledge, language, occupation).



**Ocean and Coastal Resources:** Changes such as sea level rise, intensification of coastal storms, and ocean acidification may affect ocean and coastal resources. Potential environmental impacts of these changes include coastal flooding/inundation, loss of coastal ecosystems, coastal erosion, shifts in ocean conditions (pH, salinity, etc.), and saltwater intrusion.



**Water Management:** This sector includes climate changes such as altered timing and amount of precipitation and increased temperatures that influence the availability of water supply. In addition, the sector includes an evaluation of the role that intense storms and rapid snowmelt can play in flooding.



**Forest and Rangeland:** Climate can have an influence on forest health and wildfire. In forest ecosystems, climate change can alter the species mix, moisture and fuel load, and number of wildfire ignitions. These changes in wildfire character are related to a range of forest health indicators such as growth rate, invasive species, erosion, and nutrient loss.



**Biodiversity and Habitat:** Climate change may affect terrestrial and freshwater aquatic habitats and the species that depend on them. Changes in the seasonal patterns of temperature, precipitation, and fire due to climate change can dramatically alter ecosystems that provide habitats for California's native species. These impacts can result in species loss, increased invasive species' ranges, loss of ecosystem functions, and changes in growing ranges for vegetation.



**Agriculture:** The threats posed by climate change have the potential to influence both crop and livestock operations. Climate change can affect agriculture through extreme events (e.g., flooding, fire) that result in large losses over shorter durations, or through more subtle impacts such as changes in annual temperature and precipitation patterns that influence growing seasons or livestock health.



**Infrastructure:** Infrastructure provides the resources and services critical to community function. Roads, rail, water (pipes, canals, and dams), waste (sewer, storm, and solid waste), electricity, gas, and communication systems are all needed for community function. Climate change increases the likelihood of both delays and failures of infrastructure.

# INTRODUCTION

The Adaptation Planning Guide (APG) is part of the ongoing efforts by the State of California to address climate change. The APG provides guidance to support communities in addressing the unavoidable consequences of climate change. The APG is made up of four documents (see Figure 1). *APG: Planning for Adaptive Communities* 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 (see Figure 2). It is supported by three supplemental documents that provide additional detail and resources. This document, *APG: Defining Local & Regional Impacts*, is one of these supplemental documents.

YOU  
ARE  
HERE

- *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.

- ***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 local 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 *APG: Defining Local & Regional Impacts*. The document includes examples from jurisdictions already pursuing adaptation strategies and offers considerations for tailoring strategies to meet local needs.



Figure 1. The four California Adaptation Planning Guide (APG) documents. All APG users should start with *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 *APG: Defining Local & Regional Impacts* and how should it be used?

APG: Defining Local & Regional Impacts presents seven, interrelated categories of climate impacts, referred to as sectors. The document describes how each sector is affected by climate change and summarizes some of the potential consequences. The document's primary aim is to provide additional information and guidance for completing the first five steps in vulnerability assessment for each sector of climate impact (see Figure 2). The steps – presented in *APG: Planning for Adaptive Communities* – are titled : 1. Exposure; 2. Sensitivity; 3. Potential impacts; 4. Adaptive capacity; and 5. Risk and Onset.

The vulnerability that a community experiences as a result of climate change is a product of its biophysical setting in combination with the characteristics of the community, ranging from its built pattern to social, political, and economic characteristics. As a result, a locally appropriate vulnerability assessment cannot be developed at a statewide scale. This document identifies potential impacts, but a team of local and regional staff and stakeholders must complete the assessment accounting for local and regional context.

## CREATING A CLIMATE CHANGE ADAPTATION TEAM

The critical members of the climate change adaptation team will vary by community. Categories of expertise that should be considered when constructing an adaptation team include the following:



- Long-range planning or community development
- Emergency response and natural hazards planning
- Economic development
- Parks and open space
- Transportation or engineering
- Utilities (water, wastewater, etc.)
- Administration/finance
- Chamber of commerce
- Public health
- Social services
- Regional entities (e.g., air districts, metropolitan planning organizations, regional transportation planning agencies, etc.)
- Regional science organizations or universities
- Local non-governmental organizations (NGOs) (environmental, social, etc.)
- Professional organizations (agricultural, fisheries, communications, etc.)

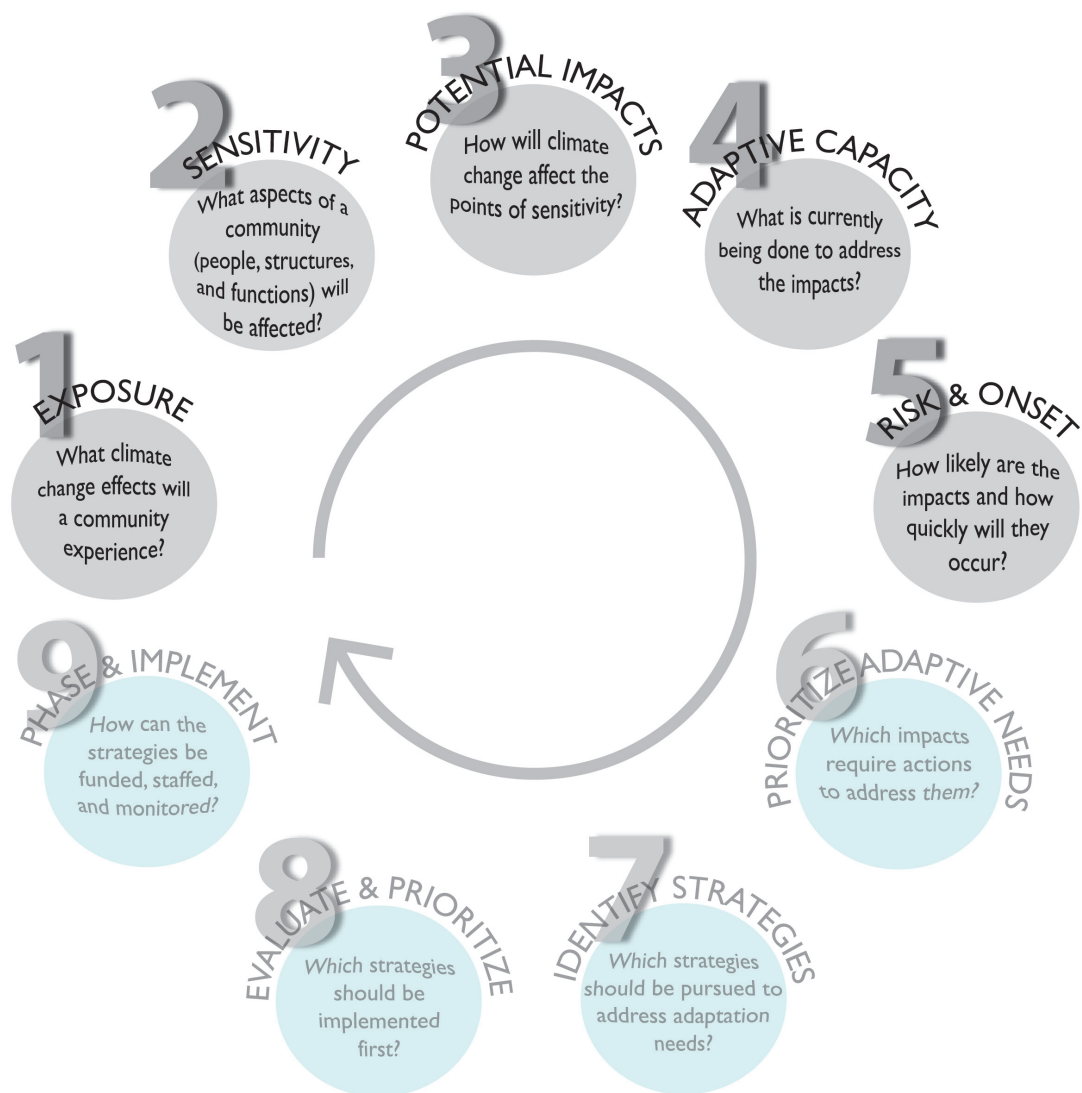


Figure 2. The nine steps in adaptation strategy development.

The blue steps are part of vulnerability assessment (Steps 1-5) and the gray steps are adaptation strategy development (Steps 6-9). The APG: Defining Local & Regional Impacts focuses on Steps 1-5.



## Direct Climate Impacts

An assessment of a community's vulnerability to climate change begins with an understanding of local exposure to direct impacts. The range of direct impacts anticipated for California is summarized below.

### Temperature

Climate change alters seasonal temperature patterns. Effects can include changes in average temperature, the timing of seasons, and the degree of cooling that occurs in the evening. In addition to new seasonal temperature patterns, extreme events such as heat waves are projected to occur more frequently and/or last for longer periods of time. Changes in average temperature, when evaluated on large scales (state, national, or global), have a fairly high level of certainty with consistency among various models (IPCC, 2007).

In California, temperature increases are expected to be more pronounced in the summer and in inland areas. Heat waves are projected to increase not only in frequency but in spatial extent (CNRA, 2009). The degree of change experienced partially depends on global greenhouse gas (GHG) emissions and atmospheric concentrations; by 2050, however, temperature increases between 1.8 ° Fahrenheit (F) to 5.4 °F are projected under both emissions scenarios examined by the State of California (CNRA, 2009).

At the local level, specific changes to seasonal temperature profiles are more difficult to project precisely, due to the interaction with other factors such as cloud cover, moisture presence, topography, and regional air mass circulation that can lead to inversions (IPCC, 2007; Iacobellis et al., 2009).

### Precipitation

Similar to temperature, seasonal precipitation patterns, including the timing, intensity, and form of precipitation, are projected to change. Precipitation differs from temperature in that it has greater spatial variability and is more difficult to predict. Climate models demonstrate less consistency in projecting the amount and timing of precipitation and rain vs. snowfall patterns (IPCC, 2007; CNRA, 2009).

Despite this variability, most models project reduced precipitation in California as a whole. Northern California is projected to have a 12 to 35 percent decrease in precipitation. Mountainous regions are expected to see precipitation fall more frequently as rain instead of snow. These changes have implications for the state's water supply. Increased likelihood of drought, punctuated by occasional intense rainfall, is also expected (CNRA, 2009).

Changes in precipitation and temperature interact. Higher temperatures increase evaporation, which can result in a drier climate. In addition, temperature variation can result in earlier and faster snowmelt (CNRA, 2009).

### Sea Level Rise

Sea level has risen about seven inches over the last century due to global melting of land-based ice and thermal expansion (i.e., water expanding as it warms) (IPCC, 2007; CNRA, 2009; NAS 2012). Climate change projections estimate a range of sea level rise along the California Coast between 43 and 69 inches by 2100 (CO-CAT 2010; NAS 2012). This projected sea level rise includes global changes in sea level from thermal expansion and glacial melting, as well as regional changes in land elevation due to uplift and subsidence. As with other climate impacts, there is variation but general agreement among the various models (IPCC, 2007). This agreement provides an increased certainty for communities that projected sea level rise will occur. As a result, communities facing projected impacts due to sea level rise can feel greater urgency and confidence in taking action.

### Ocean Acidification

Atmospheric carbon dioxide is absorbed by the ocean. As a result, the concentration of carbon dioxide in oceans is increasing in parallel with atmospheric concentrations. Increased carbon dioxide lowers the pH of ocean water. Since the pre-industrial era, ocean pH has decreased 0.1 unit from 8.2 to 8.1 and is expected to decrease by another 0.3 to 0.4 by 2100 (Orr, 2005; Huari et al., 2009). This change in ocean pH affects the overall ocean chemistry (IPCC 2007). This is a rapidly growing and evolving area of investigation. Evidence indicates that a more acidic ocean water can have detrimental effects on marine life, particularly organisms with a calcium carbonate shell (Orr et al., 2005; IPCC 2007; Huari et al., 2009). Communities reliant on marine ecosystems, particularly organisms such as oysters that are likely to be affected by changing ocean acidity, should pay close attention to scientific findings as they come available.

### Wind

Wind results from temperature differences in air masses that create a pressure differential. Climate change, which is warming most marine and land surfaces of the globe, will influence wind speeds and patterns, from the jet stream to the frequency of extreme events (IPCC, 2007).

How climate change is likely to affect wind in California is unclear. Wind is a product of circulation patterns, surface energy, and topography. As a result, there is a great deal of variability among modeled outcomes (Rasmusson, Holloway, and Nemet, 2010). Despite uncertainty, wind, when combined with other direct impacts, can pose risks to California communities. For example, wind

in combination with extreme high tides can result in severe coastal storms. Similarly, wind in combination with hot, dry conditions can worsen fire risk.

## Secondary Impacts by Sector

The direct climate impacts (temperature, precipitation, sea level rise, ocean acidification, and wind) affect a wide range of community structures, populations, and basic functions. These impacts have been separated into a series of “sectors” that can serve as the organizing framework for the community assessment of climate adaptation needs. The seven identified sectors are as follows: (1) public health, socioeconomic, and equity impacts; (2) ocean and coastal resources; (3) water management; (4) forest and rangeland; (5) biodiversity and habitat; (6) agriculture; and (7) infrastructure. These sectors overlap and interact. The separating of impacts into sectors is simply a way of organizing a planning effort; it should not be viewed as absolute. Communities should categorize impacts in a manner that best matches local needs and organization.

The following section briefly defines each sector. The section that follows addresses vulnerability assessment for each sector in greater detail.



### Public Health, Socioeconomic, and Equity Impacts

This sector consists of the public health and socioeconomic impacts and related equity issues associated with climate change impacts. Public health impacts include the short-term effects of climate-related hazards — heat events, intense rainstorms and flooding, wildfires, high tide and storm surges — and long-term impacts such as cardio-respiratory morbidity and mortality, food-, water- and vector-borne diseases, food insecurity, and water contamination (Maibach et al., 2011). Socioeconomic impacts include potential effects upon California’s economic growth (Sanstad et al., 2009; CEC, 2009) and on specific industries within the state, such as agriculture (Medillin-Azuara et al., 2011; Deschenes and Kolstad, 2011) and tourism (Pendleton et al., 2011). These changes increase the vulnerability of local populations that rely on these industries. Equity concerns are based on the idea that some populations bear a disproportionate burden of the climate change effects (Morello-Frosch et al, 2010).



### Ocean and Coastal Resources

Changes such as sea level rise, intensification of coastal storms, and ocean acidification may affect ocean and coastal resources. Potential environmental impacts of these changes include coastal flooding/inundation, loss of coastal ecosystems, coastal erosion, shifts in ocean conditions (pH, salinity, etc.), and saltwater intrusion (CNRA, 2009). The combination of sea level rise and possible intensification of coastal storms presents a threat to coastal development and infrastructure. Climate-related changes to marine ecosystems may result in

altered population and ranges of fish species, which affect productivity and the commercial fishing industry. With 85 percent of California's residents living in coastal counties, sea level rise could potentially damage whole communities while also affecting tourism, the provision of basic services (e.g. wastewater treatment), and recreational economies (CNRA, 2009).

## Water Management

Climate change may result in flooding and reduced water supply in communities. Although the scientific evidence regarding increased flooding related to climate change remains uncertain, it is prudent for communities to recognize that changes to precipitation regimes and rate/timing of snowmelt may increase flooding. The water supply includes both surface water and groundwater, along with the infrastructure necessary for management, conveyance, and treatment. Water supply is expected to be affected in areas that experience less precipitation and areas that depend on snowpack.



## Biodiversity and Habitat

Climate change may affect terrestrial and freshwater aquatic habitats and the species that depend on them. California is a unique hot spot of biodiversity (CEC, 2009). Changes in the seasonal patterns of temperature, precipitation, and fire due to climate change can dramatically alter ecosystems that provide habitats for California's native species. These impacts can result in species loss, increased invasive species' ranges, loss of ecosystem functions, and changes in growing ranges for vegetation.



Reduced rain and changes in the season distribution of rainfall may reduce low flows in streams and rivers, which in turn would have consequences for aquatic ecosystems. In addition to altered flow levels that influence aquatic food webs, water temperature may increase, which could affect water quality and the health of aquatic species, particularly threatened or endangered species. For species reliant on aquatic systems that have limited extents, such as vernal pools, wetlands, and lakes, there is limited opportunity to escape when habitat conditions change due to fluctuating water levels and temperatures.

## Forest and Rangeland

Climate can have an influence on wildfire and forest health. In forest ecosystems, climate change can alter the species mix, moisture and fuel load, and number of wildfire ignitions. Changes in species mix and moisture due to dry periods can alter wildfire timing (seasonality and frequency), spatial distribution (fire size and complexity), and magnitude (intensity, severity, and type). These changes in wildfire character are related to a range of forest health indicators such as growth rate, invasive species, erosion, and nutrient loss.



In addition, climate change and fire regime together can result in conversions from forest to shrub to grassland. Each of these ecosystem types has a distinct fire frequency and behavior. It is important to understand how historic fire regimes may be altered due to climate change and the community resources that may be vulnerable.



### Agriculture

The threats posed by climate change have the potential to influence crop and livestock productivity. These changes can have far-reaching impacts, from altering the local economy to affecting food supply. Climate change can affect agriculture through extreme events (e.g., flooding, fire) that result in large losses over shorter durations, or through more subtle impacts such as changes in annual temperature and precipitation patterns that influence growing seasons or livestock health. These impacts also have the potential to result in a range of associated consequences such as altered pest and weed ranges, reduced air quality, and reduced farm worker safety (due to heat and poor air quality). This is critically important in California. As the leading producer of agricultural goods in the United States, the state's agricultural economy is valued at billions of dollars annually. Changes in agriculture could be detrimental to the economic viability of many areas of the state.



### Infrastructure

Infrastructure provides the resources and services critical to community function. Roads, rail, water (pipes, canals, and dams), waste (sewer, storm, and solid waste), electricity, gas, and communication systems are all needed for community function. Climate change increases the likelihood of both delays and failures of infrastructure. Delays and failures can result from climate-exacerbated hazards such as flooding, fire, or landslide, as well as increased demand, load, or stress on infrastructure systems that can result from climate change (e.g., heat impacts on roadway durability). Temporary delays or outages can result in inconvenience and economic loss, while larger failures can lead to disastrous economic and social effects.

# VULNERABILITY STEPS 1-5 BY SECTOR

This section seeks not to develop a vulnerability assessment, but rather to highlight some of the considerations that should be part of the process when a community conducts a vulnerability assessment. The discussion addresses considerations by sector.

The description of each sector begins by summarizing how climate change may affect the sector. In most cases, detailed state guidance can provide greater depth than what is presented in the APG. Communities seeking additional information should refer to these documents. Where available, a list of additional resources is provided for each sector. Communities seeking additional information should refer to this guidance.

Following the climate impact summary, the considerations critical to vulnerability assessment are presented. The information required to address these considerations should be developed through representatives on the community's climate change adaptation team.

This section covers vulnerability assessment, the first five steps in adaptation policy development. The final step in vulnerability assessment is “risk and onset” based on the certainty of global climate models and likelihood of secondary impacts (see Tables 1 and 2). The policy development steps (Steps 6-9) require a jurisdiction to evaluate adaptation needs and potential impacts based on local considerations. These more specific considerations are discussed at the regional scale in *APG: Understanding Regional Characteristics*.

Table 1. Probability based on Global Models

DRIVER	% PROBABILITY (IPCC)	CERTAINTY RATING
Temperature change	> 90% probability	High
Precipitation change	> 66% probability	Medium
Sea level rise	> 90% probability	High
Snow season and depth change	> 90% probability	High

Source: IPCC, 2007, WGI Physical Science Bases, Section 10 & 11

Table 2. Secondary Impact Associations.

