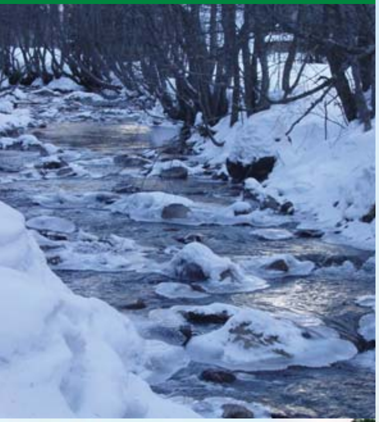
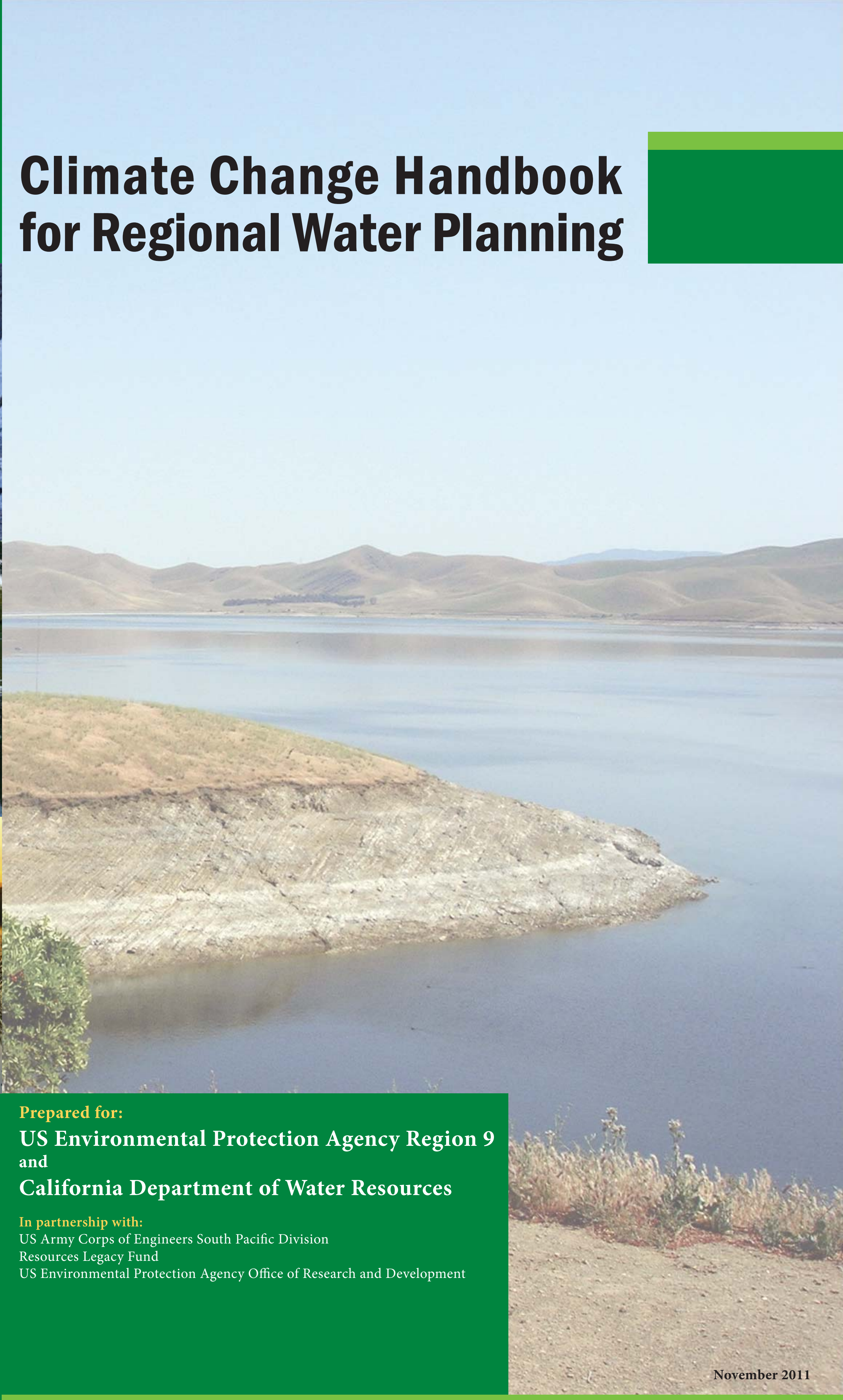
Climate Change Handbook for Regional Water Planning





Prepared for:

US Environmental Protection Agency Region 9
and
California Department of Water Resources

In partnership with:
US Army Corps of Engineers South Pacific Division
Resources Legacy Fund
US Environmental Protection Agency Office of Research and Development

November 2011

This handbook and a searchable database of climate change resources can be downloaded from:

http://www.water.ca.gov/climatechange/CCHandbook.cfm

Acknowledgements

This handbook was prepared by CDM under EPA Contract Number EPA099BOA002

Project Team:

Andrew Schwarz, DWR Climate Adaptation
Suzanne Marr, US EPA Region 9, Water Division
Karen Schwinn, US EPA Region 9, Water Division
Edwin S. Townsley, US Army Corps of Engineers South Pacific Division
Aaron O'Callaghan, Resources Legacy Fund
John Andrew, DWR Executive
Tom Quasebarth, CDM
Enrique Lopez-Calva, CDM
Paula Kulis, CDM
Gwen Pelletier, CDM
Tim Cox, CDM
Dan Rodrigo, CDM
Barbara Brown, CDM
Julie Hinchcliff, CDM
Juan Tijero, CDM

The Project Team gratefully acknowledges the valuable review and comments provided by the Technical Advisory Group:

Eric Oppenheimer and Gail Linck, California State Water Resources Control Board
Mike Dettinger, Scripps Institution of Oceanography
Mike Tansey, USBR Mid Pacific Region
Mitch Avalon, Contra Costa County Flood Control
Eric Osterling, Kings River Conservation District
Andrew Altevogt and Marian Ashe, CalEPA
Robert Webb, NOAA
Barney Austin, Interra, Inc.
Holly Alpert, Inyo-Mono IRWM
Susan Tatayon, The Nature Conservancy
Kirsten Struve, City of San Jose
Cathy Pieroni, City of San Diego
David Raff, USBR Technical Services Center

The following agencies graciously provided the information used in the case studies from their climate change-related planning efforts:

Sonoma County Water Agency (case study written by Laura Zahn and Robyn Camp from The Climate Registry)
Inland Empire Utilities Agency
East Bay Municipal Utility District
Central Puget Sound Water Supply Forum
Southwest Climate Change Initiative (case study written by Esther Conrad, PhD student, UC Berkeley Department of Environmental Science, Policy and Management)
Metropolitan Water District of Southern California

Valuable comments were also provided by:

The Climate Registry
Climate Action Reserve
Natural Resources Defense Council
California Ocean Protection Council
Jim Goodrich, US EPA Office of Research and Development
Alf Brandt, Principal Consultant, Select Committee on Regional Approaches to Addressing the State's Water Crisis-California State Assembly
Konrad Fischer, Klamath Riverkeeper

The Project Team would like to acknowledge those who attended and provided valuable feedback at the IRWM Conference session "Climate Change Handbook for Regional Water Management Discussion and Feedback Session" held on May 25, 2011 in Sacramento, CA.

This page intentionally left blank.

Foreword

As the science of climate change quickly develops and evolves, watershed planning practitioners face the challenge of interpreting new information and discerning which methods and approaches are more appropriate for their planning needs. This handbook offers an innovative analytical framework for incorporating climate change impacts into a regional and watershed planning process. This handbook was developed as a partnership of the U.S. Environmental Protection Agency (EPA) Region 9, the California Department of Water Resources, U.S. Army Corps of Engineers South Pacific Division, and the Resources Legacy Fund. Although this handbook is focused on the California Integrated Regional Water Management Planning (IRWMP) process, it can be used by other practitioners nationally and internationally when incorporating climate change into any watershed or water supply planning process.

This handbook considers both climate change adaptation (reduction of impacts) and mitigation [greenhouse gas (GHG) reduction]. Quantitative tools and techniques for addressing both are introduced and discussed in order to prepare comprehensive IRWMPs. A guide to assess the vulnerability of a watershed or region to climate change impacts is presented in this handbook, and guidelines to prioritize vulnerabilities are introduced. This handbook relies on approaches that have been developed and applied to regional watershed planning processes. This handbook also presents case studies that provide illustrative examples in which the latest science and methods on climate change, including uncertainty and adaptive management approaches, have been applied outside academia. While the available suite of climate change tools and analytical techniques for incorporating climate change is continually advancing and improving, the underlying planning processes outlined in this handbook should continue to provide a solid basis for comprehensive watershed planning. Improved decisions about water resources management systems, whether adapting them to future climate change or mitigating climate change through reductions in GHG emissions, should result from application of the framework in this handbook. This handbook presents the range of decisions that need to be made and the factors that go into making those decisions at a local or regional level.

During implementation of the decision support framework that is presented in this handbook, planners must consider the suite of available tools and the abilities and resources available to the regional/watershed planning group. The long-term goal of this handbook is to serve as a foundation for a thoughtful planning process for incorporating climate change impacts into IRWMPs and other regional and watershed management planning processes.

This page intentionally left blank.

Table of Contents

List of Appendices

List of Case Studies

List of Tables

List of Figures

Acronyms

AB	Assembly Bill
ACR	American Carbon Registry
AFY	Acre-Feet per Year
AMWA	Association of Metropolitan Water Agencies
APCD	Air Pollution Control District
AQMD	Air Quality Management District
AWWA	American Water Works Association
BCSD	Bias-Corrected Spatial Downscaling
BCT	Bonneville Cutthroat Trout
BDCP	Bay Delta Conservation Plan
BOR	U.S. Bureau of Reclamation
CA	Constructed Analogue
CABY	Consumnes, American, Bear, and Yuba Rivers
CalEPA	California Environmental Protection Agency
CAPCOA	California Air Pollution Control Officers Association
CAR	Climate Action Reserve
CARB	California Air Resources Board
CAT	Climate Action Team
CBO	Congressional Budget Office
CCAR	California Climate Action Registry
CCCC	California Climate Change Center
CCSP	Climate Change Science Program
CDFs	Cumulative Distribution Functions
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CH_4	Methane
CMIP3	Coupled Model Intercomparison Project Phase 3
CNRA	California Natural Resources Agency
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
CO-CAT	Coastal and Ocean Working Group of the California Climate Action Team
CPS	Central Puget Sound
CRA	Colorado River Aqueduct
CRE	Climate Ready Estuaries
CREAT	Climate Resilience Evaluation Awareness Tool
CRWU	Climate Ready Water Utilities
CUP+	Consumptive Use Program
CVFPP	Central Valley Flood Protection Plan
CVP	Central Valley Project
CWC	California Water Code
CWP	California Water Plan
DAC	Disadvantaged Community
Degree F	Degree Fahrenheit
Delta	Sacramento-San Joaquin Delta
DHSVM	Distributed Hydrology Soil Vegetation Model
DO	Dissolved Oxygen
DRMS	Delta Risk Management Study

DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
eGRID	Emissions & Generation Resource Integrated Database
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
ETc	Crop-Specific Evapotranspiration
ETo	Reference Evapotranspiration
EWMP	Efficient Water Management Practice
FAO	Food and Agriculture Organization of the United Nations
FEMA	Federal Emergency Management Agency
GCM	General Circulation Model
GHG	Greenhouse gas
GWh	Gigawatt Hours
HFC	Hydrofluorocarbon
IEUA	Inland Empire Utilities Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
IRWD	Irvine Ranch Water District
IRWM	Integrated Regional Water Management
IRWMP	Integrated Regional Water Management Plan
LADWP	Los Angeles Department of Water and Power
LEED	Leadership in Energy and Environmental Design
M&I	Municipal & Industrial
MART	Multi-Attribute Rating Technique
MWD	Metropolitan Water District of Southern California
N_2O	Nitrous Oxide
NAS	National Academy of Sciences
NF_3	Nitrogen Trifluoride
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRDC	Natural Resources Defense Council
NWF	National Wildlife Federation
OPC	California Ocean Protection Council
PFC	Perfluorocarbon
PIER	Public Interest Energy Research Program
PPIC	Public Policy Institute of California
PWP	Pasadena Water and Power
RDM	Robust Decision Making
RMS	Regional Management Strategy
SANDAG	San Diego Association of Governments
SCWA	Sonoma County Water Agency
SF_6	Sulfur Hexafluoride
SIMETAW	Simulation of Evapotranspiration of Applied Water
SLAMM	Sea Level Affecting Marshes Model
SMBRC	Santa Monica Bay Restoration Commission
SNA	Sierra Nevada Alliance
SPU	Seattle Public Utilities
SRES	Special Report on Emissions Scenarios
SSJDD	Sacramento-San Joaquin Drainage District

SWCCI	Southwest Climate Change Initiative
SWP	State Water Project
TCR	The Climate Registry
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
UNSW	University of New South Wales
USCCSP	US Climate Change Science Program
USGS	U.S. Geological Survey
UWMP	Urban Water Management Plan
VIC	Variable Infiltration Capacity
WBCSD	World Business Council for Sustainable Development
WCRP	World Climate Research Program
WEAP	Water Evaluation and Planning Model
WERF	Water and Environment Research Foundation
WET-CAT	Water Energy Subgroup of the Climate Action Team
WRI	World Resources Institute
WSF	Central Puget Sound Water Supply Forum
WSMP	Water Supply Management Program
WSO	Central Puget Sound Water Supply Outlook
WUCA	Water Utility Climate Alliance

This page intentionally left blank.

Section 1

Overview of IRWM Planning and Climate Change

Climate change is affecting California in many ways, several of which impact our water resources: sea levels are rising, snowpack is decreasing, and water temperatures are increasing. In the future, droughts are expected to become more frequent and more severe, and storm intensities are expected to increase. These changes affect our ability to meet crucial water management objectives such as ensuring reliable water supply and quality, managing floods, and protecting ecosystem functions and critical habitats. Water resource planners need ways to integrate climate change considerations into decisions and planning processes, today and in years to come. Integrated regional water planning is an excellent framework for addressing water-related climate impacts, as it provides a process for stakeholders with varied water-related priorities to work together to develop solutions that satisfy all water uses and needs. Because climate change impacts so many aspects of water resources, this process is ideal for addressing adaptation to climate change and for developing measures to help mitigate future climate change.

Planning for climate change can be viewed as a process of assessing risks related to climate change, evaluating and selecting strategies that appear most effective based on current knowledge, and monitoring conditions and updating strategies as knowledge improves. This handbook outlines a process for accomplishing this in the context of regional water management.

The process outlined in this handbook allows regional water management planners to conduct the necessary analyses to assess risks and possible climate change impacts. It also informs decisions concerning possible future actions. A climate change impact assessment may indicate that immediate action is required to avert unacceptable impacts or threats, even though analysis indicates that those threats may not become critical for several years. Using the results of the assessment, regional water planners will be able to prioritize resource management strategies to best serve their region. Box 1-1 provides two examples of climate change assessment results and likely actions that would follow such assessments.

Adapting to climate change impacts continues to be an ongoing process, becoming more adaptable over time is critical to addressing to climate change. This includes improving information accessibility and monitoring systems, and working together across institutional and social boundaries to leverage resources from diverse sources (National Academy of Sciences 2010a).

Examples of Climate Change Assessment Results and Likely Actions

1) *Relatively high risk in near future: The assessment identifies ways in which climate change is leading to significant consequences for water supply, quality, flooding, or other management objectives. This knowledge can help water managers adjust management strategies in ways that can reduce these impacts. For example, a coastal region might take steps to promote wetlands restoration in low-lying areas where the consequences of inundation due to sea level rise would be significant. Ongoing monitoring of sea level rise, along with the effectiveness of wetlands restoration efforts, would then be critical for informing future decisions.*
2) *Longer-term and more uncertain risks: The assessment identifies future impacts of climate change that do not appear significant now but may become so in the future, or that may be important now but uncertainty is high. In these cases, decision makers might want to identify strategies that would provide measurable benefits today while also reducing vulnerability to these possible impacts (so-called "no-regrets" strategies). For example, increased storm intensity is possible under climate change, although evidence of this in California is currently limited. However, floodplain restoration can help reduce flood impacts today, as well as protect critical habitats. If "no-regrets" strategies don't exist, then ongoing monitoring could be undertaken to enable a more informed decision at a later date.*

Box 1-1

The Integrated Regional Water Management (IRWM) planning is a well defined and clearly articulated process that addresses watershed management in California. The IRWM planning process provides a mechanism for stakeholders to work together to identify and address the challenges that potentially exist among multiple planning efforts. The IRWM planning process also provides a means to develop and update water management objectives to address a region's water resources management challenges, overcome potential water management constraints, and implement water management projects and programs. In this regard, the IRWM process provides an excellent foundation to address potential climate change impacts on water resources. As such, it will be used as a model for this handbook.

Because each planning region has a unique environmental setting, set of resources to manage, and prioritization of management objectives, there is no single "correct" approach to either identifying climate change impacts or to adapting to them.

The IRWM Planning Act (California Water Code Section 10530 et seq) directs the California Department of Water Resources (DWR) in defining components required in an IRWMP in California. DWR's guidelines for IRWMPs (DWR 2010a, http://www.water.ca.gov/irwm/docs/Guidelines/Prop84/GL_Final_07_20_10.pdf) include many planning standards, including climate change considerations. This handbook provides broad guidance to water resources planners on how to incorporate climate change analyses into regional water planning processes using the IRWM planning process as a model. This handbook outlines the necessary steps to incorporate analysis of climate change in the regional water planning process, reviews actions that various agencies and planning entities are currently taking with respect to climate change, and provides guidance for developing regionally specific strategies for addressing climate change impacts in any regional or watershed level planning process (see Box 1-2).

1.1 Using this Handbook

The purpose of this handbook is to provide a roadmap for water resources planners describing:

1. Recommended steps for including climate change impacts and adaptation in planning strategies,
2. Recommended steps to assess system-wide and project-associated greenhouse gas (GHG) emissions and identify potential mitigation measures, and
3. A strategy for incorporating the steps identified in (1) and (2) into the IRWM process or other similar water management planning efforts.

Role of this Handbook in IRWMP Development

In August 2010, DWR released the Propositions 84 and Proposition 1E IRWM Program Guidelines. These guidelines described the IRWM plan standards, including for the first time a climate change standard. DWR hopes that this handbook will be an important resource for those pursuing IRWM grant funding by outlining a comprehensive approach to addressing climate change. The handbook should be viewed as a tool that may provide useful assistance to IRWM planning efforts on how to address climate change issues. However, this handbook in no way supersedes, replaces, or adds scope to the Climate Change Plan Standard contained in the 2010 IRWM Program Guidelines. This handbook provides an overarching framework (using IRWM as a model for regional water planning) for how to integrate analysis of a changing climate into regional water management planning. Potential grant applicants are referred to the above-referenced IRWM Program Guidelines and associated Proposal Solicitation Packages for the specific grant application requirements.

Box 1-2

This handbook discusses methods to qualitatively assess vulnerabilities, and quantify climate change impacts on water resources, in addition to providing examples of mitigation and adaptation measures that can be taken to reduce impacts. Several decision-support frameworks are described for including climate change in the process of developing and implementing strategies and projects for meeting the objectives of an IRWMP or similar watershed plan.

Because each region has a unique environmental setting, set of resources to manage, and prioritization of management objectives, there is no single approach to estimating climate change impacts on water resources. Specific mitigation measures (i.e. reducing GHG emissions) or adaptation measures (i.e. developing ways to live with the effects of climate change) will likely be different for each region . Therefore, this handbook presents multiple methods, techniques, and case studies that can be useful in incorporating climate change into water resource planning based on regional vulnerabilities and objectives.

Assessing the projected impacts of climate change and attempting to plan for them involves uncertainty at nearly every step of the analysis and decision-making process. As with planning for any future condition, decisions must be made with incomplete information. Planning is an iterative process which builds on knowledge about past and current conditions to make assumptions about the future. While significant uncertainty still exists about how quickly and to what degree climate change will occur, a preponderance of the scientific evidence related to projected future climate changes compels planners to act now. It is therefore imperative that regional water planners begin to consider potential futures where temperatures have increased appreciably and precipitation patterns no longer follow the statistical distribution of past observations.

1.2 IRWM Planning

The IRWM planning process is intended to provide a collaborative, open, and accessible process for regional water management planning. The main objectives include:

- Improving water supply reliability,
- Protecting and improving water quality,
- Ensuring sustainability through environmental stewardship,
- Promoting multiple benefits, and
- Promoting integration and regional planning.

The IRWM process presented in Figure 1-1 provides an integrated approach for addressing water management issues within a region. The process identifies and involves water management stakeholders from a region and guides the stakeholder group through the following steps (see Figure 1-1):

- Identifying and organizing stakeholders to form a governance structure;
- Defining and describing the planning area;
- Establishing water management objectives and measurable targets for the region;

Figure 1-1. IRWM Planning Process Summary.

- Identifying and evaluating water management strategies applicable to the region;
- Identifying opportunities for integrating proposed regional water supply, water quality, and resource management strategies;
- Assessing the ability of the resource management strategies to meet the regional objectives;
- Establishing a system for prioritizing the strategies;
- Presenting a plan for implementing and monitoring the water management strategies; and
- Identifying a framework for overall IRWM planning in the Region, including future updates of resource management strategies and plan priorities.

The IRWM planning process provides a mechanism for stakeholders to work together to identify and address the challenges that potentially exist among multiple planning efforts. The IRWM planning process also provides a means to develop and update water management objectives to address the region's water management challenges, overcome potential water management constraints, and implement water management projects and programs. Given that climate change will impact all aspects of regional water management to some degree, the IRWM process provides an excellent forum to address potential climate change impacts on water resources.

The IRWM program guidelines (DWR 2010a) includes 16 standards that are recommended for the planning process. These standards are related to the IRWM planning process in Figure 1-2. Some of the standards, such as regional description, correspond with specific portions of the planning process. Other standards, such as stakeholder involvement, are more thematic standards that are relevant to multiple parts of the IRWM process. Climate change is one of these thematic standards.

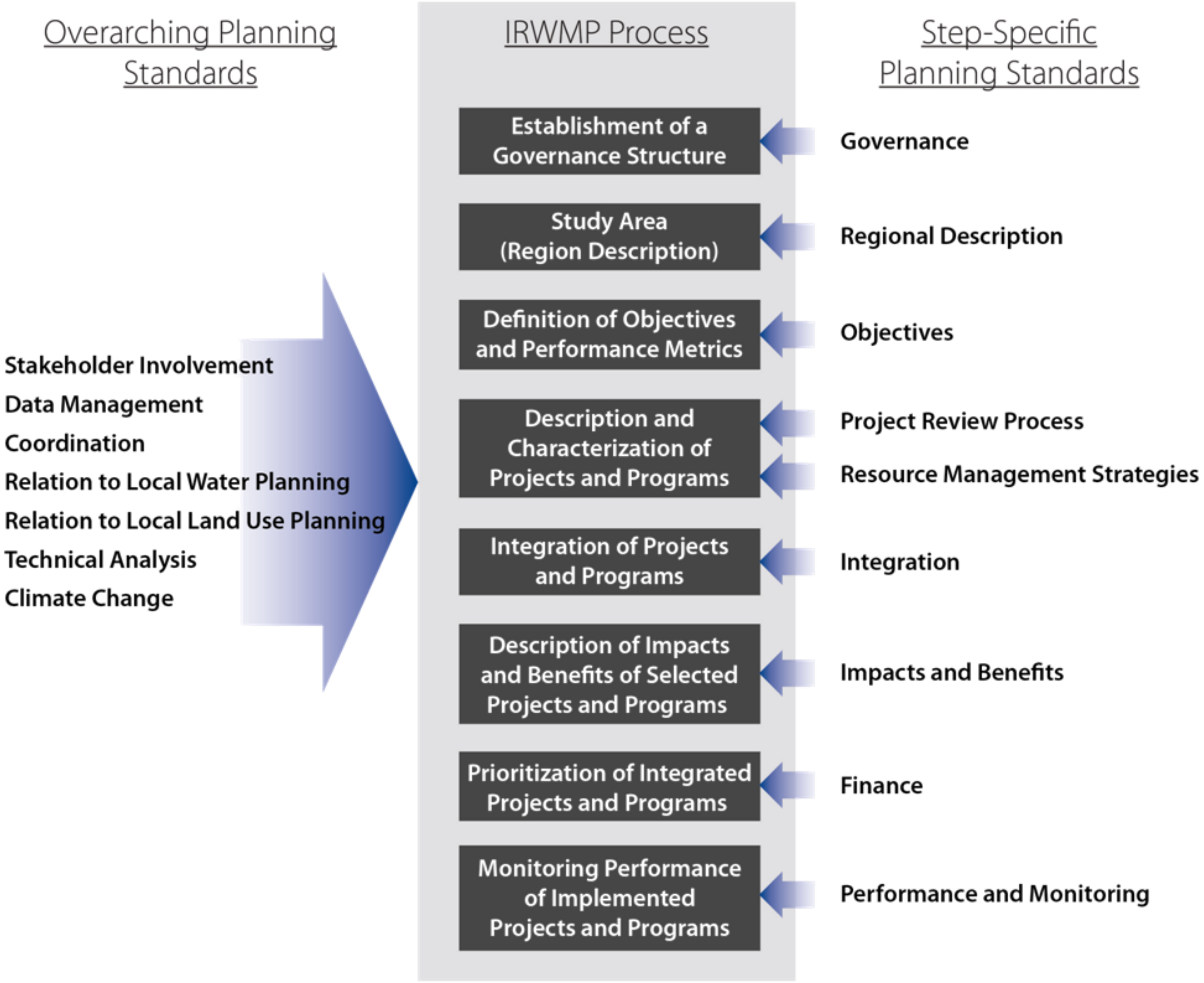


Figure 1-2: The IRWM Planning Process as it Relates to the IRWM Standards.

1.3 Linking Climate Change to IRWM Planning

Given the measured and projected climate change impacts on water resources, many local, regional, state, and national agencies around the world are starting to plan for climate change. Water resources management can play a significant role in mitigating future impacts of climate change by reducing GHG emissions. In addition, water resources projects need to be resilient or adapt to those climate change impacts that are unavoidable and, in some cases, already being observed. Climate change can impact, and is already impacting, water quality, aquatic life, water supplies, and water demands in California and globally. In California, droughts and floods are expected to be more frequent in the future, and average annual Sierra Nevada snowpack storage is expected to decrease. Many of the potential and observed impacts from climate change on water resources are depicted in Figure 1-3. This handbook discusses the role of water resources planning in both mitigation and adaptation strategies.

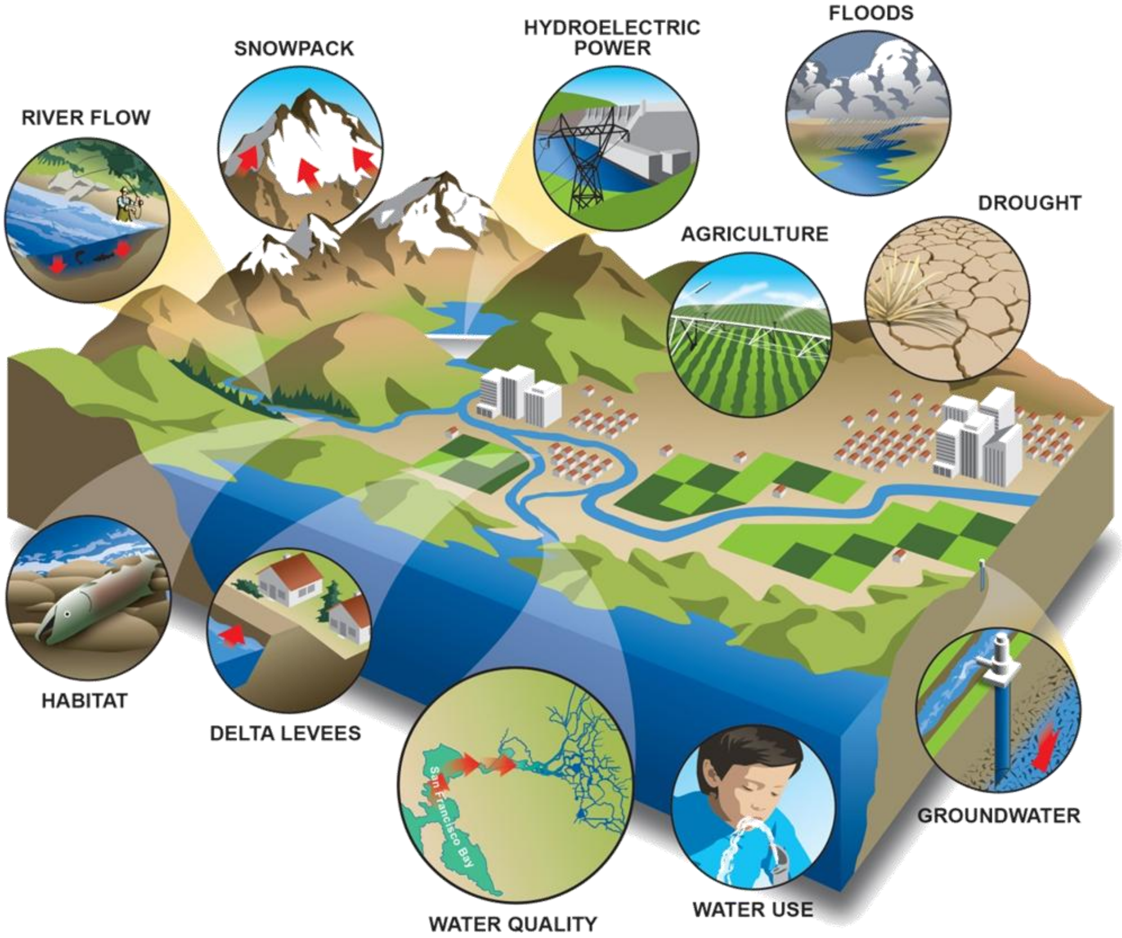


Figure 1-3: Potential and Observed Climate Change Impacts on Water Resources in California.
Source: http://www.water.ca.gov/climatechange/cc101.cfm

1.3.1 Evaluating the Water-Energy Relationship and Greenhouse Gas Emissions in the Planning Process

> ***Mitigation:*** *Human interventions to reduce the sources of greenhouse gases or enhance the sinks that remove them from the atmosphere.*
>
> *--- US Climate Change Science Program (CCSP) 2009*

The relationship between water and energy is complex. Approximately one-fifth of California's electricity is generated by hydropower, while approximately one-fifth of the state's electricity and 30% of the state's non-power plant natural gas[1] is used for conveyance, treatment, distribution, and end use of water (Climate Action Team (CAT 2008). Therefore, increases in water use efficiency translate can into energy use reduction and reductions in GHG emissions. Consideration of energy and water use as part of project evaluation is critical to

---

[1] Non-power plant natural gas is natural gas that is not used to generate electricity, but is used to provide directly used energy; for example, to heat boilers and water heaters.

reducing GHG emissions. Each molecule of CO_2 emitted to the atmosphere will enhance global warming for approximately a century (Intergovernmental Panel on Climate Change (IPCC) 2003); therefore, efforts to reduce GHG emissions to the atmosphere will reduce future impacts of climate change and are referred to as climate change mitigation.

Selection between alternative projects designed to address the same objective may yield significantly different GHG emissions. For example, a desalinization plant and a water transfer program designed to increase water supply reliability may require vastly different energy inputs. In addition, GHG emissions for water projects can be reduced in several ways, including reduction in water use, efficient design of facilities, energy efficiency for operations, and incorporation of renewable energy. Quantitative methods for evaluating GHG emissions for water resources projects are discussed in Section 3. Incorporation of GHG emissions into other planning objectives to evaluate potential projects is discussed in Section 6.

1.3.2 Completing A Climate Change Adaptation Analysis

Climate change has the potential to impact water demand, water supply, flood management, water quality, aquatic ecosystems, sea level rise, and hydroelectric resources. In some areas of the U.S., including California, the impacts of climate change on water resources are already being detected; it is expected that more prominent impacts will be seen within the next 20 to 50 years.

***Adaptation**: Adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which minimize harm or take advantage of beneficial opportunities.*

--- IPCC 2011

This handbook outlines a four-step process for completing a climate change adaptation analysis: (1) Assess Vulnerability, (2) Measure Impacts, (3) Develop and Evaluate Strategies, and (4) Implement Under Uncertainty. Figure 1-4 depicts the steps described below:

- ***Assess Vulnerability***: Identify the region-specific water resources (including source areas for imported water) that are potentially vulnerable to climate change in a way that is both significant for the stakeholders involved and measureable in some way. Section 4 provides guidance for regional planners on assessing the vulnerability of a region to climate change.

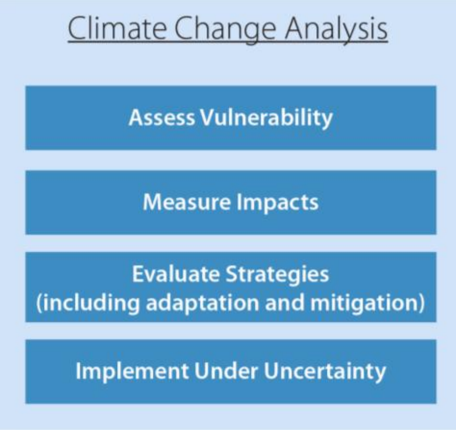


Figure 1-4: Climate Change Adaptation Assessment.

- ***Measure Impacts***: To the extent appropriate, quantify the climate change impacts to a region's most vulnerable water resources. This step can be highly analytical or qualitative, depending on the estimated level of vulnerability and system, operational complexity, and resources available for the analysis. Section 5 provides guidance for how to measure the potential impacts of climate change on a region's resources.
- ***Evaluate Strategies***: Compare and rank existing and potential resource management strategies based on their effectiveness in mitigating and adapting to climate change impacts. New potential projects or programs may be identified during this step of the process. Evaluating strategies for climate change adaptive capacity is an important component of the overall evaluation of individual strategies or projects, as well as integrated project portfolios, in any IRWM planning process. Section 6 provides guidance on how to incorporate climate change scenarios into the performance evaluation of regional strategies.
- ***Implement Under Uncertainty***: Incorporate regional management strategies into a broader planning context that considers the uncertainties associated with climate change. This can be done in many ways, for example using approaches based on adaptive management, robust decision making, and other decision-support methods. Uncertainty influences every step of a planning process involving climate change, including methods for climate change impact measurement, project selection, implementation, and performance monitoring. Section 7 presents general guidance on specific methods to incorporate uncertainty into the IRWM planning process.

There is no standard method for assessing potential climate change impacts and adaptive capacity. This handbook attempts to comprehensively discuss methods that have been used by different planning agencies. Methods discussed in this handbook must be tailored to the unique characteristics of each region.

This handbook focuses on California-specific climate change legislation and data synthesis and availability. The legislative requirements, data, and methods discussed focus on California climate change issues. However, many parts of the U.S. and the world face similar uncertainties and vulnerabilities due to climate change. Examples are provided in this handbook from studies conducted outside of California, and the methods discussed in this handbook to measure impacts and adapt to them are also applicable to other regions.

1.3.3 Decision-Support Framework

The processes of planning for climate change adaptation and GHG emissions reduction naturally overlap with the IRWM planning process. Figure 1-5 presents the relationships between the primary steps in IRWM planning and climate change-related analysis.

Figure 1-5 represents linkages and interactions among the IRWM planning process, the climate change analysis process, and GHG emissions considerations. With the exception of establishing a governance structure, every step of the IRWM planning process is either informed by climate change analysis, or potentially influences how climate change is considered. These linkages are briefly described for each step of the IRWM planning process, below. In addition, the section of this handbook which describes how to perform the step is provided in brackets after the description.

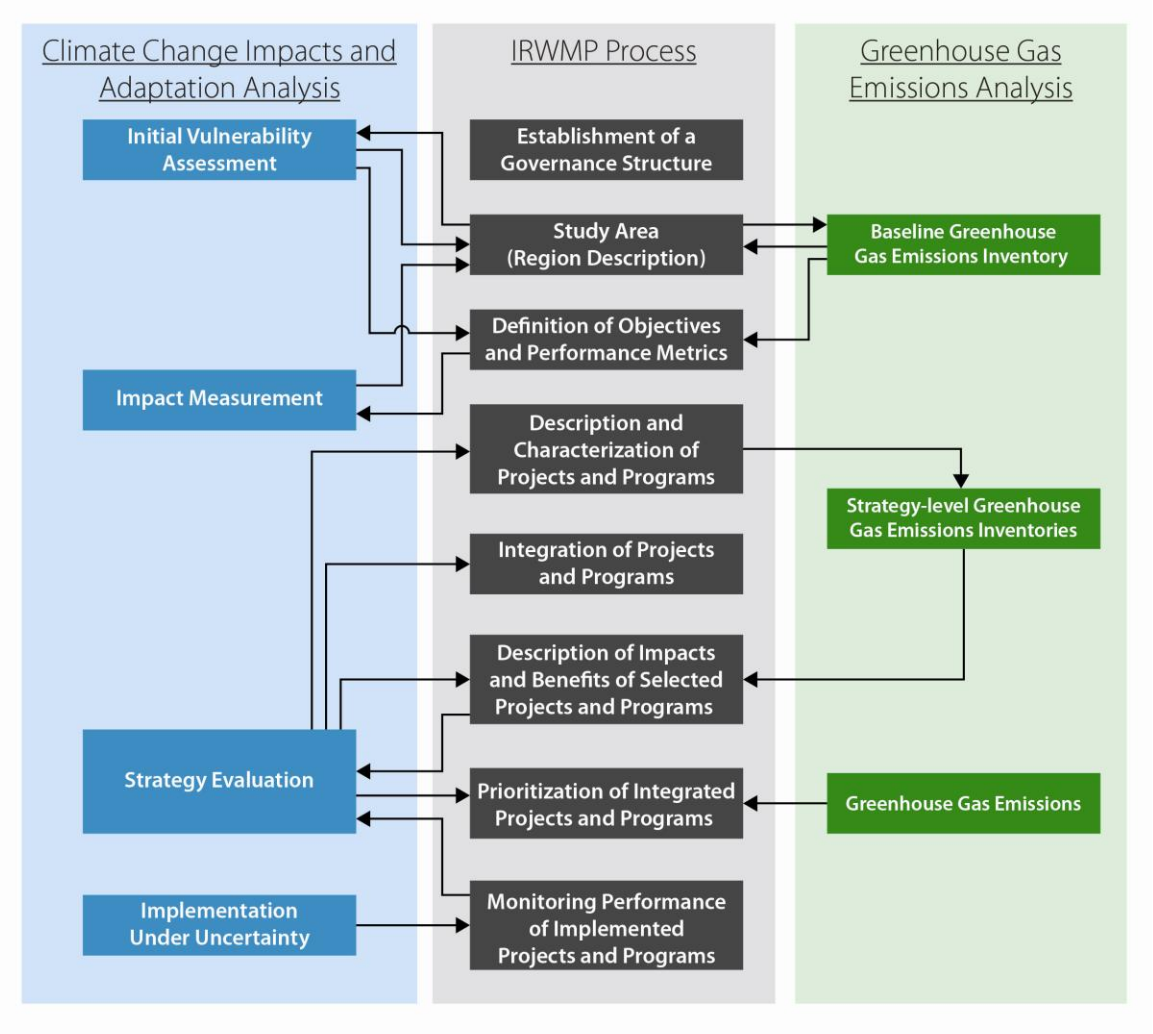


Figure 1-5: Relationship between IRWMP Process and Climate Change Analyses.

Study Area: Regional information is needed to conduct an initial qualitative climate change vulnerability assessment and to conduct a baseline GHG emissions inventory. In addition, the description of the planning region should include a discussion of qualitative potential vulnerabilities and more quantitative baseline climate change impacts (Sections 4 and 5).

Objectives and Performance Metrics: Qualitatively assessed climate change vulnerabilities and baseline GHG emissions influence the development of the overall planning objectives and more quantitative performance metrics. For those areas especially vulnerable to climate change, adaptation may become one of the objectives. Performance metrics are quantitative assessments of the degree to which an objective is achieved. The metrics developed relating to climate change can be used to measure the baseline and project-level climate change impacts (Section 4).

Description and Characterization of Projects and Programs: Quantifying the performance of resource management strategies in the future needs to take into account potential climate change. By planning for future conditions that are more challenging than current climate conditions, strategies that are more robust, resilient, and flexible can be identified. This analysis informs the sections on resource management strategies of the IRWMP (Sections 5 and 6).

Integration of Project and Programs: Many projects and programs will perform differently under different climate conditions; others may show little sensitivity to climate conditions. The synergy and interrelationships between projects can also differ when potential impacts of climate change are considered. Evaluations and integration of programs and projects under future conditions that account for potential climate change may identify important co-benefits, synergies, or tradeoffs (Section 6).

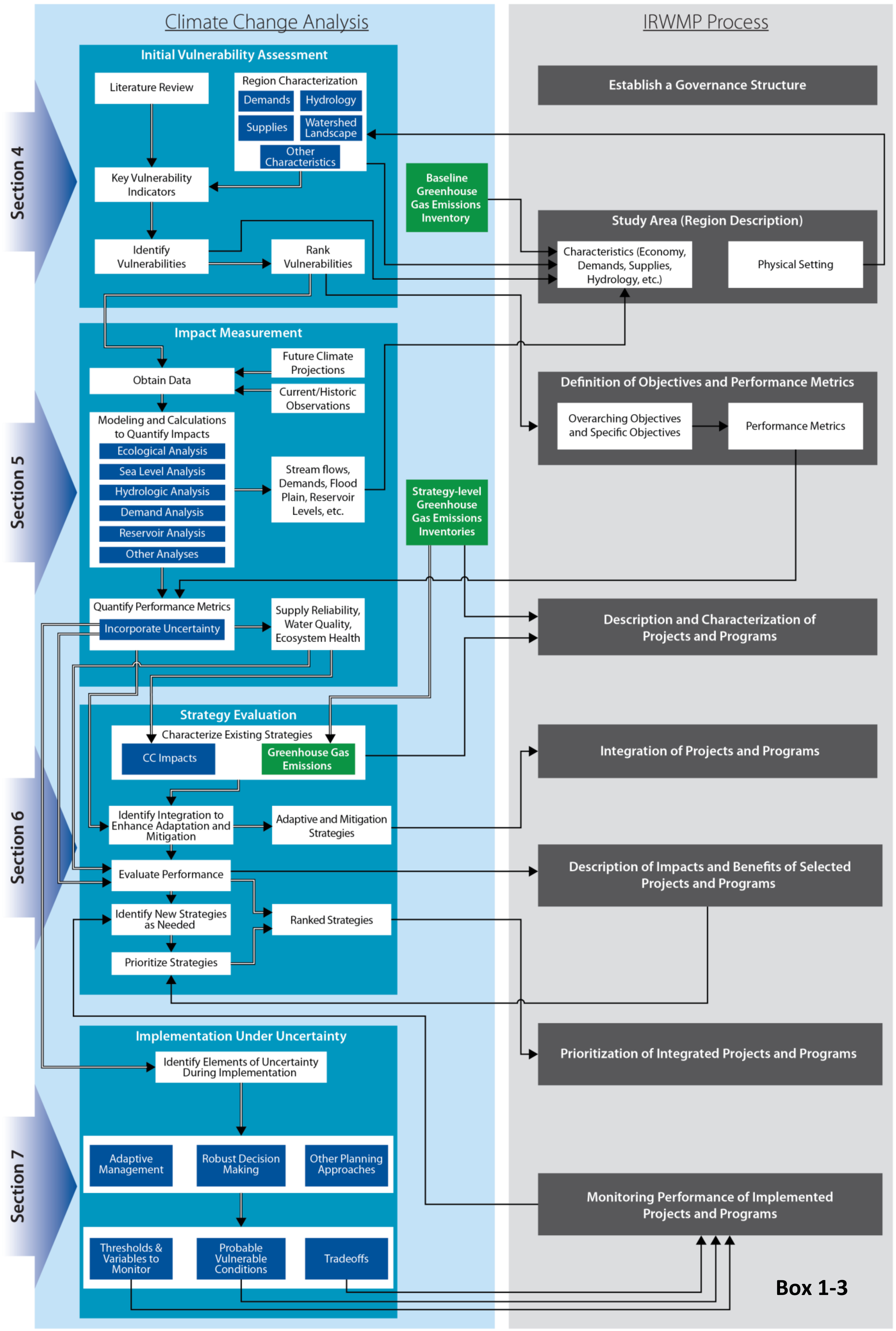
Description of Impacts and Benefits of Selected Projects and Programs: Impacts and benefits of the strategies considered in an IRWMP should be described with consideration of future conditions that account for potential impacts of climate change. The impacts and benefits help inform the decision about the best integrated strategies for the region. Impacts and benefits will typically map to specific performance measures in an IRWMP to allow decision makers to narrow down the strategies that are more beneficial. Consideration of climate change in this analysis helps gage how each project or program will perform under a range of future climate conditions (Sections 5 and 6).

Prioritization of Integrated Projects and Programs: Prioritization of strategies should be informed by a region’s vulnerability to climate change. If specific resources show high vulnerability to the potential impacts of climate change, it may warrant increasing the priority of strategies that help reduce the region’s vulnerability or help the region adapt to possible change (Sections 6 and 7).

Monitoring Performance: Monitoring performance of projects and programs helps inform the selection and evaluation of future strategies and allows past projects to be modified to better meet the objectives of the region. Because of the uncertainty associated with future climate change, monitoring can play a critical role in triggering the implementation of strategies or the modification of existing operations as the specific impacts of climate change are observed (Section 7).

Box 1-3 presents a much more detailed version of the decision-support framework schematic showing the steps in the climate change analysis and their linkages to the preparation of an IRWMP. Arrows indicate where analysis of climate change impacts needs to be considered within the IRWM process, transfers of information *between* the IRWM process and climate change analysis (solid arrows), or a flow of information *within* either the IRWM process or within an analysis that incorporates climate change (piped arrows). Climate change analysis is shown as separate and distinct from the IRWM process to illustrate what is new and different. In fact, climate change analysis is really superimposed on the existing IRWM process and in the future can easily be embedded as an integral aspect of the overall planning process.

Box 1-3 also indicates sections of the handbook that discuss various steps for incorporating climate change into the analysis and project evaluation involved in an IRWMP. It is not essential to have a detailed understanding of each of the linkages included in the diagram; rather, it is important to understand how climate change may impact water resources within a planning region, and to determine the most robust way to adapt. This handbook is intended to clarify the connections in this diagram. Application of the climate change decision-support framework requires the planner to have a general understanding of the current state-of-the-art climate change science presented in the next section.


Climate Change Analysis
IRWMP Process
Section 4
Section 5
Section 6
Section 7
Initial Vulnerability Assessment
Literature Review
Region Characterization
Demands
Hydrology
Supplies
Watershed Landscape
Other Characteristics
Key Vulnerability Indicators
Identify Vulnerabilities
Rank Vulnerabilities
Baseline Greenhouse Gas Emissions Inventory
Establish a Governance Structure
Study Area (Region Description)
Characteristics (Economy, Demands, Supplies, Hydrology, etc.)
Physical Setting
Impact Measurement
Future Climate Projections
Obtain Data
Current/Historic Observations
Modeling and Calculations to Quantify Impacts
Ecological Analysis
Sea Level Analysis
Hydrologic Analysis
Demand Analysis
Reservoir Analysis
Other Analyses
Stream flows, Demands, Flood Plain, Reservoir Levels, etc.
Definition of Objectives and Performance Metrics
Overarching Objectives and Specific Objectives
Performance Metrics
Strategy-level Greenhouse Gas Emissions Inventories
Quantify Performance Metrics
Incorporate Uncertainty
Supply Reliability, Water Quality, Ecosystem Health
Description and Characterization of Projects and Programs
Strategy Evaluation
Characterize Existing Strategies
CC Impacts
Greenhouse Gas Emissions
Integration of Projects and Programs
Identify Integration to Enhance Adaptation and Mitigation
Adaptive and Mitigation Strategies
Evaluate Performance
Description of Impacts and Benefits of Selected Projects and Programs
Identify New Strategies as Needed
Ranked Strategies
Prioritize Strategies
Prioritization of Integrated Projects and Programs
Implementation Under Uncertainty
Identify Elements of Uncertainty During Implementation
Adaptive Management
Robust Decision Making
Other Planning Approaches
Monitoring Performance of Implemented Projects and Programs
Thresholds & Variables to Monitor
Probable Vulnerable Conditions
Tradeoffs

Box 1-3

This page intentionally left blank.

Section 2

The Science of Climate Change – Global and Regional Application

To incorporate climate change into water resources planning, it is important to understand what it is, how it happens, and how to quantify it in the future. In the media and in society the terms "climate change" and "global warming" are often misused, and it is easy to mistakenly use projected changes in climate for other analyses.

This section focuses on:

- Our current scientific understanding of mechanisms for climate change;
- Current observations of climate change in California;
- Our best estimates of how the climate may change in the future;
- Potential impacts that the warming climate will have, and in some cases is already having, on water resources; and
- Modeling methods used by the scientific community to develop climate change projections.

2.1 Climate Change and Global Warming

In the most general sense, climate change is the long-term change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It is well-documented and widely accepted that the Earth's climate has fluctuated and changed throughout history. Global warming is the name given to the increase in the average temperature of the Earth's near-surface air and oceans that has been observed since the mid-20th century and is projected to continue. Warming of the climate system is now considered to be unequivocal (IPCC 2007a). Global warming, therefore, refers to a specific type of rapid climate change occurring over the last 60 years and projected to continue into the future which falls outside of the normal range of historic climate variation.

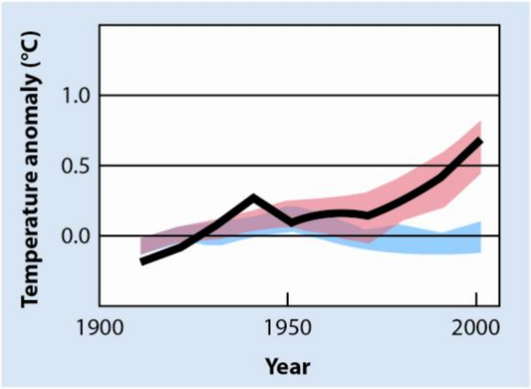


Figure 2-1: Observed and Simulated Global Temperature Trend over the Twentieth Century. The black line is observed data; blue is model results incorporating natural forcings only; and pink is model results incorporating anthropogenic GHG emissions. (Source: IPCC 2007a)

Throughout this handbook the term "climate change" is used to describe general projected changes in the Earth's climate, including those resulting from global warming.

2.1.1 Greenhouse Gases and Climate Change

There has been considerable political debate surrounding the causes of climate change; however, there is near unanimous consensus within the scientific community that observed warming trends are a result of increased GHG concentrations in the atmosphere (IPCC 2007a). According to the IPCC, "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations" (IPCC 2007b).

Understanding the basic mechanisms influencing the global warming process illustrates both the importance of reducing GHG emissions to mitigate further climate change as much as possible, and the need to adapt to future climate conditions. Understanding how future climate projections are developed also helps planners understand and incorporate the inherent uncertainties in future climate change projections.

This handbook does not provide in-depth discussion of current climate observations or the mechanisms behind climate change. Good sources for further information include:

1. Pew Center on Global Climate Change and Pew Center on the States. "Climate Change 101: Science and Impacts": http://www.pewclimate.org/docUploads/101_Science_Impacts.pdf
2. U. S. Global Change Research Program/Climate Change Science Program. "Climate Literacy: the Essential Principles of Climate Sciences": http://climate.noaa.gov/index.jsp?pg=/education/edu_index.jsp&edu=literacy
3. UNSW Climate Change Research Centre. "The Copenhagen Diagnosis": http://www.ccrc.unsw.edu.au/Copenhagen/Copenhagen_Diagnosis_HIGH.pdf
4. U. S. Global Change Research Program/Climate Change Science Program brochure. "Climate Literacy: the Essential Principles of Climate Sciences": http://www.globalchange.gov/what-we-do/assessment/previous-assessments/global-climate-change-impacts-in-the-us-2009

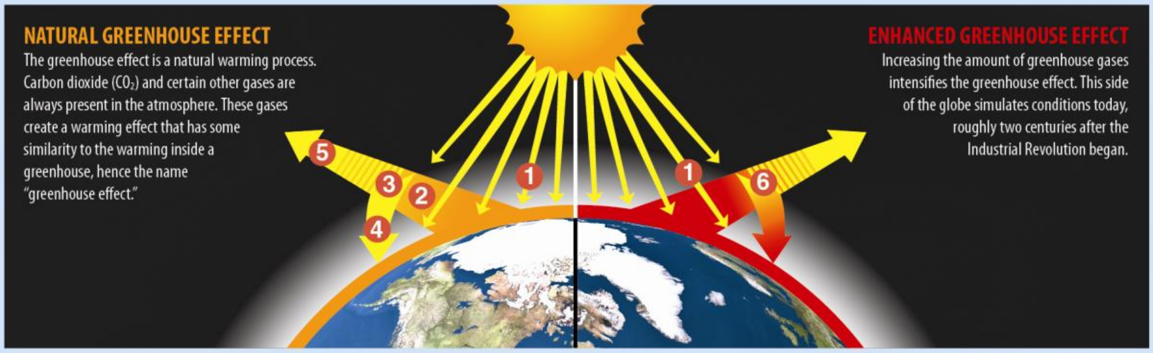
Additional sources that provide more detail than discussed in this handbook are included in the literature review presented in Appendix A.

2.1.2 The Greenhouse Effect

Certain gases in the atmosphere, including carbon dioxide, methane, and water vapor, play a natural role in keeping the Earth's atmosphere warm. When the sun's energy enters the atmosphere, much of it reflects off the land and ocean surfaces. GHGs trap some of the heat, keeping it from exiting the atmosphere. This keeps the earth's temperature fairly constant in the long-term. This process is depicted in Figure 2-2.

The principal gases associated with anthropogenic atmospheric warming are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbon (PFC), nitrogen trifluoride (NF_3), and hydrofluorocarbon (HFC) (California State law (Health & Safety Code, §38505, subd.(g); California Environmental Quality Act (CEQA) Guidelines, §15364.5)). Water vapor is also an important GHG, in that it is responsible for trapping more heat than any of the other GHGs. However, water vapor is not a GHG of concern with respect to anthropogenic activities and emissions because human activities have a relatively small impact on water vapor concentration in the atmosphere. Each of the principal GHGs associated with anthropogenic climate warming has a long atmospheric lifetime (one year to several thousand years). In addition, the potential heat-trapping ability, or global warming potential, of each of these gases varies significantly from one another. For instance, CH_4 is 23 times more potent than CO_2, while SF_6 is 22,200 times more potent than CO_2 (IPCC 2001). Conventionally, GHGs have been reported as "carbon dioxide equivalents" (CO_2e)that take into account the relative potency of non-CO_2 GHGs and convert their quantities to an equivalent amount of CO_2 so that all emissions can be reported as a single quantity.

The Greenhouse Effect



© The National Academy of Sciences, USA

Illustration of the greenhouse effect (adapted with permission from the Marian Koshland Science Museum of The National Academy of Sciences). Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth ❶ is absorbed and converted to heat, which warms the surface. The surface ❷ emits heat to the atmosphere, where some of it ❸ is absorbed by greenhouse gases and ❹ re-emitted toward the surface; some of the heat is not trapped by greenhouse gases and ❺ escapes into space. Human activities that emit additional greenhouse gases to the atmosphere ❻ increase the amount of heat that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

Figure 2-2: The Greenhouse Effect (Pew Center on Global Climate Change 2011).

When the greenhouse gas concentration in the atmosphere increases, so does the atmosphere's capability to retain heat. Large increases in the concentration of atmospheric carbon dioxide decrease the amount of solar radiation reflected back into space. As a result, more radiation is retained as heat. Over an extended period of time, this change in Earth's energy balance increases global average temperatures. Over the past century, an increase of 1.5 degrees Fahrenheit (degrees F) was observed, with most of the warming occurring in the last 30 years. In addition to a general warming trend in most places, temperature changes have already started to impact ice and snow presence, atmospheric and oceanic circulation patterns, and weather event severity (IPCC 2007a).

2.2 Climate Models

Long-term observational data are showing trends in temperature, sea levels, precipitation, and many other environmental variables. However, using historical observations to project future trends may not accurately represent these environmental changes. Use of computer models based on our understanding of global atmospheric and ocean thermodynamics has become a widely accepted method for estimating future climate change. The IPCC reviews development of several general circulation models (GCMs) that express the international community's best scientific understanding of the Earth's atmosphere and oceans over time (IPCC 2011). These complex computational models are able to simulate climate processes and provide projections of climate variables, such as temperature and precipitation, at monthly time intervals. The model results can be processed for use in other analyses. This section provides an overview of the GCM results developed through the IPCC, and ways in which these model results are being made accessible to planners in California.

2.2.1 Intergovernmental Panel on Climate Change

The IPCC is an international scientific body comprised of thousands of contributing scientists from around the world and is tasked with synthesizing climate literature for decision makers. The IPCC Assessment Reports include discussions of climate projections generated from several GCMs. Results from GCMs are varied, not only because there are several different models that represent the climate differently and solve physical circulation and chemical equations differently, but also because there is uncertainty about future GHG emissions levels will be. Future GHG emissions are dependent on future population growth, economic development, and advances in technology (e.g., energy use). The IPCC Special Report on Emissions Scenarios (SRES) has established emissions scenarios as standards for comparisons of modeling projections across a reasonable range of possible future conditions (IPCC 2000). These emissions scenarios represent various potential future scenarios of per capita energy use, economic growth, and population growth. These scenarios are:

- A1: The A1 emissions scenarios represent a future with both rapid economic growth and rapid transition to more efficient technologies. These scenarios represent a global population that peaks in mid-century. The A1 scenario is divided into three groups that describe alternative directions of technological change:
  - A1FI represents fossil fuel-intensive energy consumption,
  - A1T represents use of non-fossil energy resources, and
  - A1B represents a balance of energy sources.
- B1: This scenario represents a more environmentally friendly future, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.

- A2: This scenario represents emissions in a very heterogeneous future with high population growth, slower and more fragmented economic development, and technological change.
- B2: This scenario represents emissions in a future with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.

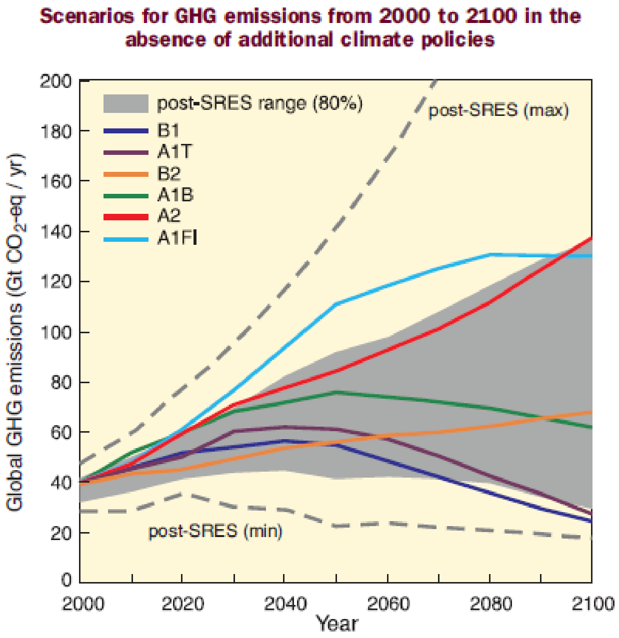


Figure 2-3: SRES Emissions Scenarios. (Source: IPCC 2007b)

The emissions associated with each scenario are depicted in Figure 2-3. More information on the models and emissions scenarios can be found in the IPCC 4th Assessment Synthesis Report (IPCC 2007a), and online via the IPCC Data Distribution Center (http://www.ipcc-data.org/index.html). The Fifth IPCC Assessment Report will be completed in 2013/2014, and will reflect climate projections using a new set of emissions scenarios (IPCC 2010). It is important to use the most current data and climate projections for IRWMPs. The concepts and methods presented in this handbook can be applied to any set of simulations. The new data and simulations will not change the general framework presented in the handbook. Uncertainties associated with climate projections are discussed in Box 2-1.

2.2.2 Regional Climate Analysis

The GCM projections provide estimates of future climate on a global scale, but do not provide data on a scale useful for local planning. Analyses on the scale of a watershed, for example, require input of precipitation and other climate data of a more refined spatial resolution. GCM model results must be downscaled to local scales in order to aid in planning-level analyses. There are several ways to downscale GCM model results to finer resolution, including use of statistical models and dynamic regional models.

While there are several approaches to downscaling GCM data for local analysis, a comprehensive set of model projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset is widely used (US Bureau of Reclamation (BOR) 2011a , Cox et al 2011, e.g.). The CMIP3 archive can be retrieved from: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/, and is described by Maurer et al. (2007). The CMIP3 archive is downscaled using bias-corrected spatial downscaling (BCSD). This dataset contains 16 different GCM models run with three different emissions scenarios (A1B, A2, and B1) resulting in a total of 112 climate projections spanning the years 1950-2099.

Uncertainties in Climate Projections

The scientific community is continually updating the GCMs to make them as accurate as possible. However, there are many sources of uncertainty inherent in projections of future climate variables, and these uncertainties add an additional layer of complexity to planning. There is uncertainty associated with (IPCC 2007):

- *The emissions scenarios*. The scenarios supported by the IPCC are their best representation of potential futures, and encompass "best" and "worst" cases as well as they can estimate them. However, there is significant uncertainty associated with future global GHG emissions.
- *Data limitations*. The historical dataset available for calibrating GCMs is spatially biased towards developed nations. In addition, difficulties associated with monitoring extreme events make model-data comparisons difficult.
- *Scientific Understanding*. The models represent current understanding of the Earth's physical response to increased GHG emissions. There are still many open questions regarding how the Earth responds to a warming climate. For example, uncertainties associated with ice flows in Antarctica and Greenland impact GCM results. The relative strength of various global feedback loops is also unclear.

There are many other sources of uncertainty associated with the climate models. The IPCC Fourth Assessment Report (IPCC 2007a) provides a discussion of these and other uncertainties, and also discusses more robust outcomes of the models (some of which are included in this section of the handbook). Ways of quantifying uncertainty and incorporating it into the planning process are discussed in Appendix B and Section 7, respectively.

Box 2-1

BCSD has been widely used in studies analyzing climate change impacts on water resources throughout California. A comparison of stream flows estimated in the Sacramento and San Joaquin Valleys using climate projections downscaled with BCSD and Constructed Analogue (CA), another downscaling technique, shows that BCSD data more accurately estimates stream flows than CA (Chung et al 2009). Some benefits to using BCSD-data include (BOR 2011a):

- BCSD is well documented for applications in the United States.
- The BCSD method is efficient, allowing the CMIP3 archive to develop downscaled projections from several models and emissions scenarios. This makes it possible to capture uncertainties in GCM projections.
- Projections downscaled using BCSD are often able to statistically reflect observed regional characteristics.

- The BCSD methodology results in a spatially continuous set of precipitation and temperature data that is appropriate for watershed and other smaller-scale analyses.

While there are many advantages to using BCSD-downscaled GCM projections for local planning, there are also limitations. An underlying assumption inherent in BCSD downscaling is that the relationship between large-scale phenomena modeled by the GCMs and smaller-scale, local phenomena will remain the same in the future as it has been in the past. Bias correction methods in BCSD assume that GCM biases observed on historical-modeled data comparisons will also be present in model results representing future conditions. These and other limitations of the CMIP3 archive are discussed at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/#Limitations. Other downscaling methods may be better for some types of analysis. Maurer and Hidalgo (2008) conclude that the CA downscaling method is generally better than BCSD for capturing fall and winter low-temperature extremes and summer high-temperature extremes (Mastrandrea et al. 2009).

2.3 Observed and Modeled Climate Trends

The GCMs provide our best estimate of climate in the future, but many climate impacts are already being observed in California and around the world. Current observations are useful for localized climate information and also for fine-tuning GCMs. This section discusses some observations that highlight the importance of data monitoring such as that conducted on a regional scale as part of an IRWMP.

2.3.1 Current Observed Climate Trends in California

Evidence of climate change is already being observed in California. In the last century, the California coast has seen a sea level rise of seven inches (DWR 2008). The average April 1 snow-pack in the Sierra Nevada region has decreased in the last half century (Howat and Tulaczyk 2005, CCSP 2008), and wildfires are becoming more frequent, longer, and more wide-spread (Sierra Nevada Alliance (SNA) 2010, CCSP 2008).