PRIMARY IMPACT	ASSOCIATED SECONDARY IMPACTS	CERTAINTY
Sea level rise	Inundation or long-term waterline change	High
	Extreme high tide	High
	Coastal erosion	High
	Saltwater intrusion	High
Changed temperature and/or precipitation patterns	Changed seasonal patterns	Medium
Increased temperature	Heat wave	High
Increased temperature and/or changed precipitation	Intense rainstorms	Medium
Wildfire and/or increased precipitation	Landslide	Medium
Increased temperature and/or reduced precipitation	Drought	Medium
	Wildfire	Medium
	Reduced snowpack	High

Estimated based on most conservative driver from Table 1  
Source: IPCC, 2007, WGI Physical Science Bases, Section 10 & 11

The impacts associated with each sector overlap. For example, flooding may affect infrastructure. Thus, the evaluation of this disruption could be housed in either the sector focused on flooding or that evaluating infrastructure. Where overlap occurs, the other location where a particular impact is discussed is identified by using an icon associated with the overlapping sector.

The intent of *APG: Defining Local & Regional Impacts* is not to comprehensively address impacts in each sector. Many state agencies have or are developing much more comprehensive evaluations of climate change that address impacts on particular sectors or agency missions. The APG identifies in-depth guidance where it is available. The aim of this section is to highlight some of the issues that may emerge during a vulnerability assessment and identify possible sources and methods for addressing them.





## Public Health, Socioeconomic, and Equity Impacts

This sector consists of the public health and socioeconomic impacts and related equity issues associated with climate change impacts. Public health impacts include the short-term effects of climate-related hazards—heat events, intense rainstorms and flooding, wildfires, and high tide and storm surges—and long-term impacts such as cardio-respiratory morbidity and mortality, food-, water- and vector-borne diseases, food insecurity, and water contamination (Maibach et al., 2011). Because public health agencies currently address related health impacts, they can provide community planners and emergency responders with resources (such as databases of vulnerable populations), guidance (such as health-related policies for inclusion in climate action plans and general plans), and literature on the co-benefits of climate action planning on public health and health-related policies (CDPH, 2012).

Recent literature on the economic impacts of climate change covers potential effects on California’s economic growth (Sanstad et al., 2009; CEC, 2009) and on specific industries within the state, such as agriculture (Medillin-Azuara et al., 2011; Deschenes and Kolstad, 2011) and tourism (Pendleton et al., 2011). While this literature does not always directly address impacts on individuals or groups, it provides a context for assessing local populations that may be vulnerable because they rely on industries affected by climate change. In addition, many indirect impacts of climate change may cause economic hardship, including increasing insurance, food, energy, and fuel costs.

Equity (and social vulnerability) discussions bring together analyses of a wide range of climate change impacts—social, economic, health, environmental—to highlight individuals and groups who are most vulnerable. Equity concerns are based on an assertion that climate change impacts do “not affect everyone equally” (Morello-Frosch et al., 2009, pg. 1) and highlight the disproportionate effects of climate change on people of color, the poor (Pastor, 2010; Cutter et al., 2009), and other vulnerable and socially marginalized populations (Shonkoff et al., 2011; OEHHA, 2010b). Data provided in the public health literature (CDPH, 2012) support concerns regarding the inequitable impacts of climate change.

## EXPOSURE

This section covers the direct and secondary climate change impacts that affect the public health, socioeconomics, and equity of communities. Detailed discussions and instructions regarding the identification of many of these climate change impacts can be found in other sectors and, thus, are only discussed briefly here.



## Temperature

Short-term extreme temperature changes such as heat events and long-term increases in average temperature are expected to affect public health (OEHHA, 2010a; Pacific Institute, 2010; Cayan et al., 2008; Gershunov and Cayan, 2009). The web-based Cal-Adapt tool ([www.Cal-Adapt.org](http://www.Cal-Adapt.org)) can be used to identify the following:

- The change in average daily temperature projected for 2050 and 2100
- The number of additional heat events projected for 2100 as compared to current conditions
  - What is the change in the frequency and duration of these events?
  - What is the projected change in nighttime temperatures?

## Precipitation

Changes in precipitation may produce wildfires and reduced snowpack, intense rainstorms, flooding, landslides, drought, water supply shortages, and changes in seasonal patterns, agricultural production, and the food supply. In combination, changes in temperature and precipitation may exacerbate impacts.

Cal-Adapt can be used to identify the following:

- The projected change in precipitation by 2050 and 2090
- The additional areas that will be at risk for wildfire by 2020, 2050, and 2085
- The projected change in snowpack by 2050 and 2090



For additional information, please refer to the “Exposure” sections of the Water Management, Forest and Rangeland, and Agriculture impact sectors below.

Finally, changes in average temperature and precipitation exacerbate already impaired air quality, particularly levels of ozone and particulate matter, in certain regions. In addition, wildfires will temporarily affect air quality. Regional air quality management districts can provide information on air quality changes predicted for the region.



## Sea Level Rise

Sea level rise will adversely affect people living and working in coastal and delta areas and along coastal rivers. Instructions provided in the discussion of the Ocean and Coastal Resources impact sector below can be used to determine the following:

- Areas that may be subject to inundation/long-term waterline change
- Additional areas that will be vulnerable to a 100-year flood
- Projected changes in the mean high tide level
- Changes to erosion rates for bluff, beach, dune, or other shoreline types
- Areas subject to saltwater intrusion

## SENSITIVITY

This section describes conditions/groups with increased sensitivity to climate change. Individuals are sensitive to climate change impacts because of both intrinsic factors (e.g., age, race/ethnicity, gender) and extrinsic factors (e.g., geographic location, financial resources, knowledge, language, occupation). This section should be used to identify populations, and associated critical facilities or services, that might be affected.

### Geographic Location/Condition of the Built Environment

This category includes individuals who live, work or visit in areas susceptible to the impacts of climate changes covered in the previous section, “Exposure.” Moreover, those living in such areas may be more severely affected because of the condition of the built environment. For instance, people might be more severely affected by heat waves because they live in inner cities that contain “heat islands” (geographic zones that are warmer than surrounding suburban and rural areas because of pavement, buildings, other infrastructure, and lack of vegetation) or they live in buildings that are poorly insulated (CDPH, 2008; English et al., 2007; Schonkoff, 2011; OEHHA, 2010b).

### Lacking Material Resources

This category includes low-income individuals, individuals who are homeless, and others who may lack the material resources to prepare for, respond to, or recover from impacts. For instance, low-income communities are often under-insured and therefore slower to recover from natural disasters caused by climate change (Shonkoff et al., 2011; OEHHA, 2010a; Fothergill and Peek, 2004; Bolin and Bolton, 1986).

### Lacking Information/Knowledge/Familiarity

The following groups are included in this category: non-English speakers, individuals without a formal education or who recently moved to the area, and individuals who live in areas currently not experiencing any extreme events related to climate change. Individuals in this category may lack the knowledge necessary to prepare for, respond to, or recover from climate change impacts. For instance, extreme heat events are less likely along the coast than in inland valleys. Thus, when extreme heat events occur, vulnerable populations may be severely affected because they are accustomed to historically milder temperatures and are not able to adapt.

### Physical Conditions/Dependence on Others

The elderly, children, individuals with disabilities or who are institutionalized, and the chronically ill fall into this category. The category includes individuals who

may be physically unable to prepare for, respond to, or recover from climate change impacts or who may be dependent on others for assistance. Elderly persons (older than 65) are more physically susceptible to changes in temperature because of their “reduced ability to acclimatize” and “higher likelihood of pre-existing chronic health conditions” (Health Canada, 2006). People over the age of 65 also have the largest increase in mortality with increased concentrations of ozone (Medina-Ramon and Schwartz, 2008). In addition, many elderly people suffer from impaired cognitive function, which can cause them to underestimate extreme weather conditions and put their health at risk as a result, especially if they fail to seek the necessary medical attention or are unable to take recommended precautions. Extrinsic factors that can affect the elderly are social isolation (Wang and Yasui, 2008) and dependence on others. These factors are common among the elderly living in institutional settings (Moser and Ekstrom, 2010; Caruson and MacManus, 2008).

Infants and children (younger than 5) are also extremely susceptible to heat and air quality problems. Children require more time to acclimatize than do adults, and they are less likely to sense thirst and voluntarily replenish fluids during extended physical activity, which can lead to dehydration (Medina-Ramon and Schwartz, 2008). Children are particularly vulnerable to high levels of ozone and particulate matter (Medina-Ramon and Schwartz, 2008). Like the elderly, children are dependent on others within the family for their care, which means in times of emergency they may receive less attention and therefore need more recovery time (Shonkoff, 2011; CDPH, 2008).

Extremes and changes in average temperature, reduced air quality, and increases in food-, water-, and vector-borne diseases put greater stress on the already underlying health status of a population, including the chronically ill, people with disabilities, and families with disabled members (Pacific Institute, 2010). Chronic diseases can include obesity, diabetes, and coronary heart disease. Higher pollen counts brought on by excessive rain have a disproportionate effect on asthmatics (Shonkoff et al., 2011; CDPH, 2008). Extrinsic factors that affect some of these groups include their dependence on others for assistance during evacuation (Moser and Ekstrom, 2010; Caruson and MacManus, 2008).

### Lacking Basic Lifelines

Individuals in this category are without basic lifelines, such as access to public transit, cars, or telephones, which are necessary in the event of climate-induced disaster.

## Occupation/Activities

This category includes people who work in industries that will be affected by climate change or who work/play outdoors or in buildings without air conditioning (Medina-Ramon and Schwartz, 2008). People who work or spend a lot of time outdoors are particularly vulnerable to heat events and air quality impacts, such as high levels of ozone and particulate matter (Medina-Ramon and Schwartz, 2008). For instance, agricultural workers and farmers may be affected by job losses, production changes, or heat events. Young athletes and other people who exercise outdoors can put themselves at risk by working too strenuously at elevated temperatures (Shonkoff et al., 2011; CDPH, 2008; Basu and English, 2008).

## Equity Concerns/Existing Exposure/Disenfranchisement

This category includes low-income individuals, individuals who are homeless, communities of color, women, and the lesbian, gay, bisexual, and transgender (LGBT) community. Abundant research demonstrates that individuals in this category are more susceptible to climate change because they currently have higher exposure to economic or environmental degradation. For instance, analysis of census data has shown that people of color, regardless of income, tend to live closer to the heaviest-polluting industries and experience more exposure to the effects of air pollution and urban heat islands due to the concentration of these populations in more disadvantaged urban areas (Pastor, 2010; Shonkoff et al., 2011; OEHHA, 2010b).

Changes in the cost of basic services (water, energy) and products (food) are felt disproportionately by poorer households. Ethnicity may carry with it extrinsic factors, such as linguistic isolation (affecting access to information) and immigration status (affecting access to political representation) that increase vulnerability (Cox et al., 2007; Shonkoff et al., 2009 and 2011, OEHHA, 2010b). Communities of color, women, and members of the LGBT community may have been misrepresented or disenfranchised from the political process, which may affect exposure, sensitivity, and adaptive capacity to hazards. These groups may experience a “cumulative burden” of harmful exposures and a higher rate of some chronic diseases, such as obesity, diabetes, and hypertension; climate impacts should be considered with this in mind (Shonkoff et al., 2011; Pacific Institute, 2010; Shonkoff et al., 2006; Morello-Frosch et al., 2010; Cutter et al., 2009; Cox et al., 2007).

## Fitting into More Than One of the Above Categories

Individuals may have more than one condition or belong to more than one group with sensitivity. This overlap ultimately can help identify the people at greatest risk of being adversely affected by climate change. The California Environmental

Protection Agency (Cal EPA), California Office of Environmental Health Hazard Assessment (OEHHA), and the California Department of Public Health have recently completed studies, listed at the end of this sector discussion, regarding assessment methods for cumulative impacts that are of use to local agencies. Equity/social vulnerability studies frequently identify the poor, communities of color, the elderly, children, individuals with chronic diseases or with disabilities, and agricultural and other outdoor workers as particularly susceptible to climate change impacts because they may fit into several additional categories of sensitivity (Shonkoff et al., 2009).

## POTENTIAL IMPACTS

This section discusses the potential public health and socioeconomic impacts resulting from climate change. These impacts are divided into two categories: climate-related hazards (short-term impacts) and long-term impacts. The impacts reviewed are taken from a number of sources (CDPH, 2012; Shonkoff et al., 2011; OEHHA, 2010; Pacific Institute, 2010; CNRA, 2009; Maibach et al., 2011; CDPH, 2008; English et al., 2007; Basu and English, 2008; Dreschler et al., 2006). All of the populations discussed in the previous section should be considered for their sensitivity to the impacts listed here. Specific sensitivities to potential impacts were noted in previous sections.

### Climate-Related Hazards

While the magnitude of risk associated with immediate and long-term impacts is still somewhat uncertain, the literature does appear to agree that among the most significant public health impacts are those resulting from extreme heat events, temperature and precipitation changes that produce flooding and wildfire, and sea level rise that produces high tide, storm surges, and flooding. These short-term events can result in significant damage to property, displacement, injuries, and death (OEHHA, 2010; Pacific Institute, 2010; Cayan et al., 2008; Gershunov and Cayan, 2009).

#### *Heat Events*

The rising average surface temperatures brought on by climate change predict a substantial increase in the number, duration, and severity of heat waves (CDPH, 2012). Impacts associated with heat events include premature death, cardiovascular stress and failure, and heat-related illnesses such as heat stroke, heat exhaustion, and kidney stones. Extreme heat events can also require evacuation and temporary displacement of people.

Inland low-lying areas of California are predicted to have more extreme heat events. During the 2006 heat wave in California, the majority of the 140 deaths immediately associated with the heat wave occurred in inland low-lying areas

of California such as the Central Valley and Imperial and Riverside counties (Drechshler et al., 2006). Urban dwellers are more at risk in heat events because they may reside in “heat islands” in urban areas. Heat islands experience higher temperatures due to several factors, including a lack of natural cooling from shade trees, increased impervious surfaces, and waste heat from vehicles, factories, and air conditioners (Basu and English, 2008). The highest percentages of impervious surfaces are in the urban areas of Los Angeles and San Diego counties (English et al., 2007). Southern California’s urban centers are warming more rapidly than other parts of the state (English et al., 2007).

#### *Intense Rainstorms and Flooding*

Intense rainstorms and/or sea level rise may produce flooding resulting in injuries and death from drowning. Potential contamination of potable water, wastewater, and irrigation systems may negatively affect the quality of water supply, resulting in an increase of water- and food-borne diseases (Confalonieri et al., 2007; USGCRP, 2009). Intense rainstorms and flooding can contaminate food crops through overflows from sewage treatment plants into fresh water sources and through increases in water-borne parasites, such as *Cryptosporidium* and *Giardia*, found in drinking water. Heavy stormwater runoff can contaminate the ocean, lakes, and other bodies of water with other bacteria (EPA, 2012). Intense rainstorms could require evacuation and temporary or permanent displacement of people and result in property damage or loss.

#### *Wildfires*

The increased severity and frequency of wildfires and length of the fire season may result in additional injuries and death from burns and smoke inhalation, eye and respiratory illnesses and exacerbation of asthma, allergies, chronic obstructive pulmonary disease (COPD) and other cardiovascular diseases from air pollution (Lipsett et al., 2008; Pacific Institute, 2010). Increased incidence of wildfires can lead to evacuation, temporary displacement, and property damage. Risk of erosion and land slippage subsequent to fires can lead to temporary or permanent displacement and property damage or loss (CDPH, 2008; Pacific Institute, 2010).



#### *Extreme High Tide and Storm Surges Related to Sea Level Rise*

The extreme high tide and storm surges associated with sea level rise may result in injuries and drowning, compromise of nuclear power plants leading to contamination, temporary loss of other essential critical facilities, and contamination of the water supply (NRC, 2010). These impacts may require evacuation and temporary and/or permanent displacement of people and may result in property damage or loss. Compromised nuclear power plants and other critical facilities might also result in loss of electric power and other critical services.



## Long-Term Public Health Impacts

This section describes the long-term impacts on public health that might result from climate change. Along with the long-term public health impacts listed here, related impacts on service providers and facilities should be considered. The additional response necessary to address long-term public health impacts exacerbated by climate change may overburden existing service providers and facilities.

### *Cardio-Respiratory Health and Mortality*

Research suggests increased mortality associated not only with extreme heat events, but with less acute temperature increases (CDPH, 2008). Increasing temperature will exacerbate already-impaired air quality, including levels of ozone and particulate matter in certain regions, leading to an increased incidence of chronic obstructive pulmonary disease (COPD) and other cardiovascular and respiratory diseases, damage to the lungs, and asthma (Samet, 2010; Confalonieri et al., 2007; Kahrl and Roland-Holst, 2008; Pacific Institute, 2010, CDPH 2008).

Many Californians living in or near urban areas currently experience the worst air quality in the nation (Messner et al., 2009). Foothills and mountainous communities 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). Creation of ground-level ozone “is driven by photochemical reactions, and warmer temperatures result in increased production” (Pacific Institute, 2010, pg. 5).

### *Other Temperature and Air-Quality-Related Health Impacts*

Changes in temperature and/or changes in air quality may also lead to an increased risk of cancer (from particulate matter and ultraviolet radiation exposure), allergies (from increased pollen, fungal growth, and spore release from increased temperatures and carbon dioxide), and cataracts (from stratospheric ozone depletion) (CDPH, 2008).

### *Food-, Water-, and Vector-Borne Diseases*

Climate change may also accelerate the incidence and geographic distribution of diseases and conditions that are transmitted through “food, water, and animals such as deer, birds, mice, and insects.” Salmonella and other bacteria-related food poisoning grow more rapidly in warm environments, causing “gastrointestinal distress and, in severe cases death” (EPA, 2012). As water levels decrease in reservoirs, the likelihood of algal and bacterial growth is increased (CDPH, 2008). Increases in air temperature and change in precipitation may expand the territory

of many pests. In California, three vector-borne diseases are of particular concern: West Nile virus, human hanta virus, and Lyme disease. Greater rainfall accompanied by higher temperatures also lengthens the window for disease transmission in many places where certain diseases are already likely to occur. Marine biotoxins in seafood, affected by sea surface temperature, upwelling, nutrient flux, and salinity, can produce serious health impacts, including illness and death, for consumers (CDPH, 2008).

#### *Increased Food Insecurity/Contamination of the Water Supply*

A reduction in precipitation in combination with an increase in average temperatures may worsen incidence of drought and reduced snowpack, affecting crop yields and disrupting food and water supplies (Cutter et al., 2009; Shonkoff et al., 2011; CDPH, 2008). These impacts may, in turn, have a number of deleterious impacts on human populations, including increased cost and conflict over food and water leading to hunger and malnutrition. Changes in ocean conditions, including an increase in marine biotoxins, which can substantially alter the distribution and abundance of major fish stocks and shellfish, can lead to increased seafood prices or shortages (CDPH, 2008).

Along with the water-borne diseases discussed above, long-term impacts from sea level rise can affect the water supply. These impacts include flooding of septic systems near coastlines, potentially polluting the ocean; compromise of nuclear power plants, leading to long-term contamination of water; and extension of the fresh water/salt water transition zone farther inland (NRC, 2010).

### **Long-Term Socioeconomic Impacts**

#### *Impacts on Agricultural, Forestry, and Fishing Sectors and Employment*

Changes in average temperature, precipitation, drought, and reduced snowpack can alter the agriculture and forestry sectors (including changing patterns and yields of crops, pests, and weed species). These impacts may, in turn, produce unemployment and displaced jobs (Shonkoff et al., 2011; Pacific Institute, 2010; CDPH, 2008). Changes in ocean conditions, including an increase in marine biotoxins, that substantially alter the distribution and abundance of major fish stocks and shellfish may damage the fishing industry and result in unemployment and displacement of those who work in the fishing industries (CDPH, 2008).

#### *Impacts on Tourism Industry and Employment*

High seas that erode beaches and too much or too little snowfall at ski resorts exemplify climate burdens placed on areas that rely on tourism for their economic well-being (Shonkoff et al., 2011; CDPH, 2008; Basu and English, 2008). Coastal erosion can harm recreational activities, tourism, and the tourism industry, resulting in unemployment and displacement (Pacific Institute, 2010).