While California's average temperatures have increased by 1 degree F in the last hundred years, trends are not uniform across the state. The Central Valley has actually been experiencing a slight cooling trend in the summer, likely due to an increase in irrigation (California Energy Commission (CEC) 2008). Higher elevations have experienced the highest temperature increases (DWR 2008). Many of the state's rivers have seen increases in peak flows in the last 50 years (DWR 2008).

While historical trends in precipitation do not show a statistically significant change in average precipitation over the last century (DWR 2006), regional precipitation data show a trend of increasing annual precipitation in northern California (DWR 2006) and decreasing annual precipitation throughout Southern California over the last 30 years (DWR 2008).

2.3.2 Anticipated Future Climate Trends in California

Climate change has a complex impact on various climate variables. Mean temperatures are expected to shift in response to GHGs in the atmosphere. In addition, the distribution of various climate variables may change. These shifts in distribution are harder to quantify, but are potentially important, as they influence the frequency of extreme events, such as heat waves and droughts. Figure 2-4 depicts some of the ways that climate can change in the future for temperature and precipitation.

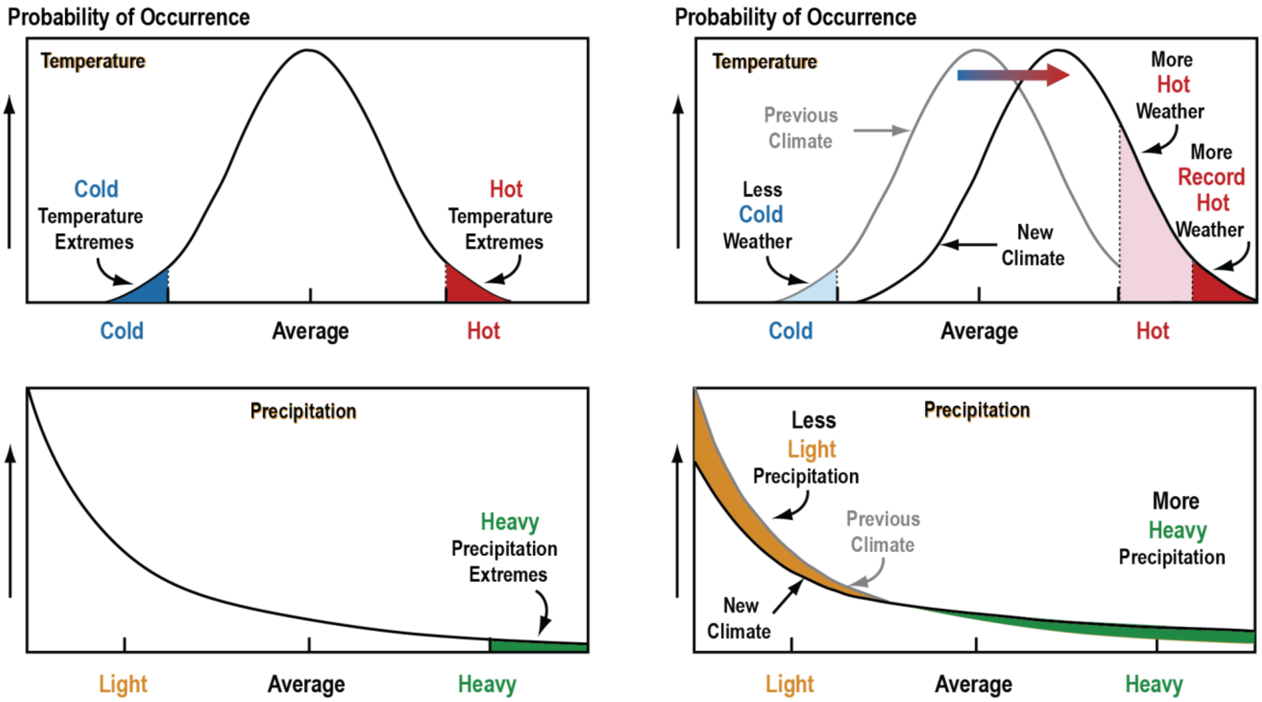


Figure 2-4: Graphical description of extreme events and potential event probability distributions related to climate variables (Source: CCSP 2008).

2.3.2.1 Projected Climate Changes

Models project that in the first 30 years of the 21st Century, overall summertime temperatures in California will increase by 0.9 to 3.6 degrees F (CAT 2009). Average temperatures in California are expected to increase by 3.6 to 10.8 degrees F by the end of this century (Cayan et al 2006). This large divergence in temperature for longer time horizons is a result of uncertainty in future GHG emissions. If future global emissions continue to increase, temperatures are more likely to increase at a faster pace (CAT 2009). This aspect of climate projection is discussed further in Section 2.2.1. As an example, temperature increases in Pasadena over the next century are shown in Figure 2-5.

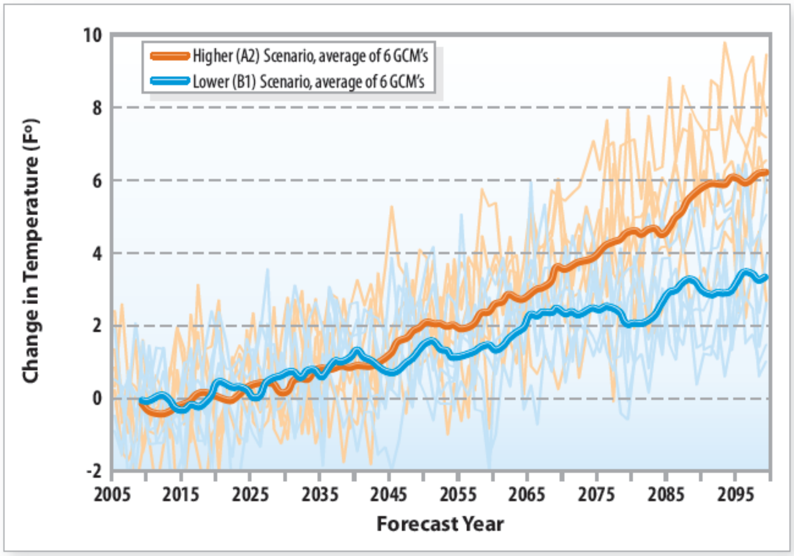


Figure 2-5: Projected Temperatures Resulting from 6 GCMs and 2 emissions scenarios. Lighter lines are individual GCM results, darker lines are average A2 and B1 projections. Models used include CNRM CM3, GFDL CM2.1, Miroc3.2 (medium resolution), MPI ECHAM5, NCAR CCSM3, NCAR PCM1. (Source: Pasadena Water and Power 2011)

Increases in temperature are not likely to be felt uniformly everywhere. Model projections generally agree that warming will be greater in California in the summer than in the winter (CAT 2009) and inland areas are likely to experience more extreme warming than coastal areas (California Natural Resources Agency (CNRA) 2009). These non-uniform warming trends are one of the reasons that regional approaches to addressing climate change are important.

While projections of temperature show high levels of agreement across various models and emissions scenarios, projected changes in precipitation are more varied. Taken as an ensemble, downscaled GCM results show little, if any, change in average precipitation for California before 2050 (DWR 2006), with a drying trend emerging after 2050 (BOR 2011a, CCSP 2009). While little change in precipitation is projected by the ensemble average of several GCMs, individual GCM results are considerably varied. Climate projections therefore imply an increase in the uncertainty of future precipitation conditions.

2.3.2.2 Extreme Weather Events

As the climate warms, extreme events are expected to become more frequent, including wildfires, floods, droughts, and heat waves.

In contrast, freezing spells are expected to decrease in frequency over most of California (Mastrandrea 2009). While GCM projections may indicate little, if any, change in average precipitation moving into the future, extreme precipitation events are expected to become more common-place (Congressional Budget Office (CBO) 2009). Atmospheric rivers, sometimes also called "pineapple express storms," have historically been responsible for creating the heaviest storms in California. These storms are characterized by long, thin bands of air with a high water vapor content that occasionally stretch over California from the Pacific Ocean. Years with several atmospheric river events could become more frequent over the next century (Dettinger 2011).

In addition to pineapple express storms, droughts and heat waves are also expected to become more frequent, longer, and more spatially extensive (CNRA 2009). The combination of drier and warmer weather compounds expected impacts on water supplies and ecosystems in the Southwestern US (CCSP 2009). Wildfires are also expected to continue to increase in frequency and severity (CCSP 2009, SNA 2010).

2.4 Current and Future Impacts on Water Resources

Water resources in California and across the US are already being impacted by climate change. The impacts will affect water supplies, water quality, flood management, hydropower production, water demands, ecosystems, and coastal areas, often in unexpected ways. For example, increased temperatures can exacerbate dissolved oxygen (DO) deficiencies in water bodies. Temperature increases are already causing more precipitation to fall as rain than as snow, which has impacts on snowpack storage for water supplies. As droughts become more common, water demands for irrigation uses will increase.

Climate change also introduces an added level of uncertainty to water resources. Future climate projections are far from certain, and variables like precipitation show large disagreement among GCMs. Impacts to water resources are summarized below. More details on these impacts are also discussed in Section 4, and ways of assessing and planning for their associated uncertainties are discussed in Sections 5 and 7, and Appendix B.

Water Supply. Increased temperatures will result in more winter precipitation in the mountains falling as rain rather than snow. DWR anticipates a 20 to 40 percent decrease in the state's snowpack water storage by the year 2050 (DWR 2008). This snowpack reduction impacts large water systems such as the State Water Project (SWP), the Central Valley Project (CVP), and water systems that rely on the Colorado River. It also impacts smaller watersheds relying on snowpack for water supply. Shifts in run-off timing have already been observed: the fraction of total annual runoff occurring between April and July has decreased by 23 percent in the Sacramento Basin and by 19 percent in the San Joaquin Basin (CEC 2008).

The 2009 SWP/CVP impacts report (Chung et al 2009) evaluates climate change impacts on both the SWP and CVP supply projects. The results from this report are the basis for taking climate change into account in the SWP 2009 Delivery Reliability Report (DWR 2010b). Using the BCSD downscaling method, climate change projections were applied to hydrologic and hydraulic models to develop flows into the Sacramento-San Joaquin Delta (Delta). This study indicates that Delta exports may be reduced by up to 25% by the end of the century, under certain emissions scenarios. Figure 2-6 shows Delta exports at the end of the century projected with and without climate change, as well as the frequency at which total Delta exports are likely to exceed various flows.

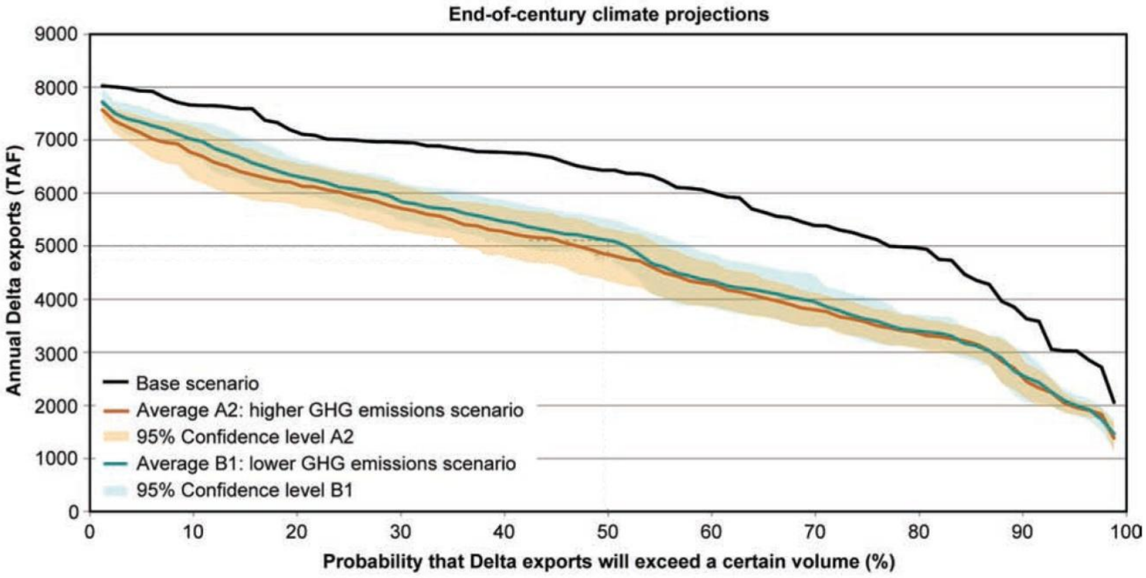


Figure 2-6: End-of-century projected Delta exports using various emissions scenarios. (Source: Chung et al 2009)

In addition to the timing of stream flows, climate change may also alter the total amounts of runoff in watersheds. While precipitation projections do not show a clear trend in the future, an ensemble of twelve climate models shows a trend of decreasing runoff for Southern California between the end of the twentieth and twenty first centuries (IPCC 2008).

Water Demand. The seasonal component of water demands (e.g., landscape irrigation and water used for cooling processes) will likely increase with climate change as droughts become more common and more severe, temperatures alter evapotranspiration rates, and growing seasons become longer. Without accounting for changes in evapotranspiration rates, agricultural crop and urban outdoor demands are expected to increase in the Sacramento Valley by as much as 6% (Chung et al 2009).

Water Quality. Water quality can be impacted by both extreme increases and decreases in precipitation. Increases in storm event severity may result in increased turbidity in surface water supplies (DWR 2008). Lowered summertime precipitation may also leave contaminants more concentrated in streamflows. Higher water temperatures may exacerbate reservoir water quality issues associated with dissolved oxygen levels; and increased algal blooms (DWR 2008). Salt intrusion may also impact coastal water supplies like the Delta (Chung et al 2009) and coastal aquifers (CNRA 2009). Water quality concerns may impact both drinking water supplies and instream flows for environmental uses. Water quality issues may also have impacts on wastewater treatment, the altered assimilative capacity of receiving waters may alter treatment standards, and collection systems may be inundated in flooding events. More prevalent wildfires may result in aerial deposition of pollutants into water bodies.

<u>Sea Level Rise</u>. There is little debate that sea levels will rise in the next century, but there are several approaches to estimating the extent of the rising. The Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) has developed guidance estimating that sea levels will rise between 10 and 17 inches by 2050, and between 31 and 69 inches by the end of the century (CO-CAT 2010), as shown in Figure 2-7. This projection has been adopted by the California Ocean Protection Council (OPC) in a resolution on sea level rise (OPC 2010). Rising sea levels threaten levees, especially in the Delta. Sea level rise increases the risk of storm surges and the flooding of coastal residences and infrastructure. Intruding salinity, due to sea level rise, may threaten water quality for some of California's water supplies in places like the Delta. Sea level rise and changes in precipitation patterns will also impact ecosystems in coastal areas that rely on a balance between freshwater and salt water, and may increase saline infiltration into coastal aquifers.

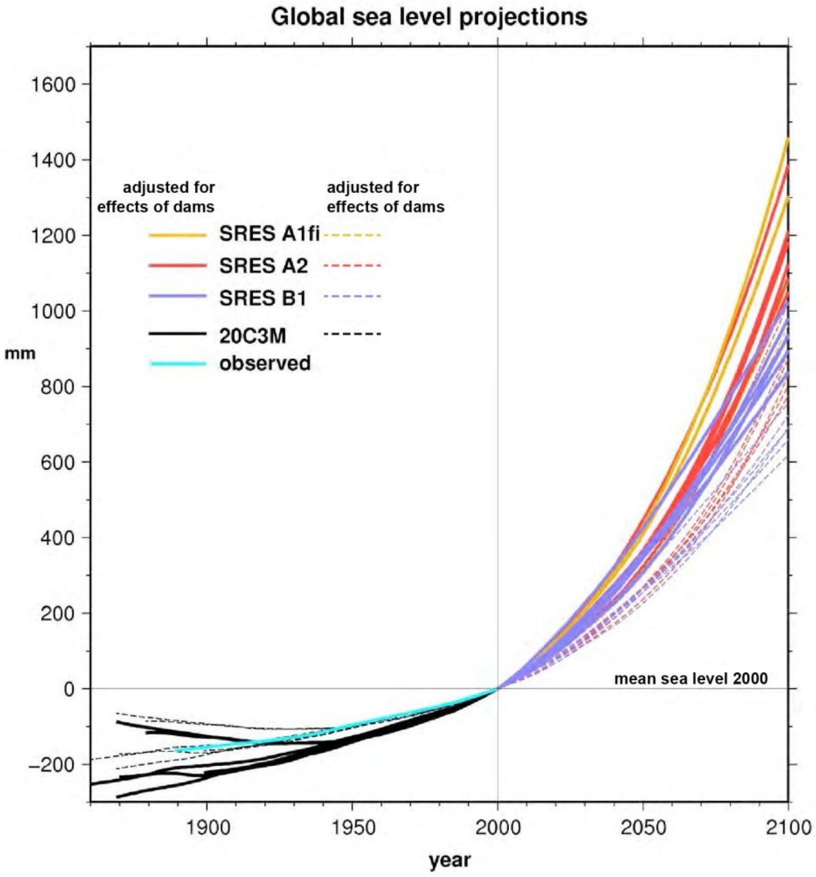


Figure 2-7: Projected Sea Level Rise from several GCM/emissions model results. (Source: Cayan et al 2009)

<u>Flooding</u>. In addition to increased coastal flooding resulting from sea level rise, severity of non-coastal flooding will also increase in the future. The current suite of climate models is not designed to project extreme precipitation events that cause flooding. However, there is some agreement among climate experts that the climatological conditions which drive extreme precipitation events will become more common, increasing the likelihood of extreme weather events. Rising snowlines will also increase the surface area in watersheds receiving precipitation as rain instead of snow (DWR 2008).

Ecological Effects. Habitats for temperature-sensitive fish may be impacted by increased water temperatures (DWR 2008). Surface water bodies will also be more susceptible to eutrophication with increased temperatures. Species susceptible to heat waves, droughts, and flooding may be in danger. Invasive species may become even more challenging to manage (CCSP 2009). Climate change will stress forested areas, making them more susceptible to pests, disease, and changes in species composition. With less frequent but more intense rainfall, wildfires are likely to become more frequent and intense, potentially resulting in changes in vegetative cover (CCSP 2009, SNA 2010). Coastal ecosystems that are sensitive to acidification and changes in salinity balances, sedimentation, and nutrient flows (such as estuaries and coastal wetlands) may be particularly vulnerable (CNRA 2009).

Hydropower Generation. Hydropower is a significant clean energy source in California: 21% of the state's electricity is generated from hydropower (CAT 2008). As spring snow-melt timing shifts, power generation operations may also need to shift to accommodate flood control (DWR 2008). Maximum power generation capacity may not coincide with maximum energy demands in the hot summer months. Several studies have projected various levels of hydropower losses. The California Climate Action Team projected that power generation will decrease by 6% by the end of the century for the State Water Project system, and by 10% for the Central Valley system (CAT 2009). Higher elevation hydropower generation units may see a decrease of as much as 20% of annual power generation (Medellin-Azuara et al 2009).

2.5 Summary

This section lays the foundation for most of the topics discussed in this handbook, including climate change mitigation, climate projections, climate change impacts analyses, and uncertainty involved in climate change science and future climate projections. Understanding the mechanisms of climate change helps planners assess and reduce a region's local contribution to future climate change. Local GHG emissions inventories are discussed in Section 3. Understanding currently observed and anticipated water resources impacts help regions identify and prioritize local vulnerabilities to climate change impacts, which is discussed further in section 4. The IPCC modeling suite is used, at least indirectly, as a basis for most future climate conditions assessments and impacts analyses (discussed in Section 5). Ways of incorporating uncertainty into both climate impacts analyses and into the planning process overall are discussed further in Appendix C and Section 7, respectively.

This page intentionally left blank.

Section 3

Evaluating the Energy-Water Connection and Greenhouse Gas Emissions

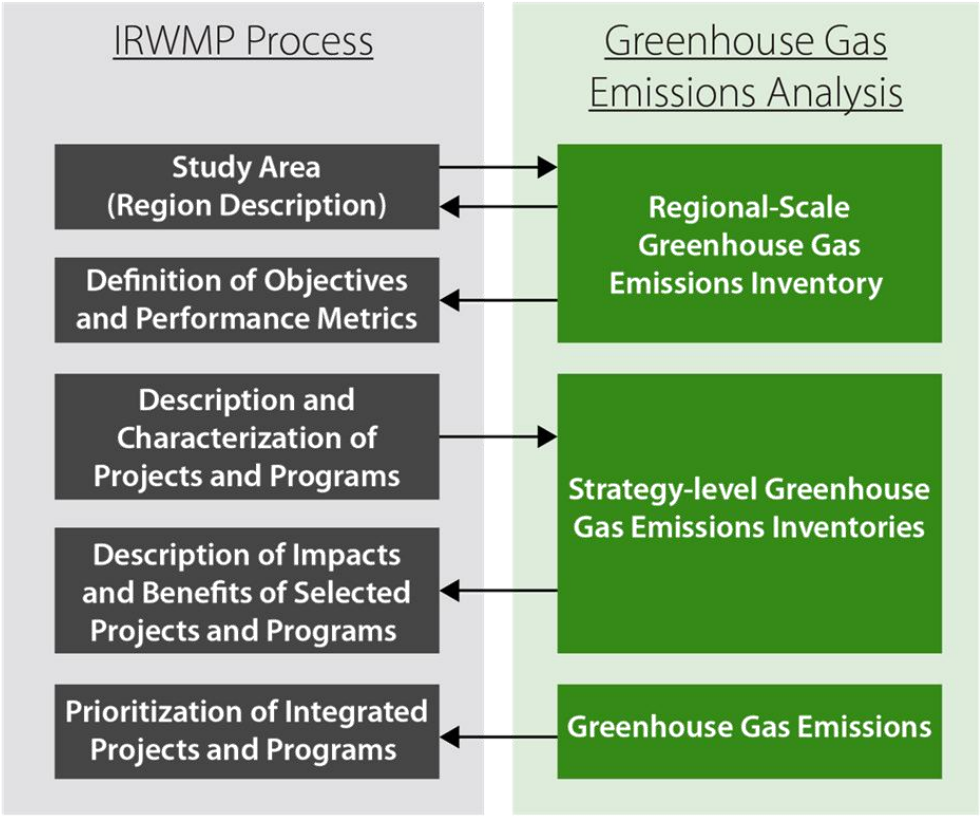


Figure 3-1. GHG Emissions Inventories and Emissions Reductions in IRWM Planning.

The water sector plays a significant role in California's energy consumption. In 2005, studies showed that 19% of the state's electricity was spent on water-related activities (CEC 2005). As discussed in Section 2, GHGs emitted into the atmosphere now and in the future will contribute to further impacts on climate and will likely result in more severe impacts in the latter half of the century (California Air Resources Board (CARB) 2008). Because the water sector is such a large user of electricity, it must play an important role in reducing energy demand and GHG emissions.

The IRWM guidelines, briefly described in Box 1-2, state: "The intent of the Climate Change Standard is to ensure that IRWM Plans … disclose, consider, and reduce when possible GHG emissions when developing and implementing projects." The IRWM program encourages minimizing GHG emissions to the extent practical; the IRWM Grant Program list of Statewide Priorities includes water management actions that lower energy use and reduce GHG emissions. The IRWM guidelines also include a project's contribution to reducing GHG emissions (as compared to other alternatives) as a factor in project evaluation (DWR 2010a).

The IRWM guidelines encourage consideration of GHG emissions consistent with California legislation, including Executive Order (EO) S-3-05, Assembly Bill (AB) 32, and the revised CEQA guidelines (discussed below). Several tools and protocols already exist to provide standardized methods for emissions evaluations and assessments. Discussion of how GHG emissions could be included with other planning objectives and metrics in overall project evaluation is included in Section 6, along with additional mitigation measures that could be considered in the planning process. Figure 3-1 depicts the relationship between GHG emissions inventories and IRWM planning. A baseline GHG emissions inventory could help describe a region's water resources, including identifying the largest sources of emissions, and could also be useful in defining planning objectives. Inventories at the project level could be useful in measuring performance metrics in the project evaluation process. Additionally, CEQA requires project-level inventories to be completed in order to evaluate the GHG-related impacts associated with construction and operation of a specific project. Calculated emissions values are also useful in describing project impacts and benefits, and in project prioritization.

This section focuses on:

- Summarizing the relevant legislation, policies, and plans governing the state of California which relate to GHG emissions,
- Clarifying the benefits to conducting both large-scale and project-scale GHG emissions inventories,
- Providing background on the carbon registries and other resources available when conducting an inventory, and
- Reviewing the major components of conducting a GHG emissions inventory, and providing resources for more detailed information.

3.1 Legislation, Policies, and Plans

The State of California has passed several laws requiring monitoring and reduction of GHG emissions. In addition, several regional air quality control districts and local governments have adopted policies and plans for reducing GHG emissions within their jurisdictions. Projects within these jurisdictions may be subject to additional regulation to comply with these policies and plans. The following review is a summary of the major legislation, policies, and plans specific to California. However, as new policies and plans are being developed constantly, planners may need to consider additional regulations not included in this handbook. Planning efforts in other regions in the United States will need to obtain equivalent information specific to their region.

Executive Order (EO) S-3-05 (2005)

California's EO S-3-05 (State of California, 2005) established statewide GHG reduction goals for California. Because EO S-3-05 only applies to state agencies, it is not binding for the broader economy. EO S-3-05 establishes the following GHG reduction goals:

- Reduce statewide emissions to 2000 levels by 2010,
- Reduce statewide emissions to 1990 levels by 2020, and
- Reduce statewide emissions to 80% below 1990 levels by 2050.

These ambitious emissions reduction goals are consistent with the IPCC estimates of emissions reductions required to stabilize long-term climate impacts (IPCC 2007a). The parties responsible for implementing EO S-3-05 formed the CAT (http://www.climatechange.ca.gov/climate_action_team/index.html). CAT is a work group with representatives from the California Environmental Protection Agency (CalEPA), the Business, Housing and Transportation Agency, the Department of Food and Agriculture, and many other state agencies. CAT develops sector-specific implementation plans for adapting to climate change in California and for reducing emissions. CAT also produces biennial reports that describe the potential impacts of climate change on key state resources, and reports on progress toward meeting the goals set forth in AB 32 (see below).

Assembly Bill (AB) 32 (2006)

AB 32 (California Health & Safety Code § 38500 et seq.; California State Assembly 2006, also known as the 2006 Global Warming Solutions Act), establishes a statewide mandate for reducing GHG emissions to 1990 levels by 2020. On December 12, 2008, CARB, the state agency tasked with developing the regulations to meet the GHG reduction goal, approved the final Climate Change Scoping Plan (Scoping Plan) for implantation of AB 32. The Scoping Plan includes recommendations for reducing GHG emissions statewide through a series of actions. Specific Scoping Plan actions which relate directly to the water sector and to water resource planning and management include (CARB 2008):

- Water use efficiency,
- Water recycling,
- Water system energy efficiency,
- Urban runoff reuse,
- Increase renewable energy production, and
- Public goods charge.

In addition to the actions described in the Scoping Plan, a number of near-term implementation plans have been developed by CAT. The Water-Energy Subgroup of the Climate Action Team

(WET-CAT) has taken the lead on developing near-term plans to aggressively increase water use and energy efficiency in the water sector. Below are the key plans that have been developed related to the water sector:

- 20X2020 Near-Term Implementation Plan: http://www.climatechange.ca.gov/climate_action_team/reports/catnip/water_energy/Water%201%20-%2020x2020%20Reduction%20CATNIP.pdf
- Water Recycling Near-Term Implementation Plan: http://www.climatechange.ca.gov/climate_action_team/reports/catnip/water_energy/Water%202%20-%20Water%20Recycling%20CATNIP.pdf
- Low Impact Development Near-Term Implementation Plan: http://www.climatechange.ca.gov/climate_action_team/reports/catnip/water_energy/Water%203%20-%20Low%20Impact%20Development%20CATNIP.pdf
- Improved Monitoring Near-Term Implementation Plan: http://www.climatechange.ca.gov/climate_action_team/reports/catnip/water_energy/Water%204%20-%20Improved%20Monitoring%20CATNIP.pdf

More information on AB 32 is available at http://www.arb.ca.gov/cc/ab32/ab32.htm.

Senate Bill (SB) 97 (2007)

In 2007, the California Legislature recognized the need for guidance on the analysis of climate change for CEQA compliance, and with SB 97 (California Public Resources Code - Section 21083.05; California State Senate 2007), directed the Natural Resources Agency, in coordination with the Governor's Office of Planning and Research, to develop amendments to the CEQA Guidelines. As a result of SB 97, new CEQA Guideline amendments provide direction to lead agencies about evaluating, quantifying, and mitigating a project's potential GHG emissions. The new regulations are viewable at: http://www.ceres.ca.gov/ceqa/guidelines/ and have also been codified under Title 14 of the California Code of Regulations.

Local and Regional Policies and Plans

Unlike many other states, California's air quality and GHG emissions are managed at the regional level by 35 local air districts. Each air district is responsible for establishing how it will evaluate the significance of GHG emissions within its region. While the air districts are not required to adopt district-specific procedures and standards for determining the significance of GHG emissions, several air districts have developed their own standards.

Air districts that have adopted CEQA thresholds of significance for GHG emissions and methods for evaluating impacts include:

- Bay Area Air Quality Management District (AQMD),
- Sacramento Metropolitan AQMD,

- San Diego Air Pollution Control District (APCD),
- San Joaquin Valley APCD,
- Santa Barbara County APCD,
- South Coast AQMD, and
- Tehama County APCD.

Some air districts have adopted quantitative thresholds of significance (e.g., Bay Area AQMD and South Coast AQMD both use 10,000 metric tons of carbon dioxide equivalents per year as the significance threshold for industrial sources), while other air districts, like the San Joaquin Valley APCD, use a qualitative approach, such as requiring Best Performance Standards in project design. It is critical that agencies check with their local air district about standards for assessing the significance of GHG emissions before commencing new projects.

Additionally, several cities, counties, and other land use jurisdictions require GHG reductions or have been proactive in creating climate action plans to guide emissions reductions. For example, the City of Los Angeles released its climate action plan (Green LA) in 2007, which sets a goal of reducing the City's GHG emissions to 35 percent below 1990 levels by 2030. Agencies should also be cognizant of local GHG reduction goals that may affect proposed projects.

3.2 Greenhouse Gas Emissions Inventories

Regions are encouraged to conduct a region-wide inventory (or several smaller inventories by agency) of the water sector as part of the IRWM regional description process. This type of analysis informs potential emissions reductions and regional planning objectives. Inventories can be performed on a project level as well to establish carbon credits and to aid in project evaluation; this type of analysis is also required as part of the CEQA process and regions are encouraged to combine analyses where possible.

3.2.1 Carbon Registries

Protocols created by carbon registries can help with GHG emissions inventories, whether at the regional level or the project level. While there are benefits to becoming members of a climate registry, this action would also commit the agency to completing annual GHG emissions inventories and would have financial obligations. Carbon registries also require entity-wide disclosures of emissions and are not tuned to project-level emissions inventories. While it may not be practical for a region or agency to become a member of a carbon registry, the resources available from the registries can be instructive. Carbon registries are organizations that provide guidance in measuring and reducing GHG emissions. They also provide an accepted platform for measuring and reporting emissions. Most registries either:

1. Provide agencies with a method of inventorying and reporting emissions, such as The Climate Registry (TCR); or

2. Serve as a basis for developing GHG emissions reductions, potentially at the project level, such as the American Carbon Registry (ACR) and the Climate Action Reserve (CAR).

This handbook does not necessarily recommend that agencies become members of reporting registries like TCR; however, the protocols and methods established by the registries serve as a useful basis for completing GHG emissions inventories.

3.2.1.1 Emissions Inventories Registries – Organization-Level

Function of Registries

Registries that provide inventorying methods allow agencies to voluntarily commit to annually reporting GHG emissions. This helps identify areas where mitigation measures may be implemented, emissions reductions documented, and carbon offsets obtained. When the voluntary carbon registries were first established, GHG management in California was still in its infancy. Without rules and regulations dictating how carbon would be managed, the registries served an important function by documenting the early actions taken by organizations to reduce GHG emissions. CARB publicly stated that it would work with registries to allow organizations to take "credit" for their voluntary early actions and to partially shield them from further emissions reduction requirements under future regulatory regimes.

While reporting registries like TCR can help identify areas where carbon offsets could be attained, they are not platforms for actually obtaining carbon offsets. Rather, projects must be submitted through registries like ACR or CAR to obtain quantifiable carbon offsets that could then be sold on the open market.

The GHG Protocol Initiative and TCR

The GHG Protocol Corporate Standard (World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD)) and TCR's GHG reporting protocols are voluntary reporting standards that focus solely on inventorying emissions, rather than generating carbon offsets. Both systems provide a transparent and standardized method of inventorying emissions.

TCR is a non-profit organization whose board is comprised of representatives from over 41 states, all 13 Canadian Provinces and territories, six Mexican states, and four native sovereign nations. TCR empowers organizations to assess and reduce their GHG emissions by providing the tools to measure and manage them, including the Local Government Operation Protocol – a GHG reporting protocol developed in partnership with the California Climate Action Registry (CCAR), TCR, ICLEI-Local Governments for Sustainability, and CARB. TCR is the current North American standard for GHG emissions inventories and public reporting, other than the state and federal mandatory programs, and is recommended if an organization chooses to voluntarily assess its emissions. Organizations looking to inventory their GHG emissions should report their 2010 and later emissions data to TCR. Even if an agency elects to not become a member of TCR, its protocols can be used to develop GHG emissions inventories.

The GHG Protocol Initiative provides an accounting framework for agencies to quantify and manage GHG emissions. Representing a partnership between WRI and WBCSD, the GHG Protocol works with businesses, governments, and environmental groups to create consistent methods for estimating GHG emissions. The GHG Protocol provides useful tools and resources including spreadsheets to aid in GHG emissions calculations, but does not provide a reporting platform.

3.2.1.2 Emissions Credits Registries – Project-Level

For specific mitigation projects, ACR and CAR can be used to document GHG emissions reductions for the purpose of generating tradable emissions credits or offsets. These carbon offsets can then be bought or sold on the open market. Offsets generated through the CAR program may also be used in the cap-and-trade program that California intends recently adopted. ACR works individually with agencies to conduct a GHG emissions inventory and regular monitoring protocol. The case study at the end of this section describes a monitoring protocol developed by the Inland Empire Utilities Agency (IEUA) for a digester project using the ACR protocol.

For potential project evaluations, a project-level inventory may be conducted based on the protocols available through an emissions credit registry, and a final selected project alternative may be registered in an emissions credit registry like CAR, if practical, to aid in documenting emissions savings and obtaining carbon offsets.

3.2.1.3 Additional Registry and Inventory Information

Accessing Registry Resources

Regardless of whether agencies and water resource entities join a registry, agencies and regions are encouraged to consider the principles outlined by emissions inventory protocols in the planning process, to the extent practical. The following web links are useful for finding out more information about the various carbon registries:

- The Climate Registry (http://www.theclimateregistry.org/),
- The Greenhouse Gas Protocol Initiative (http://www.GHGprotocol.org/),
- The American Carbon Registry (http://www.americancarbonregistry.org/aboutus), and
- The Climate Action Reserve (http://www.climateactionreserve.org/).

Large-Scale Inventories

Statewide or national GHG emissions inventories may also be useful; however, these inventories are typically created using coarse data about inputs and outputs from each sector of the economy to estimate gross emissions from the sector. For regional entities, this coarse data is not typically available. References to state-level and national inventories are provided below:

- The 2010 state-level inventory for California includes emissions for years 2000 to 2008 http://www.arb.ca.gov/cc/inventory/inventory.htm,
- The nation-wide inventory http://www.epa.gov/climatechange/emissions/usinventoryreport.html , and
- All state-level GHG emissions inventories http://www.epa.gov/statelocalclimate/state/state-examples/ghg-inventory.html.

Other Resources

Several resources are also available in the literature. For example, the California Air Pollution Control Officers Association (CAPCOA)'s "Quantifying Greenhouse Gas Mitigation Measures" (2010, http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf) can be used to estimate the effectiveness of various GHG mitigation measures. Other sources are also listed in the literature review in Appendix A of this handbook. It should also be noted that climate change literature is in a continued state of evolution, so regions are encouraged to conduct their own investigation to make sure that the methodologies they use are up to date.

ICLEI – Local Governments for Sustainability (http://www.icleiusa.org) is a membership association of local governments that are committed to reducing GHG emissions and practicing sustainability. While ICLEI is geared towards cities, towns, and counties, several of its tools could be useful for the creation of a GHG emissions inventory. Many tools, including the Clean Air & Climate Protection Software, can only be assessed by member governments and so may not be available to water agencies. The Local Government Operations Protocol, which was created in partnership with CARB, CCAR, ICLEI, and TCR, is a useful document for creating GHG emissions inventories.

3.2.2 Measuring Emissions

The organizations mentioned in the previous section provide standardized instructions for conducting a GHG emissions inventory for an IRWM region or for a potential project. Whether emissions calculations are for a project or for an entire region, the general steps involved in measuring carbon emissions are the same:

1. Define inventory/project boundaries,
2. Define all relevant GHG sources and sinks,
3. Obtain emissions measurements and convert all GHGs to a CO_2 equivalent value based on their global warming potential[1], and
4. Verification of calculation by a third party (optional).

---

[1] The concept of a global warming potential (GWP) was developed to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. The definition of a GWP for a particular greenhouse gas is the ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO_2 over a specified time period" (EPA, 2011). Because different gases have different GWPs, carbon dioxide equivalents represent GHGs in terms of their GWP. This allows emissions of different GHGs to be compared with one another.

A description of each step is provided below:

1. Define project boundaries. While most protocols give detailed information about defining boundaries, the required information for most water agencies can be simplified. Generally, when completing an emissions inventory, regardless of the type or purpose, a water agency should consider all points that would be involved with delivering water. As a starting point, an agency should consider all direct and indirect emissions that could occur from combusting fuel or using electricity. Stationary sources like engines, generators, anaerobic digesters, and boilers should be considered, as well as mobile sources including agency owned or leased vehicles and forklifts. Emissions associated with worker transportation, water pumping for groundwater extraction and for conveyance, water and wastewater treatment, should all be included in a regional inventory. In conducting an agency- or system-wide inventory, care must be taken to account for GHG emissions associated with any water imported into the region.

   Institutional boundaries define which organizations' activities will be included in the analysis. For example, a region may decide to include emissions released by certain water-related agencies. Emissions related to water end-use (such as domestic water heating) may be beyond the institutional boundaries set by the inventory.

   It is also important to define which gases to record. Most inventories should include, at a minimum, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), especially if combustion sources are used by an agency or if indirect emissions from purchased electricity could occur. These three pollutants are consistently required to be reported in various voluntary and mandatory reporting regulations and should not be excluded, even if emissions may seem to be negligible.

2. Define all GHG sources and sinks inside the project boundaries, such as:

   a. Electricity use (and source mix of electricity),
   b. Fuel generation (for instance, from digesters),
   c. Carbon sequestration,
   d. Transportation of materials and people, and
   e. Fuel consumption (from equipment/machinery use).

It is important to know what mix of energy sources (e.g., the percentage of electricity supplied from renewable sources, coal, natural gas, etc.) is used to produce any electricity consumed for the project. The Emissions & Generation Resource Integrated Database (eGRID) is an excellent resource to determine emissions from electricity in a particular region and to determine the region's fuel mix (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html). Utilities that report emissions to TCR or have previously reported to the CCAR are encouraged to use the CO_2(2) emission factor (i.e., CO_2/Megawatt hour of generation) from these public reports instead of the eGRID emission factor.

Some sources and sinks, such as sequestration via photosynthesis, may be more difficult to quantify. The EPA also provides a summary of agricultural and forestry practices that sequester carbon. This summary is provided in Tables 3-1 and 3-2. The EPA website on sequestration practices also provides reference carbon sequestration rates for some specific forestry and agricultural practices (http://www.epa.gov/sequestration/practices.html). The CAR also provides protocols for quantifying sequestration rates for forests, urban forests, landfills and other projects (http://www.climateactionreserve.org/how/protocols/). Not all sequestration practices have established carbon sequestration rates. Certain practices may require a detailed literature review or may need to be discussed qualitatively. The tables below may also help inform land use planning where carbon sequestration and/or GHG emissions reductions are a planning objective.

---

[2] The public reports only include CO_2 emission factors; therefore, CH_4 and N_2O emission factors should still be obtained from eGRID.

Table 3-1: Agricultural Practices that Sequester Carbon and/or Reduce Emissions of Other Greenhouse Gases (Source: http://www.epa.gov/sequestration/ag.html)

Key Agricultural Practices	Typical Definition and Some Examples	Effect on Greenhouse Gases
Conservation or riparian buffers	Grasses or trees planted along streams and croplands to prevent soil erosion and nutrient runoff into waterways.	Increases carbon storage through sequestration.
Conservation tillage on croplands	Typically defined as any tillage and planting system in which 30% or more of the crop residue remains on the soil after planting. This disturbs the soil less, and therefore allows soil carbon to accumulate. There are different kinds of conservation tillage systems, including no till, ridge till, minimum till, and mulch till.	Increases carbon storage through enhanced soil sequestration may reduce energy-related CO_2 emissions from farm equipment, and could affect N_2O positively or negatively.
Grazing land management	Modification to grazing practices that produce beef and dairy products that lead to net greenhouse gas reductions (e.g., rotational grazing).	Increases carbon storage through enhanced soil sequestration, may affect emissions of CH_4 and N_2O.
Biofuel substitution	Displacement of fossil fuels with biomass (e.g., agricultural and forestry wastes, or crops and trees grown for biomass purposes) in energy production, or in the production of energy-intensive products like steel.	Substitutes carbon for fossil fuel and energy-intensive products. Burning and growing of biomass can also affect soil N_2O emissions.

Table 3-2: Forestry Practices that Sequester or Preserve Carbon (Source: http://www.epa.gov/sequestration/forestry.html)

Key Forestry Practices	Typical Definition and Some Examples	Effect on Greenhouse Gases
Afforestation	Tree planting on lands previously not in forestry (e.g., conversion of marginal cropland to trees).	Increases carbon storage through sequestration.
Reforestation	Tree planting on lands that in the more recent past were in forestry, excluding the planting of trees immediately after harvest (e.g., restoring trees on severely burned lands that will demonstrably not regenerate without intervention).	Increases carbon storage through sequestration.
Forest preservation or avoided deforestation	Protection of forests that are threatened by logging or clearing.	Avoids CO_2 emissions via conservation of existing carbon stocks.
Forest management	Modification to forestry practices that produce wood products to enhance sequestration over time (e.g., lengthening the harvest-regeneration cycle, adopting low-impact logging).	Increases carbon storage by sequestration and may also avoid CO_2 emissions by altering management. May generate some N_2O emissions due to fertilization practices.

3. Obtain emissions measurements and convert all GHGs to a CO_2 equivalent. For existing projects or regional inventories, records of electricity use, fuel consumption, etc., need to be assembled. For potential projects, these data will need to be estimated based on professional judgment. If construction will be involved for a proposed project, then construction-related emissions must also be estimated for CEQA.

   Many tools are available to help quantify GHG emissions. Some examples include:

   a. California's Regulation for the Mandatory Reporting of GHG Emissions contains methods to estimate emissions, specifically in §95105 for stationary combustion sources (http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-rep.htm).

   b. TCR's General Reporting Protocol contains methods for estimating emissions from stationary combustion, mobile combustion, and electricity use (http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/).

   c. The Local Government Operations Protocol expands on TCR's General Reporting Protocol and also includes methods for estimating emissions from power generation facilities, solid waste facilities, and wastewater treatment facilities (http://www.theclimateregistry.org/resources/protocols/local-government-operations-protocol/).

   d. Calculations based on electricity use and transportation are produced by the GHG Protocol: http://www.GHGprotocol.org/calculation-tools/all-tools.

   e. Detailed protocols for specific procedures can also be found through the USEPA at: http://www.epa.gov/climatechange/emissions/index.html.

   f. The Task Force on GHG Inventories for IPCC provides guidance on a larger, national scale: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

4. Verify that GHG emissions calculations are conducted correctly. For mandatory emissions reporting, emissions calculations must be verified by an accredited verification body. The CARB provides guidance for verification at http://www.arb.ca.gov/cc/reporting/GHG-ver/GHG-ver.htm. Voluntary emissions reporting platforms also encourage verification. TCR requires that organizations who are publically reporting emissions go through third-party verification, and provides verification guidance for voluntary GHG reporting in its General Reporting Protocol (http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/).

While third party verification is an important process for validating an emissions inventory and ensuring its quality and accuracy, it may not be practical for planning evaluations. For GHG inventories that are not going to be publicly reported, verification also may not be cost effective. This process is also described in the IEUA and Sonoma County Water Agency (SCWA) GHG emissions inventory case studies (Boxes 3-1 and 3-2, respectively). The IEUA case study highlights an inventory developed for a complex dairy manure digester system used to power recycled water facilities. IEUA registered the project with the ACR. The SCWA inventory highlights an agency-level inventory conducted through TCR.

3.2.3 Monitoring

Consistent with the IRWMP Performance and Monitoring standard, regional emissions should be monitored regularly, as projects are implemented. This step may be simplified if either agencies in the region or projects being implemented are registered with one of the registries discussed in Section 3.2.1. The American Carbon Registry helps establish a protocol for monitoring and reporting for individual projects. WRI and TCR also have protocols for monitoring and reporting emissions over time. Ultimately, the registry an agency joins (if it chooses to do so) and monitoring method used depend on both the nature of the project(s) and the objectives of the region.

3.2.4 Using Project GHG Emissions in Planning

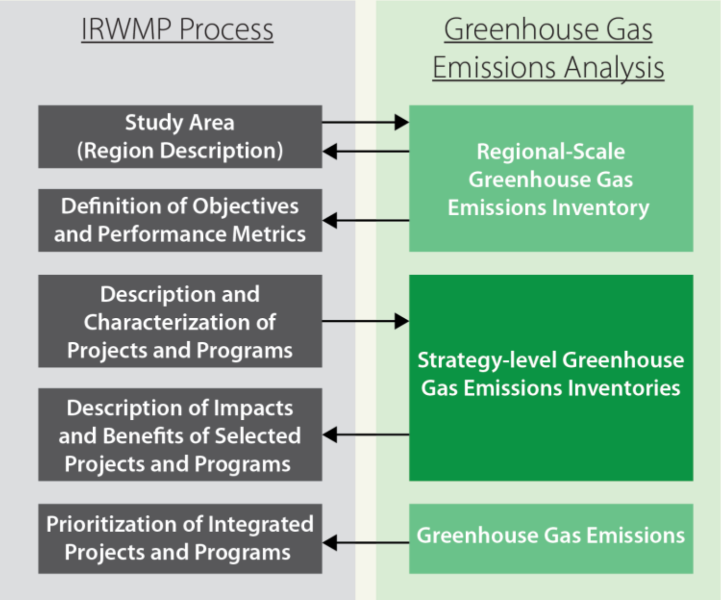
In California, IRWM guidelines state that in the project review process, project contribution to reducing GHG emissions (relative to other project alternatives) must be considered. This may be done by assessing the carbon emissions associated with one project alternative versus another.

Selection amongst IRWMP resource management strategies should consider the relative GHG emissions from different approaches to achieve the same water management objectives (i.e., surface storage vs. groundwater storage; drip irrigation vs. canal lining). Resource management strategies that provide similar water benefits may involve very different GHG emissions.

The information and resources provided in this section discuss *both* regional and project level inventories of GHG emissions. A regional inventory can contribute to the regional description in an IRWMP. Information from a regional inventory may also be used in the definition of regional objectives and performance metrics. Emissions inventories of individual potential projects can be used to evaluate potential projects, and can also be included in an IRWMP's description of the impacts and benefits from individual projects. The project evaluation process is discussed in more detail in Section 6.

Case Study: Project GHG Inventories

Inland Empire Utilities Agency – Regional Digester Inventory
Inland Empire Utilities Agency, CA



Background:

- Inland Empire Utilities Agency (IEUA) is a regional utility providing imported and recycled water and wastewater services and treatment to the Cities of Chino, Chino Hills, Fontana, Montclair, Ontario, and Upland; the Cucamonga Valley Water District; and Montevista Water District (Figure 1). Major facilities include water recycling facilities, two biosolids handling facilities and a composting facility. The energy generated from digesters contained in the biosolids facilities (RP-1 and RP-5) is used to power water recycling facilities. The flow of materials and energy among the IEUA facilities is shown in Figure 2.
- **Anaerobic Digester Project:** The anaerobic digester project originally operated as a centralized manure management facility for local dairies, and is registered at the American Carbon Registry (ACR). Because the digesters generate electricity and reduce the overall carbon footprint of IEUA, annual emissions reports with the ACR report both overall emissions and emissions reductions associated with the digester project. The digester project currently operates primarily on food waste, but the original emissions evaluations as a manure handling facility are presented here.
- **Methodology:** The methodology of this inventory was developed by the Environmental Resources Trust and Eastern Research Group (prepared for the CEC and IEUA), and relies heavily on conversion factors and recommended assumptions made by the IPCC, the USDA, EPA, and others. These source materials are cited in the Literature Review presented in Appendix A, and are also cited in the documents listed at the end of this case study. The inventory itself was conducted through a spreadsheet-based model.

Figure 1: Inland Empire Service Area (Source: Jones and Matson, 2009). For larger image, please see http://www.ieua.org/news_reports/docs/reports/2009/CWEA_PresentationMay09.pdf.

Box 3-1

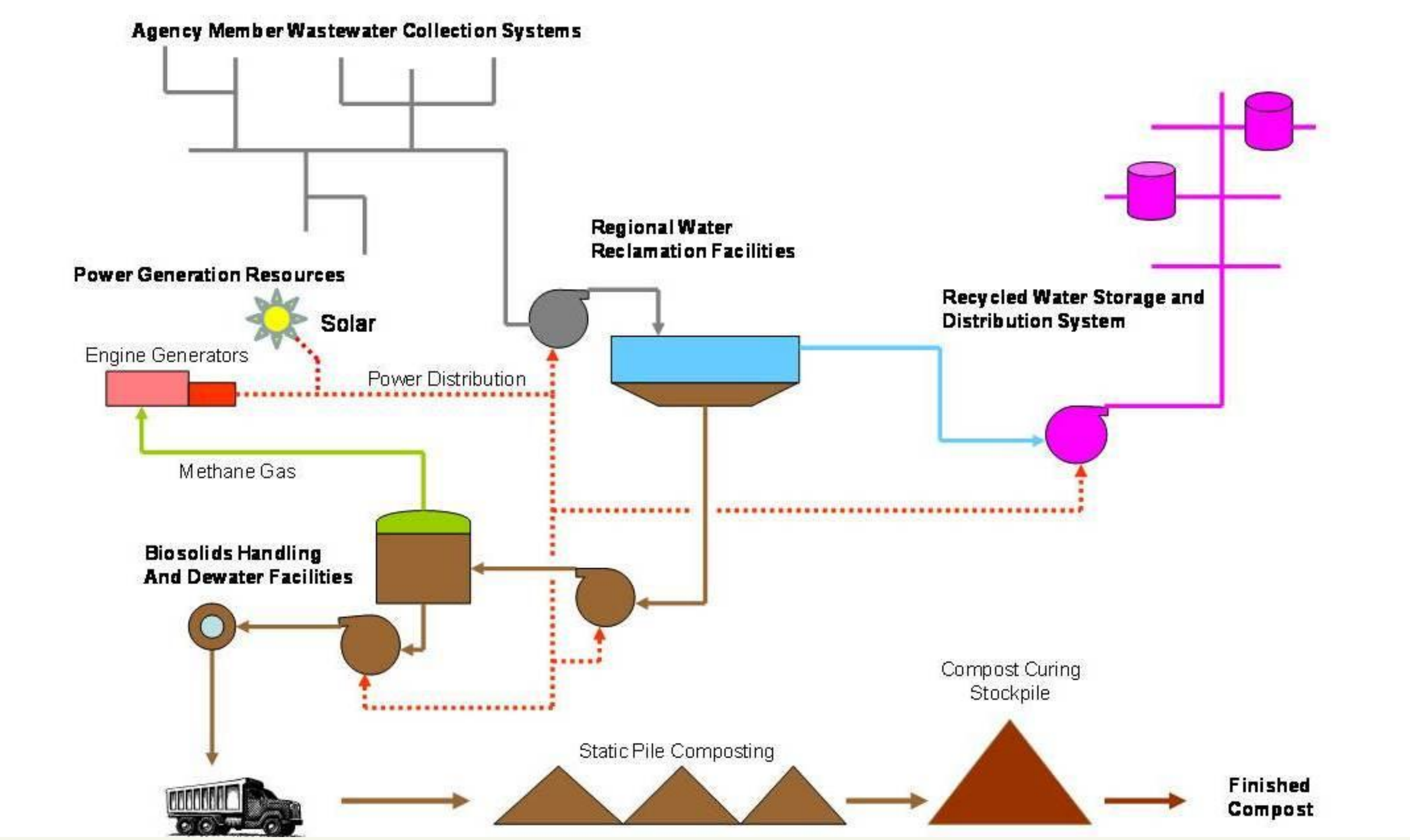


Figure 2: IEUA system flow diagram. (Source: http://www.ieua.org/facilities/img/Facilities-Overview.jpg)

Box 3-1 (Continued)

Step 1: Define Project Boundaries and Obtain Applicable Data

Boundaries Consist of:

- Facilities/activities of IEUA evaluated in this study
- Types of emissions included in this study

Data Consists of:

- Emissions source data
- Standard emissions estimates

Defining project boundaries is the first step in inventorying GHG emissions, and includes defining the processes that are considered in the inventory. Figures 3-5 depict the flow of methane for the "with project" scenario, and nitrous oxide and methane for the "baseline", no-project scenario.

Emissions Gases Included:

- Methane (direct emissions)
- Nitrous Oxide (indirect emissions)
- Ammonia (indirect Nitrous Oxide emissions)
- Carbon Dioxide (direct emissions)

Emissions Sources Included:

- All operations contained within the two solids handling facilities:
  - RP-1: flare, engine, boiler emissions
  - RP-5: flare, engine, water heater emissions
- Emissions from transporting manure to digester facilities
- *For baseline comparison*: baseline manure management and disposal processes
  - Dairy cattle enteric fermentation
  - Manure management in corrals and lagoons
  - Co-composting

Box 3-1 (Continued)

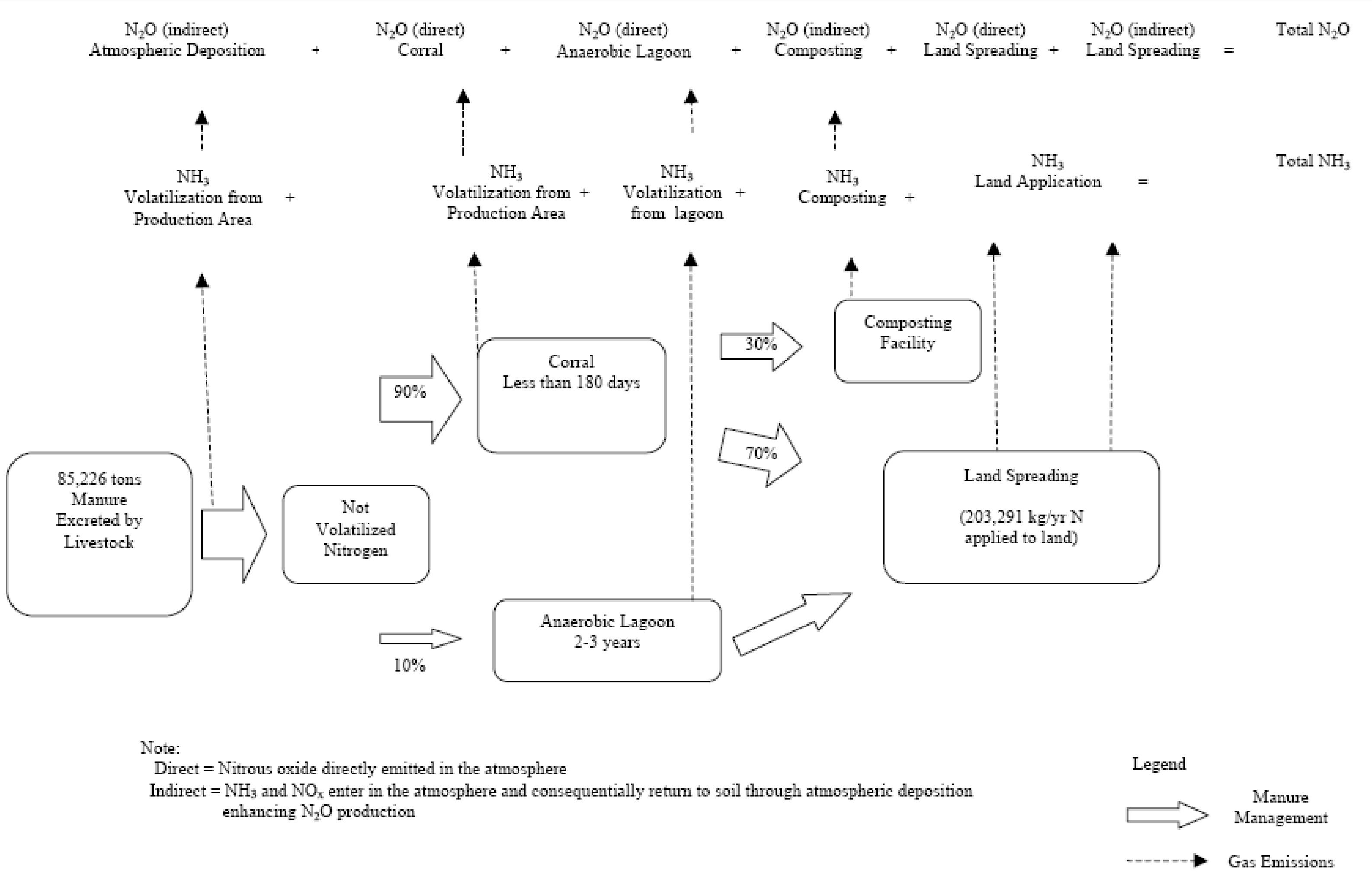


Figure 3: Inventory boundaries and N$_2$O pathways for baseline system. (Source: ERT, 2006)

Box 3-1 (Continued)

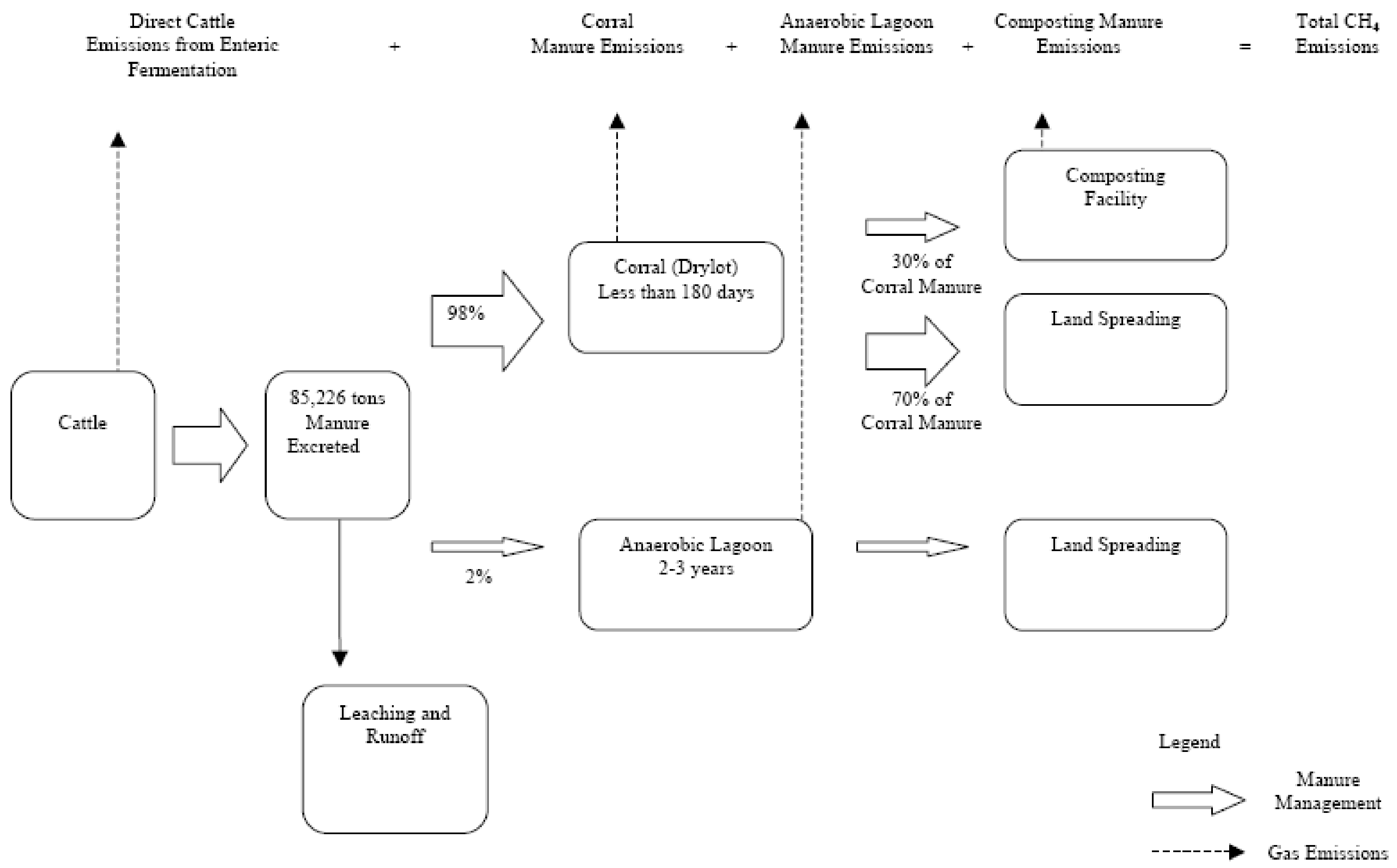
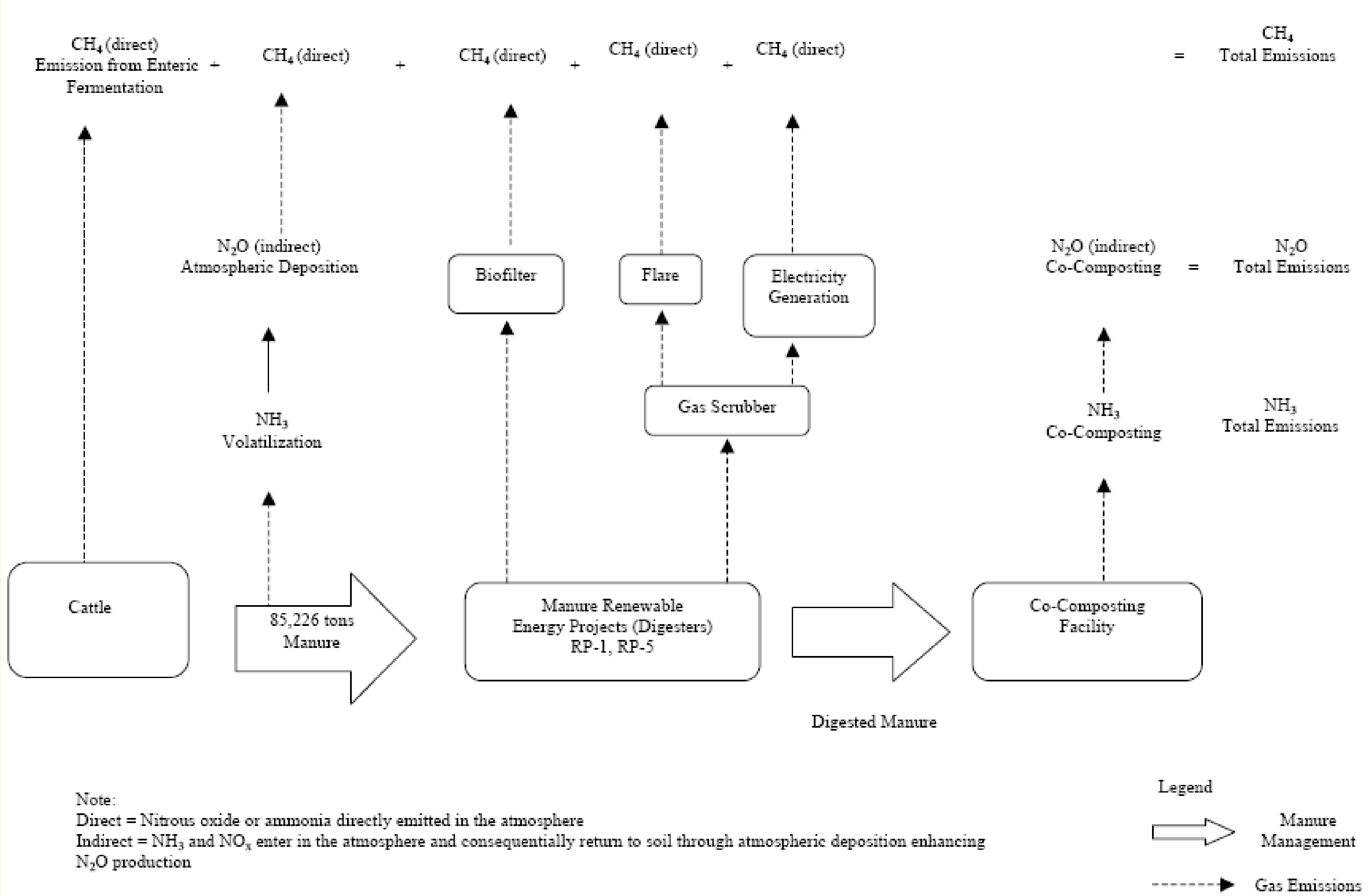


Figure 4: Inventory boundaries and CH_4 pathways for baseline system. (Source: ERT, 2006)

Box 3-1 (Continued)



Note:
Direct = Nitrous oxide or ammonia directly emitted in the atmosphere
Indirect = NH_3 and NO_x enter in the atmosphere and consequentially return to soil through atmospheric deposition enhancing N_2O production

Figure 5: Inventory boundaries and GHG pathways for digester system. (Source: ERT, 2006)

Box 3-1 (Continued)

Data Obtained:

- Daily records of manure delivery to digesters, volatile solids content
- Biogas production
- Biogas use at flares and other on-site uses
- Biogas exported
- Flare operation
- Transportation data
- *For baseline*: manure loadings to corrals, lagoons, composting facility

Conversion Factors and GHG Emissions Estimates Assembled:

- Emissions associated with consuming biogas - based on measured data from digesters. The composition is constantly being measured, so changes over time can be included.
- Emissions associated with manure management process: lagoons, corrals, composting
- Emissions associated with vehicle transportation

Step 2: Baseline and Project GHG Emissions

Results Assessed:

- Absolute emissions of CO_2 equivalent
- Reductions in CO_2 emissions resulting from project

2003 Emissions Totals

	CH_4 Emissions (tons)	N_2O Emissions (tons)	Total GHG Emissions CO_2 equivalent (tons)
Baseline	337	23	14,245
"With Project"	280	1	6,221
Project Emissions Reduction	57	22	8,023

Source: ERT, 2006.