### *Permanent Displacement, Property Damage or Loss*

Erosion and land slippage subsequent to intense rainstorms and fires can lead to permanent displacement of people and property damage or loss (CDPH, 2008; Pacific Institute, 2010). Impacts associated with changes in precipitation and sea level rise—inundation, flooding, changes in the mean high tide level, and additional bluff or dune erosion—could cause permanent damage or loss of property. Extension of the freshwater/saltwater transition zone farther inland may affect aquifers and require treatment or abandonment of fresh water wells (CDPH, 2008; Pacific Institute, 2010). The possibility of property damages and losses could increase insurance rates or restrict coverage in vulnerable areas. The cost of replacement of critical facilities could significantly affect the fiscal concerns of state and local governments.

## **ADAPTIVE CAPACITY**

This section reviews questions to help jurisdictions determine their adaptive capacity for addressing the predicted impacts on sensitive populations discussed in the previous sections.

Questions to consider include the following:

- **Collaboration of efforts:** To maximize efficiency and efficacy, have local planning efforts related to addressing climate change impacts been linked with efforts to address public health, economic, and social equity efforts in the community? Has there been support at state and federal levels, either through legislation or action, of local/regional planning efforts for adaptation? Is there local involvement with state and federal agencies to promote support?
- **Community-wide involvement:** Has a local network/committee been formed, or an existing committee used, to work on climate change impacts and adaptation efforts? Does this committee include representation from a broad array of agencies, organizations (local and regional, public health, emergency responders, non-profits), community members (residents, employers, and business owners), and members of groups who may be most sensitive to climate change? Are local employers and business associations participating in local efforts to address climate change and health and socioeconomic impacts upon employees?
- **Education:** Are public education and community outreach efforts related to climate change impacts and adaptation underway and are they accessible to diverse groups and through a diversity of agencies and media? Can they be combined with public education and community outreach efforts on other issues? Are special efforts made to address the participation of disadvantaged communities? Are there educational programs available to familiarize

these communities with governmental functions and to empower them to participate in their own governance? If the jurisdiction is unaccustomed to extreme heat events or participation, has it begun to educate the community about a change in preparedness?

- Use of other agencies' information: Does the local health department or department responsible for emergency preparedness have community-wide assessments of the location of the most sensitive populations, such as the elderly, persons with disabilities/special needs, immigrants and non-English-speaking residents, and others who might lack material resources and or have physical limitations?
- Incorporation into existing planning documents and analyses: Do the jurisdiction's plans and CEQA analyses include approaches to land use and transportation that promote health (such as walkability), improvements to the physical environment (such as the promotion of urban forests and reduction of impervious surfaces), and economic diversity? Does the general plan include a health element?
- Heat events: Have strategies been employed to address heat events and other hazards, such as the installation of early warning systems, creation of cooling centers, or adoption of community-level cooling strategies such as white or green roofs, cool pavements, cool parking lots, and land use and building design that can result in cooling? Are there programs available to provide air conditioning units or subsidize use of air conditioners for high-risk populations? Do plans require or promote additional open space, green space, shade cover, urban forests, community gardens, parks, and trees and other vegetation that address the impacts of heat islands and heat events upon both residents and workers?
- Air quality: In coordination with the air quality management district, have the locations of polluting facilities and populations adjacent to these facilities been mapped? Have local planning efforts related to attaining better air quality been linked to addressing climate change impacts and social equity issues?
- Flooding: Do policies and regulations address the reduction of impervious surfaces and require the use of permeable surfaces (in parking lots and roads, for instance)? Has the capacity of local water and sewage treatment facilities been modernized or expanded to meet predicted worst-case precipitation scenarios? Does the Local Coastal Program contain policies to minimize impacts from coastal flooding, including flooding due to future sea level rise? If the jurisdiction includes coastal communities, has it begun to educate communities most likely to be displaced as a result of sea level rise? Do land use plans address the need to change permitted uses and structures in these areas?

- Wildfires: Do local regulations address wildfire prevention through minimum brush clearance requirements, use of fire-resistant landscaping and non-combustible materials for roofs and exteriors, clearing of areas around propane tanks, and proper storage of flammable materials?

## RISK AND ONSET

In the Public Health Climate Change Adaptation Strategy for California (2008), the California Department of Public Health identifies numerous health impacts resulting from anticipated increases in temperature, changes in precipitation, and sea level rise, including heat stress and heat-related illness, heat stroke, skin cancer, allergies, asthma, flooding, drowning, and increases in water-borne and vector-borne illnesses. Concerns about these impacts, along with many others, can be found throughout the academic literature on climate change and public health. Unfortunately, the relationship between climate change and the magnitude of many of these impacts is still uncertain (Basu and English, 2008), making a precise assessment of onset and risk difficult.

While the magnitude of risk associated with immediate and long-term impacts is still somewhat uncertain, the literature does appear to agree that among the most significant public health impacts are those resulting from extreme heat events, air pollution (primarily from ozone and particulate matter), and precipitation changes that produce flooding and wildfire. These short-term events can result in significant damage to property, displacement, injuries, and death. Social vulnerability analyses have documented the sensitivity and adaptive capacity of a number of populations to these impacts, and because these events have potentially catastrophic effects (e.g., Hurricane Katrina), many jurisdictions may judge them to hold the greatest risk and require immediate attention. If a positive note can be heard in all of this, it is that these impacts are not new, and as such, public health officials and emergency responders have been addressing them and have tools to identify and reach out to vulnerable populations. A partnership among agencies and organizations concerned with public health and social equity will be the most efficient and effective way to address these concerns.

## ADDITIONAL RESOURCES

- *A Review of the Social and Economic Factors that Increase Vulnerability to Climate Change Impacts in California*, Pacific Institute (2010). This paper provides a clear and comprehensive review of the factors that contribute to social vulnerability—"the intersection of the exposure, sensitivity, and adaptive capacity of a person or group of people." The report summarizes the following climate change impacts upon these groups: the extreme heat, air quality, natural hazards, environmental infectious diseases, managed and natural ecosystems, water availability, and costs of basic goods and services.

- *The Climate Gap: Environmental Health and Equity Impacts from Climate Change Mitigation Policies in California*, Shonkoff et al (2011). This paper explores the disproportionate effects of climate change on vulnerable groups in California and looks at the costs and benefits of climate change mitigation strategies.
- *Climate Action for Health: Integrating Public Health into Climate Action Planning*, California Department of Public Health (2012). This document addresses key greenhouse gas (GHG) emissions reduction efforts in climate action plans (CAPs) that have health co-benefits. Information provided is also useful for adaptation planning. Several helpful examples of communities' approaches to adaptation are included.
- *California Climate Adaptation Strategy*, Chapter 4, Public Health, California Natural Resources Agency (2009) and *Public Health Climate Change Adaptation Strategy for California*, California Department of Public Health (2008). These two documents provide a summary of the impacts of climate change on public health, as well as a detailed list of adaptation strategies.
- The State of California's Climate Change Portal provides a link to Climate Action Team Reports, including the Public Health Working Group's Near Term Implementation Plans ([http://www.climatechange.ca.gov/climate\\_action\\_team/reports/catnip/public\\_health/](http://www.climatechange.ca.gov/climate_action_team/reports/catnip/public_health/)). This website provides information on strategies, outreach training, emergency response preparedness, public health surveillance data, community resilience, and research and evaluation.
- The California Environmental Protection Agency (Cal EPA) website: <http://www.calepa.ca.gov/>. Along with providing a wide variety of reports on climate change impacts, this website has a search engine with links to resources to Cal EPA's boards, departments, and offices.
- The California Office of Environmental Health Hazards Assessment (OEHHA) website: <http://oehha.ca.gov/ej/index.html>. This website provides links to information regarding the environmental justice activities at OEHHA. Information focuses on both cumulative impacts and precautionary approaches.
- The California Department of Public Health's website devoted to climate change: <http://www.cdph.ca.gov/programs/CCDPHP/Pages/ClimateChange.aspx>. This website provides access to reports, webinars, and other forms of information on climate change and public health in California.
- The United States Environmental Protection Agency (EPA) website, Human Health Impacts and Adaptation from Climate Change: <http://www.epa.gov/climatechange/impacts-adaptation/health.html#impactsdiseases>. This site provides useful summaries of climate change impacts on public health and adaptation strategies. The site also contains a list of useful links to other sites with information related to these issues.



## Ocean and Coastal Resources

The ocean and coastal resources sector addresses natural resource issues within the coastal zone and coastal dependent development (land uses and infrastructure) that may be affected by climate change. The most prominent climate change factor is sea level rise (SLR), which will exacerbate an existing problem with coastal erosion and flooding. The entire coastal zone of California, including bays and estuaries, is susceptible to the effects of SLR. At the start of the adaptation planning process, local governments located within the coastal zone should contact the California Coastal Commission to work collaboratively on adaptation strategies that are consistent with the Coastal Act.

California has about 1,100 miles of coastline and 1.5 million acres of land within the coastal zone. Major cities such as Los Angeles, San Diego, San Francisco, and Long Beach lie within the coastal zone and are highly dependent on the cultural, social, and economic benefits that access to the coast and oceans provides.

The Pacific Institute (2009) estimates that a 1.4-meter rise in sea level by 2100 would:

- Put 480,000 people at risk of a 100-year flood event, given today's population; this includes large numbers of people at risk with heightened vulnerability, including low-income households and communities of color.
- Put a wide range of critical infrastructure, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants, power plants, seaports and airports, and hazardous waste facilities/sites, and at increased risk of inundation in a 100 year flood event.
- Put nearly \$100 billion worth of property, measured in year 2000 dollars and as the current replacement value of buildings and contents, at risk of flooding from a 100-year event.
- Require approximately 1,100 miles of new or modified coastal protection structures on the Pacific Coast and San Francisco Bay to protect against coastal flooding. The total cost of building new or upgrading existing structures is estimated at about \$14 billion (in year 2000 dollars).
- Result in a loss of 41 square miles of California's coast by 2100 due to accelerated erosion.

The California Coastal Commission (<http://www.coastal.ca.gov/climate/climatechange.html>) identifies the following six areas of concern for climate change in the coastal zone:

1. Storms and flooding
2. Coastal erosion and loss of sandy beaches
3. Coastal habitats

4. Marine ecosystems
5. Land use planning decisions
6. Shoreline access

Local Coastal Programs (LCPs) should be integrated with a vulnerability assessment that examines these issues. The CCC states (<http://www.coastal.ca.gov/lcps.html>, ¶11):

*LCPs are basic planning tools used by local governments to guide development in the coastal zone, in partnership with the Coastal Commission. LCPs contain the ground rules for future development and protection of coastal resources in the 76 coastal cities and counties. The LCPs specify appropriate location, type, and scale of new or changed uses of land and water. Each LCP includes a land use plan and measures to implement the plan (such as zoning ordinances). Prepared by local government, these programs govern decisions that determine the short- and long-term conservation and use of coastal resources.*

The land use and coastal resources policies in the LCP will be useful for examining the potential impacts of climate change in the coastal zone. In addition, under the California Coastal Act, the Coastal Commission retains significant permit authority in certain areas including tidelands, submerged lands or public trust lands, even after certification of Local Coastal Programs (Public Resources Code section 30519). As a result, adaptation strategies may fall within the Commission's continuing permit jurisdiction. Plans other than LCPs may also fall within the Commission's jurisdiction; therefore, local governments and other entities should work with the Commission to formulate adaptation strategies that are consistent with the Coastal Act and applicable LCP policies. The California Climate Adaptation Strategy (2009) suggests amending LCPs to account for the impacts of climate change. Other plans such as Public Works Plans and Long Range Development Plans may also need to be updated.

In this section, consideration will be given to the following sub-sectors of ocean and coastal resources:

- Coastal dependent development: infrastructure and land uses that require a site located near or on the ocean for functional or operational reasons (adapted from Public Resources Code 30101).
- Coastal development: existing and proposed residential, commercial, industrial, and public facilities development (adapted from Public Resources Code 30106).
- Recreational resources and shoreline access: parks, beaches, and shoreline access points and trails (including the California Coastal Trail).



- Water supplies: surface water and groundwater sources for municipal supplies.
- Fisheries operations and facilities: fisheries and associated operations and facilities such as aquaculture areas and processing facilities.
- Agricultural operations and facilities: agricultural operations and facilities within the coastal zone especially those subject to flooding or dependent on groundwater resources susceptible to saltwater intrusion.
- Coastal habitats: dunes, wetlands and estuaries, littoral zone habitats, near-shore marine ecosystems, and other coastal habitats.

## EXPOSURE

Three primary climate change impacts will affect the immediate shoreline and ocean: sea level rise, changed storm frequency and severity, and ocean acidification. Because LCPs cover the entire coastal zone, including inland areas, climate change impacts discussed elsewhere in this report also should be considered when updating LCP policies, such as wildfire, flooding, and environmentally sensitive habitat areas (ESHA).

The State Of California Sea level Rise Interim Guidance Document (October 2010) provides projections on future sea level rise (see Table 3).

Table 3: Sea Level Rise Projections using 2000 as the Baseline Year

		AVERAGE OF MODELS	RANGE OF MODELS
2030		7 in (18 cm)	5-8 in (13-21 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	Low	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	Low	40 in (101 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

Note: These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown – based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

The state guidance document on SLR provides considerations that influence exposure, including trends in relative local mean sea level. Relative sea level is the sea level relative to the elevation of the land. In California, the land elevation along the coast is changing due to factors including tectonic activity and subsidence.

The world's oceans have experienced approximately 0.12 inch of SLR over the past decade. This rate is expected to increase as the 2100 forecast year is approached; thus, SLR will appear to be a relatively slow-moving phenomenon through the first part of the century and then accelerate during the latter half.

With SLR are the following associated effects:

- Inundation/long-term waterline change
- Extreme high tide
- Flooding
- Coastal erosion and loss of sandy beaches
- Salt water intrusion

In addition to SLR, “climate models project two important trends: higher sea level extremes resulting from increasing storm intensity and more frequent extreme events” (CEC, 2009, p. 50). The combination of SLR and potential increased storm frequency and severity is problematic: “Most severe impacts result from the coincidence of sea level rise with storm surge, tides, and other climatic fluctuations (like El Niño)” (CEC, 2009, p. 49).

Cal-Adapt shows maps of inundation areas for the 100-year storm using data from the Pacific Institute and the United States Geological Survey (USGS). The maps show the current 100-year storm inundation as well as inundation scenarios for 19 inches (low GHG emissions), 39 inches (medium GHG emissions), and 55 inches (medium-high GHG emissions) of SLR by 2100. Other more detailed maps include new high-resolution LiDAR data, which can be used to create detailed inundation maps: <http://www.opc.ca.gov/2012/03/coastal-mapping-lidar-data-available/>

Ocean acidification remains an area that is not fully understood. Although there has been a measured increase in the acidity of the world's oceans including California coastal waters, less is known about local variability and the effect that acidification may have on coastal and ocean resources. With acidification, oceans have the potential “to deteriorate to conditions detrimental to shell-forming organisms, coral reefs, and the marine food chain, thus threatening fisheries and marine ecosystems generally” (Pew Center on Global Climate Change, 2009, p. 1). Ocean acidification is not addressed in further detail in the APG, but coastal jurisdictions that depend on fisheries (especially shellfish) should be aware of the issue.

One last exposure issue to consider is the potential for changes in inland rainfall and snowmelt conditions. Coastal flooding, especially in bays, estuaries, and river mouths, could be exacerbated by changes in rainfall or Sierra snowmelt. Cal-



Adapt provides maps showing potential changes in rainfall. Coastal communities can examine expected changes within upstream watersheds.

## SENSITIVITY

Numerous assets and resources should be considered when assessing the potential impact of climate change in the coastal zone. Planners should assess the following:

- Coastal Infrastructure and Land Uses
- Coastal development (existing and proposed)
- Recreational resources and shoreline access
- Water supplies
- Fisheries operations and facilities
- Agricultural operations and facilities
- Coastal habitats



### Coastal Infrastructure and Land Uses

Assessment of sensitivity should include the inventorying and mapping of the following types of assets: piers, marinas, moorings, breakwaters/seawalls, ports and related facilities, airports, roads, boat launches/ramps, oil/gas facilities, aquariums, tourist areas, shipyards, coastal-related business and industry, wastewater treatment plants (WWTPs), stormwater facilities, and power plants. For those assets under control of the local jurisdiction—such as WWTPs—additional analysis should include an examination of vulnerability to flooding/inundation based on each asset's elevation, flood-proofing, and other factors. This analysis should be coordinated with the department or agency that manages the asset. For assets not under the control of the local jurisdiction, appropriate outreach efforts should be conducted to encourage the owners/operators of those assets to consider the vulnerability to sea level rise.

### Coastal Development

Assessment of sensitivity should include the inventorying and mapping of existing and proposed residential, commercial, industrial, and public facilities development within the potential inundation zones. Particular attention should be given to critical facilities such as hospitals and emergency services. The inventory should also draw on U.S. Census or similar local data to identify populations that are especially vulnerable. If possible, the inventory should include the economic value of these land uses for use in economic impact assessment.

### Recreational Resources and Shoreline Access

Assessment of sensitivity should include the inventorying and mapping of coastal recreational resources (especially beaches) public parks, shoreline access points and trail networks including the California Coastal Trail and any vulnerable areas

of Highway 1. Local, state, and federal agencies that manage these resources should be contacted for information regarding vulnerability assessments and adaptive practices.

### Water Supplies

Assessment of sensitivity should include the inventorying of surface water and groundwater supplies within the inundation zone and within the area susceptible to saltwater intrusion. The assessment should be coordinated with the water provider. A more detailed discussion is included below as part of the Water Management sector.



### Fisheries Operations and Facilities

Assessment of sensitivity should include the inventorying of fisheries operations and facilities such as aquaculture areas, processing facilities, and other related facilities not covered in the previous areas. Local jurisdictions should encourage owners/operators of those assets to consider the vulnerability to sea level rise.

### Agricultural Operations and Facilities

Assessment of sensitivity should include the inventorying of agricultural operations and facilities such as farming and grazing lands, processing facilities, and other related facilities not covered in the previous areas. Local jurisdictions should encourage owners/operators of those assets to consider the vulnerability to sea level rise.



### Coastal Habitats

Assessment of sensitivity should include the inventorying and mapping of beaches, dunes, wetlands and estuaries, littoral zone habitats, and other coastal habitats. Special attention should be paid to habitat areas with species listed by federal or state agencies for protection. Land uses adjacent to coastal habitats should be assessed to evaluate possibilities for habitats to migrate inland as SLR intensifies. This may include identification of future habitats areas that will require protection. Connectivity of habitat should also be assessed to allow protection of critical corridors. In communities with coastal habitat, it is important that biology and conservation staff play key roles on the climate adaptation team to accurately identify the aspects of these habitats potentially sensitive to projected changes.



## POTENTIAL IMPACTS

### Coastal Infrastructure and Land Uses

Coastal dependent assets cannot usually be moved away from the coast. Thus, jurisdictions will need to consider how effectively these assets may continue



to function when exposed to a potential increase in severity and frequency of coastal storms and high tides, associated erosion, and potential long-term inundation. The periodic or permanent failure of these assets may compromise community safety and local economies.

Of particular concern to local communities should be wastewater treatment plants (both the plants themselves and their operations), as well as ocean outfall facilities. Without adequate advance planning, the expense of armoring or relocating these facilities could place a tremendous burden on local governments.

An additional concern is the potential economic impact if these assets are compromised, especially where the assets make up significant portions of the local economic base. Many California communities depend on tourism as a key part of their economies. Many coastal uses such as hotels, restaurants, and entertainment facilities generate tourist tax dollars.

### Coastal Development

Much of the California coast is undergoing a “coastal squeeze” with beaches squeezed between flooding and erosion from the ocean side and fixed development on the inland side. This “squeeze” will worsen with rising sea level. Threats to development, such as erosion and coastal storms are a problem now, and will increase with rising sea level. Jurisdictions with coastal development will see this problem exacerbated and should focus on identifying existing structures at risk and planned structures that may be at risk if built.

### Recreational Resources and Shoreline Access

Recreation resources tend to be less capital-intensive than the assets described above. They primarily consist of parking areas, bathrooms, trails and stairs, boardwalks and overlooks, and moderate recreational amenities. Jurisdiction will need to consider the potential effect of SLR on these assets. If there is coastline retreat (i.e., erosion and/or loss of sandy beaches), the public may experience the loss of the key amenity itself: access to the ocean and the beach. Jurisdictions should consider the number, size, quality, and distribution of beach and coastal recreation areas and the possibility that these qualities will be changed or diminished with SLR. These impacts will also be related to the tourism-related economic impacts discussed above.

### Water Supplies

Saltwater intrusion into shallow aquifers may increase in coastal areas that experience more frequent and severe inundation. Jurisdiction should work with geologic and hydraulic specialists to determine the potential effect on groundwater supplies. This may also be a concern for coastal agriculture (discussed in the Agriculture sector).

## Fisheries Operations and Facilities

The issue here is similar to the issue described for coastal dependent development. In addition, aquaculture activities within or near the ocean and estuaries may be affected by SLR and coastal storms.

## Agricultural Operations and Facilities

The issue here is similar to the issue described for coastal dependent development. Of particular concern are agricultural areas dependent on groundwater susceptible to saltwater intrusion. The degree to which this poses a problem will depend on the local and regional water table, the rate of water withdrawal, and the relative recharge rate.



## Coastal Habitats

As SLR advances, it will force a migration or succession of coastal habitats. Of particular concern will be habitat areas that are small, isolated, and/or of poor quality. These factors will exacerbate impacts since they will restrict the ability of species to migrate or adjust to changing conditions. In addition, particular attention will need to be given to impacts on critical habitat or listed species.



## ADAPTIVE CAPACITY

Jurisdictions should review their current policy and program documents and coordinate with owners/operators of other assets and resources to determine what capacity currently exists to adapt to the consequences of SLR and coastal storms. Questions to ask include the following:

### General Questions

- Are there currently plans to strengthen or relocate assets and facilities? Is funding identified for implementation of these plans? Of particular interest are:
  - General plans (and associated implementation plans/ordinances)
  - Local coastal plans (LCPs) (including land use plans and implementing ordinances as defined by PRC 30108.6)
  - Local hazard mitigation plans (LHMPs)
- Do regulations exist that seek to reduce or eliminate impacts?
- Have alternatives been identified for assets and facilities that cannot be strengthened or relocated?
- Do alternative technologies exist that may support adaptation?
- For assets and facilities that generate social or economic benefits, do alternatives or substitutes for these benefits exist?
- What external resources or agencies exist to assist in adaptation?

- What is the current position of state agencies that may support or impede adaptation actions? Of particular importance are the California Coastal Commission, California State Lands Commission, California Department of Fish and Game, California State Parks, San Francisco Bay Conservation and Development Commission, State Water Resources Control Board, California Public Utilities Commission, State Coastal Conservancy, and California Department of Transportation
- Will some adaptation actions exacerbate erosion problems?
- Will some adaptation actions limit or affect public beaches and access?
- How will different adaptation options affect the local economy and resources?



### Questions Regarding Coastal Infrastructure and Land Uses

- Are these uses necessary or needed? Does the community depend on these uses?
- Can these uses be protected or relocated within the coastal zone? What resources would be needed to do so? Do these resources exist and are they available?
- How prepared are owners/operators to deal with the impacts of climate change?

### Questions Regarding Coastal Development

- Can the development be protected or relocated? What resources would be needed to do so? Do these resources exist and are they available?
- Do regulations exist to control future development to reduce risks?
- Are amendments needed to a certified LCP land use plan and implementing ordinances that control future development to reduce risks?
- How prepared are the owners to deal with the impacts of climate change?
- Will the demographic/social/economic characteristics of the owners and residents impede adaptation activities?

### Questions Regarding Recreational Resources and Shoreline Access

- What are the strategies or development standards in place to protect or relocate public access and recreational facilities? What resources or LCP Amendments would be needed to do so? Do these resources exist and are they available?
- What is the capacity for beach protection, renourishment, and regional sediment management?

### Questions Regarding Water Supplies



- How dependent is the community on these supplies?
- Are alternative water supplies or other options (including water conservation) available?

### Questions Regarding Fisheries Operations and Facilities

- Are these operations and facilities necessary or needed? How does the community depend on these?
- Can the resources be protected or relocated? What resources would be needed to do so? Do these resources exist and are they available?

### Questions Regarding Agricultural Operations and Facilities



- Are the impacted operations and/or facilities needed? Are alternatives available for the services provided by the facilities? How does the community depend on them?
- Can the operations and facilities be protected or relocated? What resources would be needed to do so? Do these resources exist and are they available?

### Questions Regarding Coastal Habitats



- How unique are these habitats?
- Can the habitats be recreated elsewhere? Are adequate sites available and can or does the jurisdiction have access to these sites?
- Are there species already vulnerable (endangered or threatened) that may be further stressed by the projected changes?
- Are there existing plans or policies, including certified LCPs, protecting and/or promoting vulnerable habitats? Are LCP Amendments needed?
- What ecosystem services (e.g., flood protection, wave attenuation, water quality benefits) do existing coastal habitats provide?
- Is there room for habitats to shift or migrate inland?
- What land use designations, policies and implementing ordinances are in place through the LCP that protect environmentally sensitive habitats, wetlands, and/or other rare and special habitats or species? Are LCP Amendments needed?
- How will climate change affect these habitats and species?

## RISK AND ONSET

The Intergovernmental Panel on Climate Change (IPCC) considers SLR to be of high probability; therefore, coastal communities should consider the potential

impacts of SLR to be of higher priority for adaptive planning than other lower probability effects of climate change.

The current rate of SLR over the last decade is about 0.12 inch per year. The current onset of SLR is relatively slow, but SLR is forecasted to accelerate over time. Local jurisdictions have time to implement adaptation strategies. Planning should start now and implementation should be timed to meet the expected onset of the effects of SLR. Coastal jurisdictions should keep in mind that many issues, such as coastal storms, erosion, storm surge, and loss of sandy beaches, are currently problems, and that the sooner action is taken the sooner it can resolve both current problems as well as the expected future ones.

## ADDITIONAL RESOURCES

- *State of California Sea Level Rise Interim Guidance Document*, developed by the Sea Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust (October 2010): <http://www.opc.ca.gov/2011/07/sea-level-rise-task-force-interim-guidance-document/>
- California Coastal Commission. Global Warming and Climate Change web resources. <http://www.coastal.ca.gov/climate/climatechange.html>
- San Francisco Bay Conservation and Development Commission (BCDC). Climate Change web resources. [http://www.bcdc.ca.gov/planning/climate\\_change/climate\\_change.shtml](http://www.bcdc.ca.gov/planning/climate_change/climate_change.shtml)
- The San Diego Foundation & ICLEI. *Sea Level Rise Adaptation Strategy for San Diego Bay* (January 2012). [http://www.icleiusa.org/static/San\\_Diego\\_Bay\\_SLR\\_Adaptation\\_Strategy\\_Complete.pdf](http://www.icleiusa.org/static/San_Diego_Bay_SLR_Adaptation_Strategy_Complete.pdf)



## Water Management

The water management sector addresses flooding and water supply in communities. Both of these areas may be affected by climate change. Although scientific evidence regarding increased flooding impacts of climate change in specific regions may be somewhat unclear, it is prudent for California communities to recognize that changes in precipitation, the rate and timing of snowmelt, and other conditions such as increased wildfire may aggravate flood hazard conditions. Water supply is expected to be affected in areas that experience less precipitation and areas dependent on snowpack. Flood and water supply issues are described separately below. However, climate adaptation strategies should address these issues together in light of their interrelated nature in most communities.



## Flooding

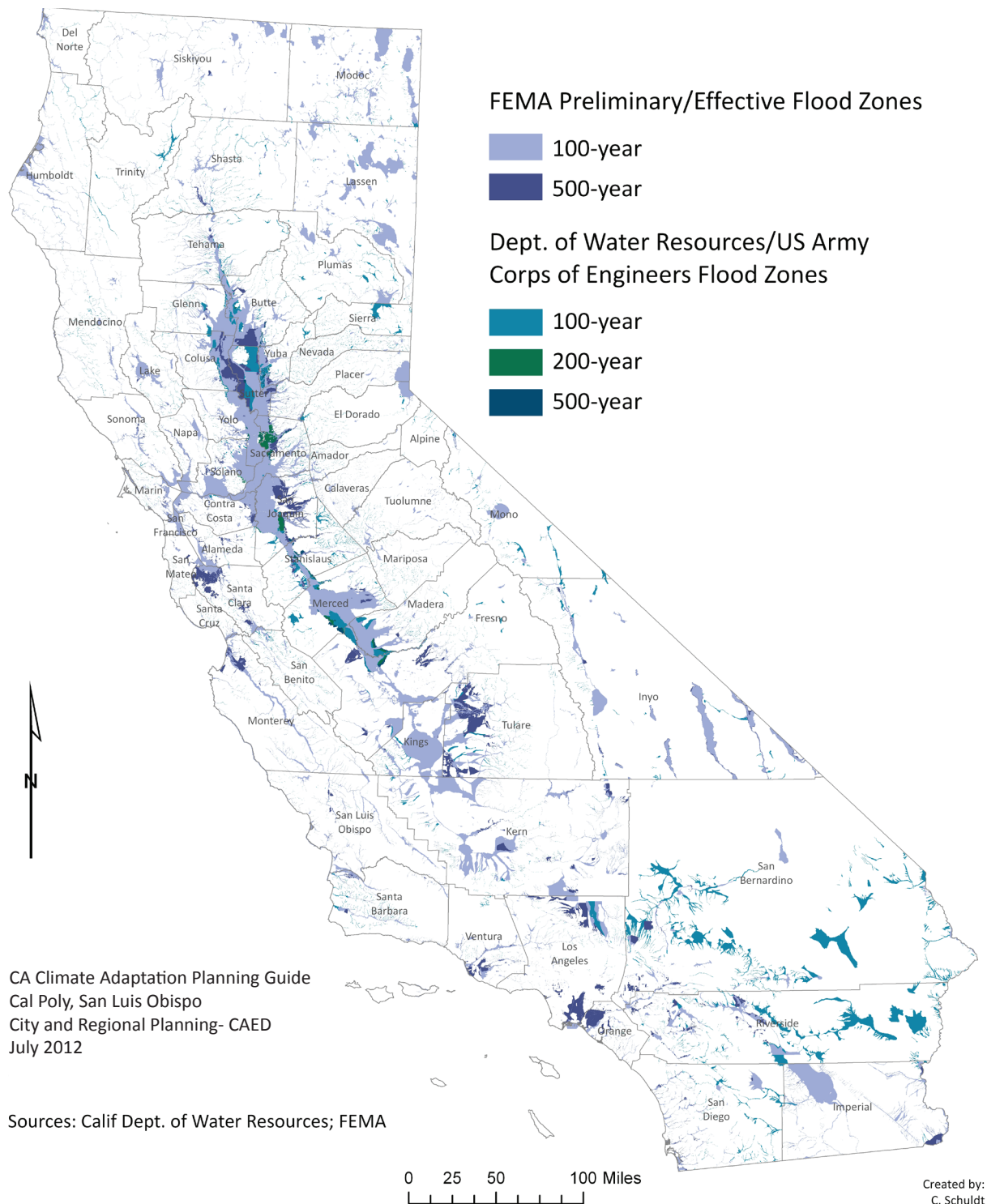
California's diverse geography, including coasts, coastal and inland mountains, valleys, and highly varied and distinct desert regions, creates the potential for a variety of flood types: alluvial fan, coastal, flash, fluvial, lake, levee, mudslide, and riverine. Secondary impacts include flooding, erosion, and debris flows that may occur during the months and years following wildfires.

Flooding is a very real and growing threat within most regions and deserves careful attention as one of the more deadly potential impacts of climate change. Although climate change may lead to declining precipitation in some parts of California, it is also may generate increasingly severe storms that exacerbate flooding. Additionally, earlier Sierra snowmelt is leading to heavier spring flooding, especially in the Central Valley. Conversely, declining precipitation and long-term reductions in snowpack will yield less flooding in other areas, such as desert regions. These changes affect the frequency and severity of flood hazards in many regions of California.

The impacts must be interpreted on a regional and local watershed basis in relation to factors such as types of terrain, overall gradients of the watercourses, levels of development and impervious surfaces, degree to which human settlements are located in flood-prone areas, and the flood management systems that are in place or planned. Changes in flow regimes also affect biodiversity and aquatic ecosystems, as addressed in the Biodiversity and Habitat section.

Thus, there are no “one-size-fits-all” flood management strategies suitable for the entire state. Adaptation strategies and flood management solutions will necessarily be highly localized within each region and watershed. Figure 3 shows that many areas of the state – including populated areas in the Central Valley – are vulnerable to flooding.

The Federal Emergency Management Agency (FEMA) and California Department of Water Resources (DWR) flood hazard maps are now available statewide on MyPlan, a web-based GIS map service sponsored by the California Emergency Management Agency (Cal EMA) and the California Natural Resources Agency (<http://myplan.calema.ca.gov/>). MyPlan provides one-stop access to flooding, wildfire, and earthquake information provided by separate agencies.



**Figure 3. FEMA 100-Year Flood Hazard Areas.**  
Source: California 2010 State Hazard Mitigation Plan Executive Summary

## EXPOSURE

Climate change impacts directly affecting flooding and flood management during the 21st century are likely to include the following (CNRA, 2009):

- Possible precipitation decreases ranging from 12 percent to 35 percent compared to historical averages, depending upon location;
- More winter precipitation falling as rain instead of snow; and
- Intense rainfall events leading to more frequent and/or more extensive flooding.

Climate change impacts interact; this, too, has consequences for flood risk. Specific Cal-Adapt guidance and data important for assessing exposure in a given region include three separate climate change factors: (1) precipitation trends, (2) snowpack scenarios, and (3) wildfire projections. Cal-Adapt mapping shows a general redistribution of heavy precipitation away from southern and inland hydrologic regions and toward central and northern regions.

It is important to note, however, that general decreases in annual precipitation in southern and inland hydrologic regions may not be accompanied by a reduction in flooding. On the contrary, such regions are likely to experience heavier, more intense, episodic rainfall and flooding events due to transport of hotter, moisture-laden air from the ocean.

Substantial reductions in snowpack in coastal and northern mountains as well as the Sierra Nevada range are expected to be accompanied by earlier rainfall and runoff downstream, most particularly in the Sacramento River and San Joaquin River watersheds, which converge in the California Delta. When combined with the continued northeastward flow of moisture-laden air from tropical zones from the Central Pacific depositing more rainfall in the northern portions of the state, these trends suggest the possibility of more intense flooding in the northern and central portions of the Central Valley as well as in the San Francisco Bay region.

Adding to these factors are Cal-Adapt projections in these same mountainous regions that show substantial increases in wildfire. According to the 2010 State Hazard Mitigation Plan, "...Wildfires greatly reduce the amount of vegetation, which in turn reduces the amount of rainwater absorption, allowing excessive water runoff that often includes large amounts of debris, dirt, and other sediments... Periods of high intensity rainfall are of particular concern, but post-fire flooding can also occur during a normal rainy season" (Cal EMA, 2010, pp. 198-199).

A key question for assessing exposure is the extent to which climate change impacts might change current flooding conditions. Although overall projections for total annual precipitation show little change, trends vary substantially by region and are considered uncertain. Taken together, however, the preceding factors suggest that northern portions of the state, especially the Central Valley, are more likely to experience increased and more widespread flooding in the remainder of the century.

The Central Valley is ripe for more frequent and/or more extensive flooding due to climate change factors cited previously as well as existing patterns of development in flood-prone areas. By comparison, heavily developed areas of Los Angeles and San Diego counties that are equipped with extensive, hardened flood control systems that carry storm flows rapidly to the ocean are more vulnerable to increased landslide and mudflow risk in hillside areas in the aftermath of major wildfires experienced in the past decade (Cal EMA, 2010).

Regions that experience substantially wetter conditions due to heavier rainfall and earlier snowmelt can expect to have more pressure placed on flood management systems of all kinds. When combined with sea level rise and intensification of coastal surge and erosion, riverine flooding along low-lying coastal areas will back up into inland areas, creating new floodplains and the need for adaptation of both flood control and flood management systems.

The standard references for establishing location of flood hazards throughout the nation are the Flood Insurance Rate Map (FIRM)-designated floodplains, part of a national insurance system maintained under the National Flood Insurance Program (NFIP). The FIRM maps identify standard flood hazard zones for insurance and flood management purposes and provide a statement of probability of future occurrence based on past experience.

Flood zones are areas depicted on a FIRM map that are defined by FEMA according to levels of risk. Under the NFIP, FEMA publishes and maintains “500 year” and “100-year” FIRM maps. The 500-year maps show areas subject to flooding on an average of every 500 years, and the 100-year maps show areas subject to flooding on an average of every 100 years. A flood of a magnitude recurring on an average of every 500 years has a 0.2 percent chance of occurring in any given year. A flood of a magnitude recurring every 200 years has a 0.5 percent chance, and a flood of a magnitude recurring every 100 years has a 1 percent chance (see Table 4).

Zones with a 1 percent annual chance of flooding are considered to have high risk and are part of the Standard Flood Hazard Area (SFHA). In communities that

participate in the NFIP, mandatory flood insurance purchase requirements apply to the following zones: A, AE, AI-30, AH, AO, AR, A99, V, and VE or VI through 30. Table 4 shows a general classification of FEMA flood zones.

Table 4. Flood Insurance Rate Map (FIRM) Flood Zones

ZONE	DESCRIPTION
<b>A</b>	Area with a 1% annual chance of flooding. No depths or Base Flood Elevations (BFEs) are shown.
<b>AE</b>	Base floodplain where BFEs are provided. AE Zones are now used on digital FIRMs instead of AI_A30 Zones.
<b>AI through 30</b>	Known as numbered A Zones, these are the base floodplains in the old FIRM format where a BFE is shown.
<b>AH</b>	Area with a 1% annual chance of shallow flooding with an average depth ranging from 1 to 3 feet. BFEs are shown at selected intervals.
<b>AO</b>	River or stream flood hazard area, or area with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow with an average depth ranging from 1 to 3 feet. Average flood depths derived from detailed analyses are shown.
<b>AR</b>	Area with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam).
<b>A99</b>	Area with a 1% annual chance of flooding protected by a federal flood control system where construction has reached specified legal requirements. No depths or BFEs are shown.
<b>V</b>	Coastal area with a 1% or greater chance of flooding and an additional hazard associated with storm waves. No BFEs are shown within these zones.
<b>VE or VI through 30</b>	Coastal area with a 1% or greater chance of flooding and an additional hazard associated with storm waves. BFEs are shown at selected intervals.
<b>B, C, X</b>	Zones considered to have moderate to low risk of flooding, although flood insurance is available to property owners and renters in communities that participate in the NFIP.
<b>D</b>	Area with possible but undetermined flood hazards, where no flood hazard analysis has been conducted.

Source: California Emergency Management Agency. (2010). State of California Multi-hazard Mitigation Plan. Sacramento, CA: Retrieved from [http://hazardmitigation.calema.ca.gov/docs/2010\\_SHMP\\_Final.pdf](http://hazardmitigation.calema.ca.gov/docs/2010_SHMP_Final.pdf)

The California Department of Water Resources (DWR) is developing 200-year (0.5 percent) flood maps for the Central Valley and other regions. Based on bond proposals (Propositions 1E and 84) passed by voters in 2006, DWR has been preparing maps showing the 200-year flood (0.5 percent chance of occurrence in a given year) areas in the Central Valley (Sacramento River and San Joaquin River drainages) under its FloodSAFE program. While other areas of the state are being mapped over time, the primary mapping progress to date has been in the Central Valley where flooding problems are most severe.