*Emissions from dairy manure processing were **reduced by 56%** for the year 2003. Power from the digesters also supplies other facilities within IEUA.*

IEUA System-Wide Inventory

Using similar techniques, IEUA has also conducted a GHG emissions inventory extending over all of IEUA (excluding emissions associated with imported water). Some summary information is provided below.

Emissions Gases Included:

- Methane
- Nitrous Oxide
- Carbon Dioxide
- Hydrofluorocarbons
- Sulfur Hexafluoride

Emissions Sources Included:

- All water recycling facilities
- All company vehicle use
- The headquarters building
- Purchased electricity and gas
- Digester facilities

Box 3-1 (Continued)

Results:

Major emitting facilities for IEUA are the recycled water and desalting facilities, even with power provided by the IEUA digesters taken into account. The major source of emissions in the treatment system is purchased electricity. It is important to note that this system-wide inventory only includes processes associated with IEUA's footprint specifically, not the overall regional footprint. If imported water were included in this inventory, it would be possible to compare emissions from recycled water treatment with emissions from imported water delivery.

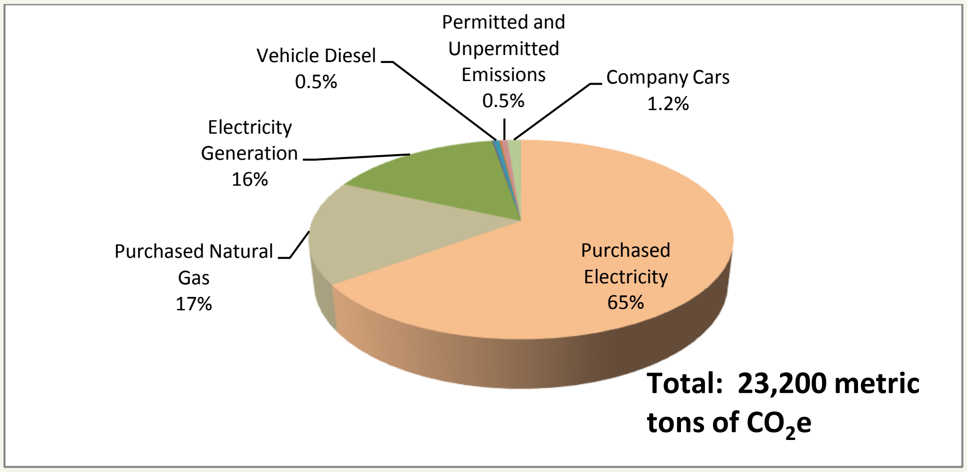


Figure 6: IEUA system-wide emissions by facility in 2003. (Data Source: Arifian and Swenson, 2008)

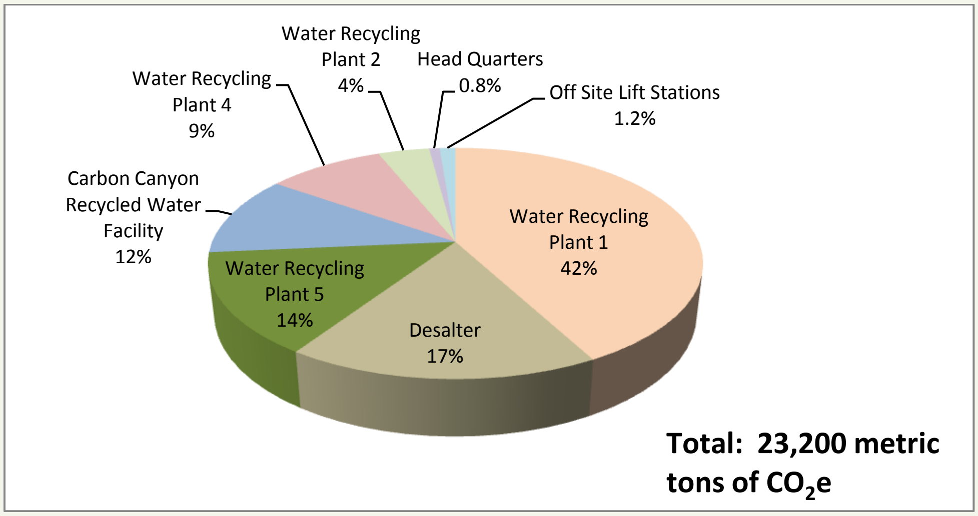


Figure 7: IEUA system-wide emissions by emission source type in 2003. (Data source: Arifian and Swenson, 2008)

Box 3-1 (Continued)

For More Information

Jones, Amy and Mike Matson. (2009). Maximizing a Valuable Resource – IEUA Recycled Water Program. Available: http://www.ieua.org/news_reports/docs/reports/2009/CWEA_PresentationMay09.pdf

Arifian, Greg and Laura Swenson. (2008). Carbon Footprinting: Using Carbon Emissions to Achieve Energy Independence. Proceedings of the Water Environment Federation, WEFTEC 2008: Session 11 through Session 20, pp. 1293-1310(18). Available: http://www.ingentaconnect.com/content/wef/wefproc/2008/00002008/00000016/art00030.

Environmental Resources Trust, Inc. (ERT). (2006). Monitoring, Reporting and Verification Protocol for IEUA Anaerobic Digester Project. Prepared for Inland Empire Utilities Agency. January 24, 2006. Available: http://www.americancarbonregistry.org/carbon-registry/projects/inland-empire-utilities-agency-anaerobic-digester-project/Inland_MRV_Protocol_01-24-2006.pdf/view.

American Carbon Registry. (n.d.). http://www.americancarbonregistry.org/.

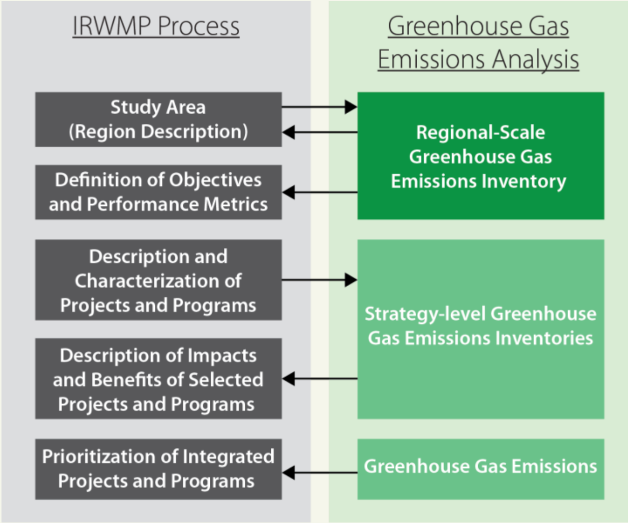
Inland Empire Utilities Agency (2010). http://www.ieua.org/.

Bartram, D. and W. Barpour. (2004). Estimating Greenhouse Gas Reductions for a Regional Digester Treating Dairy Manure. Proceedings of the 13th International Emission Inventory Conference: "*Working for Clean Air in Clearwater*". Available: http://www.epa.gov/ttn/chief/conference/ei13/ghg/bartram.pdf.

Box 3-1 (Continued)

Case Study: Agency GHG Inventories

**Sonoma County Water Agency –
Agency-wide Carbon Footprint**
Santa Rosa, CA



Background:

- The Sonoma County Water Agency (SCWA) provides wholesale water supply, flood control, stream maintenance services, and sanitation services to 600,000 people in portions of Sonoma and Marin Counties. As one of the largest energy users in Sonoma County, SCWA is actively working to reduce its carbon footprint. In 2006, SCWA committed to achieving a carbon-free water system by 2015. To help achieve that goal, SCWA has registered with The Climate Registry (TCR) and reports agency-wide emissions on an annual basis.

Step 1: Define Project Boundaries

Boundaries based on facility types

The water agency's GHG inventory is framed around facility types, which include:

- water supply,
- wastewater processing
- administrative facilities, and
- vehicle fleet.

The largest sources of emissions are fleet vehicles and electricity use for water transmission, transmission booster pumps, and wastewater treatment.

Institutional Boundaries: Members of The Climate Registry determine which facilities, operations, and sources to include within their organizational boundary and how to account for those emissions. SCWA chose to report using operational control, which means it reports for emissions from facilities where it has control over the operating policies.

Operational Boundaries: GHG emissions are divided into three scopes to provide a comprehensive accounting framework for managing and reducing direct and indirect emissions. In 2010, SCWA's GHG inventory included the following emissions:

Scope 1:

- Natural gas combustion
- Diesel combustion
- Fleet vehicles
- Fugitive emissions from building and vehicle air-conditioning
- Process emissions from wastewater treatment

Scope 2:

- Electricity purchase from Power and Water Resources Pooling Authority
- Electricity purchase from PG&E
- Biogenic emissions: biodiesel fleet vehicles

Box 3-2

Step 2: Baseline and Project GHG Emissions

Results assessed: direct and indirect emissions of CO_2 equivalent

Compiling Data and Calculating Emissions:

SCWA's electricity manager provides electricity consumption data from electricity bills on an annual basis. GHGs are pre-calculated from electricity use using formulas outlined in TCR's General Reporting Protocol (GRP) and a utility-specific emission factor from SCWA's local utility. This allows SCWA to determine its own power mix and purchase electricity that comes from renewable sources.

SCWA's fleet manager collects fuel consumption data from fuel purchase and mileage records on a monthly basis. GHG totals are calculated using GRP methodologies and EPA mileage estimates for each vehicle type.

SCWA managers track and organize data in an Excel spreadsheet. They also use the built-in calculators in TCR's reporting software to calculate GHG totals from certain data sources.

Verification:

After inputting the data, an accredited third party verifies the inventory.

Results:

Table 1 shows the results from SCWA's 2010 inventory. The largest emissions are from vehicles and from electricity for water and wastewater transmission and treatment.

Generating the verified GHG inventory costs SCWA about $25,000 each year.

Table 1

	Metric Tonnes CO2 Equivalent		
	Direct Emissions	Indirect Emissions	Biogenic Emissions
Water Supply	130.6	2505.92	-
Wastewater Processing	725	1004.1	-
Administrative	270.8	105.8	-
Fleet Vehicles	922.8	-	18
Total	**2049.2**	**3615.82**	**18**

A detailed report of SCWA's 2010 emissions can be obtained from The Climate Registry's web site: https://www.crisreport.org/web/guest.

For More Information

SCWA web site: http://www.scwa.ca.gov/index.php
The Climate Registry web site: http://www.theclimateregistry.org/
SCWA and other TCR annual reports: https://www.crisreport.org/web/guest

Box 3-2 (Continued)

Section 4

Assessing Regional Vulnerability to Climate Change

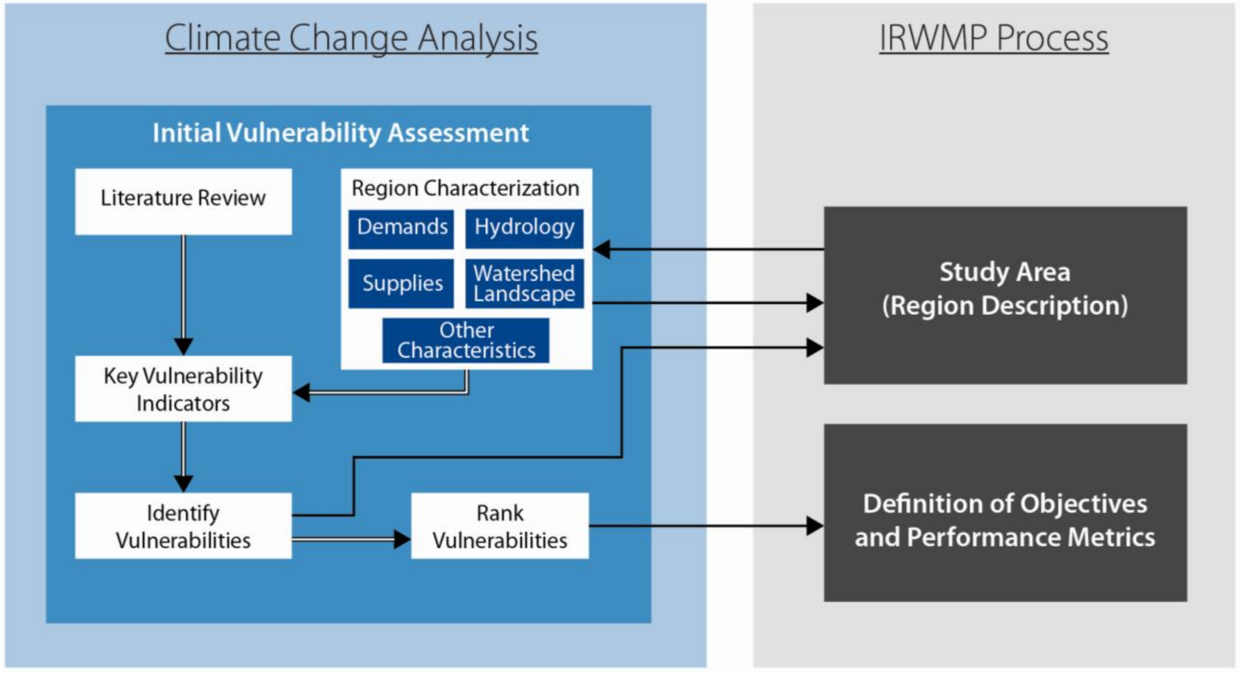


Figure 4-1. Process for Assessing Vulnerability to Climate Change as part of an IRWMP.

Each region will have unique vulnerabilities to climate change, and assessing these vulnerabilities is the first step in considering potential changes in future climate. For the purposes of this handbook, vulnerability is defined as the degree to which a system is exposed to, susceptible to, and able to cope with and adapt to, the adverse effects of climate change. The vulnerability assessment highlights those water-related resources that are important to a region and are sensitive to climate change. These resources may require further analysis and consideration, and may direct some IRWMP objectives. The vulnerability assessment may also identify water-related resources which are relatively resilient to climate change and therefore do not warrant additional analysis.

This section focuses on:

- Finding key literature resources which describe the anticipated climate change impacts throughout the state and within the specific region in question;
- Identifying the specific water-related resources in a region that are sensitive to climate change and could, in turn, impact the region's water resources; and
- Targeting a subset of water-related resources which demand additional consideration when analyzing future conditions.

A preliminary vulnerability assessment requires both scientific information and value judgments about regional priorities and thresholds of acceptable risk. Assessing potential climate change vulnerabilities is much more efficient with regional collaboration (Natural Resources Defense Council (NRDC) 2007). To that end, stakeholder involvement is critical in this part of a larger regional planning process (such as IRWM planning). Vulnerability assessments include:

- **Characterizing a Region:** This step is part of any regional planning framework and involves identifying key water-related resources in the region and related infrastructure (see Section 4.1). For IRWMPs, this climate-related characterization should be incorporated into other information normally included in an IRWM regional description;
- **Identifying Qualitative Water-Related Climate Change Impacts:** Conduct a literature review of anticipated climate change impacts specific to the region and resources identified (see Section 4.2);
- **Identifying Key Indicators of Potential Vulnerability:** Identify simple, "back of the envelope" metrics for qualitatively assessing vulnerability to climate change for key water resources (see Section 4.3; a key indicators' checklist is also provided in Box 4-1, and also in Appendix B); and
- **Prioritizing Vulnerable Water Resources**: Based on qualitative metrics, prioritize the resources that are more likely to be vulnerable to climate change effects and that would have a significant impact on water management in the region (see Section 4.4). Stakeholder involvement is crucial to this step in the process.

> ***Vulnerability*** *is a function of the character, magnitude, and rate of climate variation (the climate hazard) to which a system is* ***exposed****, as well as of non-climatic characteristics of the system, including its* ***sensitivity****, and its coping and* ***adaptive capacity****.*
>
> *--- IPCC 2001*

These steps are illustrated in the decision-support framework in Figure 4-1 and are discussed in detail below.

4.1 Characterizing the Planning Region

Most water planning processes begin with characterizing the water resources encompassed by a planning jurisdiction. This includes coordinating with all stakeholders involved in the planning process to identify the scope of the water resources and other related resources in a geographic region that would be included in a planning process.

In California, a regional description in IRWMPs is required, independently of the new climate change IRWM planning standard. However, the climate change standard requires IRWMP regional descriptions to include information relevant to climate change, indicating areas of potential climate exposure, sensitivity, and ability to cope with or adapt to climate change. Much of this information will already be included in prior IRWMPs prepared for the region, without explicitly addressing the climate change standard. These may include, for example:

> ***Exposure*** *is the degree to which a system is at risk.* ***External exposure*** *relates to a physical climatic threat or hazard.* ***Internal exposure*** *considers specific factors relevant to potentially affected populations.*
>
> *Characterizing a planning region could be considered assessing internal exposure, while identifying anticipated regional climate changes could be considered assessing external exposure.*

- **Watershed(s) setting**, including the general hydrology, geography, and land uses;
- **Water service area(s),** including type of service and use characteristics, such as demand patterns;
- **Wastewater and stormwater service area(s)**, including wastewater flow and water quality characteristics, conveyance, and treatment facilities;
- **Water supply sources,** including reservoirs, watersheds, rivers, wells, imported water, and any associated existing or potential water quality and quantity issues;
- **Water demands,** including composition and seasonality of agricultural, municipal, environmental, and industrial demands;
- **Flooding potential**, including the floodplains of local rivers and coastal areas and recent flooding history. Critical infrastructure located in floodplains including water-related and non water-related structures, such as hospitals, water and wastewater treatment plants, and power facilities;
- **Riparian, aquatic, shallow groundwater-dependent habitat and ecosystem characteristics**, including endangered, threatened, and climate-sensitive species and climate-sensitive habitats such as wetlands, lakes, rivers, and estuaries;
- **Recreational and economic resources***,* including beaches, lakes, and fisheries;
- **Hydropower resources**, including dams, powerhouses, and transmission lines; and
- **Regional water balance,** including watershed yield, use of imported water, and ability to meet environmental, municipal, and agricultural demands.

4.2 Identifying Climate Change Impacts

There have been several studies of climate change impacts on water resources specific to California. All climate change impact analyses have begun with a review of literature relevant to the region and the resources within a region. EPA's Climate Ready Water Utilities (CRWU)'s Climate Ready Adaptive Response Framework also begins the planning process with a focused understanding of anticipated climate impacts in a region (CRU 2010). This initial assessment identifies water resources-related climate change impacts that are relevant to specific local characteristics.

Section 2 discusses climate change impacts on temperature and other climate variables, and it also introduces some of the repercussions that climate will have on water resources. The literature search suggested in this section is intended to identify region and resource-specific climate change impacts, rather than just climate changes themselves. The literature review in Appendix A is intended to be a resource for this task, and the DWR Climate Change Clearinghouse (http://www.water.ca.gov/climatechange/docs/IRWM-ClimateChangeClearinghouse.pdf) was developed to assist IRWM practitioners with understanding and incorporating climate change considerations into their planning process. This document catalogues more than forty recently published documents on climate change and water resources, and provides links to relevant websites. Several key sources used by other California water agencies in conducting a climate change analysis are also highlighted below:

Resources with California-Specific Information

- Using Future Climate Projections to Support Water Resource Decision Making, DWR (2009) http://www.water.ca.gov/pubs/climate/using_future_climate_projections_to_support_water_resources_decision_making_in_california/usingfutureclimateprojtosuppwater_jun09_web.pdf ,
- Westwide Climate Assessment, US Bureau of Reclamation (2011) http://www.usbr.gov/WaterSMART/wcra/index.html, and
- CAT Report (2010) http://www.energy.ca.gov/2010publications/CAT-1000-2010-005/CAT-1000-2010-005.PDF.

Resources Discussing Nationwide or Global Climate Impacts

- Global Climate Change Impacts in the United States, US Global Change Research Program (2009) http://www.globalchange.gov/what-we-do/assessment/previous-assessments/global-climate-change-impacts-in-the-us-2009,
- Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007)

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm, and

- Climate Change and Water, Intergovernmental Panel on Climate Change (2008) http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf .

Sources of Up-to-Date Information and Assessment Tools

- California Climate Change Portal (http://www.climatechange.ca.gov/),
- DWR Climate Change web site (http://www.water.ca.gov/climatechange/),
- Climate Ready Water Utilities web site (http://water.epa.gov/infrastructure/watersecurity/climate/),
- Climate Resilience Evaluation and Awareness Tool (CREAT) (http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm), and
- Climate Ready Estuaries (http://www.epa.gov/climatereadyestuaries/).

DWR has also compiled a summary of some anticipated climate change impacts (http://www.water.ca.gov/climatechange/docs/CC_Vulnerabilities_Chart_w_schematic_on_back_11X17_1-21-11.pdf). Some key climate change impacts anticipated on California's water resources are also listed below. Many impacts in the list are cross-cutting and apply to multiple resource areas, although they are included in only one category in the list.

Water Demand

- Seasonal needs associated with agricultural water use are expected to increase (DWR 2008). Non-irrigated agriculture and rangeland will be especially vulnerable to reduced surface flows and soil moisture (DWR 2008, CNRA 2009).
- Evapotranspiration rates are expected to increase (CNRA 2009), which will increase agricultural water demands.
- A longer growing season will also increase agricultural water demands (CNRA 2009).
- Landscaping and other domestic seasonal use, such as cooling processes, is expected to increase (DWR 2008, CNRA 2009).

Water Supply

- Snowpack quantity is expected to decrease overall as snowlines recede (DWR 2008, CNRA 2009).
- Snowmelt runoff timing is expected to shift as flows increase in the winter and decrease in the late spring/early summer (DWR 2008). This could result in shifted timing of flood-control dam functionality and changes in reservoir storage throughout the year.

- While precipitation projections are less definitive than other climate variables, there is general consensus that precipitation in the Southwestern US will decline over the second half of the 21st Century (CCSP 2009).
- SWP, CVP, and Colorado River supplies are expected to be subject to environmental flow restrictions and other flow limitations (DWR 2008, Chung et al 2009) which may become more difficult to meet as climate changes.
- Coastal aquifers will be subject to seawater intrusion, especially in aquifers with high pumping rates (DWR 2008).
- Droughts are expected to be more severe and potentially more frequent (DWR 2008, CNRA 2009).

Water Quality

- Eutrophication is expected to occur more often in surface waters as water temperatures increase (DWR 2008).
- Longer low-flow conditions may lead to higher contaminant concentrations (CNRA 2009).
- High turbidity is expected to become more of a concern as storm severity increases and wildfires become more frequent (DWR 2008).
- Other water quality issues that typically accompany severe storms (such as spikes in *E. coli* or *cryptosporidium*) are expected to become more frequent (Bates et al 2008).
- Pollutant loads may increase with more intense storms (DWR 2008).
- Increased salinity intrusion into estuaries and brackish environments as seasonal freshwater flows decrease and sea levels rise (DWR 2008, IPCC 2008).

Sea Level Rise

- Coastal erosion is expected to increase in severity in many locations (EPA 2009, Phillip Williams & Associates 2009).
- Coastal structures, especially earthen levees, are placed under additional stress and are more likely to fail as sea level rises (DWR 2008, CNRA 2009).
- Coastal flooding is more likely to inundate coastal infrastructure as base sea levels increase (DWR 2008). Areas within the tidal reach may also be more susceptible to flooding.
- Salinity intrusion may increase in the Delta, impacting SWP/CVP supplies (CNRA 2009).

Flooding

- Delta levee breeches may occur, causing damage and reducing reliability of SWP and CVP supplies (DWR 2008).

- Storms are expected to increase in intensity. The 2009 California Water Plan recommends that no new critical facilities (e.g., fire stations, hospitals, schools, emergency shelters) be built within a 200-year flood plain (DWR 2008, DWR 2009, CNRA 2009).
- Higher volumes of floodwater are anticipated as more precipitation falls as rain (DWR 2008).

Ecosystem and Habitat Vulnerability

- Changes in migration patterns and species distribution are anticipated (EPA 2009a, NAS 2010a).
- Aquatic and terrestrial invasive species may spread in some areas (NAS 2010a).
- Certain habitats, such as estuaries and other coastal habitats, are especially vulnerable to climate change effects (EPA 2009a).
- Certain species, such as Sequoia and Redwood trees and some temperature-sensitive fish species, are especially sensitive to climate change (DWR 2008).
- Water quality issues associated with increased erosion and sedimentation may be detrimental to some benthic and aquatic communities (DWR 2008, EPA 2009a).

Hydropower

- Changing volumes of total snowpack and changing seasonal melting patterns of snow may require changes in reservoir management strategies. Depending on other reservoir release constraints (such as environmental flow release requirements), this could negatively impact hydropower generation (DWR 2008).
- Increasing temperatures will also increase energy demands, especially during peak demand times (DWR 2008).

More detailed descriptions of the mechanism of each impact can be found in the following sources:

- Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water (DWR 2008),
- Adapting California's Water Management to Climate Change (Public Policy Institute of California 2008),
- Synthesis of Adaptation Options for Coastal Areas (EPA 2009a),
- A Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change (EPA 2009b),
- Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment (NWF 2011),

- Ecological Impacts of Climate Change (NAS 2009), and
- California Climate Adaptation Strategy (CNRA, 2010).

An extensive literature summary is presented in Appendix A, synthesized into a summary table that identifies climate change documents specifically linked to IRWM planning standards. This table is intended to provide guidance for IRWM planners and stakeholders to address climate change at key stages within their planning process. IRWM planners can use this literature search table as a tool to quickly access climate change information pertinent to specific planning steps, or the IRWM elements they are working on. The literature summary table is not intended to be a comprehensive survey of the scientific literature regarding climate change, which is vast. Rather, it is a targeted survey which identifies the body of literature which is directly applicable to the IRWMP process. Climate change science is rapidly evolving, and due diligence will require planners to ensure that they use the most pertinent and recent references.

4.3 Identifying Key Indicators of Potential Vulnerability

***Climate Sensitivity** is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.*

At this point in the analysis process, the actual magnitude of impacts or consequences resulting from a potential vulnerability is not required. Framing some qualitative questions can help assess resource sensitivity to climate change and prioritize actual climate change vulnerabilities within a region or watershed area. Measuring those impacts is presented in Section 5. The questions in Box 4-1 provide a checklist for determining areas of potential vulnerability within a region, and this checklist is reproduced in Appendix B. There may be additional questions which may become apparent once a region's specific vulnerabilities are understood. It is important that planners tailor their questions to the impacts relevant to the resources in their region of concern, and the questions that planners ask themselves should identify:

- Currently observable climate change impacts (climate sensitivity),
- The presence of particularly climate sensitive features, such as specific habitats and flood control infrastructure (internal exposure), and
- The resiliency of a region's resources (adaptive capacity).

Affirmative answers to the questions below indicate that the region would likely be affected by the projected impacts of climate change. This information is used to prioritize regional planning objectives, define performance metrics, and focus a more detailed analysis to quantitatively measure impacts as presented in Section 5.

I. Water Demand

☐ *Are there major industries that require cooling/process water in your planning region?*

- As average temperatures increase, cooling water needs may also increase.
- Identify major industrial water users in your region and assess their current and projected needs for cooling and process water.

☐ *Does water use vary by more than 50% seasonally in parts of your region?*

- Seasonal water use, which is primarily outdoor water use, is expected to increase as average temperatures increase and droughts become more frequent.
- Where water use records are available, look at total monthly water uses averaged over the last five years (if available). If maximum and minimum monthly water uses vary by more than 25%, then the answer to this question is "yes".
- Where no water use records exist, is crop irrigation responsible for a significant (say >50%) percentage of water demand in parts of your region?

☐ *Are crops grown in your region climate-sensitive? Would shifts in daily heat patterns, such as how long heat lingers before night-time cooling, be prohibitive for some crops?*

- Fruit and nut crops are climate-sensitive and may require additional water as the climate warms.

☐ *Do groundwater supplies in your region lack resiliency after drought events?*

- Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be particularly vulnerable to droughts and may become more dependent on groundwater pumping.

☐ *Are water use curtailment measures effective in your region?*

- Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be particularly vulnerable to droughts.

☐ *Are some instream flow requirements in your region either currently insufficient to support aquatic life, or occasionally unmet?*

- Changes in snowmelt patterns in the future may make it difficult to balance water demands. Vulnerabilities for ecosystems and municipal/agricultural water needs may be exacerbated by instream flow requirements that are:
    1. not quantified,
    2. not accurate for ecosystem needs under multiple environmental conditions including droughts, and
    3. not met by regional water managers.

II. Water Supply

☐ *Does a portion of the water supply in your region come from snowmelt?*

- Snowmelt is expected to decrease as the climate warms. Water systems supplied by snowmelt are therefore potentially vulnerable to climate change.
- Where watershed planning documents are available, refer to these in identifying parts of your region that rely on surface water for supplies; if your region contains surface water supplies originating in watersheds where snowpack accumulates, the answer to this question is "Yes."
- Where planning documents are not available, identify major rivers in your region with large users. Identify whether the river's headwaters are fed by snowpack.

Box 4-1

☐ *Does part of your region rely on water diverted from the Delta, imported from the Colorado River, or imported from other climate-sensitive systems outside your region?*

- Some imported or transferred water supplies are sources from climate-sensitive watersheds, such as water imported from the Delta and the Colorado River.

☐ *Does part of your region rely on coastal aquifers? Has salt intrusion been a problem in the past?*

- Coastal aquifers are susceptible to salt intrusion as sea levels rise, and many have already observed salt intrusion due to over-extraction, such as the West Coast Basin in southern California.

☐ *Would your region have difficulty in storing carryover supply surpluses from year to year?*

- Droughts are expected to become more severe in the future. Systems that can store more water may be more resilient to droughts.