The 100-year, 200-year, and 500-year recurrence intervals represent the long-term average periods between floods of specific magnitudes; significant floods can occur at shorter intervals or even within the same year. It is also important

to note that recurrence intervals for currently published floodplain maps reflect probabilities based on past experience and do not take into account anticipated climate change impacts.

Unfortunately, information on local-level, changes in flooding will not exist until updates are done by FEMA, DWR, or local governments. Analysts will have to consider their community's current flood risk in light of the expected climate changes described above. FEMA flood maps generally represent conservative estimates of exposure to potential floods. Communities need to consider 200-year and 500-year floodplains, in addition to 100-year floodplains, when developing flood policies and programs.

## SENSITIVITY

Numerous assets and resources should be considered when assessing the potential impact of climate change on flooding. Planners should assess the following:

- Flood/stormwater management infrastructure and systems
- Development and infrastructure within floodplains (100-, 200-, and 500-year), especially:
  - Critical facilities
  - Lifeline infrastructure including bridges, tunnels, major roads

Procedures for assessing sensitivity of flood management systems should focus on detailed GIS mapping to more completely identify existing and potential flood-prone areas.

Greater collaboration among FEMA, DWR, regional flood control districts, and local governments will be needed not only for evaluating local sensitivity to climate change flooding exposures, but also for devising more adaptive solutions.

## POTENTIAL IMPACTS

Changes in flood frequency and severity and impacts on flood management systems have the potential to affect a variety of community resources, functions, and populations. Impacts are closely related to the arrangement of land use, infrastructure, and other community assets relative to flood-prone areas.



Extensive below-sea-level areas with exceedingly poor drainage have the propensity to retain flood waters for extended periods of weeks or months, interrupting transportation and hurting local commerce. With a serious Delta levee break, business recovery would become problematic for an extensive period, and conveyance of waters originating in the northern regions of the state to the people living in southern regions of the state via the State Water Project would be seriously interrupted, injuring the entire state's economy.



## Community Resources and Functions

Residential, commercial, and industrial are the predominant uses of land in human settlements, interspersed with infrastructure and open spaces needed to support these activities. Access to flowing streams as a water source is a historical reason why so many cities are overlaid directly on flood-prone areas.

Sensitivity of community resources to climate change flooding impacts generally can be assessed in relation to the degree to which individual communities are either built out or have future growth potential. Built-out communities have little choice but to retrofit existing neighborhoods either by intensifying flood control systems, elevating existing development above base flood elevations, or buying out existing homes for open space.

Many older communities, such as Los Angeles or San Luis Obispo, have downtowns located adjacent to their original water sources, with accompanying flood hazards, risks, and vulnerability. In many communities, this has necessitated after-the-fact construction of channels and culverts to divert storm flows around and under previously developed areas.

### *Identifying Flooding Impacts*

Approaches to assessing particular flooding impacts can include (1) assessing older vs. newer neighborhoods, and (2) involving the community's climate change adaptation team.

Flooding impacts generally are not linked to specific populations, such as seniors, children, or individuals with disabilities. However, older housing inventories are sometimes located in low-lying, more flood-prone areas near where the community was originally established. In such areas, there may tend to be greater concentrations of renters, elderly, and communities of color, and such neighborhoods are likely to be more affected by historical flooding than more recently developed communities. In growing communities, wiser land use decisions that avoid placing residential, commercial, industrial, and infrastructure development in flood-prone areas can reduce future losses of life and property and conserve expenditure of public funds for buy-outs. Wise land use decision-making can also minimize climate change flooding impacts on specific populations living in growing communities.

The climate change adaptation team can help a community complete a careful determination of climate change-related flooding impacts. In areas with vulnerable populations, the team should include representatives of potentially affected population groups and should use MyPlan and other GIS map services to identify where flood hazard areas and vulnerable populations overlap. Flooding impacts on business continuity may also be a concern that the team can assess.



### *Flood Management Systems*

Climate change impacts have a very direct effect on flooding and flood management systems. Flood control systems currently in place may eventually prove insufficient to handle flows generated by strong rainfall in regions that are becoming drier, as well as those that are becoming wetter.

Southern regions that can expect substantially drier conditions may experience both less regular and more intense flooding. Declining overall precipitation within such regions may be accompanied by occasional intense storms, creating flood events as damaging as in the past, or even more so. When combined with unanticipated wildfires, such events can place great pressure on flood control systems. Likely outcomes are greater flooding and related losses (e.g., from mudslides).

A highly-publicized example of pressure placed on flood control systems in post-wildfire areas was the aftermath of the devastating August 2009 Station Fire. The fire started in the Angeles National Forest above La Canada Flintridge and burned over 250 square miles, leading to the deaths of firefighters and evacuation of thousands of homes. The Station Fire was followed in the winter by severe mudflows that quickly overflowed debris basins built in the early 1900s and inundated dozens of homes and closed many streets. Re-engineering and reconstruction of check dams to improve capacity would be costly and take many years.

Beyond the current state of flood control systems is the presence in many FEMA flood zones of large numbers of people due to prior development in the floodplain.

According to the 2010 State Hazard Mitigation Plan (Cal EMA, 2010, p. 207):

*Studies comparing 2000 U.S. Census data with NFIP FIRM maps found that over 5 million Californians (15 percent of total population) lived in a FIRM-designated floodplain and nearly 2 million (5.8 percent of total population) lived in the 100-year floodplain. Based on these studies, California would normally expect approximately 20,000 people per year to be affected by 1 percent and 0.2 percent annual flooding; however, the state's flood risk is not evenly distributed. Approximately 84 percent of the 5 million Californians living in a FIRM-designated floodplain were in 13 counties having 100,000 or more people within 100-year and 500-year FIRM-designated floodplains (see Table 5.U). In 2000, the leader by far was Orange County, with 1.4 million people at risk.*

Collaboration in the evaluation of climate change-related flooding impacts should include not only technical staffs of federal and state agencies (FEMA, Cal EMA, and DWR) but also, at the local level, broadened participation of vulnerable populations that are stakeholders in climate adaptation planning.

## ADAPTIVE CAPACITY

Jurisdictions should review their current policy and program documents and coordinate with owners/operators of other assets and resources to determine what capacity currently exists to adapt to increased flooding.

### General Questions

General questions to ask include the following:

- Are there currently plans to strengthen or relocate community assets or to improve flood/stormwater management infrastructure? Is funding identified for implementation of these plans? Of particular interest are:
  - General plans (and associated implementation plans/ordinances)
  - Capital improvement plans
  - Local coastal plans (for coastal jurisdictions)
  - Local hazard mitigation plans (LHMPs)
  - Actions taken in response to Senate Bill (SB) 5 and SB 17 and Assembly Bill (AB) 5, AB 70, AB 156, and AB 162
- Does the jurisdiction have regulations (such as floodplain development ordinances) that seek to reduce or eliminate impacts?
- Have alternatives been identified for assets and facilities that cannot be moved or strengthened?
- Do alternative technologies exist that may support adaptation?
- For assets and facilities that generate social or economic benefits, do alternatives or substitutes for these benefits exist?
- What external resources or agencies exist to assist in adaptation?
- What is the current position of state agencies that may support or impede adaptation actions? Of particular importance are the California Coastal Commission, California Fish and Game, and State Water Resources Control Board.

An important variable in determining local adaptive capacity in the future is the manner in which communities have previously dealt with flooding. Cities, counties, and flood control districts that have created extensive networks of concrete-lined channels are already faced with the dilemma of raising or spreading channel walls to accommodate heavier flows, on the one hand, and softening channel bottoms to better meet federally mandated environmental requirements, on the other.

Parallel to that are situations where flood management and/or land use planning has ignored the existence of floodplains, allowing development in areas where flooding is already recurring in 10- or 20-year return periods and repetitive damages and loss of life are already costly.

### Questions Regarding Factors Affecting Adaptive Capacity

Other basic factors affecting the capacity of communities to devise suitable adaptation strategies counteracting climate-change-induced flooding include the following:

1. Built-out communities: existing vulnerabilities to flooding – i.e., how bad is flooding under present-day conditions?
2. Growing communities: availability of options for managing future flooding impacts – i.e., what choices does the community have to avoid further aggravation of existing flood vulnerabilities?
3. Governance: local government capabilities for addressing adaptation through informed public policy supported by wide-ranging stakeholder involvement – i.e., to what extent is local decision-making informed by new climate change information and varying stakeholder perspectives?

Other factors include economic resources by which the community can fashion effective adaptation strategies, accessibility of information identifying locally relevant climate change impacts, availability of relevant skills and knowledge-sharing within members of the community, natural resources providing adaptation options, and resilient infrastructure.

In 2007, the California legislature passed and the Governor signed six interrelated bills—SB 5, SB 17, AB 5, AB 70, AB 156, and AB 162—aimed at addressing flood protection and liability and helping direct use of bond funds. Some of the requirements of the 2007 flood risk management legislation apply statewide, others are applicable to lands within the Sacramento-San Joaquin Valley, and others apply solely to lands within the Sacramento-San Joaquin Drainage District. For example, under SB 5, the Central Valley Flood Management Planning Program is being pursued to develop integrated, sustainable flood management for areas protected by state-federal flood protection systems in the Central Valley (<http://www.water.ca.gov/cvfmpl>). A Central Valley Flood Protection Plan was adopted by the Central Valley Flood Protection District in late June 2012.

AB 162 requires additional consideration of flood risk in local land use planning throughout California. The California Department of Water Resources (DWR) has prepared a guidance document that describes the new legislative requirements that affect city and county local planning responsibilities such as general plans, zoning ordinances, development agreements, tentative subdivision

maps, and other actions. The document, entitled “Implementing California Flood Legislation into Local Land Use Planning: A Handbook for Local Communities” (available at [www.water.ca.gov/LocalFloodRiskPlanning/](http://www.water.ca.gov/LocalFloodRiskPlanning/)), is intended to help cities and counties comply with the new legislation.

## RISK AND ONSET

The rapidity of onset and the probability of more intense or widespread flooding conditions are unknown at this time. The climate change adaptation team should start with a solid understanding of the scope and extent of existing flood hazards as a precondition for probable intensification of risk.

## Water Supply

Water supply consists of the water resources available for societal uses such as agricultural irrigation and production, drinking water, urban landscaping, cooling, and power generation (steam turbines and hydropower). In California, water resources originate in the form of rain or snowfall and are spread among the Sierra snowpack, the state’s water network (streams, rivers, aqueducts, and reservoirs), and groundwater.

The California Department of Water Resources Climate Change Handbook for Regional Water Planning (2011) provides extensive detail and guidance on climate and vulnerability assessment, including a list of vulnerability assessment questions. The questions fall into three primary areas: water demand, water supply, and water quality. Along with the growing population and the health of ecosystems, climate change is one of the major influences on the availability of water resources (Christian-Smith et al., 2011). The availability or lack of water influences agricultural output, ecosystem health, energy production, provision of basic community services, and water-reliant businesses and industries.

The effects of climate change on water supplies will have impacts on agriculture, recreation and tourism, and the economy overall as well as on natural ecosystems. The environment (i.e., ecosystem maintenance) accounts for 48 percent of water use in California. Agriculture accounts for 41 percent and urban use for 11 percent. However, urban water use is expected to increase by more than half by 2050 due to projected population growth (Kahrl and Roland-Host, 2008).

The water supply for much of the state flows through the California Delta. The document *APG: Understanding Regional Characteristics* includes a regional section focused specifically on the Delta. Communities reliant on water from the California Delta should review this section.

## EXPOSURE

Climate change threatens several aspects of a community's water supply. It can affect the source of a community's water (e.g., Sierra snowpack, California Delta, or groundwater aquifer) as well as a community's water use behavior. Several direct climate impacts—particularly temperature and precipitation variation—affect water availability. For coastal communities, sea level rise can threaten groundwater resources due to seawater intrusion, particularly for agricultural water supplies.

Assessing exposure to climate change impacts requires a community to assess not only local conditions, but also the projected conditions for its water source. If a portion of a community's water supply comes from snowmelt, the Cal-Adapt forecast for changes in snowpack should be examined. On a seasonal basis, water scarcity will become far more common, as the Sierra snowpack is projected to shrink at least 30 percent and as much as 80 percent by 2099 (Kahrl and Roland-Host, 2008).

Water flow will actually increase in winter due to more precipitation falling as rain instead of snow and to snow melting more quickly. However, summertime flow will decrease. Therefore, more water will be available in winter when demand is lowest and less will be available in summer when demand is greatest. Seasonal variability in water availability will also reduce the state's hydropower supply, which, in 2007 accounted for 14.5 percent of the state's total power (Kahrl and Roland-Host, 2008). Additionally, drought frequency is likely to increase by a factor of 2.5 under “dry” climate projection scenarios (Luers et al., 2006). If a portion of a community's water supply comes from surface reservoirs supplied by rainfall, then Cal-Adapt information on expected changes in rainfall should be examined.

If a portion of the community's water supply comes from coastal aquifers, on the other hand, then Cal-Adapt information on sea level rise should be examined to determine if saltwater intrusion could become a problem. Climate change will lead to sea level rise and encroachment of saltwater into coastal groundwater aquifers, affecting water supply.

If a portion of a community's water supply comes from the California Delta (delivered by one of the aqueducts), then the region focused specifically on the Bay-Delta should be referenced (see *APG: Understanding Regional Characteristics, Bay-Delta Region*).

## SENSITIVITY

Resilient resources are those able to withstand a higher degree of climate change. Sensitive water supply sources are those most in need of adaptation planning to add resilience. To assess the extent of climate change impacts on water supply, communities should consider the following questions (adapted from Appendix B of *The Climate Change Handbook for Regional Water Planning* – available at <http://www.water.ca.gov/climatechange/CCHandbook.cfm>):

- Does water demand vary by more than 50 percent seasonally in the community?
- Does the community rely on a large percentage of groundwater? If so, is additional groundwater pumping necessary during drought years?
- If crops are grown in your region, are they sensitive to climate variation (especially drought and extreme heat)?
- Are there any major industries in the community that require water for cooling or as part of their process?
- Are there vulnerable populations occupying buildings that rely on water for cooling (such as schools, hospitals, senior homes, and low-income housing units)?
- Are there recreational water uses that cannot always be met due to water quantity or quality issues?
- Does the community's water quality vary during rain events in a way that affects water treatment facility operation?

## POTENTIAL IMPACTS

Communities may want to consider employing the California Department of Water Resources Climate Change Handbook for Regional Water Planning (2011) to evaluate the impact of climate change on water supply, especially if the water supply is very exposed or sensitive.

### Surface Water Supplies

Communities with water supply sources that will experience reduced rainfall or snowpack will likely see a long-term reduction in the amount and reliability of those sources. Water supply shortages are familiar to most California communities; therefore, climate change impacts will not create a novel problem. Communities with coastal aquifers may be subject to seawater intrusion, especially in aquifers with high pumping rates. Communities should assess current levels of intrusion and employ specialists to determine how sea level rise may affect the rate.



## ADAPTIVE CAPACITY

Adaptive capacity is a community's ability—through its plans and implemented policies—to effectively react to or reduce the magnitude of climate change. Jurisdictions should work with the owners, operators, and major consumers of water resources to learn what current capacity exists to deal with climate change impacts.

### Questions to ask include:

- How dependent is the community on imported water brought in from distant sources?
- Are those distant sources likely to decline due to climate change impacts (e.g., reduced snowpack)?
- What alternate sources, if any, might be available in the face of declining imported water deliveries?
- What water conservation measures are already used or might be used in the future by the community?
- Does the community have proven and effective emergency water curtailment measures for droughts?
- What is the community's drought readiness?
  - Has the community faced a recent drought in which water demands could not be met?
  - Is the water system able to store and keep surpluses?
- Does the community have a local and/or regional Urban Water Management Plan?
  - Are the measures in this plan adequate given projected supply and use demand?
- Does the community have existing policy (general plan, programs, ordinances) to promote or mandate demand management (e.g., water efficiency)?

## RISK AND ONSET

Rainfall projections through the end of the century vary widely depending on the climate model used. However, all of the models used on Cal-Adapt show a significant decline in the Sierra snowpack through the year 2090, which will result in a reduction of stored water throughout the state. The IPCC has established changes in precipitation as medium probability (see Table 2).



## ADDITIONAL RESOURCES

- California Department of Water Resources Climate Change Handbook for Regional Water Planning, 2011: [http://www.water.ca.gov/climatechange/docs/Climate\\_Change\\_Handbook\\_Regional\\_Water\\_Planning.pdf](http://www.water.ca.gov/climatechange/docs/Climate_Change_Handbook_Regional_Water_Planning.pdf)  
This Department of Water Resources document provides a comprehensive guide to water supply planning in California, including vulnerability assessment and practical strategies for addressing climate impacts.
- California Drought Contingency Plan, August 2010: [http://www.acwa.com/sites/default/files/news/conservation/2010/08/ca\\_drought\\_contingency\\_plan-public\\_review\\_draft-081010.pdf](http://www.acwa.com/sites/default/files/news/conservation/2010/08/ca_drought_contingency_plan-public_review_draft-081010.pdf)  
This Department of Water Resources document provides a guide to actions to be taken to prepare for, respond to, or recover from severe drought conditions.
- California Data Exchange Center: <http://cdec.water.ca.gov/>  
This Department of Water Resources website provides various statewide and regional water data, covering water supply, river flow levels, snow levels, and projected runoff.
- California Irrigation Management Information System:  
<http://www.cimis.water.ca.gov/cimis/welcome.jsp>  
This database from DWR's Office of Water Use Efficiency allows users to generate reports on temperature, precipitation, and evapotranspiration.
- California Water Plan Update 2009:  
<http://www.waterplan.water.ca.gov/cwpu2009/index.cfm>  
The State Water Plan collects water supply and use data in the Regional Reports (Volume 3 of the plan). Additionally, the appendix includes the raw data sources for the State Water Plan, found here: <http://www.waterplan.water.ca.gov/technical/datasources/index.cfm>
- Water Data Library: <http://www.water.ca.gov/waterdatalibrary/index.cfm>  
DWR's interactive map application enables users to find local data on groundwater use, water quality, and water flow.



## Forest and Rangeland

Forest and rangeland occupies the vast majority of California's land area (CNRA, 2009). These areas support many of the state's ecosystems and associated wildlife, as well as economic activities such as timber harvest and livestock grazing. Climate change alters temperature and precipitation regimes. These changes can influence tree survival and growth, forest composition, forest health and productivity, and will likely increase the intensity of ecosystem disturbances from wildfire, insects, and pathogens. These changes will also affect watershed function and habitat suitability for reliant species. The watershed and habitat impacts are discussed in other sector sections, Water Management and Biodiversity and Habitat. The Forest and Rangeland sector discussion focuses on climate impacts and wildfire. Wildfire risk is affected by seasonal temperature and precipitation, forest health, forest composition, and other factors such as land use and human actions.

While wildfire is a critical ecosystem process in much of California, climate change is expected to contribute to increases in fire frequency, size, and severity beyond the historic range of natural wildfire variability. In general, more frequent, larger, and higher-severity fires have been predicted due to increasing length of the fire season, drier fuels, and decreasing forest health. These changes are being driven by alterations in temperature and precipitation regimes (generally, warmer and drier). Under various GHG emissions scenarios, climate change is predicted to result in substantial increases in both fire occurrence and area burned, with especially acute increases in mid-elevation forests of the Sierra Nevada, the northern California coast, and the southern Cascade Ranges (Westerling et al., 2009).