☐ *Has your region faced a drought in the past during which it failed to meet local water demands?*

- Droughts are expected to become more severe in the future. Systems that have already come close to their supply thresholds may be especially vulnerable to droughts in the future.

☐ *Does your region have invasive species management issues at your facilities, along conveyance structures, or in habitat areas?*

- As invasive species are expected to become more prevalent with climate change, existing invasive species issues may indicate an ecological vulnerability to climate change.

III. Water Quality

☐ *Are increased wildfires a threat in your region? If so, does your region include reservoirs with fire-susceptible vegetation nearby which could pose a water quality concern from increased erosion?*

- Some areas are expected to become more vulnerable to wildfires over time. To identify whether this is the case for parts of your region, the California Public Interest Energy Research (PIER) Program has posted wildfire susceptibility projections as a Google Earth application at: http://cal-adapt.org/fire/. These projections are only the results of a single study and are not intended for analysis, but can aid in qualitatively answering this question. Read the application's disclaimers carefully to be aware of its limitations.

☐ *Does part of your region rely on surface water bodies with current or recurrent water quality issues related to eutrophication, such as low dissolved oxygen or algal blooms? Are there other water quality constituents potentially exacerbated by climate change?*

- Warming temperatures will result in lower dissolved oxygen levels in water bodies, which are exacerbated by algal blooms and in turn enhance eutrophication. Changes in streamflows may alter pollutant concentrations in water bodies.

☐ *Are seasonal low flows decreasing for some waterbodies in your region? If so, are the reduced low flows limiting the waterbodies' assimilative capacity?*

- In the future, low flow conditions are expected to be more extreme and last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

Box 4-1 (Continued)

☐ *Are there beneficial uses designated for some water bodies in your region that cannot always be met due to water quality issues?*

- In the future, low flows are expected decrease, and to last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

☐ *Does part of your region currently observe water quality shifts during rain events that impact treatment facility operation?*

- While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to increased erosion, which will increase turbidity in surface waters. Areas that already observe water quality responses to rainstorm intensity may be especially vulnerable.

IV. Sea Level Rise

☐ *Has coastal erosion already been observed in your region?*

- Coastal erosion is expected to occur over the next century as sea levels rise.

☐ *Are there coastal structures, such as levees or breakwaters, in your region?*

- Coastal structures designed for a specific mean sea level may be impacted by sea level rise.

☐ *Is there significant coastal infrastructure, such as residences, recreation, water and wastewater treatment, tourism, and transportation) at less than six feet above mean sea level in your region?*

- Coastal flooding will become more common, and will impact a greater extent of property, as sea levels rise. Critical infrastructure in the coastal floodplain may be at risk.
- Digital elevation maps should be compared with locations of coastal infrastructure.

☐ *Are there climate-sensitive low-lying coastal habitats in your region?*

- Low-lying coastal habitats that are particularly vulnerable to climate change include estuaries and coastal wetlands that rely on a delicate balance of freshwater and salt water.

☐ *Are there areas in your region that currently flood during extreme high tides or storm surges?*

- Areas that are already experiencing flooding during storm surges and very high tides, are more likely to experience increased flooding as sea levels rise.

☐ *Is there land subsidence in the coastal areas of your region?*

- Land subsidence may compound the impacts of sea level rise.

☐ *Do tidal gauges along the coastal parts of your region show an increase over the past several decades?*

- Local sea level rise may be higher or lower than state, national, or continental projections.
- Planners can find information on local tidal gauges at http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca.

Box 4-1 (Continued)

V. Flooding

☐ *Does critical infrastructure in your region lie within the 200-year floodplain? DWR's best available floodplain maps are available at: http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/best_available_maps/.*

- While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to higher peak flows and more severe floods.
- Refer to FEMA floodplain maps and any recent FEMA, US Army Corps of Engineers, or DWR studies that might help identify specific local vulnerabilities for your region. Other follow-up questions that might help answer this question:
    1. What public safety issues could be affected by increased flooding events or intensity? For example, evacuation routes, emergency personnel access, hospitals, water treatment and wastewater treatment plants, power generation plants and fire stations should be considered.
    2. Could key regional or economic functions be impacted from more frequent and/or intense flooding?

☐ *Does part of your region lie within the Sacramento-San Joaquin Drainage District?*

- The SSJDD contains lands that are susceptible to overflows from the Sacramento and San Joaquin Rivers, and are a key focus of the Central Valley Flood Protection Plan. (http://www.water.ca.gov/cvfmp/program.cfm).

☐ *Does aging critical flood protection infrastructure exist in your region?*

- Levees and other flood protection facilities across the state of California are aging and in need of repair. Due to their overall lowered resiliency, these facilities may be particularly vulnerable to climate change impacts.
- DWR is evaluating more than 300 miles of levees in the San Joaquin and Sacramento Rivers Valleys and the Delta (http://www.water.ca.gov/levees/).

☐ *Have flood control facilities (such as impoundment structures) been insufficient in the past?*

- Reservoirs and other facilities with impoundment capacity may be insufficient for severe storms in the future. Facilities that have been insufficient in the past may be particularly vulnerable.

☐ *Are wildfires a concern in parts of your region?*

- Wildfires alter the landscape and soil conditions, increasing the risk of flooding within the burn and downstream areas. Some areas are expected to become more vulnerable to wildfires over time. To identify whether this is the case for parts of your region, the California Public Interest Energy Research Program (PIER) has posted wildfire susceptibility projections as a Google Earth application at: http://cal-adapt.org/fire/. These projections are the results of only a single study and are not intended for analysis, but can aid in qualitatively answering this question. Read the application's disclaimers carefully to be aware of its limitations.

VI. Ecosystem and Habitat Vulnerability

☐ *Does your region include inland or coastal aquatic habitats vulnerable to erosion and sedimentation issues?*

- Erosion is expected to increase with climate change, and sedimentation is expected to shift. Habitats sensitive to these events may be particularly vulnerable to climate change.

☐ *Does your region include estuarine habitats which rely on seasonal freshwater flow patterns?*

- Seasonal high and low flows, especially those originating from snowmelt, are already shifting in many locations.

Box 4-1 (Continued)

☐ *Do climate-sensitive fauna or flora populations live in your region?*

- Some specific species are more sensitive to climate variations than others.

☐ *Do endangered or threatened species exist in your region? Are changes in species distribution already being observed in parts of your region?*

- Species that are already threatened or endangered may have a lowered capacity to adapt to climate change.

☐ *Does the region rely on aquatic or water-dependent habitats for recreation or other economic activities?*

- Economic values associated with natural habitat can influence prioritization.

☐ *Are there rivers in your region with quantified environmental flow requirements or known water quality/quantity stressors to aquatic life?*

- Constrained water quality and quantity requirements may be difficult to meet in the future.

☐ *Do estuaries, coastal dunes, wetlands, marshes, or exposed beaches exist in your region? If so, are coastal storms possible/frequent in your region?*

- Storm surges are expected to result in greater damage in the future due to sea level rise. This makes fragile coastal ecosystems vulnerable.

☐ *Does your region include one or more of the habitats described in the Endangered Species Coalition's Top 10 habitats vulnerable to climate change (http://www.itsgettinghotoutthere.org/)?*

- These ecosystems are particularly vulnerable to climate change.

☐ *Are there areas of fragmented estuarine, aquatic, or wetland wildlife habitat within your region? Are there movement corridors for species to naturally migrate? Are there infrastructure projects planned that might preclude species movement?*

- These ecosystems are particularly vulnerable to climate change.

VII. Hydropower

☐ *Is hydropower a source of electricity in your region?*

- As seasonal river flows shift, hydropower is expected to become less reliable in the future.

☐ *Are energy needs in your region expected to increase in the future? If so, are there future plans for hydropower generation facilities or conditions for hydropower generation in your region?*

- Energy needs are expected to increase in many locations as the climate warms. This increase in electricity demand may compound decreases in hydropower production, increasing its priority for a region.

Box 4-1 (Continued)

4.4 Prioritizing Vulnerable Water Resources

Once the key indicators of climate vulnerability are identified, vulnerabilities should be ranked to identify how to most effectively allocate resources moving forward in the planning process. Highly ranked vulnerabilities should be analyzed in more detail, and should also be incorporated into regional objectives. Stakeholder involvement is critical in the process of ranking vulnerabilities, as this process prioritizes protection of critical resources (CRU 2010). This ranking is influenced subjectively by several factors:

***Objective**: An overarching statement that reflects the purpose of a plan. Objectives shape project evaluation and selection.*

1. A region's overall planning priorities may factor into ranking of the vulnerabilities. For example:
    a. Regional priorities influence willingness to pay. A region with a large fishing industry may put a high priority on preservation of habitat that supports the industry. Therefore, water supplies or habitat conditions that support the fisheries and are vulnerable to climate change would likely be prioritized for further analysis.
    b. State and regional priorities, such as environmental equity and environmental justice, may also help prioritize potential vulnerabilities. It may be a higher priority for a region to quantify potential water resources impacts that could be felt by disadvantaged communities (DACs) than potential impacts that would have less of an effect on DACs.
2. Risks associated with vulnerabilities. Risk is defined as the probability of an event occurring, multiplied by the consequence of its occurrence.
3. Presence of multiple potential stressors.
    a. Resources that are exposed to multiple climate change impacts may be more vulnerable overall than others, even if the resources have a high adaptive capacity. For example, a region with a significant agricultural water demand and a water supply that comes mostly from snowmelt may prioritize quantifying and securing water supply reliability more highly than a region with only one of these two potential stressors.
    b. Resources that are exposed to *non climate-related* stressors may also have lower overall adaptive capacity. For example, a region where water demands are expected to increase significantly in the future due to a population increase may more highly prioritize water supply reliability.

***Sub-objective**: A statement, directly related to an objective, that further explains the meaning of the objective.*

4. The potential for a vulnerability to shape regional objectives and inform IRWMP decisions. Some vulnerabilities exist that, even after being quantified, will not be useful for decision making. For example, if adaptation options for addressing a climate vulnerability are limited, little may be gained from further analysis or forming a related planning objective.

4.5 Summary

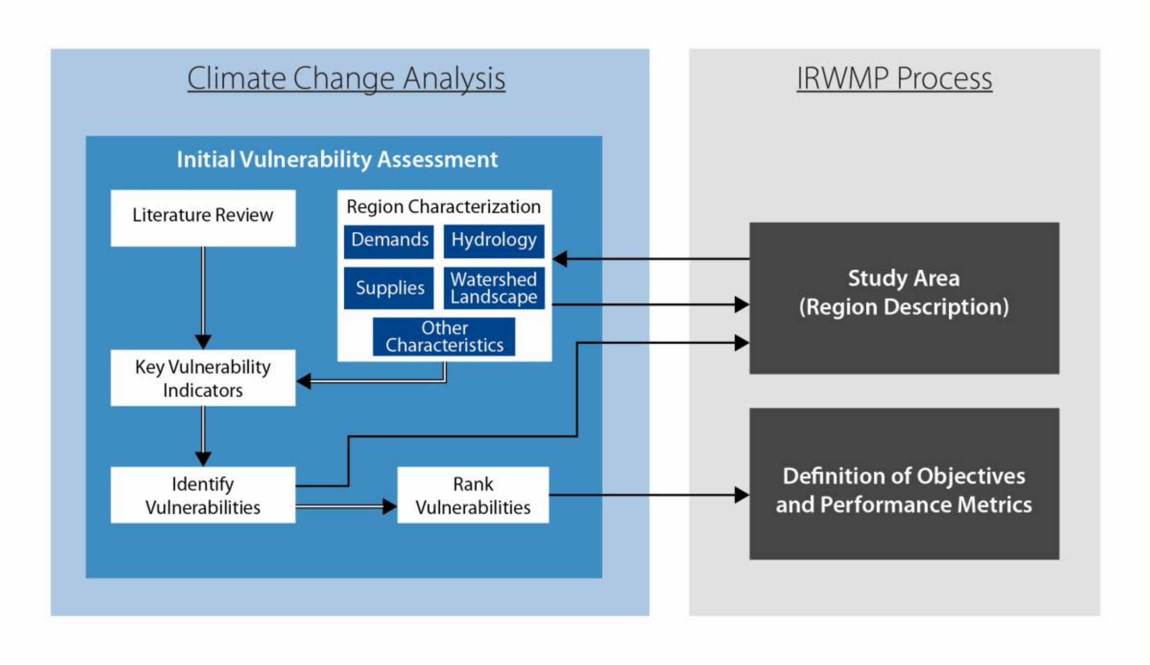
This section provides guidance for finding key references and literature that describe expected and potential impacts of climate change in a planning region. It also guides identification of important water resources and aspects of water resource management that are vulnerable to anticipated climate changes. Using the list of water resources that are specifically vulnerable to climate change and the prioritization factors provided in Section 4.4, the reader should be able to prioritize the identified vulnerabilities. This section also discusses ways to incorporate a vulnerability assessment into an IRWMP.

The prioritization of vulnerable resources feeds back to an updated description of the region in an IRWMP, and also informs the regional objectives and performance metrics for the IRWM planning process. Identification of highly vulnerable water resources, especially those that expose the region to high levels of risk, should lead to the development of objectives (and performance metrics) that result in and measure adaptation to climate change.

***Performance Metric**: quantitative or qualitative criteria, directly related to an objective (or sub-objective), that measures how well the objective is being accomplished.*

Case Study: Vulnerability Assessment

East Bay Municipal Utility District Water Supply Management Plan 2040
Oakland, CA



Background:

East Bay Municipal Utility District (EBMUD) supplies water to 1.4 million customers east of the San Francisco Bay. It serves a largely residential, urban population.

EBMUD's Water Supply Management Program (WSMP) 2040 Plan, developed in 2009, is a 30-year management program updating the 1993 Water Supply Management Program. The plan incorporates climate change mitigation and adaptation into long-term water supply planning.

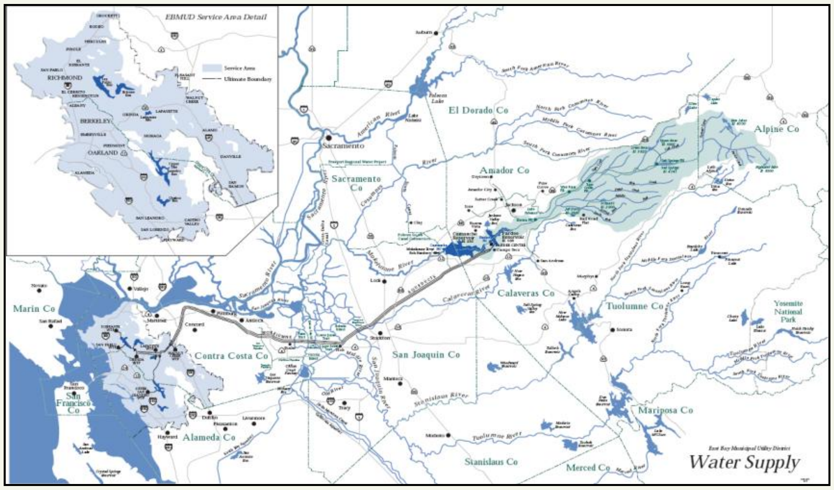


Figure 1: EBMUD Water Supply System (For a high resolution map, please see http://portal.ebmud.com/our-water/water-supply/current-water-supply-outlook/water-system-map)

While the WSMP 2040 incorporates all four steps of the climate change vulnerability analysis process presented in this handbook, this case study focuses on the initial qualitative analysis and research EBMUD did to determine what aspects of their water supply system were vulnerable to climate change, requiring further analysis.

Box 4-2

General approach:

- Assess current state of knowledge on climate change science
- Examine historical record for trends and system resilience in past shortage events
- Use current water supply challenges to infer potential future challenges

Step 1: Data Collection: System Characterization

Sectors Relevant:

- Supply
- Demand
- Sea Level Rise
- Flooding
- Hydropower

General Information

- System infrastructure
    - Reservoirs
    - Hydropower generation
    - Aqueducts
- Transmission lines across the Delta: Mokelumne Aqueducts
- Customer characteristics: mostly residential (UWMP 2005)

Supplies

- 90% from snowmelt in Mokelumne Watershed
- 10% from local watersheds in the Bay Area
- System storage increases tolerance to drought

Demands

- Average demand 2008: 215 mgd
- Large seasonal use
- Primarily residential use
- Population growth in service area is expected to increase demand to 230 mgd by 2030, not including demands offset by conservation and water recycling programs

Water Quality

- High quality source water
- Treatment plants designed for low-turbidity water

Habitat

- Environmental flow requirements downstream of reservoirs:
    - Dissolved oxygen
    - Temperature

Sea Level Rise & Flooding

- 90 mile-long aqueduct across the Delta
- Flood-control releases currently included in reservoir management practices

Hydropower

- Annual power production: 180 GWh (Wallis et al, 2008)
- Power revenue offsets customer costs
- Restrictions on dam releases:
    - Release agreements
    - Requirements to maintain DO/temperature downstream

Step 2: Review Regional Climate Change Effects

Literature Review Included:

- DWR: Progress on Incorporating Climate Change into Management of California's Resources: Technical Memorandum Report
- IPCC Fourth Assessment Report Synthesis Report: Climate Change 2007
- California Climate Change Center: Climate Change in California: An Overview
- California Energy Commission 2006.
- Climate Action Team Report 2007.

Box 4-2 (Continued)

Supplies

- Decreased snow pack
  - DWR: 5˚F increase in temperature could reduce April 1 snowpack by up to 60% in EBMUD's watershed (Wallis et al, 2008, DWR, 2006)
  - Snowmelt earlier in year

Demands

- Increased seasonal uses
- Longer growing season
- Lower soil moisture
- Higher evapo-transpiration
- Warmer nights
- More frequent/severe droughts

Water Quality

- Increased turbidity due to more severe storms
- Algal blooms due to higher temps

Habitat

- Higher water temperatures – some fish are temperature-sensitive

Sea Level Rise & Flooding

- Higher potential for coastal flooding
- Change in timing of peak river flows may alter timing/capacities for flood control dam releases

Hydropower

- Higher peak demand by 4-19% (Wallis et al, 2008)

Step 3: Develop Key Indicators for System

For Each Sector, Look At:

- Combination of literature and region-specific characteristics
- Historical trends for current evidence of climate change
- Historical performance under stress/general Resiliency

Between information on climate change science and knowledge of the EBMUD system, certain pieces of information could be identified as indications that resources might be vulnerable to climate change.

Water Supplies:

- Reliance on snowpack implies likely vulnerability
- Climate change is *already* being observed in EBMUD's water supply:
  - Timing of flows – historically, a high percentage of annual flows in the Mokelumne River have occurred between April and July. Figure 2 shows that in the last 60 years this is changing.

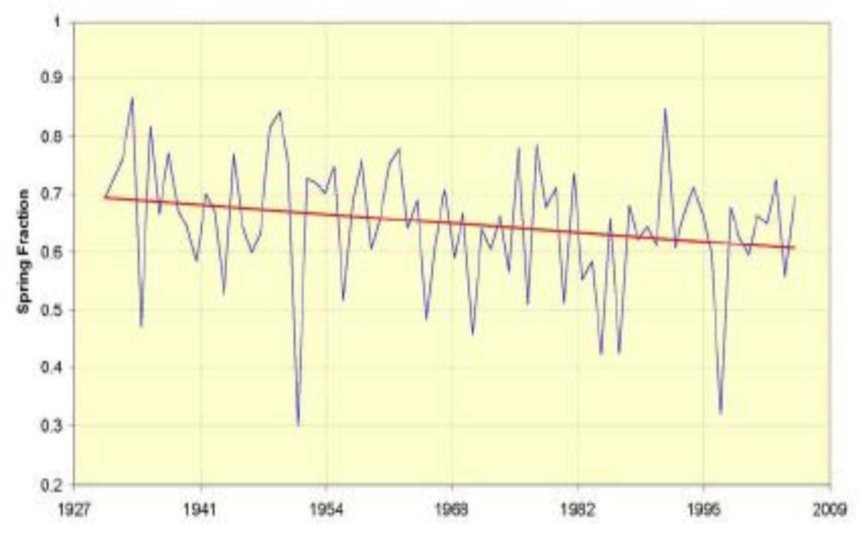


Figure 2: "April-July Flow as Fraction of Water Year – Mokelumne River". Source: Figure 1-2 in EBMUD, 2009a, page 4.

Box 4-2 (Continued)

Water Demand:

- Have had difficulty meeting demands in the past: Drought 1976-77
    - Runoff was 25% of average
    - Total reservoir storage went down to 30% of capacity
- Demands expected to increase through 2030
- Largest land use types have high seasonal component:
    - low-med density residential
    - low density residential

Water Quality:

- Severe storms *already* pose a turbidity problem for EBMUD's treatment system
    - Future storms are expected to become more severe with climate change
- Temperature trends (Figure 3) – maximum and minimum observed temperatures are increasing over long-term trends.
    - Concern for algal blooms

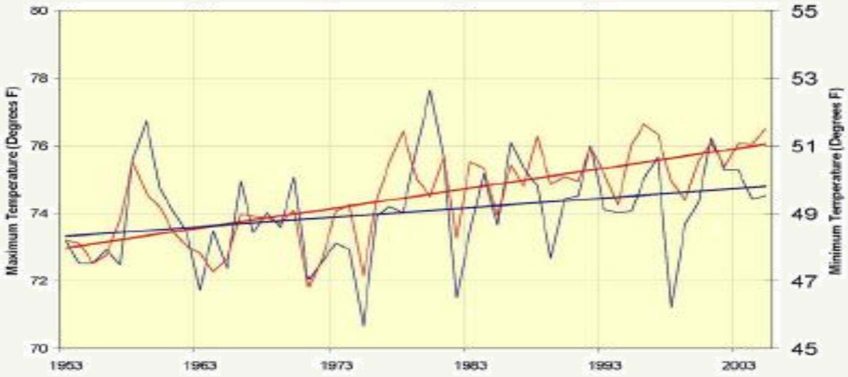


Figure 3: "Camp Pardee Average Annual Temperature". Source: Figure 1-1 in EBMUD, 2009a, page 4.

Sea level Rise:

- A Delta levee breach has submerged the EBMUD aqueducts in the past
    - 2004 levee breach
    - 5 miles of aqueducts all submerged for several months
- Other infrastructure is beyond scope of study

Hydropower:

- Water source for reservoirs is snowpack – timing likely to shift
- Low resiliency/flexibility:
    - environmental flow restrictions dictate dam releases
    - flood control requirements dictate dam releases
- Low generation capacity relative to potential releases resulting in "wasted" releases
- Power demands expected to increase

Box 4-2 (Continued)

Step 4: Identify Vulnerabilities

The key indicators that are present for the EBMUD system help identify areas for further investigation, in some cases leading to an in-depth climate-change impacts analysis.

Sea Level Rise & Flooding – aqueducts vulnerable to Delta levee breach, vulnerable to altered dam release requirements and potential resulting floods

Power Generation – vulnerable to increased customer demands and decreased power production at peak times

Water Quality – vulnerable to algal blooms and increased turbidity

Water Demands – vulnerable to increased summertime demands, longer duration of summertime peak demands and more frequent/severe droughts

Water Supply – vulnerable to decreased snowpack and more frequent/severe droughts

Impacts Analysis:

EBMUD proceeded to conduct a detailed supply and demand analysis. The water supply analysis involved hydrologic modeling, and the demand analysis involved performing a regression analysis correlating water demand to temperature. The model WEAP (Water Evaluation and Planning, SEI 2011), coupled with EBMUD's own model, was used to assess water supply reliability and water quality impacts. More qualitative analyses were conducted for other areas of vulnerability, due to high levels of uncertainty or less severe projected impacts. The results from these studies were used to evaluate project portfolios for improving water supply reliability. The studies are not included in this case study, but the references below provide detailed information on the remaining steps of the EBMUD climate change analysis and planning process.

For More Information

California Climate Change Center. 2006. Scenarios of Climate Change in California: An Overview. http://www.energy.ca.gov/2005publications/CEC-500-2005-186/CEC-500-2005-186-SF.PDF

California Department of Water Resources. 2006. Progress on Incorporating Climate Change into Management of California's Water Resources. http://www.water.ca.gov/climatechange/docs/DWRClimateChangeJuly06.pdf#pagemode=bookmarks&page=1

California Environmental Protection Agency Climate Action Team. 2006. Climate Action Team Report to Governor Schwarzenegger and the Legislature. http://www.climatechange.ca.gov/climate_action_team/reports/2006report/2006-04-03_FINAL_CAT_REPORT.PDF

Dettinger, Michael. 2005. Climate Change and Water Supplies in the West. Presentation for University of California, Santa Barbara, Bren School of Environmental Science and Management. http://www2.bren.ucsb.edu/~keller/energy-water/1-4%20Michael%20Dettinger.pdf

East Bay Municipal Utility District (EBMUD). 2005. East Bay Municipal Utility District Urban Water Management Plan 2005. http://portal.ebmud.com/our-water/water-supply/long-term-planning/urban-water-management-plan

Box 4-2 (Continued)

EBMUD. 2009a. Climate change analysis technical memorandum. In East Bay Municipal Utility District Water Supply Management Program 2040 Plan, Appendix C. http://www.ebmud.com/our-water/water-supply/projects-and-long-term-planning/water-supply-management-program/water-supply-0

EBMUD. 2009b. Water Supply Management Program 2040 Plan. http://www.ebmud.com/our-water/water-supply/projects-and-long-term-planning/water-supply-management-program/water-supply-0

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Wallis, Michael J., Michael R. Ambrose and Clifford C. Chan. 2008. Climate Change: Charting a water course in an uncertain future. Journal AWWA. 100:6. http://www.ebmud.com/sites/default/files/pdfs/Journal-06-08_0.pdf. Reprinted by EBMUD with permission.

Box 4-2 (Continued)

This page intentionally left blank.

Section 5

Measuring Regional Impacts

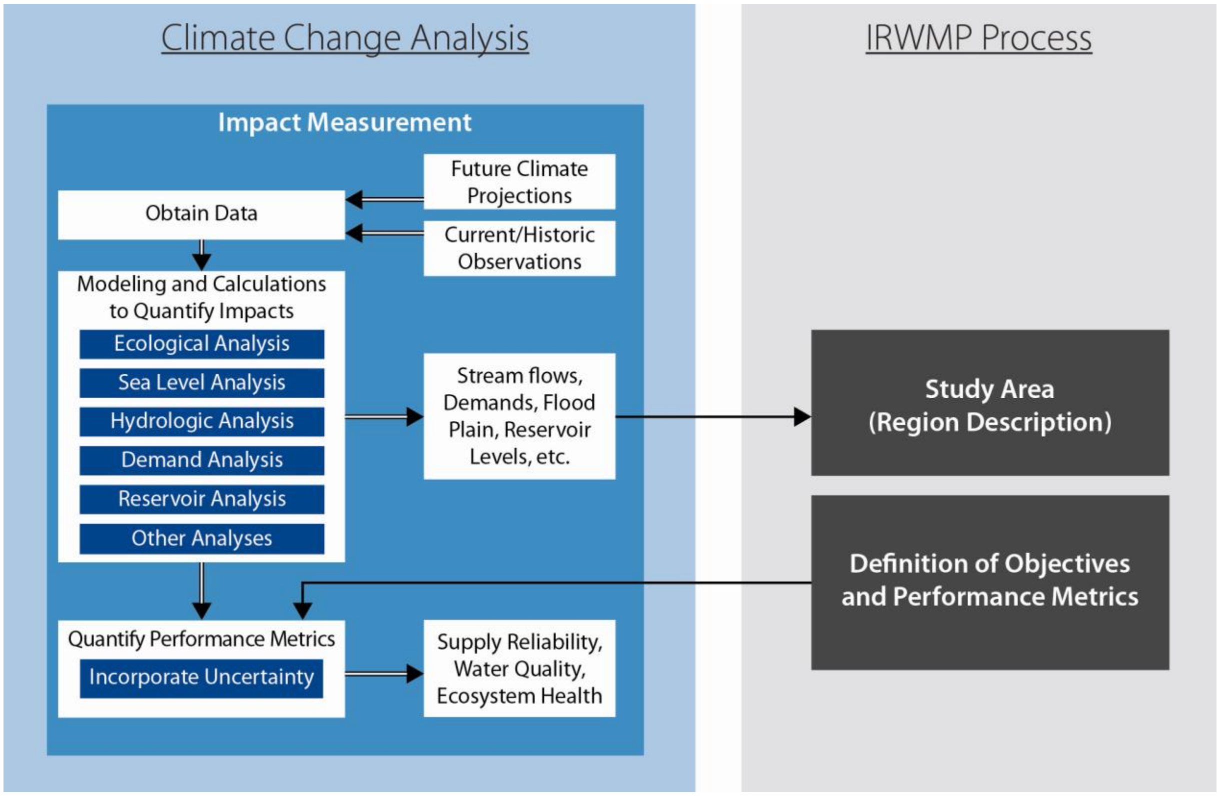


Figure 5-1: Process for Measuring Impacts of Climate Change as part of an IRWMP.

Once a regional planning group has identified and prioritized its key areas of climate change vulnerability, they must determine how to analyze these vulnerabilities and start quantifying the impacts on important resources. The vulnerability assessment discussed in Section 4 provides planners with a way to identify resources with a “warning flag” where they are particularly vulnerable. The analyses discussed in Section 5 are a way of responding to these warning flags. During this step, the climate change analysis becomes fully integrated with traditional planning analyses.

All planning is based on making estimates of future conditions. Planners are familiar with projecting future population or land use trends. Considering climate change involves altering our assumptions about future conditions related to climate. Standard planning exercises have been done in the past assuming that climate conditions in the future will vary in the same way that past climate conditions have varied. This is no longer an appropriate assumption. Incorporating climate change projections into planning analyses increases the uncertainties that need to be taken into account.

This section focuses on:

- Comparing various analytical approaches and determining which approach or approaches will work best for each of the vulnerabilities identified for a region,
- Understanding the data and technical resource requirements associated with various analytical approaches,
- Finding additional references for approaches that look appropriate, and
- Gathering required data and conducting the necessary analysis using the chosen analytical approach.

Several tools are available to assist planners in making assumptions about future climate and using those assumptions to inform analysis of important impacts. This section provides a discussion of the decision-making process required to determine which tools and which analytical approach will work best for a region. Several typical analytical approaches for measuring regional climate change impacts on water resources are presented and discussed. This process is highly specific for each region, and no one-size-fits-all approach can be recommended. Instead, this section lays out the factors that a region should consider when selecting an analytical approach and specific tools. Each region is unique and requires analytical methods that are matched to their specific water resources challenges, local technical and financial capabilities, and priorities of the region. The general elements associated with measuring climate change impacts are depicted in Figure 5-1.

Specific climate change impacts resulting from the analyses discussed in this section can be used to quantify planning performance metrics, help guide planning decisions, and direct development of new projects. For IRWMPs, baseline analyses may feed back into the regional description, as well. The tools discussed in this section are useful in quantifying performance metrics for strategy or project evaluation.

5.1 Overall Approach

This chapter discusses the two main steps in measuring regional climate change impacts:

1) Determining an analytical response and selecting appropriate tools (Section 5.2), and
2) Conducting the analysis (Section 5.3).

Figure 5-2 shows steps to determine the type of impact analysis that is most appropriate and the steps that will be necessary to complete the impact analysis.

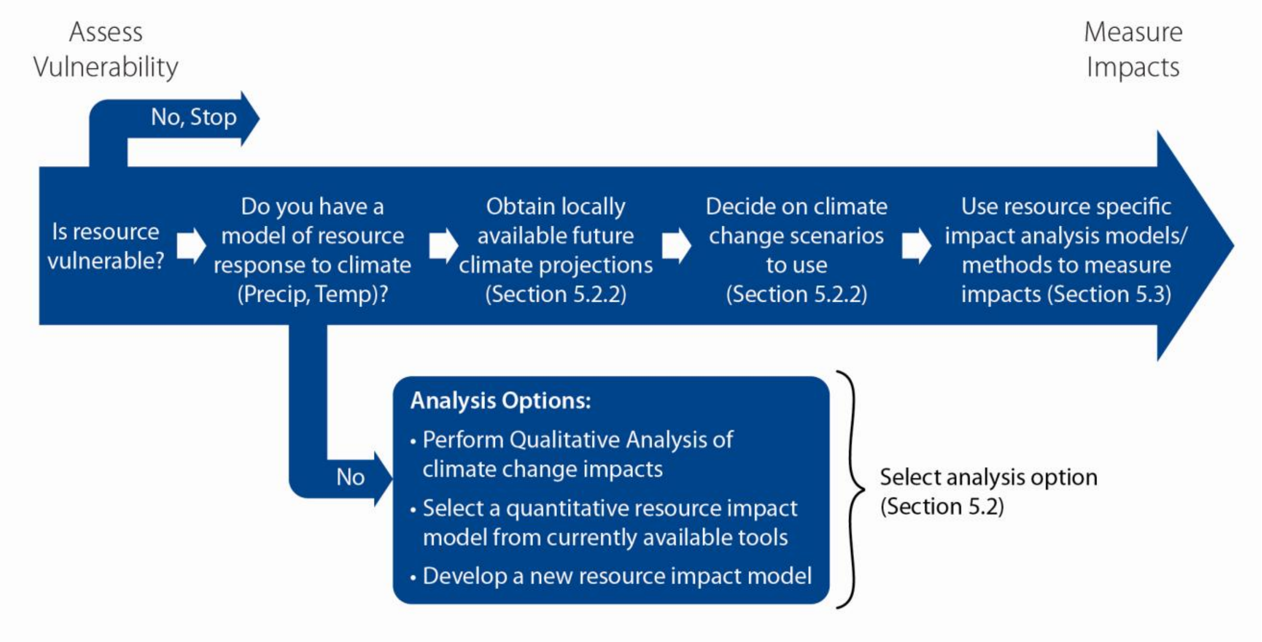


Figure 5-2: Roadmap for Analysis Approach from Assessing Vulnerability to Measuring Impacts

This handbook follows a “bottom-up” approach to climate change analysis, in which local, agency-specific vulnerabilities are prioritized. This approach minimizes conducting costly analyses on water resource sectors that are unlikely to be vulnerable or significant in the region. Therefore, it is imperative that the region complete its Vulnerability Assessment (Section 4) prior to beginning the Measure Regional Impacts step.

5.1.1 Using Existing Studies for Quantitative Analysis

In many regions, studies have already been undertaken to quantify future conditions with climate change taken into account. Whether existing or ongoing studies are being conducted on a local or regional scale, it is prudent to make use of them for an IRWMP or other planning process. Regions that import SWP water are encouraged to make use of DWR’s State Water Project Delivery Reliability Report 2009 Update (DWR 2010b) to project supply reliability in the future.

A region with multiple water supply sources may need to combine supply-reliabilities from multiple analyses. For example, the Metropolitan Water District of Southern California (MWD) 2010 Integrated Resource Plan (IRP) combines delivery projections from the SWP and the Colorado River (MWD 2010). These supply-reliability results are compared with water demand study results (see MWD case study on adaptive management in Section 7). The use of multiple studies may be difficult if each analysis uses different emissions scenarios and GCM results as a basis for identifying future conditions.

5.1.2 Additional Resources for Quantitative Analysis

Appendix D-1 presents several large data repositories that may be useful in climate or hydrologic analysis described later in this section. These sources are only a starting point and planners should tap into regional and local sources as well. Much of the observational hydrologic data needed for the resource impact models can be obtained from the California Data Exchange Center maintained by DWR (http://cdec.water.ca.gov/).

Once an analytical technique has been chosen and calibrated for the specific area and purpose for which it will be used, a climate change scenario needs to be selected for the analysis in order to generate information about the system response to potential future climate conditions.

5.2 Selecting Analytical Methods and Tools

There are a multitude of potential analysis methods that could be used to account for climate impacts on regional water resources and planning projects. This section discusses several potential analysis methods. Appendix D-2 contains information on several analysis tools for the various methods discussed in this section; however, new methods are constantly being developed and planners are encouraged to investigate the most current analysis methods available. There is a wide range in sophistication and accuracy of the various methods available, and determining the appropriate way of considering climate change in the planning process is not always straightforward. This section discusses elements of both qualitative and quantitative analysis methods and provides some guidance on selecting an appropriate analysis method. Ultimately, an appropriate analysis can only be determined on a case-by-case basis.

Uncertainty in Planning

Uncertainty influences every aspect of planning, whether climate change is explicitly included or not. Accounting for uncertainty in planning is an established component of good planning practices and needs to reflect uncertainties associated with future population and economic conditions, as well as future technological advances and social trends. Climate change involves added uncertainties associated with future GHG emissions conditions and the hydroclimatic response to current and future emissions. Section 5.3 describes the sources of climate change-related uncertainty and ways to include it with other uncertainties in planning. Additionally, Appendix C presents information on how to quantify uncertainty in climate change analysis. Uncertainty considerations are part of the definition of an analytical approach for climate change impacts.

5.2.1 Considerations for Selecting Analytical Approaches

In many cases, currently used analytical planning tools can be adjusted to incorporate climate change. For example, most hydrologic models used to evaluate streamflows and reservoir levels may be adjusted to account for future temperatures and precipitation. However, where tools currently used by regional planners cannot be used, planners can select analytical methods based on the regional data available, capabilities of existing technologies, potential use of analysis results in the planning effort, uncertainty considerations, and local technical and financial capabilities.

Considerations that should be taken into account when making this decision include:

- The sector's sensitivity to climate change impacts (e.g., if a small change in temperature could have a large impact on the resource). Information from the vulnerability assessment can be useful in this step.
- The sector's exposure to climate change impacts (e.g., if a very large portion of the region's water supply could be affected by climate change). Information from the vulnerability assessment can be useful in this step.
- The sector's adaptive capacity (e.g., would the region have the ability to adapt quickly and with minimal disruption of services or environmental damage if an extreme change in climate were to occur). Information from the vulnerability assessment can be useful in this step.
- Does the region have existing analytical tools that can incorporate projections of future climate and can be effectively deployed to analyze the potential impacts of climate change?
- Do "off-the-shelf" tools exist to effectively analyze the potential impacts of climate change?
- Does the region possess the technical expertise, or the financial resources to engage the technical expertise, necessary to select or create models or other analytical tools for analyzing the potential impacts of climate change?
- Does the region have appropriate data on current/historical conditions to effectively analyze the potential impacts of climate change?
- How could information generated from analyzing the impacts of climate change be used to quantify performance metrics in project evaluation?

Measuring regional climate change impacts can be a highly analytical process—requiring downscaled climate data from GCMs, along with the use of various water resources models (e.g., water demand, hydrologic, water quality, runoff, and coastal). However, if sophisticated climate projections or models are not available and/or are not appropriate, more qualitative assessment of impacts can be used.

Analysis options vary greatly with respect to complexity and sophistication. The various methods included in this handbook are intended to give a representative overview of the most common options that have been used by others. However, it is not possible to include all methods that have been used, as the literature is constantly evolving. This handbook provides descriptions of several methods, and directs the reader to more comprehensive detailed descriptions of the methods, data required, and type of data resulting from the analysis.

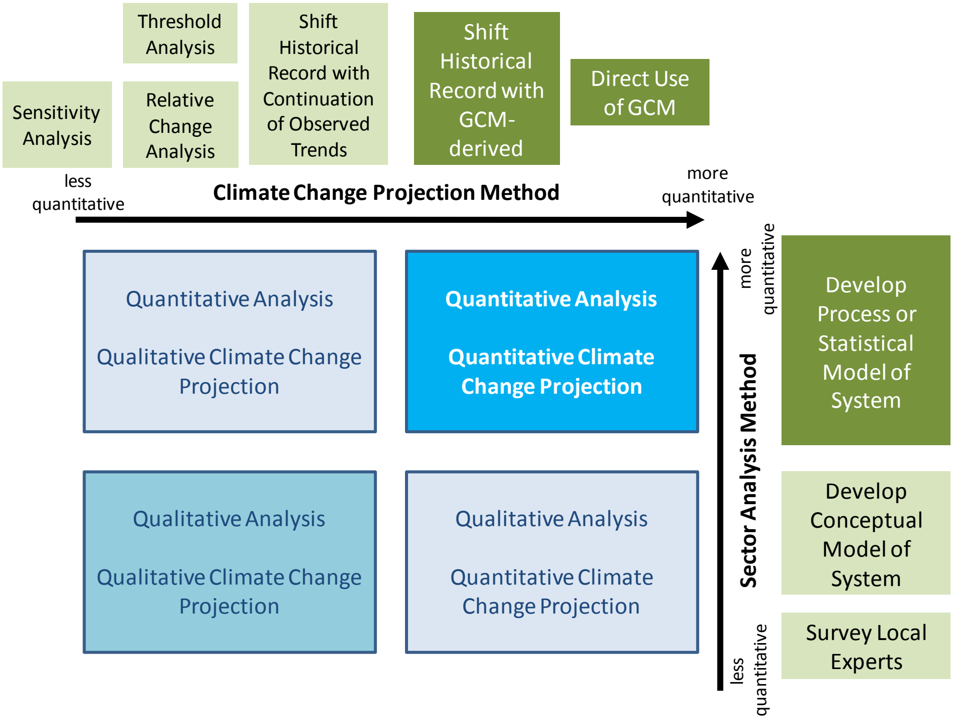


Figure 5-3: Quantitative versus Qualitative Climate Change Analysis.

Planners are encouraged to use analysis methods that are consistent with the region's prioritization of climate change vulnerabilities (see Section 4), and the quality of data and GCM projections available. Figure 5-3 shows various analysis methods (vertical axis) and climate projection applications (horizontal axis) and how quantitative they can be. Each of the sector analysis methods and climate change projection methods shown in the figure are discussed in this section. The sections below are broken up into Quantitative Approach Tools (Section 5.2.2) and Qualitative Approach Tools (Section 5.2.3). This distinction is made between approaches that rely on very specific data or projections, like time series of future daily temperatures, and approaches that rely on more general data or projections, like an assumption such as "droughts will become 20 percent more common or more severe in the future." Many of the tools described below can be combined in various ways to generate hybrid approaches as well. Hybrid approaches are descibed in Section 5.2.4.

For some water resources concerns, such as flooding and other extreme events, GCM projections are not accurate enough to yield high-accuracy analysis results. In these cases, it may be more effective to use qualitative methods. The Water Utility Climate Alliance (WUCA) produced a whitepaper in which they identified the relative appropriateness for applying climate model results to various management decisions. The table is repeated here for reference as Table 5-1.

Table 5.1: Climate model variables and relative reliability for water resources analysis (Source: WUCA 2009)

Water Management Issue	Climate Model Variables	Relative Reliability of Climate Model Output
Water Supply		
Long-term supplies - mean annual basin yield	Annual average temperature and precipitation	- High on temperature - Precipitation depends on geographic scale, higher at sub-continental scale - Regional climate model precipitation projections are more reliable than GCM projections
Long-term demand	Warm-season temperature and precipitation	Same as above
Shift in seasonality of runoff in snowmelt-dominated areas	Monthly temperature	Medium-High
Shift in seasonality of runoff in non-snowmelt-dominated areas	Seasonal precipitation	Medium-Low
Long-term supplies - variability in yield	Monthly temperature and precipitation	Medium-Low
Flooding		
Seasonal floods	Winter and spring precipitation	Medium-Low
Major storms/cyclones	Frontal systems; cyclone information and track	Low
Flash floods	Hourly precipitation in small geographic areas	Very Low
Water Quality		
Biological oxygen demand	Annual, seasonal, monthly air temperature (to estimate water temperature)	Medium-High
Dissolved oxygen	Annual, seasonal, monthly air temperature (to estimate water temperature)	Medium-High
Flow reduction	Annual, seasonal, monthly temperature, precipitation	Medium-High
Saline intrusion of groundwater	Sea level rise; annual temperature and precipitation	Medium-High
Algal bloom	Annual, seasonal, monthly temperature	Medium-Low
Turbidity	Daily, hourly precipitation intensity	Low
Cryptosporidium	Daily, hourly precipitation intensity	Low

5.2.2 Quantitative Approach Tools

5.2.2.1 Quantitative Analysis Methods

For each resource sector, there are many ways to quantitatively represent the relationship between climate variables (e.g., temperature and precipitation) and regional water planning variables of interest (e.g., streamflow, water demand, or ecological response).

Process-based models and regression-based models are two of the most commonly used quantitative tools for assessing the impact of climate variables, such as temperature and precipitation, on resources. Both types of models have been in use in academia and industry for many decades, and have traditionally utilized historic climate data. This handbook makes reference to these models since they can be used in climate change assessment once new values for climatic variables are introduced.

Process-based Models

Process-based models simulate the physical processes that are occurring in the real world. These models use mathematical formulas to approximate the effect that a change in one or more variables to the system will have on the resulting behavior of the system. For example, a process-based model of a watershed would use precipitation and temperature data as inputs. The model would calculate how precipitation makes its way through the watershed, falling as snow or rain, percolating through aquifers, evaporating to the atmosphere, and finally flowing down stream channels and, perhaps, into a reservoir.

This method requires sufficient data to understand the underlying physical processes and represent them mathematically. Observational data to test and calibrate the model is also required. However, once the model is constructed and calibrated it should be able to simulate the system's response over a wide range of climate conditions—assuming the climate conditions don't affect the underlying physical processes.

Regression-based models

Regression relationships and other statistical models are based solely on measured data. This method requires more historical data but less understanding of the underlying physical processes. For example, a regression relationship may correlate precipitation data with streamflow data, so that a statistical relationship can be developed which projects the streamflow response of a given precipitation input.

Care should be taken when using a regression-based model to estimate system response for input levels that vary greatly from the observed data used to generate the regression relationship. For example, a regression relationship of temperature vs. agricultural water demand that is based on agricultural water demand at summer time temperatures between 50 and 90 degrees Fahrenheit may not be reliable when temperatures exceed 100 degrees because of factors that have discontinuous effects on water demand.

Specific information and direction on building and calibrating process-based models and developing regression relationships is beyond the scope of this handbook. Regions should exercise care in selecting a modeling approach and developing the approach to represent their systems, considering:

- *Selecting a model that is designed to represent the processes that are important in the region*. Some models do not accurately represent features that are either atypical or occur at a small spatial scale. For example, the Water Supply Forum case study (Box 5-2) discusses a watershed containing a glacier. The modeled representation of this watershed was developed using a model that had the capability to represent the influence of glacial activity on streamflows.

- *Selecting a model that maximizes information contained in the available data.* Different models make use of different datasets to calculate relationships among variables. For example, if the historic temperature record contains little variability and future projected temperatures are outside of the historic range, a regression analysis may not accurately reflect projected conditions as well as a process-based model could. However, if limited data or understanding is available to develop a process-based model while an extensive historical record of a few variables is available, a regression analysis may be best.

5.2.2.2 Climate Change Projections

This section describes methods for obtaining locally applicable projections of future climate change. This information is required in order to complete a quantitative analysis of future conditions and will be used as an input to drive process-based models, regression relationships, or other analytical tools.

As discussed in Section 2, the most rigorous and readily available source for this information comes from downscaled GCM projections. GCMs generate projections of future climate at very large scales; model grid cells can be hundreds of square miles. Downscaled GCM data can be used with other, more resource-specific models to analyze local impacts. For instance, temperature and precipitation data from a downscaled GCM can be used to drive a rainfall-runoff model to project future streamflow. Alternatively, temperature, precipitation, and humidity data from a downscaled GCM could be used to drive an agricultural water demand model.

The CMIP3 archive of downscaled GCM projections (discussed in Section 2) includes 16 of the 25 models included in the CMIP3, run with three future GHG emissions scenarios (A2, B1, and A1B). The data set contains a total of 112 downscaled climate projections. The downscaled projections use the BCSD downscaling technique to increase the resolution from greater than 1 degree of latitude-longitude for GCM outputs to 1/8th degree of latitude-longitude (approximately 12 km by 12 km). The downscaled outputs cover the time period from 1950 to 2099 at monthly time steps and contain mean daily precipitation and mean monthly surface air temperature values. The data set is available at:
http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#About.

There are other sources of locally applicable climate change data that a region could reasonably select and use for performing climate change analyses. However, regional planners should consider using the CMIP3 archive, as it has been widely adopted in the water resource planning field and has been used to study potential climate change impacts on various resources systems, including watershed hydrology and reservoir systems (DWR 2010c).

Planners need to define a limited number of future climate scenarios to use in successive resource-specific models in order to constrain the amount of modeling and analysis that will be done. This section discusses options for developing climate change scenarios using downscaled GCM data. The recent California Department of Water Resources report on characterizing and analyzing climate change in planning studies (DWR 2010c) outlines two general approaches that have been widely used for selecting climate change scenarios for use in planning studies: selecting discrete projections, and developing ensemble projections. Both methods have strengths and weaknesses, and neither is considered more rigorous than the other.

Selection of Discrete Projections

Selecting a single downscaled GCM projection or a subset of projections from a full set should be based on predetermined selection criteria. These criteria may include how well a given model is able to represent locally important climate processes. For example, in the CAT 2009 study, six GCMs were selected to drive subsequent impact analyses (Cayan et al 2009). These specific GCMs were selected based largely on their ability to simulate historical seasonal precipitation and temperature *patterns*, annual precipitation *variability*, and the El Nino/Southern Oscillation (DWR 2010c). Alternatively, discrete projections might be selected based on a statistical analysis of the available suite of future projections. For example, in their 2010 study of Oklahoma climate change and hydrology, the US Bureau of Reclamation (BOR) selected four discrete GCM projections that "bracket" the changes possible from all considered projections and a fifth that represents the central tendency of those projections (BOR 2010). The four bracketing projections can be viewed as "bookends" of dry and warm, dry and hot, wet and warm, and wet and hot. These discrete scenarios were used in subsequent hydrologic analyses as part of their "Hybrid-Delta" approach (BOR 2010).

Some studies have even selected a single projection from the data set. This may be appropriate for some types of analysis but great caution should be exercised with selecting only a single projection, as it will not provide information about the range of possible impacts from climate change that are more or less extreme than the chosen projection. Selecting a single projection will provide limited information about the range of uncertainty associated with climate change impacts.

The Nature Conservancy's Climate Wizard (http://www.climatewizard.org/#) allows planners and technical experts to view the CMIP3 archive of downscaled GCM results geographically. This tool facilitates visual and quantitative comparisons among emissions scenarios and GCMs, and also facilitates comparison of ensemble projections. SimCLIM (http://www.climsystems.com/simclim/) also allows geographic visualization of GCM projections (downscaled or direct GCM results). SimCLIM interfaces with several impact models and also provides a platform for comparisons between GCM projections and observed data.

Ensemble Scenarios

Developing ensemble projections involves combining multiple climate model projections into a single scenario that reflects model-to-model variability and uncertainty. For example, for the Delta Conservation Plan (BDCP), DWR uses data from 112 individual projections to arrive at five projections that bracket the range of climate projections. For the BDCP study, each of the five projections was formed by aggregating an ensemble of discrete scenarios. The projections used for each ensemble set were identified through a statistical analysis focused on projected average annual changes in precipitation and temperature using a procedure known as “quantile mapping” (DWR 2010c). For these analyses, percentile distributions were then fit to each ensemble dataset to quantify perturbation factors (“delta values”) that were applied to historical data in subsequent hydrologic analyses.

Alternative approaches to generating ensembles also exist. Cox et al (2011) used a selection of six GCMs and two emissions scenarios, for a total of twelve GCM projections. For each model scenario, a “pool” was developed by combining model results within the planning horizon from all of the six GCMs. A projected set of precipitation and temperature conditions for the planning horizon was developed by randomly sampling projections. By using a sampling method of GCM results rather than applying a shift to the historic record, the assumption that the historic record’s variability is representative of hydrologic variability in the future is avoided. However, this method also assumes that the full range of hydrologic variability is represented in the GCM results. DWR (2010c) provides an overview of several downscaled GCM projection processing approaches, additional references for obtaining further information on various approaches, and a summary of the strengths and weaknesses of each approach.

Using Downscaled GCM Outputs When Historical Observational Data is Available

In many areas good historical observational datasets of temperature and precipitation are available. In these cases, planners and modelers may wish to use the historical data to help inform projections of future conditions. Conversely, planners and modelers may also choose to ignore these data so as not want to constrain the climate model outputs. There are two primary methodologies that have been used in previous water resource studies to generate projections of future climate: perturbed historical data and direct use of GCM-generated output.

- Perturbed historical data uses observed historical data that is modified by applying a perturbation factor to the observed value (e.g., precipitation from January 1998 is modified to reflect climate change conditions). The perturbation factor is derived statistically from the downscaled GCM outputs. Perturbation factors can be probabilistic or deterministic. BOR (2010) provides additional information on the “Delta Method” for perturbing historical data. This method guarantees that historical climate variability is maintained in future projections.
- GCM-generated output can also be used directly. This means that the temperature and precipitation outputs from the downscaled GCM are taken as-is and used as inputs to drive other resource-specific impact models.

Both of these methods are considered acceptable ways of characterizing future climate conditions. Each of these methods has strengths and weaknesses. Perturbing historical data preserves the historical variability observed in the historical record. However, this may mask increased climatic variability driven by climate change. Conversely, GCM-generated outputs may project levels of variability in the climate system that have no precedent and may be unrealistic.

5.2.3 Qualitative Analysis Methods

Planners are encouraged to use methods that are as quantitative as possible. However, lack of resources, expertise, or appropriate data to complete a quantitative analysis of climate change impacts does not preclude a region from developing useful climate change analysis information. Several qualitative analysis methods exist that do not require as much time, money, technical expertise, or data.

Surveying local experts, shifting historic records based on qualitative studies and uncertainty buffers, threshold analysis, and sensitivity analysis are four of the most common qualitative approaches and are discussed in greater detail below.

5.2.3.1 Surveying Local Experts

In the absence of reliable data for conducting a quantitative analysis, a survey of local expert opinions on potential and likely climate change impacts can be useful in consolidating available information. As part of the EPA's Climate Ready Estuaries program, the Partnership for the Delaware Estuary conducted a drinking water survey to prioritize potential climate impacts to address (Kreeger et al 2010). The survey also identified data gaps and future research needs. Figure 5-4 depicts the general steps needed for surveying local experts.

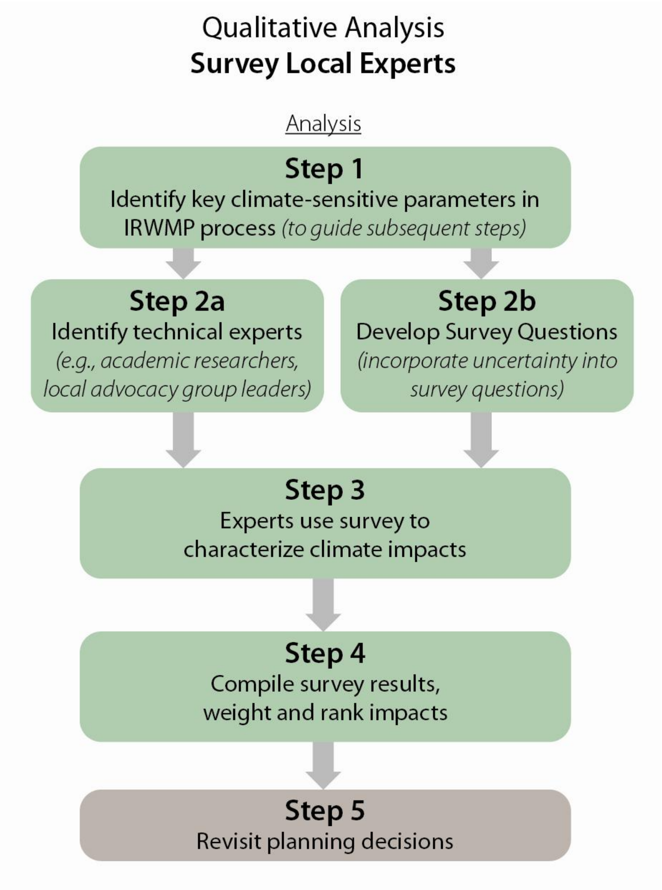


Figure 5-4: Surveying Process Flow-chart

Before conducting the survey, it is necessary to identify a comprehensive list of potential climate change vulnerabilities. Section 4 provides guidance in assembling this list. From the completed list of climate change vulnerabilities, a list of local technical experts can be generated to target the vulnerabilities. The local experts can be from a combination of government and municipal agencies, academia, local consultants, or other relevant entities.

A survey that allows experts to rate their responses, for example, on a scale of 1 to 5, facilitates consolidating survey results into meaningful statistics and scores. Questions included should target both expert opinions and the uncertainties inherent in their opinions. The natural performance metrics to use in this study are the ranked survey results.

5.2.3.2 Other Qualitative Methods

Other qualitative methods for considering climate change impacts exist. Simple conceptual models may help planners to postulate on potential climate change impacts, and simple, "back of the envelope" model representations of resources may also be useful qualitative tools in assessing climate change impacts (Johnson and Weaver 2009).

For water and wastewater resource sectors, the EPA has developed the Climate Ready Water Utilities (CRWU) website with a number of resources, including the Climate Resilience Evaluation and Assessment Tool (CREAT), which allows users to evaluate potential impacts of climate change on their utility and to evaluate adaptive options to address these impacts using both traditional risk assessment and scenario-based decision making. (http://water.epa.gov/infrastructure/watersecurity/climate/.) This suite of tools and resources from the EPA can provide a region with the ability to conduct a qualitative (semi-quantitative) analysis, at least in terms of the water and wastewater sectors.

5.2.4 Combining Qualitative and Quantitative Methods

As shown in Figure 5.3, there is no sharp distinction between qualitative and quantitative methods; regions should select methods that make sense for the questions relevant to the region and the resources (e.g., data, finance) available. Some methods that may make use of sophisticated existing models (e.g., hydrologic/hydraulic models), but account for climate change in a less quantitative way, are described below.

5.2.4.1 Shifting historic record based on qualitative studies and uncertainty buffers

Some climate change studies have adjusted the historical record by quantities loosely based on GCM or other modeling studies, but without rigorously processing GCM or other data. In many cases, a "buffer" is added to the climate change projection, to estimate climate change impacts in a "worst case" scenario. This method, sometimes referred to as "relative change," may be most appropriate for analyses that require data that is unavailable, such as future flood return periods. For example, the 200-year floodplain has become the planning standard for the Central Valley of California. The size of the "buffer" used to represent climate change is based on analysis of the available data, system properties and response characteristics, and ultimately, expert judgment.

Some useful studies that have identified and measured climate change impacts, with results that can serve regions as a starting point for a local climate change analysis, are listed below:

- State Water Project Reliability reports,
- California Water Plan studies,
- Data from the Climate Action Team reports,
- Pacific Institute coastal flood plain maps that incorporate sea level rise, and
- California Ocean Protection Council sea level rise guidance.

There may be other local analyses that a thorough literature and knowledge search may uncover. Regions are encouraged to make use of previous studies where appropriate.

5.2.4.2 Threshold Analysis

For some regions, rigorously incorporating GCM-based climate change projections is not practical. In these cases a more "bottom-up" approach is to identify system vulnerability thresholds and potential climate conditions that could produce the limiting conditions. For example, after identifying the minimum streamflows that a region considers acceptable or desirable, planners can then identify the temperature increase at which a reduced snowpack would result in streamflows below this threshold. Identifying the likelihood of future climate characteristics that create conditions that exceed identified thresholds may be quite difficult. However, it should be possible to make qualitative judgments about the *change* in likelihood of future climate characteristics that might create conditions that exceed identified thresholds. In the above example relating to minimum streamflows, it should be possible to state that the probability of streamflow falling below the critical threshold is more likely as temperatures rise and snowpack feeding the river diminishes. The Central Valley Flood Management Planning Program is using a threshold analysis to incorporate climate change into the planning process, and the program's Draft Climate Change Threshold Analysis Work Plan (DWR 2010d) could potentially serve as a rough template for regions.

5.2.4.3 Sensitivity Analysis

Sensitivity analysis provides insight into the potential magnitude of impacts. It involves perturbing a single input variable to quantify a model's response to that variable. This method requires a quantitative analysis model or other tool for analyzing the impact of climate change. The perturbation of the variable can be done arbitrarily, just to give an idea of what the impacts might be of various variable values (e.g., analyzing the impact of 2, 4, and 6 degrees of temperature increase). The perturbation can also be done more systematically, using other studies or analyses that suggest the magnitude of change in the variable that climate change would be expected to cause. The Cosumnes, American, Bear, and Yuba Watersheds (CABY) IRWMP (Ecosystem Sciences Foundation 2006) discusses a sensitivity analysis where historical temperature was increased by 2 degrees Celsius to account for climate change in a watershed model. No other variables were altered from the historical record.

5.2.5 Uncertainty

This section describes the sources of climate change-related uncertainty and ways to include it with other uncertainties in planning. Additionally, Appendix C presents information on how to quantify uncertainty in climate change analysis.

There are several methods for incorporating uncertainty into the IRWM planning process, including:

- **Probabilistic Method**: This method involves identifying which variables are most uncertain, and defining these variables in terms of probability functions. The performance of a climate change adaptation strategy, or group of strategies, is measured in terms of joint probability functions based on the selected model projections. The result of this analysis is an overall assessment of risk. This method can be applied at different stages of the plan development. It can be applied at the earliest stages to define temperature, precipitation, and sea level rise data (described in Sections 2 and 5); and can also be applied to assess climate change impacts (described in Sections 5 and 6). The method is described in Section 7, "Implementing Under Uncertainty," given that the probabilistic results of the technical analysis are useful for planners and decision makers during plan implementation.

- **Scenario Planning**: This method is widely used and simple to understand. First, several plausible scenarios of potential future conditions are defined. Then, projects within the IRWMP are evaluated under these different scenarios to determine the most robust strategies.
- **Scenario Planning with Probabilistic Variables:** In some cases, variables with probability distributions are evaluated using scenarios. The result is a probable outcome under specific scenarios. The State Water Project (SWP) provides water delivery projections in this way.
- **Qualitative Uncertainty Assessment:** Some qualitative methods do not provide or use enough data or calculations to evaluate uncertainty, in terms of probabilities or specific scenarios. In these cases, it is important to quantify uncertainty to the extent possible and maintain uncertainty information throughout the planning process.

These methods are discussed in detail in Appendix C, and must be incorporated into any analysis involving climate change.

5.3 Conduct Analysis

Analytical methods vary greatly across the range of sector-specific impact analyses. Therefore, this subsection provides several examples of sector-specific impact analyses. It discusses the level of sophistication involved in each method, and the uses and limitations of each method. In addition, several case studies of analyses are included here. Resource sectors included in this section:

- Water Demands,
- Water Supplies,
- Water Quality,
- Ecosystem and Habitat Vulnerability,
- Sea Level Rise,
- Flooding, and
- Hydropower.

5.3.1 Water Demands

Climate change is expected to influence outdoor urban and agricultural water demands. Many agencies, such as Metropolitan Water District of Southern California (MWD 2010), Irvine Ranch Water District (IRWD, Rodrigo and Heiertz 2009), the San Diego Water Department (CDM 2008), and Central Puget Sound Water Supply Forum (WSF 2009), have developed a regression based on historical records to develop a relationship between climate variations and water usage. This relationship is then projected onto projected future climate conditions to develop future water demands under climate change.

5.3.1.1 Urban Demand

Though there are several options for calculating climate change impacts on urban water demands, many urban demand climate change analyses use regression methods (see discussion of regression methods in Section 5.3.1). The general approach of regression analysis involves developing a regression relationship between water demand versus temperature and precipitation. Planners can then use this relationship to evaluate future conditions.

Case studies for water demand impacts using regression analyses are included at the end of this section. They include the Central Puget Sound Water Supply Outlook (WSO) case study (Box 5-1). The WSO case study reference material provides details on the regression equation used. The MWD case study (Box 7-1) presented in Section 7 also discusses a demand regression analysis, with details provided in the reference materials for the case study.