The influence of climate change on wildfires in California, however, is variable and extremely complex. In general, wildland fire behavior is the result of the interactions of fuels, weather during the event, and topography. Thus, climatic shifts may induce not only changes in weather (via wind, temperature, relative humidity, etc.), but also wildland fuels (via fuel type, amount, moisture, etc.), which subsequently will influence fire number, size, and severity. In addition, impacts depend upon a myriad of interacting factors including geographical region, ecotypes within a region (as influenced by elevation, aspect, etc.), past land management, future demographic shifts, past and future wildfires, suppression infrastructure and effectiveness, and others.

The vast majority of annual acreage burned in California is caused by a small percentage of fires that occur during extreme fire weather events that inhibit successful suppression, especially in chaparral ecosystems (Moritz, 1997). Climate

change will likely increase the number of days in which large, high-intensity fires are expected. Indeed, mean temperatures and temperature extremes are increasing throughout California and are predicted to increase between  $\sim 2.0^{\circ}\text{C}$  and  $\sim 6.0^{\circ}\text{C}$  by the end of the century (Cayan et al., 2006), which will influence fuel type and fuel moisture. Predictions in precipitation patterns vary (Cayan et al., 2008); while less change is predicted in mean annual precipitation in many parts of California, there is expected to be greater fluctuation between years and decades (Cayan et al., 2006). Also, many areas are predicted to have less snow and more rain (Anderson, 2008; Mote, 2005; cal-adapt.org); this change translates into longer periods without moisture, which in turn strongly influence fuel moisture and subsequent fire potential and behavior. Further, climatic shifts could influence ignitions via lightning (Price and Rind, 1994; Lutz et al., 2009) and also winds (Miller and Schlegel, 2006) that facilitate large, high-intensity fires.

## EXPOSURE

Climate change impacts on temperature and precipitation regimes will drive multiple factors that influence habitat structure, moisture of vegetation that fuels fires, and subsequent fire risk.

Cal-Adapt is one source that can aid a community in understanding its exposure to climate change effects. Cal-Adapt shows increase in fire risk relative to 2010 for 2020, 2050, and 2085. When evaluating Cal-Adapt data, the degree of change from current conditions is a critical aspect of understanding potential exposure to climate change. The change is measured in averages and totals, but seasonal changes may be equally important. In addition to the fire risk information, Cal-Adapt allows for average high and low temperatures to be evaluated on a monthly basis. Changes in the seasonal temperature and precipitation pattern will affect vegetative and moisture conditions.

Communities will need to have a clear understanding of the surrounding habitat and health, as well as topography and land use patterns. These factors are not addressed in Cal-Adapt. Experts familiar with the local or regional conditions relating to forest health and wildfire regimes should be included on the climate adaptation team.

## SENSITIVITY

While fire is an important part of ecosystem function, it can create problems in populated areas. Climate change may alter the frequency, size, type, and severity of wildfire events. These events can also impact the viability of associated economic activities such as timber harvest and grazing. Planners and policy-makers should assess the fire sensitivity of the following categories of community assets:

- Development at the wildland-urban interface (existing and proposed)
- Forest- and rangeland-reliant industries
- Forest and rangeland ecosystems

### Development at the Wildland-Urban Interface (Existing and Proposed)

Assessment of sensitivity should include an inventory of existing and proposed development (residential, commercial, industrial, and public facilities) in terms of adjoining habitat type, topography, and level of access. This inventory should also include the building materials, condition, and form (e.g., wood shingles or decks). These factors influence the level to which structures can withstand potential impacts such as fire, landslide, or erosion. The economic value of these areas and populations that live and/or work in the wildland-urban interface areas should also be assessed. The populations should be evaluated to identify individuals who may be particularly vulnerable to impacts such as smoke inhalation. In addition to development, assessment of sensitivity should include the inventory of structures in or near the wildland-urban interface. The inventory should also note what services are provided and to whom. Special consideration should be given to



impacts that may cut off a critical link. Given the need to move emergency equipment and personnel as well as the need to evacuate people during a fire event, transportation infrastructure is often one of the most critical community assets.

### Forest- and Rangeland-Reliant Industries

Communities should assess the potential impacts on the continuity and viability of commercial operations that rely on these ecosystems or that may be sensitive to potential climate change effects. They should assess changes to forest health and evaluate how these impacts will affect a community's economic continuity. The climate adaptation team should include representatives of these businesses and work with them to identify risks and incorporate climate change into their management plans.



### Forest and Rangeland Ecosystems

Assessment of sensitivity should include inventorying and mapping regional forest and range habitats. Special attention should be paid to habitats at risk to change in type due to altered seasonal patterns and/or fire regimes. In addition, species listed for protection by state or federal agencies should be identified, particularly if their habitat is vulnerable to climate change impacts. This assessment relies on having local biologists and land managers as part of the adaptation team. Additional detail on the evaluation of ecosystem impact is presented in the Biodiversity and Habitat section (p. 56).

## POTENTIAL IMPACTS

### Development at the Wildland-Urban Interface (Existing and Proposed)

Although fire at the wildland-urban interface (WUI) may already be a problem, climate change will exacerbate this problem in areas shown to have increasing wildfire risk. In areas with historically lower wildfire risk, development and infrastructure in the WUI may not have landscaping, building materials and designs, or proper siting to resist wildfire. Thus, the combination of increased risk and poor fire resistance may represent a new type or scale of impact for a community. Moreover, depending on the emergency response capacity (discussed below) communities may not be capable of dealing with these impacts. These impacts can include damage to physical structures such as schools or emergency facilities that result in the services provided being unavailable. This widens the range of potentially impacted community members. Another consideration is the air quality impacts of wildfire, particularly on sensitive community populations (this is covered the Public Health, Socioeconomic, and Equity section, p. 12).



### Forest- and Rangeland-Reliant Industries

Changes in temperature, precipitation, and wildfire risk will change forest and rangeland productivity. Consequences for the forestry industry are likely to be slower growth, stressed trees, or insect epidemic. Some forests are at greater risk of stand-replacement wildfires that damage or destroy long-term investment while requiring post-fire planting, road maintenance, and other actions. It is possible, however, that some areas that are currently shut down each winter could see extended logging seasons.

The impact on livestock grazing is less clear. If precipitation decreases and/or temperature increases, then forage quantity could decrease. Livestock would experience increased heat stress and ranchers would likely have to increase water supply for livestock. Also, earlier curing of grasses would facilitate an earlier fire season in grasslands, putting forage at risk.



### Forest and Rangeland Ecosystems

There will likely be changes to species composition and distribution across the state, especially across elevational gradients. In areas where migration is restricted or adaptation cannot occur, species could be lost. Local or regional experts in local ecosystems should evaluate potential impacts including ecosystem interaction with focus on identifying the most vulnerable species due to altered habitat conditions (health, extent, and suitability).



## ADAPTIVE CAPACITY

Jurisdictions should review their current policy and program documents, and coordinate with owners/operators of other assets and resources, to determine what capacity currently exists to adapt to changes in wildfire regimes. Questions to ask include the following:

- Are there currently plans to strengthen or relocate structures in the WUI? Is funding identified for implementation of these plans? Of particular interest are:
  - General plans (and associated implementation plans/ordinances)
  - Local hazard mitigation plans (LHMPs)
- Do regulations exist that seek to reduce or eliminate impacts?
- Have alternatives been identified for structures that cannot be strengthened or relocated?
- Have changes to emergency response resources and functions (especially suppression initial response) been identified?
- Do alternative technologies exist that may support adaptation?
- For assets and facilities that generate social or economic benefits, do alternatives or substitutes for these benefits exist?
- What external resources or agencies exist to assist in adaptation?
- What is the current position of state agencies that may support or impede adaptation actions? Of particular importance are CAL FIRE and the Department of Fish and Game.

Forest and Rangeland impacts are closely related to other sectors. Communities concerned about Forest and Rangeland impacts should also review the Biodiversity and Habitat (p. 56) and Public Health, Socioeconomic, and Equity (p. 12) sector sections for a more detailed evaluation of adaptive capacity.

Climate change will likely alter the effectiveness of suppression. Depending on location, current suppression activities may be adequate with minor adjustment for projected change. In other cases, more drastic change may be required. In one study of a forested area in the Sierra Nevada (Fried et al., 2006), researchers concluded that small increases in fire personnel and equipment could offset climate-induced increases in fire frequency and severity. However, this would necessitate active fuels management by prescribed fire or mechanical treatment, which is costly and triggers environmental regulatory scrutiny that may deter active pre-fire management in some areas. Added fire personnel and equipment may not significantly influence successful initial attack in more volatile fuel types such as Southern California chaparral, where fire agencies are currently extremely effective except in extreme weather events when suppression efforts are largely ineffective.

## RISK AND ONSET

The IPCC has not established probabilities for change in wildfire risk. The Cal-Adapt wildfire model considers changes in precipitation and temperature, but the interaction of these is complex and dependent on other factors, particularly change in vegetation. The IPCC has indicated that changes in precipitation are “medium probability” and changes in temperature are “high probability” (table 1 & 2). Therefore, using the more conservative of the two, changes in wildfire regimes should be considered to be of medium probability.

## ADDITIONAL RESOURCES

- California Department of Forestry and Fire Protection provides a great deal of information from fire science as it relates to climate change and strategies for adapting to climate change. ([http://www.fire.ca.gov/resource\\_mgt/resource\\_mgt\\_EPRP\\_Climate/climate\\_change\\_adaptation.php](http://www.fire.ca.gov/resource_mgt/resource_mgt_EPRP_Climate/climate_change_adaptation.php))
- US Forest Service and the Climate Change Resource Center provides information and strategies for land managers. (<http://www.fs.fed.us/ccrc/>)
- Association for Fire Ecology developed San Diego Declaration on Climate Change. (<http://fireecology.org/policy-papers/sandiego/>)



## Biodiversity and Habitat

California is home to a greater diversity of plants and animals than any other state (Steinhart, 1990). These species are part of the many ecosystems found in California including forests, grasslands, wetlands, rivers, lakes, chaparral, deserts, mountain ranges, and many others (CNRA, 2009; CDFG, 2007; CDFG, 2011). These ecosystems are critical to the quality of life experienced in California, including clean water and air, food resources, recreation, economic opportunities, and safety from natural hazards (CNRA, 2009; CDFG, 2011). This rich setting draws people to the state, but the associated development stresses existing ecosystems through processes such as land use change, water allocation, and introduction of invasive species (CDFG, 2007). Over 20 percent of species native to California are classified as endangered, threatened, or “of special concern” by state or federal agencies (Steinhart, 1990; CDFG, 2011).

Climate change has the potential to further stress the native biodiversity and alter the conditions in existing ecosystems. Temperature and precipitation changes can result in habitat loss, species loss, alteration of the range and distribution of species, increased competition with non-native species, and





disruption of ecosystem interactions such as pollinator and plant (Snover et al., 2007; CNRA, 2009). Other climate change impacts such as sea level rise, ocean acidification, wildfire, and coastal and inland flooding will also stress native species and alter ecosystem conditions. Not only do climate change impacts pose a risk to the biodiversity in the state, they will have detrimental economic impacts due to loss of ecosystem services. Climate change is estimated to place \$2.5 trillion in assets at risk in California (CDFG, 2011).

The range of potential impacts resulting from climate change is as broad as the diversity of ecosystems in California. Climate change impacts on biodiversity can be loosely divided into categories: species range, invasive species, community composition, hydrologic change, and disturbance regimes.

## EXPOSURE

The climate change impacts most likely to affect biodiversity and habitat are alterations in temperature, precipitation, and sea level rise resulting in changes such as altered seasons, flooding, heat wave, and drought. A secondary effect, wildfire, also has the potential to alter ecosystems and the species dependent on them.

A community assessing how climate change may affect local and regional ecosystems must first evaluate the projected changes and determine the degree to which these changes differ from current conditions. Questions to ask include the following:

- What are the near-term, mid-term, and long-term projections for the following factors?
  - Temperature
  - Precipitation
  - Sea level rise
  - Wildfire
  - Snowpack reduction
  - Heat wave
- What are the potential secondary impacts such as flooding, landslide, erosion, and drought?
- To what extent do these projections differ from current conditions?

While climate models rarely project extreme event occurrence, communities should evaluate existing flood maps (inland and coastal), acknowledging that floodplains may expand. Pay particular attention to low-lying areas adjacent to existing floodplains.

## SENSITIVITY

Determining sensitivity requires identifying a target (i.e., what should be evaluated for sensitivity?) (Glick, Stein, and Edelson, 2011). Determining those habitats and species that may be sensitive to projected climate-change impacts requires detailed knowledge of the surrounding ecosystem. To assure accurate assessment and evaluation of sensitivity and impact, communities should involve biologists, conservation entities, and/or land managers as part of the climate adaptation team. This assessment can bolster the evaluation with data from the databases made accessible by the California Department of Fish and Game (<http://www.dfg.ca.gov/biogeodata/>). The team should assess the following:

- Critical habitats
- Special-status species
- Ecosystem services

### Critical Habitats

Assessment of sensitivity should include inventorying and mapping of critical habitats. The inventory should identify the conditions required for this habitat (temperature, moisture, etc.) that may be affected by climate change. In addition, the assessment should identify threats other than climate change to these habitats and/or species, such as pollution and development planned for the future.

### Special-Status Species

Assessment of sensitivity should include inventorying and mapping of special-status species (threatened species, endangered species, species of concern). The inventory should include the conditions required for all stages of the species' life cycle and how they may be affected by climate change. In addition, the assessment should identify threats other than climate change to these habitats and/or species, such as pollution and development planned for the future.

### Ecosystem Services

The focus of this sector is on ecosystems, habitat, and species. Impacts on these systems may have consequences for residents. Changes in habitat characteristics or species distribution and health will affect several community assets and resources. The potential for these impacts should also be recognized during vulnerability assessment. These points of sensitivity are evaluated in other sectors as well. Affected community assets and resources may include the following:

- Public safety: Impacted ecosystems can result in changes such as altering pest populations that can carry disease. In addition, ecosystems provide a wide range of services that benefit public safety. Climate change can result in ecosystems being less able to provide flood control, wave surge protection, erosion control, nutrient retention and many other services.



- Agriculture, forestry, and fishery productivity: All of these industries rely on ecosystem health for productivity. Communities should be aware that habitat and species impacts may also detrimentally influence productivity.
- Recreational resources: Many of the ecosystems that support biodiversity also support recreation for residents and visitors alike. Impacts on these ecosystems will also harm their recreational value, which may result in economic consequences.

## POTENTIAL IMPACTS

Non-climate-related threats to species and associated habitats should be identified, as climate change may amplify their impact. These threats can include existing and planned development, water diversion, and other uses of the habitat areas. The focus of this stage in vulnerability assessment is to determine how much the threats will affect the areas of sensitivity identified above.

Evaluating these species and habitats for potential impact requires assessment by staff or stakeholders with knowledge of the local landscape and resident species. These experts should be included in the climate adaptation team.

### Species Range

Based on current population size and distribution, some species may comfortably persist in the face of climate change. This assessment of impact seeks to identify those species that will struggle.



Plant and animal species have a preferred temperature range and ecological setting. Climate change results in altered seasonal temperature and precipitation patterns. In combination, this can alter the suitability of habitats for species. For example, species already surviving at the upper end of their preferred temperature range are likely to experience more frequent and prolonged thermal stress (CNRA, 2007; CDFG, 2007). These changes not only alter the physical comfort of species, but also may alter the entire habitat type. This is particularly true for confined habitats such as lakes, wetlands, or vernal pools, where the combination of reduced precipitation and increased temperature reduces not only the extent but potentially the existence of these habitats and all species that rely on them, due to the species' inability to slowly shift in location. Species that experience stress due to climate change may migrate (shift their range) to more suitable conditions. However, migration implies a level of habitat accessibility and species mobility that may not be present. Few species—particularly those endemic to California that are adapted to a specific microclimate—are able to adapt to changes without shifting location. If migration is not possible, species risk extinction (CNRA, 2007; CDFG, 2007). The pressures that may lead a species to seek possible relocation affect all habitat types, including aquatic, marine, and terrestrial.

## Invasive Species

The same changes that threaten endemic species described above also influence the ranges and distribution of invasive species. Non-native species, some of which are better equipped for altered conditions, may outcompete native species (CDFG, 2007). Invasive species, a particularly threatening class of non-native species, can tolerate a wide range of environmental conditions and reproduce—particularly following a disturbance such as wildfire, landslide, or flood—more quickly and to a greater spatial extent than native species. The threat of invasive species is not confined to any one habitat or ecosystem type (CNRA, 2009).

While the short-term biodiversity (native and non-native) may increase, invasive species result in competition for resources (food and habitat), physical damage to invaded habitat, and other impacts that may lead to a long-term loss of native species diversity. Invasive species can predate native species, introduce or transmit disease, or dramatically alter environmental conditions from physical characteristics to chemical, such as water quality (CDFG, 2007). Invasive species threaten not only natural ecosystems but also many ecosystem services, such as agriculture and navigable waterways (CNRA, 2009).

## Ecosystem Relationships

Ecosystems function through a set of interactions, such as pollinator and plant or predator and prey. Climate change can alter the seasonal patterns in an ecosystem such as the timing of flowering, which can end up out of step with pollinators. Some of these impacts can have consequences for the survival of species (CNRA, 2009; CDFG, 2007).

Species that experience stress due to changes in ecosystem condition, such as temperature, do not all have the same capacity to migrate. As a result, newly established ranges are unlikely to have the same complement of ecosystem members (plants and species). These new combinations of species, that may not all be native, must establish interactions that are difficult to predict. Climate change may further affect species due to changes in ecosystem interactions, but the extent and consequences of these changes are not definitively known (CNRA, 2009). Similar to other evaluations, assessment of potential impacts to ecosystem relationships should include local and regional scientists familiar with local ecosystems.



## Hydrologic Cycle

The challenges discussed above regarding habitat range, invasive species, and ecosystem interactions all apply to aquatic systems as well as terrestrial. Wetlands, estuaries, vernal pools, creeks, and other aquatic ecosystems are some of the most biodiverse in California and home to many special-status species. Decreased rainfall, altered timing for snowmelt and storm events, and sea level rise may result in altered water levels in aquatic settings (CNRA, 2009; CDFG, 2007). Aquatic and riparian ecosystems will be detrimentally affected by these changes. This will limit the available habitat for species dependent on the ecosystems. Increased temperature not only changes evaporation rates but also alters water chemistry and vegetative characteristics in aquatic ecosystems, exacerbating the changes already occurring due to altered water availability. These changes to aquatic ecosystems will also affect recreation and the associated economic activities.



The change in water timing and availability will have impacts beyond aquatic species and habitats. Terrestrial species, wild or agricultural, also depend on water. Agricultural crops rely on water that is often diverted from surface water systems (rivers and lakes). The reduction in flow level will affect provision of this ecosystem service.

## Disturbance Regime



Flood, drought, and wildfire are all projected to increase in frequency and severity due to climate change. Each of these impacts is addressed in other sectors with respect to their impact on human systems. The focus in this sector is on the impact on natural systems. Ecosystems typically have a recurring disturbance regime that, over the long term, supports biodiversity. By changing the character of these regimes, climate change may detrimentally affect these ecosystems. Results can range from unusually large physical alteration from erosion, to pest outbreaks, to ecosystem shifts (CNRA, 2009). Each of these changes stresses or eliminates native species.

## ADAPTIVE CAPACITY

Adaptive capacity for habitats and species is a product of two factors. First, some species and habitats have a greater ability to adapt to change than others. Second, local management practices can support or detract from the capacity of local ecosystems to support a high level of biodiversity. Questions to consider are listed below (CDFG, 2007; Glick, Stein, and Edelson, 2011; NatureServe, 2012).

## Questions Regarding Characteristics of an Ecosystem

- What is the current condition of existing ecosystems and habitats?
- Is the landscape permeable, allowing ease of movement across and between habitat patches and types?
- What is the level of redundancy in the ecosystem, particularly for special-status species?
- Does the conservation and open space element in the general plan protect contiguous tracks of habitat?
- What natural protections currently exist for local ecosystems?
- Are there management plans, programs or policies in place to protect open space and associated ecosystems in the community?
  - Do these plans explicitly protect sensitive species and habitats?
- Has the community established a monitoring program to track changes in species population and ecosystem health?
- Is there a land conservancy or similar organization that works to protect vulnerable habitat?
- Has the community established an impact fee to fund land management and/or acquisition?
  - Is there a plan guiding this investment?
- Does existing or proposed development affect the ecosystems services that have public safety benefits?

## Questions Regarding Characteristics of Species

- Is the species able to modify behavior or physiology with shifting conditions?
- Is the species able to move over large distances (e.g., through seed dispersal mechanisms)?
- Does the species have robust genetic diversity (related to population size)?

## RISK AND ONSET

Many of the factors that influence a changed seasonal pattern are labeled as moderately certain. Wildfire, drought, and extreme rainfall also are viewed as moderately certain. The impact of climate change on biodiversity is not due to any single factor, but rather the collective outcome of several impacts. Change in the seasonal distribution of precipitation and temperature will affect biodiversity. The fact that these impacts cannot be precisely projected on small spatial scales does not imply that change is not occurring. It simply places a burden on a community to track the behavior and health of local ecosystems.

## ADDITIONAL RESOURCES

- 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 provides an excellent explanation of climate change impacts on wildlife and the specific impacts likely to be experienced in various regions in the state. In addition, strategies for addressing these impacts are explored.
- Glick, P., B.A. Stein, and N.A. Edelson (eds.). 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington D.C. Retrieved from <http://www.nwf.org/vulnerabilityguide>  
This is a clear guide to vulnerability assessment focused on biodiversity and habitat.
- NatureServe. 2012. NatureServe Climate Change Vulnerability Index. Retrieved from <http://www.natureserve.org/prodServices/climatechange/ccvi.jsp>  
This is a step-by-step vulnerability assessment for plant and animal species. You can download an interactive Excel spreadsheet, guidance, and a training session.
- There are several organizations that develop science reports and resources that are often focused on a particular species or habitat. These include the following:
  - The Nature Conservancy: <http://www.nature.org/>
  - Natural Resources Defense Council: <http://www.nrdc.org/wildlife/default.asp>
  - PRBO Conservation Research Science: <http://www.prbo.org/cms/index.php>



## Agriculture

California produces well over 250 agricultural products, making it both the most diverse and profitable agricultural economy in the United States (Cavagnaro, Jackson, and Scow, 2006). More than 50 percent of these products are fruits, vegetables, and tree nuts.

Dairy products make up the largest portion of the state's agricultural economy (Cavagnaro, Jackson, and Scow, 2006). Climate change impacts on California's agricultural sector will have far-reaching consequences from altering local economic conditions to affecting the food supply for the state and—due to the scale of the market—the nation.

Climate change poses threats that may negatively influence crop and livestock yield. These threats include extreme events (e.g., flooding, fire) that result in



large losses experienced over shorter time durations, as well as more subtle impacts such as changed annual temperature, precipitation patterns, and water scarcity (e.g. reduced precipitation or irrigation availability) that influence growing seasons, weed and pest populations, and livestock health. These impacts also have the potential to result in a range of associated consequences such as reduced air quality and farm worker safety.

The California Climate Adaptation Strategy identifies the following threats to agriculture in California (CNRA, 2009, p. 96):

- Loss of water supply and reliability
- Loss of food security as water supply diminishes and/or becomes less reliable
- Loss of irrigated lands, crop production, and food security
- Lack of water for agriculture and livestock
- Drier conditions that may affect agricultural crop yields
- Increased fire risk to rangeland
- Dry steep terrain - increased soil erosion and sedimentation from agricultural lands
- Changes in pests, diseases, and invasive species
- Changes in ozone and air quality - likely adverse affects on crop production

The severity of impacts depends on a variety of factors, from the type of agricultural operation to water distribution to geographic location. This assessment briefly reviews some of the impacts and issues faced by the agriculture industry in California, but the specifics of determining community vulnerability are left to local community representatives who are most familiar with the specific geographic characteristics, agricultural practices, water availability, and local conditions including vulnerability to impacts such as flood or wildfire.

Agriculture activity primarily occurs on private property. Local and regional governments have limited ability to directly influence agricultural operations. Governmental entities must focus on the ways climate-change impacts affect community assets, functions, and populations. The two most common ways are:

- **Business continuity:** Communities in which agriculture makes up a large portion of the economic base must assess not only direct climate threats to agricultural operations, but also the secondary consequences for other businesses in the community. These consequences can include direct and indirect employment and overall community economic security.
- **Public health:** Increased temperature, including heat waves, reduced rainfall, and air quality impacts can have health consequences for local residents, particularly the agricultural workforce. Changes in weed and pest distributions can result in altered pathways for infection. These impacts are also discussed in the Public Health, Socioeconomic, and Equity sector.



Agriculture can be threatened by climate-change impacts such as water scarcity, flooding, and wildfire. Each of these threats is summarized in the discussion of other sectors. The considerations identified in these sections also apply to agricultural areas.

## EXPOSURE

There are two primary climate change impacts that will affect agriculture: temperature changes and precipitation changes. Several secondary impacts, such as changed seasonal weather patterns, heat waves, intense rainstorms, flooding, drought, erosion, and wildfire, are also of concern. The Cal-Adapt maps show expected changes in temperature, precipitation, coastal inundation, heat wave, and wildfire but do not show the areas affected by the other impacts. Nevertheless, communities that experience increasing temperatures and/or decreasing precipitation are likely to have increased susceptibility to drought and water supply limitations—a key concern in agricultural communities.

Since sensitivity to temperature and precipitation is dependent on the type of agricultural operation. Communities will need to identify their current crop mix in order to decide whether crops would be affected by the anticipated climate exposures or which climate exposures will be of most interest. For livestock operations, the type of animal, facility characteristics, and specific microclimate will need to be evaluated. This evaluation should be conducted by the climate adaptation team that should include local and regional agricultural landowners. A critical exposure consideration will be precipitation and/or snowpack changes in basins that supply water for the community either through surface water or groundwater. If the agriculture sector is supplied with water from sources outside of the community, projected changes in precipitation or snowpack in those source areas must be examined.

## SENSITIVITY

Several resources and assets should be assessed when considering the impacts of climate change on agriculture. Members of the agricultural community should be members of the climate adaptation team to aid in this evaluation. The examination of climate impact on agriculture is similar to the type of assessment conducted for biodiversity. A community should consider the following issues in developing the sensitivity analysis:

- Agricultural product mix and needed conditions
- Water supply
- Socioeconomic assets

## Agricultural Product Mix and Needed Conditions

Assessment of sensitivity should include the inventorying of agricultural products grown or processed within the community. This inventory should describe the temperature and precipitation regimes needed to support optimal productivity of the agricultural product. Some products may have very narrow growing conditions that could be affected by small changes in temperature or precipitation. Others may be tolerant of changing conditions such as drought and thus more resistant to the effects of climate change.

## Water Supply

Assessment of sensitivity should include an evaluation of the reliability of the water supply given changing precipitation regimes. This assessment of reliability must include local source, sources arriving via transfer (e.g. aqueducts), and potential future water sources. The assessment of reliability should consider both physical and legal issues.



## Socioeconomic Assets

Assessment of sensitivity should include a study of the local social and economic assets that depend on agricultural productivity. Because jurisdictions have little authority over agricultural operations, the points of sensitivity come where a community interacts with agricultural operations. These can include the following:



- Economic continuity: Businesses in an agricultural community often rely on the agricultural industry even if they do not directly participate. Changes in the economic viability of agricultural operations can affect the commercial and business sector of a whole community.
- Employment base: Economic continuity can be affected by the changes to the employment base: agricultural workers and those employed at dependent businesses.
- Public health: Climate change may alter the type, severity, and frequency of human health ailments that a community must address.

## POTENTIAL IMPACTS

The extent to which a community's points of sensitivity (identified above) will be affected will depend on local environmental conditions and the extent to which the local economy and employment base rely on the agricultural sector. This evaluation should include the following considerations:

- Will climate change push agricultural operations beyond the range of optimal temperature and water conditions?
- How sensitive are the agricultural operations to climate change impacts (e.g., will productivity decrease a little or a lot)?
- How long will the changes take to occur?

- How likely is a reduction in water supply due to climate change?
- How likely is a change in cost of water and how will this impact agricultural operations?
- How susceptible are agricultural operations to altered pest and weed distribution?
- What proportion of the community employment base is reliant on agriculture?
- Do local health services have the capacity to meet the challenges of worsening heat and air quality impacts on agricultural workers?

## ADAPTIVE CAPACITY

The capacity for adaptation is most often related to the degree to which agricultural operations can accommodate changing conditions. This ability can vary widely depending on the type of operation being considered. In addition to the adaptability of community agricultural practices, government policy can support agricultural operations stressed by climate change. Adaptive capacity can be evaluated by considering the following:

- How easy or difficult is it to change to a more tolerant agricultural operation (change in crop type, change in grazing practice, etc.)?
- Is the product able to be changed (e.g., through a shift in annual crop type)?
- Is the operation able to be altered to better accommodate climate change (e.g., through a shift to drip irrigation, shade provision for dairy operations, etc.)?
- Is there a robust drought plan in place?
- Is there a regional management plan for weed and/or pest distribution?
- Do the local health services have plans in place for accommodating heat or respiratory ailments experienced by farm workers? Do they have additional capacity if conditions worsen?
- Are there local entities that support agricultural adaptation activities (e.g., resource conservation districts, cooperative extension, land trusts, etc.)?
- Is there a funding mechanism (e.g., impact fee, carbon offset or capture, etc.) to fund operational shifts?

## RISK AND ONSET

The IPCC labels temperature change as an impact with high certainty, whereas precipitation change is considered to have medium certainty of occurring (see table 1). The interaction of these two factors yields changes in seasonal weather patterns, which are also labeled as having a medium level of certainty (see table 2). Further complicating the challenge of projecting climate impacts is the degree to which local operations influence the level of impact that will be experienced. Climate change will affect agricultural operations, but greater specificity with regard to the degree of impact is only possible through close collaboration with the agricultural community in a given setting.

## ADDITIONAL RESOURCES

- U.S. Environmental Protection Agency (EPA), Agriculture and Food Supply Impacts & Adaptation: <http://www.epa.gov/climatechange/impacts-adaptation/agriculture.html>  
Provides information about climate change impacts and adaptation by agricultural operation type (e.g. crops, livestock, fisheries).
- California Department of Food and Agriculture (CDFA): <http://www.cdfa.ca.gov/>  
CDFA has many publications about climate impact and adaptation measures. Many of these publications are specific, focusing on specific crop types or regional locations.
- California Climate and Agriculture Network (CalCAN): <http://calclimateag.org/>  
CalCAN is a coalition that advances policy solutions at the nexus of climate change. The organization advocates sustainability and farmer education.
- Food and Agriculture Organization of the United Nations, Adaptation to climate change in agriculture, forestry, and fisheries: Perspective, framework, and priorities: <ftp://ftp.fao.org/docrep/fao/009/j9271e/j9271e.pdf>  
This report, though international in nature, provides an overview of impacts and potential adaptive measures including soil, land, and water management, yield forecasting, livestock systems, and capacity-building.



## Infrastructure

Infrastructure provides the resources and services critical to community function. Roads, rail, water (pipes, canals, and dams), waste (sewer, storm, and solid waste), electricity, gas, and communication systems are all needed for community function. Climate change increases the likelihood of both delays and failures of infrastructure. Temporary delays or outages can result in inconvenience and economic loss while larger failures can lead to disastrous economic and social effects.

Assessing infrastructure vulnerability and developing strategies to address threats is complicated because of the way the various systems are connected. Most infrastructure is arranged as a series system similar to a chain—when one link fails the entire chain fails. Infrastructure is designed to meet the expected load, and every blackout or traffic detour can be an example of a system exceeding its designed limit. Climate change has the potential to stress these systems and result in more frequent blackouts, detours, slowdowns, and/or service reductions.

Climate change adaptation requires identifying the points of weakness in a system and estimating how climate change may influence the load or integrity of a system. Many infrastructure systems are already vulnerable. The American Society of Civil Engineers (ASCE) has evaluated the state's current infrastructure as poor and failing in nearly every infrastructure category (ASCE, 2006).

Local jurisdictions need to assess what is within their control and what requires collaboration with regional partners or the state due to the distributed nature of infrastructure. The following categories of infrastructure are covered in this section:

- Transportation (road, rail, air, water)
- Water distribution
- Waste (sewer, storm, and solid waste)
- Electricity generation and distribution
- Gas production, storage, and distribution
- Communications

## EXPOSURE

Climate change can potentially affect infrastructure in a variety of ways. Sea level rise may damage all types of infrastructure located in the coastal zone due to storm intensity, erosion, and inundation. Inland flooding, erosion, and landslides can disrupt, damage, or destroy infrastructure. Temperature can stress these systems requiring additional maintenance or altering demand. It is critical that communities consider the location of infrastructure to determine which areas of exposure, such as the following, are most relevant:



- Sea level rise (and related issues of coastal erosion, extreme high tide, coastal flooding)
  - Identify infrastructure currently vulnerable to sea level rise and evaluate the extent to which additional infrastructure will be vulnerable by 2050 and 2100.
  - Saltwater intrusion: Identify potential impacts due to sea level rise in coastal communities that depend on groundwater.
- Temperature and heat wave
  - Heat can stress infrastructure, altering maintenance needs, particularly for roadways. Projected change from current conditions should be evaluated for 2050 and 2100.



- Precipitation, intense rainstorms, and landslide
  - If a community has infrastructure located in or near areas subject to flooding or landslide, the potential for increased frequency should be identified.

- Snowpack
  - Identify changes to snowpack projected for 2050 and 2100 if infrastructure is located in mountainous areas.
- Wildfire
  - Wildfire can interrupt or severely damage infrastructure. Projected wildfire risk for 2050 and 2100 should be identified.



The power outage that left San Diego County without power in September 2011 resulted in traffic jams, canceled flights, closed schools, and \$100 million in regional economic losses. The outage was also directly responsible for causing city sewer pumps to fail, resulting in a combined two million gallons of sewage spilling at two sites (CBS, 2011; Medina, 2011; ).

## SENSITIVITY

Because infrastructure is critical to community function, even small failures can result in large consequences. Additionally, it is important to consider how one failure can cascade into another, turning a small delay into a catastrophic system failure.

Identifying points of sensitivity requires evaluating both local and larger distribution infrastructure with respect to climate-change exposure. One way is to map these systems as they lead into and out of a jurisdiction to the source and overlay current and projected impact maps to identify potential points of sensitivity (see Figure 4). Local staff can visualize the sensitivity of each type of infrastructure to each climate change impact. The climate adaptation team representatives from utilities, transportation, and engineering departments can help identify infrastructure sensitive to relevant exposures.

The community functions and assets most likely to be affected by climate-related disruption of infrastructure systems include the following:

- Public safety
  - Evacuation routes
  - Access to services
  - Exposure to physical threats related to infrastructure disruption
  - Loss of communication networks
- Public health
  - Availability of utility services (water, sewer, natural gas, electricity)
  - Access to health services
- Business continuity
  - Disruption of supply chains



- Disruption of utilities (water, sewer, natural gas, electricity)
- Emergency services
  - Communication with residents and emergency responders
  - Access to sites
  - Evacuation routes
  - Utilities (e.g. water)
- Access (home, work, and supply chains)

Most infrastructure outages will occur during extreme conditions when the public is most reliant on access to resources and information. The disruptions of these services will limit the ability of individuals to help themselves as well as the ability of emergency services to respond to needs.

## POTENTIAL IMPACTS

Potential impacts should be viewed both internally (locally) and externally (regionally) (see Figure 4). It is important for communities to determine the location of infrastructure, its current condition, and its susceptibility to climate impacts. For infrastructure that enters from outside the jurisdiction, it is critical to trace the infrastructure back to its source and determine the risks in the infrastructure's path. Understanding the consequences of delays or failures will help to set adaptation priorities. The points of sensitivity

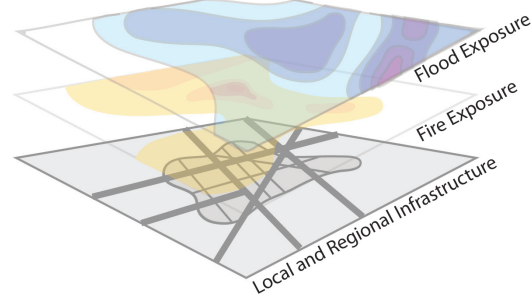


Figure 4. Illustration of layering of regional and local assets along with exposure to identify infrastructure connections and sensitivity.

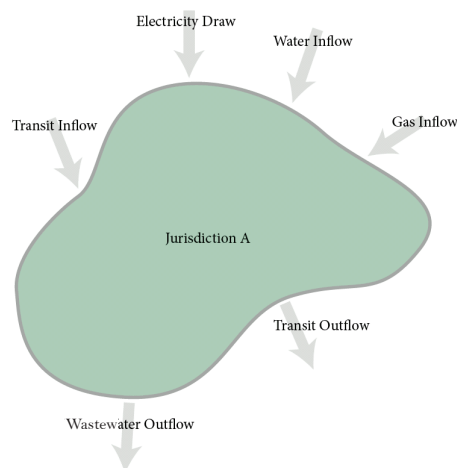


Figure 5. Conceptual map of how a jurisdiction can identify impacts on infrastructure on a regional scale.

identified in the prior section should be evaluated to assess the extent of vulnerability. Will climate change cause a minor disruption or will it result in destruction or prolonged disruption? Another point of evaluation is the extent to which these impacts relate. A minor interruption can cause drastic impacts if it occurs in tandem with other impacts or if it sets off a cascade of consequences.

## Sea Level Rise

Sea level rise is expected to affect the following systems:

- Transportation systems (road, rail, ports) through erosion and inundation
- Wastewater and stormwater systems designed for current mean sea level outfall levels
- Electricity-generation infrastructure built for current mean sea level and reliant on the sea level for cooling

Sea level rise interacts with infrastructure systems by creating two critical problems: inland flooding and erosion. With increased water level and storm intensity, inland flooding and erosion rates will increase. 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. Local coastal infrastructure distribution systems (water, wastewater, electric lines) may be affected by inundation or erosion.



Wastewater and storm drain systems are not only subject to erosion caused by sea level rise and storm intensity. In addition to those risks, the elevation difference between the ocean and draining systems will be different in the future, affecting the outfall elevation for storm and sewer systems in coastal cities.

A number of power and wastewater facilities are built near water for outflow and cooling needs. A number of these facilities are in either sea level inundation zones or are at serious risk of erosion.

Several data sources can be used to assess local exposure to sea level rise impacts: (1) Cal-Adapt, which maps inundation areas for a 55-inch increase in sea level; (2) FEMA flood maps that include sea level rise in estimating the floodplains for coastal waterways; and (3) National Oceanic and Atmospheric Administration's (NOAA) forthcoming Digital Coast resource (<http://www.csc.noaa.gov/digitalcoast/>) provides sea level rise scenarios with land use, topography, and critical facilities.



## Storm Intensity

An increase in precipitation and storm intensity is expected to affect the following systems:

- Transportation, through increased landslides caused by precipitation
- Water infrastructure, through higher loading due to larger peaks in the runoff
- Electricity infrastructure, though wind or precipitation-related outages

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.

Flooding and landslide hazards can be mapped using MyPlan (<http://myplan.calema.ca.gov>). Some soils are more prone to failures than others; organizations like the United States Geological Survey (USGS) and California Geological Survey (CGS) have created detailed maps of the soil types. Additionally, for some jurisdictions, CGS has detailed maps marking at-risk landslide zones.

Water infrastructure, such as dams and levees, has been designed based on historical records of peak runoff. An increase in the precipitation intensity can result in higher loading of these systems than they were designed for, threatening flood control and water distribution.

Increases in intensity of storms will result in an increase in failures that are common in current storms. Common infrastructure outages caused by precipitation and wind include downed power and communication lines. These failures are caused directly by the wind, or indirectly by debris and vegetation (PG&E, 2012).

The quantity of precipitation, snow, and ice will also cause an increase in delays and closures. Mountain passes will see greater quantities of snow in single-storm events. Areas that typically do not see snow and ice will have to deal with ice- and snow-covered roads, causing primary delays (slowed speed) as well as blockages (increased accidents). Rain and snow can cause immediate and delayed flooding that, when interacting directly with infrastructure, will result in failures of systems.

## Temperature

Changes in temperature can be expected to affect:

- Communication infrastructure. Changes in temperature and other climate conditions may damage communication infrastructure, which may in turn cause fires.
- Transportation infrastructure. Changes in temperature may damage materials used in roads and other transportation infrastructure.

Changes in temperature will influence fire throughout the state. Fire can have a large impact on infrastructure. Fires that intersect with infrastructure will cause blockages and potentially cause complete destruction of a section of infrastructure.

All infrastructure has the potential to be damaged by fires, but grid communication and gas lines are the most susceptible to failures. On December 1, 2011, Santa Ana winds disrupted power to 114,000 customers in Los Angeles County. The power disruption caused transportation closures and made responding to the related emergencies difficult.

Cal-Adapt (<http://cal-adapt.org/>) has temperature projections as well as changed moisture temperature regime projections that will help identify expected changes. The Forest and Rangeland sector has additional detail about the impact of climate change on wildfire.

Many fires are caused by infrastructure. High temperatures can cause electricity lines to sag, leading to contact and sparking. High winds can cause downed power lines and sparks, producing a fire adjacent to the infrastructure system. Additionally, autos can start fires on the perimeter of roads, again resulting in a fire adjacent to 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. Future concrete infrastructure will need more concrete cover to protect the core of the structure (CSIRO, 2010). Higher levels of carbon dioxide will increase the speed and penetration of concrete carbonation, which deteriorates the strength of concrete (Yoon, 2007).

## ADAPTIVE CAPACITY

Many of the threats to infrastructure are already accounted for in the planning and design of the systems. Assessing the adaptive capacity evaluates the degree to which these systems are able to withstand the conditions projected in the future as a result of climate change. Jurisdictions must evaluate current management plans for infrastructure systems, future plans, and funding allocations.

### Questions to consider include the following:

- To what extent have redundancies been built into community infrastructure systems?
  - Water/Wastewater
  - Energy
  - Transportation
  - Communication
- What emergency procedures are currently in place for infrastructure systems?
- What measures are contained in the local hazard mitigation plan (communication, evacuation, emergency services, etc.)?
- Has there been funding allocated for these systems?

Addressing each of the community functions and assets most likely to be affected by climate change is important. The following are some questions to consider:

### Public Safety

- Are there redundant means of communication for community members during a hazard event?
- Are evacuation notices communicated in all languages spoken in local households?



### Public Health

- Are there specific plans in place in the event of a loss of wastewater conveyance and treatment services?
- Are public health facilities located in areas at low risk to climate impacts?

### Business Continuity

- What businesses are vital to day-to-day operations (e.g., grocery stores, gas stations, etc.) and is redundancy built into the distribution systems so that food, energy, gas, and other essentials can be maintained?

### Emergency Services

- Have evacuation routes been assessed for climate vulnerability?

### Access (home, work, and supply chains)

- Are there neighborhoods with limited access points that are vulnerable to climate change impacts?

### RISK AND ONSET

The IPCC considers sea level rise to be of high probability, therefore coastal communities should consider the potential impacts of sea level rise to be of higher priority for adaptive planning than other potential effects of climate change. The current rate of sea level rise over the last decade is about 0.12 inch per year; thus, the current onset of sea level rise is relatively slow. The rate is expected to increase closer to the 2100 forecast year.

The IPCC considers temperature increase to be of high probability; therefore, communities should consider the potential impacts of temperature rise to be of high priority for adaptive planning. Cal-Adapt shows expected temperature until 2090. These projections can be used to determine onset and rate of change over time.

The IPCC has not established probabilities for change in storm intensity risk. The IPCC has established changes in precipitation as medium probability and changes in temperature as high probability. Therefore, using the more conservative of the two, it is recommended that changes in storm intensity be considered to be of medium probability.

### ADDITIONAL RESOURCES

- California Department of Transportation (CalTRANS) has numerous resources detailing potential climate impacts and adaptation strategies. Topics such as goods movement, roadside erosion, sea level rise, state climate adaptation strategies and more are included.
  - <http://www.dot.ca.gov/>
  - [http://www.dot.ca.gov/hq/tpp/offices/orip/climate\\_change/projects\\_and\\_studies.html](http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/projects_and_studies.html)
- California Energy Commission has sponsored several studies evaluating climate impacts and adaptation measures for infrastructure: <http://www.energy.ca.gov/research/environmental/climate.html>
  - Potential Impacts of Climate Change on California's Energy Infrastructure and Identification of Adaptation Measures: [www.energy.ca.gov/2009publications/CEC-I50-2009-001/CEC-I50-2009-001.PDF](http://www.energy.ca.gov/2009publications/CEC-I50-2009-001/CEC-I50-2009-001.PDF)

# REFERENCES

- Basu and English. (2008). Public Health Impacts from Climate Change. California Energy Commission. Retrieved from [http://www.energy.ca.gov/research/notices/2008-08-20-22\\_25\\_research\\_plan\\_meetings/draft\\_papers/Public%20Health\\_DP\\_Basu-English.pdf](http://www.energy.ca.gov/research/notices/2008-08-20-22_25_research_plan_meetings/draft_papers/Public%20Health_DP_Basu-English.pdf).
- Bolin, R., and P. Bolton. 1986. Race Religion and Ethnicity in Disaster Recovery. Monograph No. 42. Boulder: University of Colorado, Institute of Behavioral Science.
- California Climate Change Center [CCCC]. (2009). The impacts of sea-level rise on the California coast. Retrieved from [http://www.pacinst.org/reports/sea\\_level\\_rise/report.pdf](http://www.pacinst.org/reports/sea_level_rise/report.pdf).
- California Department of Fish and Game [DFG]. (2007). California Wildlife: Conservation Challenges - California's Wildlife Action Plan. Sacramento: author. Retrieved from: <http://www.dfg.ca.gov/wildlife/wap/report.html>.
- California Department of Fish and Game [DFG]. (2011). Unity, Integration, and Action: DFG's Vision for Confronting Climate Change in California. Retrieved from: <http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=37647&inline=true>.
- California Department of Public Health. 2008. Public Health Climate Change Adaptation Strategy for California. [http://resources.ca.gov/climate\\_adaptation/docs/Statewide\\_Adaptation\\_Strategy.pdf](http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf).
- California Department of Public Health. 2012. Climate Action for Health: Integrating Health into Climate Action Planning [http://www.cdph.ca.gov/programs/CCDPHP/Documents/CAPS\\_and\\_Health\\_Published3-22-12.pdf](http://www.cdph.ca.gov/programs/CCDPHP/Documents/CAPS_and_Health_Published3-22-12.pdf).
- California Department of Water Resources [DWR]. (2011). Climate Change Handbook for Regional Water Planning. Retrieved from: [http://www.water.ca.gov/climatechange/docs/Climate\\_Change\\_Handbook\\_Regional\\_Water\\_Planning.pdf](http://www.water.ca.gov/climatechange/docs/Climate_Change_Handbook_Regional_Water_Planning.pdf).
- California Department of Water Resources [DWR]. (2011). Climate Change Handbook for Regional Water Planning. Retrieved from: [http://www.water.ca.gov/climatechange/docs/Climate\\_Change\\_Handbook\\_Regional\\_Water\\_Planning.pdf](http://www.water.ca.gov/climatechange/docs/Climate_Change_Handbook_Regional_Water_Planning.pdf).
- California Emergency Management Agency. (2010). State of California Multi-hazard Mitigation Plan. Sacramento, CA: Retrieved from [http://hazardmitigation.calema.ca.gov/docs/2010\\_SHMP\\_Final.pdf](http://hazardmitigation.calema.ca.gov/docs/2010_SHMP_Final.pdf).
- California Energy Commission [CEC]. (2009). The Future is Now: An Update on Climate Change Science Impacts and Response Options for California. Retrieved from: <http://www.energy.ca.gov/2008publications/CEC-500-2008-071/CEC-500-2008-071.PDF>.
- California Energy Commission [CEC]. (2009). The Impact of Climate Change on California's Ecosystem Services. Retrieved from: <http://www.energy.ca.gov/2009publications/CEC-500-2009-025/CEC-500-2009-025-F.PDF>.



- California Natural Resources Agency. (2009). 2009 California Climate Adaptation Strategy. Retrieved from: [http://resources.ca.gov/climate\\_adaptation/docs/Statewide\\_Adaptation\\_Strategy.pdf](http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf).
- Cavagnaro, T, L Jackson, & K Scow. (2006). Climate Change: Challenges and Solutions for California Agricultural Landscapes. Sacramento: California Climate Change Center, CEC-500-2005-189-SF. Retrieved from: <http://www.uc-ciee.org/downloads/Agclimatechange.Scow.pdf>.
- Cayan, D.C., E. Maurer, M.D. Dettinger, M. Tyree, K. Hayhoe, C. Bonfils, P. Duffy, B. Santer. 2006. Climate scenarios for California. FINAL white paper from California Climate Change Center, publication # CEC-500-2005-203-SF.
- Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climatic Change* 87 (Suppl 1):S21–S42.
- Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climatic Change* 87 (Suppl 1):S21–S42.
- CBS. (2011). Cost estimate of San Diego power outage tops \$100 million. Retrieved from: <http://www.cbs8.com/story/15422811/2011/09/08/cost-estimate-of-san-diego-outage-tops-100-million>.
- Christian-Smith, Juliet et al. (2011). Impacts of the California Drought from 2007 to 2009. The Pacific Institute. Retrieved from [http://www.pacinst.org/reports/california\\_drought\\_impacts/ca\\_drought\\_impacts\\_full\\_report.pdf](http://www.pacinst.org/reports/california_drought_impacts/ca_drought_impacts_full_report.pdf).
- Confalonieri, U., and B. Menne. 2007. Human health. *Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, O. F. C. M. L. Parry, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, eds. Cambridge, UK.: Cambridge University Press 391–431.
- Cox, J. R., C. Rosenzweig, W. D. Solecki, R. Goldberg and P. L. Kinney (2007). “Social vulnerability to climate change: A neighborhood analysis of the northeast U.S. megaregion.” Technical paper prepared for the Northeast Climate Impacts Assessment. Cambridge, MA: Union of Concerned Scientists. Available at [http://www.northeastclimateimpacts.org/pdf/tech/cox\\_et\\_al.pdf](http://www.northeastclimateimpacts.org/pdf/tech/cox_et_al.pdf).
- Cutter, S., Emrich, C., Webb, J. & Morath, D. (2009). Social vulnerability to climate variability hazards: A review of the literature. Final Report to Oxfam America. Retrieved from: [http://adapt.oxfamamerica.org/resources/Literature\\_Review.pdf](http://adapt.oxfamamerica.org/resources/Literature_Review.pdf).
- Deschenes, O. & C. Kolstad. (2011) Economic impacts of climate change on California agriculture *Climatic Change*, 109 (Suppl 1):S365–S386 DOI 10.1007/s10584-011-0322-3.
- Drechsler, et al. (2006). Public Health-Related Impacts of Climate Change in California. Sacramento, CA: California Energy Commission. PIER Research Report CEC-500-2005-197-SF.
- English et al. (2007). Executive Summary, Heat-Related Illness and Mortality Information for the Public Health Network in California.

- Fothergill A., and L. Peek. (2004). Poverty and disasters in the United States: A review of Recent Sociological Findings. *Natural Hazards*. 32; 89-110
- Fried, J.S., J.K. Gilles, W.J. Riley, T.J. Moody, C. Simon de Blas, K. Hayhoe, M. Moritz, S. Stephens, and M. Torn. (2006). Predicting the effect of climate change on wildfire severity and outcomes in California: Preliminary analysis. California Climate Change Center White Paper CEC-500-2005-196-SF.
- Gershunov, A. and D. Cayan. (2009) California heat waves: July 2006 and recent history. *Journal of Climate*.
- Glick, P, BA Stein, & NA Edelson (eds.). (2011). Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C. Retrieved from <http://www.nwf.org/vulnerabilityguide>.
- Hauri, C, N Gruber, G-K Plattner, S Alin, RA Feely, B Hales, PA Wheeler. (2009). Ocean Acidification in the California Current System. *Oceanography* 22(4): 62-71.
- Health Canada (2006). Your Health and a Changing Climate. Vol. 5 December 2006.
- Iacobellis, SF, JR Norris, M Kanamitsu, M Tyree, & DC Cayan. (2009). Climate Variability and California Low-level Temperature Inversions. California Climate Change Center, CEC-500-2009-020-F.
- IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Retrieved from: [http://www.ipcc.ch/publications\\_and\\_data/publications\\_ipcc\\_fourth\\_assessment\\_report\\_wg1\\_report\\_the\\_physical\\_science\\_basis.htm](http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm).
- Kahrl, Friedrich and Roland-Host, David (2008). California Climate Risk and Response.
- Lipsett, M., B. Materna, S. L. Stone, S. Therriault, R. Blaisdell, and J. Cook. (2008). Wildfire Smoke A Guide for Public Health Officials. Retrieved September 20, 2011 from [http://oehha.ca.gov/air/risk\\_assess/wildfirev8.pdf](http://oehha.ca.gov/air/risk_assess/wildfirev8.pdf).
- Luers, Amy Lynd, Daniel R. Cayan, Guido Franco, Michael Hanemann, and Bart Croes. 2006. Our Changing Climate: Assessing the Risks to California. Summary Report by the California Climate Change Center.
- Lutz, J.A., J.W. van Wagten, A.E. Thode, J.D. Miller, and J.F. Franklin. 2009. Climate, lightning ignitions, and fire severity in Yosemite National Park, California, USA. *International Journal of Wildland Fire*, 18, 765–774.
- Maibach E, Nisbet M, & Weathers M. (2011) Conveying the Human Implications of Climate Change: A Climate Change Communication Primer for Public Health Professionals. Fairfax, VA: George Mason University Center for Climate Change Communication.

- Medellín-Azuara, J, R. Howitt, J. Duncan, J. MacEwan & J. Lund. (2011) Economic impacts of climate-related changes to California agriculture. *Climatic Change*, 109 (Suppl 1):S387–S405.
- Medina-Ramon, M., and J. Schwartz. (2008). Who is more vulnerable to die from ozone air pollution? *Epidemiology*; 19:672-679.
- Messner, et al. (2009) Climate Change Related Impacts in the San Diego Region by 2050, PIER Research Report, CEC-500-2009-027-D, Sacramento, CA: California Energy Commission.
- Miller, N.L. and N.J. Schlegal. 2006. Climate Change—Projected Santa Ana Fire Weather Occurrence. California Climate Change Center-California Energy Commission. Publication # CEC-500-2005-204-SF.
- Morello-Frosch, F, M. Pastor, J. Sadd, and S. Shonkoff. (2010) The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap. University of Southern California, Program for Environmental and Regional Equity (PERE). Retrieved from [http://college.usc.edu/pere/documents/ClimateGapReport\\_full\\_report\\_web.pdf](http://college.usc.edu/pere/documents/ClimateGapReport_full_report_web.pdf).
- Moritz, M.A. 1997. Analyzing Extreme Disturbance Events: Fire in Los Padres National Forest. *Ecological Applications* 7(4):1252-1262.
- Moser, S. C. and Julia Ekstrom. (2010). A framework to diagnose barriers to climate change adaptation, *PNAS*, 107 (51): 22026-22031, DOI:10.1073/pnas.1007887107.
- National Research Council. 2010. Adapting to the Impacts of Climate Change. Washington, DC: The National Academies Press.
- NatureServe. (2012). Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. Retrieved from [http://connect.natureserve.org/sites/default/files/documents/NatureServeConservationStatusFactors\\_Apr12.pdf](http://connect.natureserve.org/sites/default/files/documents/NatureServeConservationStatusFactors_Apr12.pdf).
- Office of Environmental Health Hazard Assessment (OEHHA), California Department of Health Services. 2010A. Cumulative Impacts: Building a Scientific Foundation. <http://oehha.ca.gov/ej/pdf/CIRreport123110.pdf>.
- Office of Environmental Health Hazard Assessment (OEHHA), California Department of Health Services. 2010B. Indicators of Climate Change in California: Environmental Justice Impacts. <http://oehha.ca.gov/multimedia/epic/epic123110.html>.
- Orr, JC, VJ Fabry, O Aumont, L Bopp, SC Doney, RA Feely, A Gnanadesikan, N Gruber, A Ishida, F Joos, and others. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437(7059): 681-686.
- Pacific Gas & Electric - PG&E. (2012) Storm Outage. Retrieved from: <http://www.pge.com/myhome/edusafety/naturaldisaster/stormsoutagessafety/poweroutage/>.
- Pacific Institute. (2010). A Review of Social and Economic Factors that Increase Vulnerability to Climate Change Impacts in California.

- Pastor et al. (2010). Minding the Climate Gap: What's at stake if California's climate law isn't done right and right away. USC Program for Environmental and Regional Equity: Los Angeles, CA. <http://college.usc.edu/pere/publications>.
- Pendleton, L. P. King, C. Mohn, D. Webster, R. Vaughn & P. Adams. (2011). Estimating the potential economic impacts of climate change on Southern California beaches. *Climatic Change*, 109 (Suppl 1):S277–S298. DOI 10.1007/s10584-011-0309-0.
- Pew Center on Global Climate Change. (2009). The Science and Consequences of Ocean Acidification. Science Brief 3. Retrieved from <http://www.c2es.org/docUploads/ocean-acidification-Aug2009.pdf>.
- Price, C., and D. Rind, 1994. Possible implications of global climate change on global lightning distributions and frequencies. *J. Geophys. Res.*, 99(10):,823-831.
- Rasmussen, D. J., Holloway, T., Nemet, G. F. (2010). Opportunities and challenges in assessing climate change impacts on wind energy: A critical comparison of wind speed projections in California. *Environmental Research Letters*, 6:1-9.
- Sanstad, Alan H., H. Johnson, N. Goldstein, G. Franco. (2009) Long-Run Socioeconomic and Demographic Scenarios for California. California Energy Commission. CEC-500-2009-013-F.
- Shonkoff S, Morello-Frosch R, Pastor M, Sadd J (2009b) Minding the climate gap: environmental health and equity implications of climate change mitigation policies in California. *Environ Justice* 2(4):173–177.
- Shonkoff S, Morello-Frosch R, Pastor M, Sadd J. (2011) The Climate Gap: Environmental Health and Equity Implications of Climate Change and Mitigation Policies in California - A Review of the Literature. *Clim Change* 109 (Suppl 1), doi:10.1007/s10584-011-0310-7.
- USGCRP. 2009. Global Climate Change Impacts in the United States: A State of Knowledge Report from the U.S. Global Change Research Program, T. R. Karl, J. M. Melillo, and T. C. Peterson, eds. New York: Cambridge.
- Wang, T., and L. Yasui. 2008. Integrating Immigrant Families in Emergency Response, Relief, and Rebuilding Efforts. Baltimore, Maryland: Annie E. Casey Foundation.
- Westerling, A. L., B. P. Bryant, H. K. Preisler, H. G. Hidalgo, T. Das, and S. R. Shrestha. (2009). Climate change, growth, and California wildfire. California Climate Change Center-California Energy Commission. Publication # CEC-500-2009-046-D.
- Yoon, In-Seok. (2007). Effect of global climate change on carbonation progress of concrete. *Atmospheric Environment* 41(34): 7274–7285.