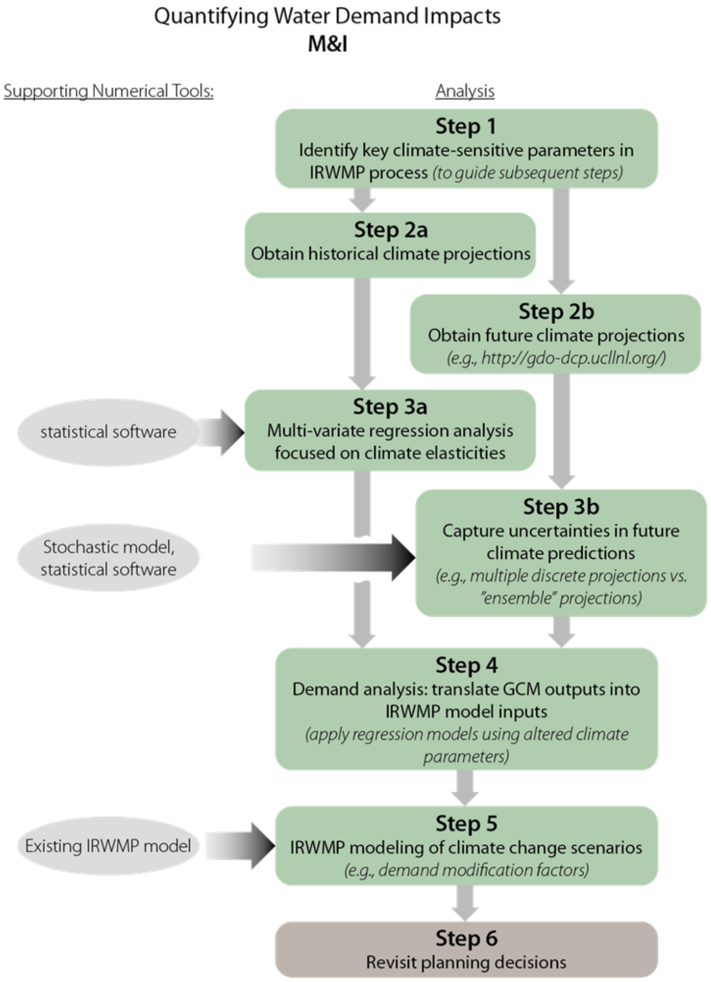


Figure 5-5: Urban Water Demands Process Flow-chart

Data Needed

To develop a regression relationship, it is necessary to obtain both historical data and a projection of future conditions. Historical data needs to span a length of time that can provide a statistically significant relationship among the variables analyzed, and must include all variables that have a significant influence on water demand. While identifying these variables includes step 1 in Figure 5-5, it also includes identifying non-climate change-related variables.

Historical data may include:

- Water deliveries,
- Temperature,
- Precipitation, and
- Population (or a proxy of population, such as number of connections).

To make use of the regression relationship to project future conditions, the relationship needs to be applied to projected future conditions. Future projections need to include the same variables as those included in the regression relationship, and may include population projections, economic projections, and of course, climate variables (see step 2 in Figure 5-5).

Conducting the Analysis

Estimating future water demands using this method requires first fitting historical water use to a regression curve that relates historical water demand to the variables for which data has been obtained (see step 3a in Figure 5-5). Future water production projections can then be calculated using the regression relationship with future climate and population data incorporated into the calculation (see steps 4 and 5 in Figure 5-5).

Incorporating Uncertainty

Primary sources of uncertainty specific to water demand analyses include:

- The inclusion of predictor variables (i.e., demand drivers) in the regression analysis. This process generally entails selecting factors *a priori* that planners deem to be the strongest drivers of demand and might include population, conservation practices, employment data, and climate variables. While multiple variables are included in the analysis, others are excluded and uncertainty therefore exists over whether all significant drivers of demand have been captured.
- Accuracy of the regression relationship established from the historical record, which is typically quantified in the form of a statistical distribution. A perfect regression fit is never achieved, as parameterized by the correlation coefficient (R^2) or similar, and therefore the model projections are uncertain.
- Future projections of the independent variables used in the regression model. How variables like population and economics will change in the future is highly uncertain. When climate change is included in the analysis, climate variables such as temperature and precipitation (see step 3b in Figure 5-5), also need to be projected with highly uncertain projections.

Two options for quantifying uncertainty in urban water demand analyses are probabilistic modeling and scenario planning. Both options are described in detail in Appendix C. Demand regression models are well-suited for use with probabilistic modeling software since the models are easily written into a spreadsheet or similar tool. Climate variables could be represented as probability functions, or simply a range of equally likely values (i.e., uniform discrete distribution), and stochastic sampling could be used to generate a range of potential outcomes. Expert judgment or climate modeling could be used to guide the distribution fitting. A simpler approach, more in line with scenario planning, is to calculate the regression result for a fixed number of discrete climate inputs representing a range of climate change projections. Results could then be presented as a discrete number of scenarios, differing according to their underlying projection assumptions.

Potential Performance Metrics

Potential performance metrics for urban water demand may include deviation from a threshold of demand that could be met with existing or projected water supplies, or may relate to a targeted water conservation goal. Performance metric evaluation takes places in steps 5 and 6 in Figure 5-5.

Case Study: Measure Impacts

Central Puget Sound Water Supply Outlook – Water Demand Analysis

Snohomish, King and Pierce Counties, WA

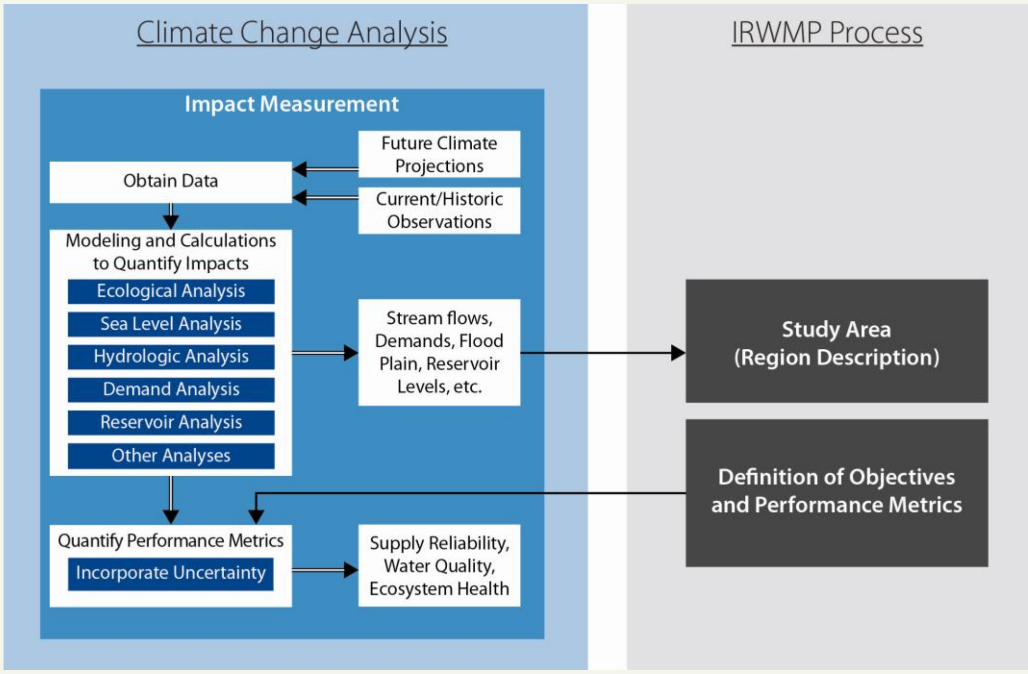


Figure 1: WSF service area. Source: http://www.watersupplyforum.org/home/resource/planning-area-map/.

Background:

The Central Puget Sound Water Supply Forum developed a Regional Water Supply Outlook that projects water demands and supplies within the region, streamflow issues and potential regional projects. Regional water demand projections through the year 2060 were developed in this process, taking climate change effects into account.

Central Puget Sound (CPS) Vulnerabilities:

- Water supply: snowpack, precipitation runoff
- Water quality
- Water demand

Box 5-1

Study region includes 3 counties:

- Snohomish
- King
- Pierce

Study region contains several major water providers, including:

- Seattle Public Utilities (SPU)
- City of Tacoma
- City of Everett
- Lakehaven Utility District
- City of Renton
- City of Kent Public Works Department
- Lakewood Water District
- Auburn Water Utility

Step 1: Obtain Locally Applicable Data

Data Obtained:

- GCM Downscaled Data
- Reported Consumption- Water Provider Survey
- Demographic Data and Projections
- Historical Meteorological Observation Data

---

1. GCM Data

- Select GC/emissions scenario couples (6 emissions scenarios, over 20 models)
- GISS_B1: "warm"
- ECHAM5_A2: "warmer", and
- IPSL_A2: "warmest"
- Reasons for choosing these scenarios:
- GCMs: good replication of Temperature and Precipitation for Pacific Northwest (Mote, 2005)
- Emissions scenarios: range of high (A2) and low (B1) emissions levels included

2. Historical Data

- Included: water use records, demographics, weather
- Data Processing
- Developed *base water use factors* – for SPU, included data from 100+ providers
- Developed *climate change-free* future water use projections based on 1) population trends and base water use factors, and 2) historical weather
- Historical Monthly Water Use Data QA/QC – identify trends from:
- Economic recessions/booms - long-term trends in annual water use minimum levels were determined
- Mandatory water use curtailments (the effects curtailments have on water use are demonstrated by portion of water production that is circled in red in Figure 2)

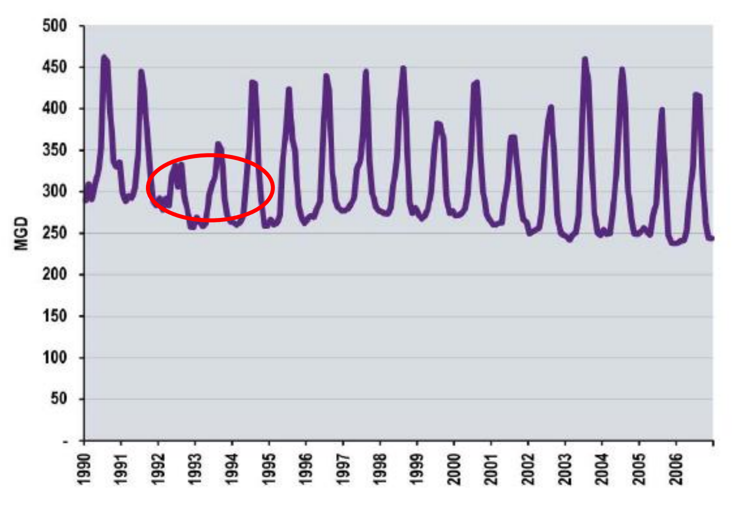


Figure 2: System-wide historical water production record. Source: WSPF, 2009.

Box 5-1 (Continued)

Step 2: Assessment and Analysis

Future Demand Analysis

1. Identify Seasonal Demands

Water demands for the study area were separated into two categories:

- Non-seasonal demands that are relatively constant over the year, and
- Seasonal demands that fluctuate over the course of the year.

Seasonal water demands are more likely to be impacted by climate change, because they already exhibit sensitivity to annual seasonal weather

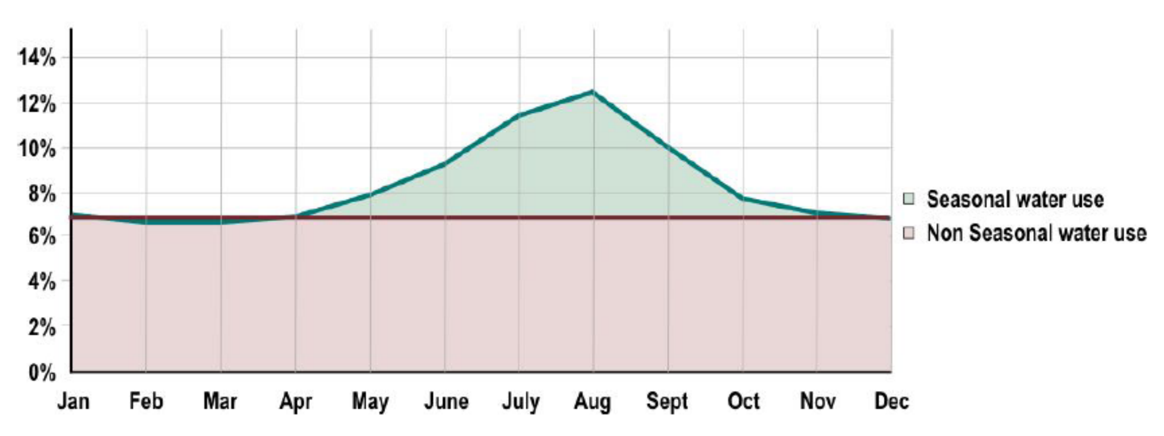


Figure 3: System-wide historical water production record. (Source: WSF, 2009.)

2. Estimate Historical Dependence on Weather: Regression Analysis (Statistical Model)

Model Inputs (all Historical Data):

- Monthly *seasonal* water production (system-wide)
- Monthly average maximum daily temperature
- Monthly total precipitation
- Annual regional employment (for long-term trends)

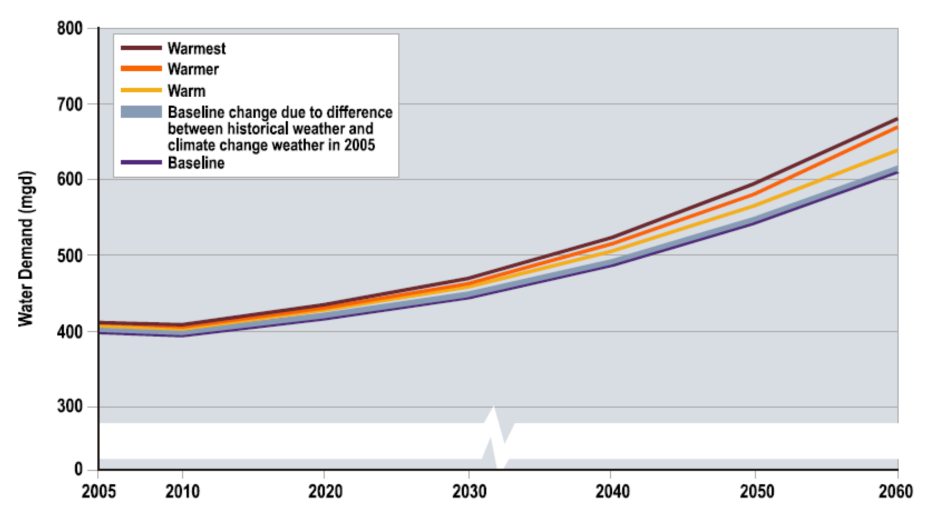


Figure 4: Water use projections using climate variables from various emissions scenarios. (Source: WSF, 2009.)

Box 5-1 (Continued)

Model Output:

- Relationship between weather variables and water use, calibrated to historical data

3. Calculate *Future* Demand: adjust future water demand projections

Inputs:

- Regression relationship from (2)
- Baseline future projection of system-wide monthly water production (from Step 1)
- Monthly average of maximum daily temperature (from GCM downscaled data)
- Monthly total precipitation (from GCM downscaled data)

Output:

- Adjusted seasonal monthly demands system-wide for future scenarios
- Seasonal monthly demands adjusted for climate change can be added to non-seasonal demands to estimate **total future demand with climate change**

Step 3: Performance Metrics

Metric Used: Current Water Demand

---

1. Demands projected to increase *due to climate change* by 5-12% between 2005 and 2060

2. Other *non-climate*-related changes could be due to:

- Variability in population projections
- Changes in economic demographics
- Changes in water conservation practices
- Mandatory Curtailments

Influence on Regional Water Management: Potential Management Strategies Being Considered to Increase Redundancy:

- Seasonal Reservoir Operation/Operational Protocol Changes
- Additional Supply Projects

For More Information

Climate Change Technical Committee. 2007. Final Report of the Climate Change Technical Committee. http://www.govlink.org/regional-water-planning/tech-committees/climate-change/index.htm

Mote, Philip, Eric Salathé, and Cynthia Peacock. 2005. Scenarios of Future Climate for the Pacific Northwest. Climate Impacts Group, University of Washington. http://cses.washington.edu/db/pdf/kc05scenarios462.pdf

Seattle Public Utilities. 2007. Seattle Public Utilities Water System Plan. http://www.cityofseattle.net/util/About_SPU/Water_System/Plans/2007WaterSystemPlan/SPU01_002126.asp

University of Washington Climate Impacts Group. (n.d.). http://cses.washington.edu/cig/

Water Supply Forum. 2009. Water Supply Forum 2009 Water Supply Outlook. http://www.watersupplyforum.org/outlook

Box 5-1 (Continued)

5.3.1.2 Agricultural Demand

Crop irrigation needs are a function of precipitation, crop type, crop-specific evapotranspiration (ETc), and the growing season length. As the earth's climate changes, all of these factors are changing. However, simultaneously, other changes are taking place. Trends in total irrigated acres of farmland are decreasing, or are projected to decrease in the future in many places in California. Cropping patterns are also likely to shift as the climate changes. At the same time, agricultural water use efficiency is increasing. Two studies have been done at the state-level involving agricultural water demand estimates:

1. California Water Plan Update 2009
2. SWP/CVP Impacts Report 2009

In both the California Water Plan (CWP) 2009 Update (DWR 2009) and the SWP/CVP Impacts Report (Chung et al 2009), a hydrologic model is used to calculate water demand per acre of irrigated land, for each crop type of interest. Once calibrated to historical data, the model can be used to calculate water demand under future hydrologic conditions for a particular crop type. Crop demand per acre of irrigated land is not modified to account for climate change impacts on evapotranspiration (ET) in these studies.

Beyond calculating irrigation demand as it correlates to irrigated area and accounting for climate projections of precipitation, there are several methods for calculating changes in ET from climate variables. DWR has developed the Simulation of Evapotranspiration of Applied Water (SIMETAW) tool and the Consumptive Use Program (CUP+) to help estimate crop and applied water evapotranspiration. CUP+ is an Excel-based application, and SIMETAW is an executable model. Both models use the Penman-Monteith method (described in detail at http://www.fao.org/docrep/X0490E/X0490E00.htm) for calculating reference ET (ETo), from which crop-specific ETc can be calculated. Other potential approaches include directly using the Blaney-Criddle or Penman Monteith equations to estimate ETo as a function of climate variables. It may also be possible to develop a regression relationship based on historical ETo data relating location-specific historical ETo with location-specific historical temperature. Determining which method to use is a component of step 1 in Figure 5-6, which depicts steps for conducting an agricultural water demand analysis.

Evapotranspiration equation

The Blaney-Criddle equation is a very simplified method for calculating ETo based on temperature and season. The Food and Agriculture Organization of the United Nations (FAO) has a manual available for using the Blaney-Criddle equation (http://www.fao.org/docrep/S2022E/S2022E00.htm). Coefficients for several crops are provided in the FAO Blaney-Criddle Manual "Irrigation Water Management: Irrigation Water Needs".

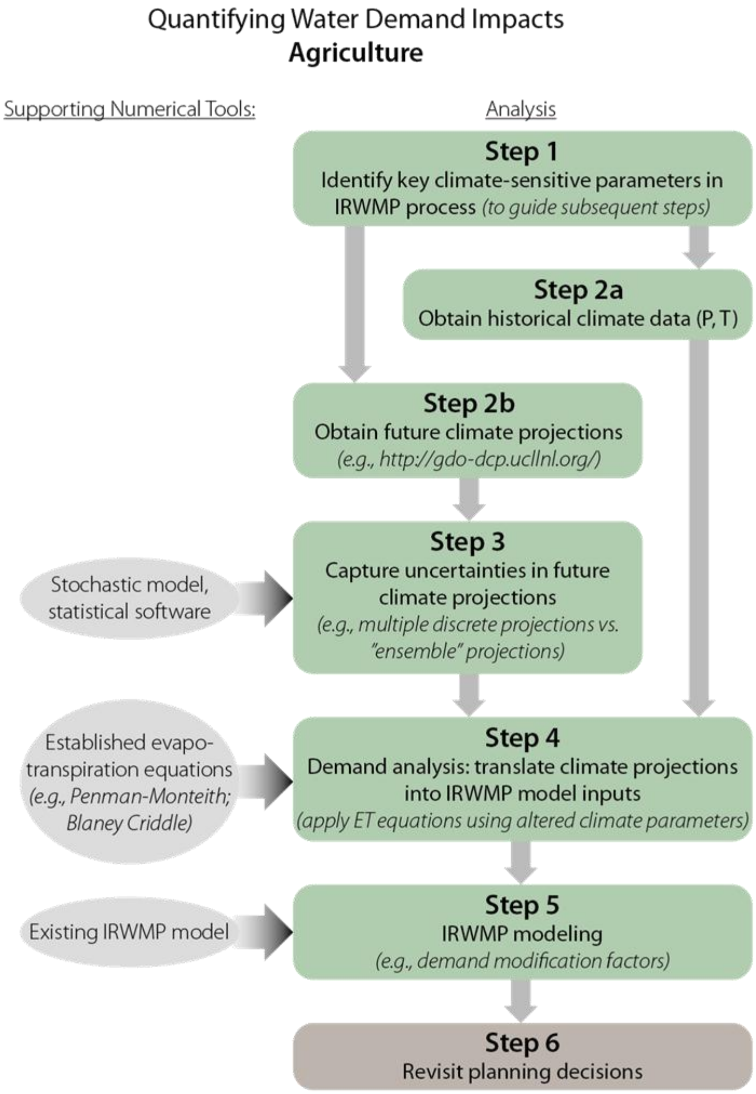


Figure 5-6: Agricultural Demand Climate Change Analysis Process Flow Chart.

Data Needed

The data required for using the Blaney-Criddle equation to estimate water needs under climate change conditions (steps 2a and 2b in Figure 5-6) include:

- Irrigated area estimate,
- Crop types and their ET coefficients (for converting ETo to Etc), Precipitation projections, and
- Temperature projections.

Conducting the Analysis

Estimating crop water needs involves:

1. Calculating ETc for each crop (step 4 in Figure 5-6),
2. Including precipitation in the estimate of water needs (step 4 in Figure 5-6), and
3. Extrapolating water needs to the irrigated areas (step 5 in Figure 5-6).

Incorporating Uncertainty

Primary sources of uncertainty specific to agricultural water demand analyses include:

- Simplifications and assumptions inherent in the method of calculating both ET (e.g., Blaney-Criddle) and water demand; and
- Future projections of the independent variables used in the ET model, including crop varieties, irrigated land estimates, and climate variables (step 3 in Figure 5-6).

Two options for quantifying uncertainty in agricultural demand analyses are probabilistic modeling and scenario planning. Both options are described in detail in Appendix C. Simple empirical models, like the Blaney-Criddle equation, are well suited for use with probabilistic modeling software since the models are easily written into a spreadsheet or similar tool. Climate variables could be represented as probability functions, or simply as a range of equally likely values (i.e., uniform discrete distribution), and stochastic sampling could be used to generate a range of potential outcomes. Expert judgment or climate modeling could be used to guide the distribution fitting. A simpler approach, more in line with scenario planning, might be to calculate the regression result for a fixed number of discrete climate inputs representing a range of climate change projections. Results could then be presented as a discrete number of scenarios, differing according to their underlying projection assumptions.

Potential Performance Metrics

Potential performance metrics for the evapotranspiration equations may include deviation from a threshold of demand that could be met with existing or projected water supplies, or may relate to a targeted water conservation goal. Performance metric evaluation takes places in steps 5 and 6 in Figure 5-6.

Models such as SIMETAW and CUP+

Both SIMETAW and CUP+ can be used to impose different climate scenarios on crop ETc rates. The CUP and SIMETAW models are both available at http://www.water.ca.gov/landwateruse/models.cfm. SIMETAW is also discussed in DWR (2006), and also in Volume 4 of the CWP Update 2009 (DWR 2009).

DWR is also developing a new model: Cal-SIMETAW. The main difference between the SIMETAW and Cal-SIMETAW application programs is that SIMETAW is used to determine the daily water balance of individual fields of crops within a region, whereas Cal-SIMETAW is designed to use batch files of input data to compute daily water balance for up to 24 crop categories over the period of record. Cal-SIMETAW is scheduled for release in late 2011.

Data Needed

Obtaining data is included in step 2 in Figure 5-6. SIMETAW and CUP+ both require more data than the Blaney-Criddle method, and both are more accurate where sufficient data is available. Required data includes:

- Monthly total precipitation,
- Daily mean wind speed by month,
- Daily mean solar radiation by month,
- Maximum and minimum daily mean temperatures by month,
- Daily mean dew point temperature by month,
- Rainy days per month,
- Canopy resistance,
- Crop and soil information, and
- Water contributions from seepage of ground water data.

It may be difficult to obtain observed and/or projected estimates for this data. The data sources listed in Appendix D-1 are useful resources. For other parameters, best professional judgment and/or sensitivity analysis may be needed to determine appropriate values and uncertainty brackets.

Conducting the analysis

Both SIMETAW and CUP+ involve assembling data, entering the data into a program, and collecting results (step 4 in Figure 5-6). CUP+ provides water requirements for crops by month, season, or year (Orang et al 2008). CUP+ is Excel-based and includes plotting and multi-scenario comparison capabilities. Water needs can be extracted to irrigated areas in a region (step 5 in Figure 5-6).

Incorporating Uncertainty

Using SIMETAW or CUP+ to estimate agricultural water demand involves estimating future changes in ET, and incorporating this into a water demand calculation for irrigated areas. Uncertainties associated with this method result from the following factors:

- Simplifications and assumptions inherent in the method of calculating both ET and water demand, and
- Projections of future conditions, including crop varieties, irrigated land estimates, and climate variables (step 3 in Figure 5-6).

Because CUP+ incorporates scenario comparison into its framework, this tool facilitates a scenario approach to accounting for uncertainties (see Appendix C).

Potential Performance Metrics

Potential performance metrics for agricultural water demand using CIMETAW or CUP+ may include deviation from a threshold of demand that could be met with existing or projected water supplies, or may relate to a targeted water conservation goal. Performance metric evaluation takes places in steps 5 and 6 in Figure 5-6.

5.3.2 Water Supplies

This section discusses projecting climate change impacts on:

1. Water supply sources within the region for municipal and industrial (M&I) or agricultural use,
2. Water imported into the region, and
3. Streamflow supplies for environmental needs.

For locally-sourced water and instream flows, regions are encouraged to build off of existing tools that are already being applied to study the region's water resources, where possible. Regions that import water are encouraged to rely on studies that have been conducted by the water purveyor, such as the SWP Delivery Reliability Report (DWR 2010b).

5.3.2.1 Rainfall Runoff Modeling

Watershed yields impact all water uses, including environmental instream flow needs, agricultural uses, and M&I demands. Increased temperatures and shifts in precipitation patterns could alter watershed-based water supplies in the future: snowpack is decreasing in the Sierras, seasonal snowmelt timing is shifting, and precipitation changes could also alter a watershed's rainfall capture. For surface water supplies and instream flows that are vulnerable to reduced snow pack and/or changes in precipitation patterns, regions may consider rainfall runoff and/or water system modeling. Rainfall runoff modeling uses watershed characteristics and environmental data to estimate streamflows.

The CABY 2006 IRWMP discusses rainfall runoff modeling that takes climate change into account (Ecosystem Sciences Foundation 2006). The CABY analysis uses the Water Evaluation and Planning (WEAP) model, as does the state-level water supply analysis conducted as part of the CWP 2009 Update (DWR 2009). The Puget Sound case study (Box 5-2) included a watershed modeling analysis using the Distributed Hydrology Soil Vegetation Model (DHSVM). Several hydrologic modeling studies are also discussed in BOR (2011b).

Future streamflows can also be projected using regression relationships developed between historical precipitation and streamflow data (Cox et al 2009, Stewart et al 2003, Nawaz and Adeloye 1999). The regression relationship can be used to relate GCM downscaled precipitation data to a projected corresponding streamflow. The regression method can be combined with a mechanistic model, like WEAP, for streamflow projections in a snowpack-driven watershed (Cox et al 2011). The steps for conducting a water-supply analysis are depicted in Figure 5-7.

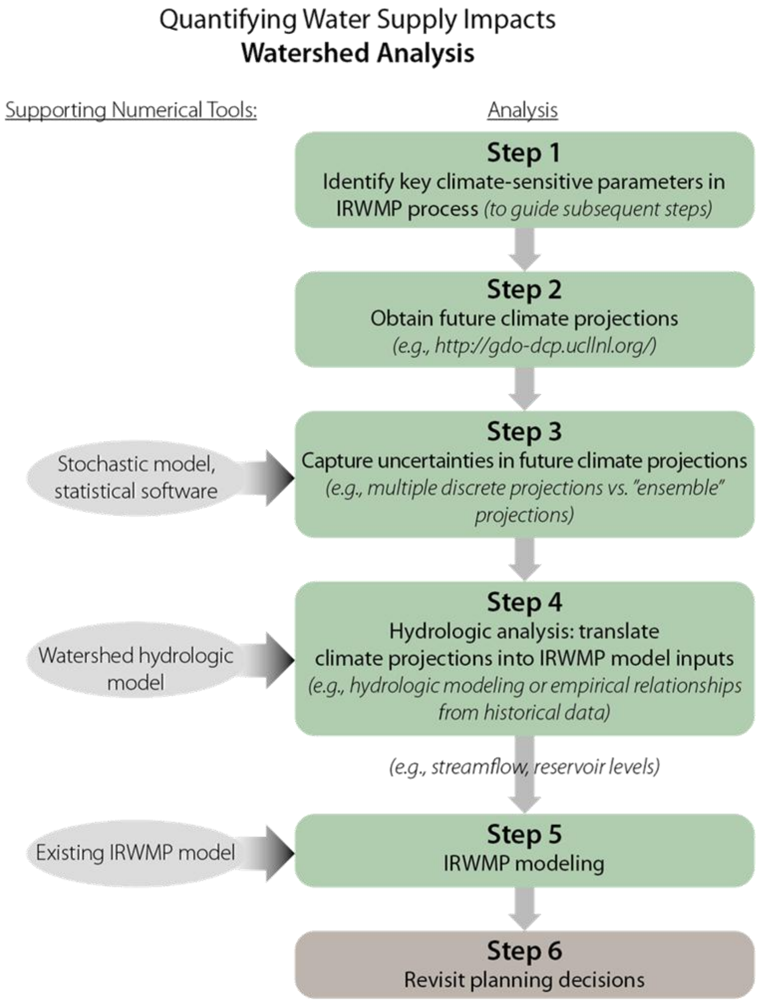


Figure 5-7: Watershed-based water supply climate change analysis process flow chart.

Data Needed

Data describing the watershed, such as topography and soil characteristics, must be included in the hydrologic model. Data describing the existing watershed may include:

- Soil characteristics,
- Vegetation type,
- Topography,
- Land area, and
- Land use / land cover.

Watershed models also include parameters and approximations that need to be calibrated against historical data before future projections can be made. Historical data required may include:

- Temperature,
- Wind records,
- Precipitation, and
- Historical streamflows.

Data representing future conditions can be specific or general, as discussed in Section 5.3. WSF obtained downscaled data from a global climate model (see case study, Box 5-2). As a sensitivity analysis, the CABY IRWMP used a 2 degree Celsius change in temperature only to estimate potential climate change impacts. This temperature change was determined consistent with the warming trends projected by most climate models (Ecosystem Sciences Foundation 2006). Obtaining and processing future climate projections corresponds to steps 2-4 in Figure 5-7.

The projected future variables may include:

- Temperature,
- Precipitation, and
- Land use.

Conducting the Analysis

The process of developing and applying a runoff model to future conditions corresponds to step 5 in Figure 5-7. As with many resource analyses discussed in Section 5, there are several possible methods for incorporating climate change into watershed models. If sufficient hydrologic variability is represented by the model simulation, this technique can provide enough data to develop a probability distribution that reflects natural variability. If using the Delta Method (see Section 5.2.2.2), the variability reflected is the variability captured in the historical record. If unperturbed GCM results are used, variability in runoff model results reflects GCM variability. The Delta Method does not reflect changes in frequency or severity of rare or extreme conditions due to climate change.

Many rainfall runoff models provide streamflow estimates, but not water supply estimates. Because water supply availability is a more useful metric than streamflow, it is therefore useful to couple watershed modeling with some type of water system modeling or water supply analysis tools (e.g., models that include aquifers, reservoirs) where watershed or rainfall runoff models do not provide water system modeling capabilities. The Puget Sound case study (Box 5-2) included water system modeling that translated streamflows into reservoir levels, taking dam operation rules into account. The WEAP model used by CABY and the CWP Update 2009 also include these capabilities.

Incorporating Uncertainty

Uncertainties associated with runoff models result from the following factors:

- Our limited understanding of how the physical system responds to climate and other variables (i.e., gaps in the science of the hydroclimate system).
- Numerical accuracy of the rainfall runoff model. This uncertainty is associated with limitations of the underlying mathematical equations and the way the model solves these equations. There is also uncertainty associated with the assumption that the historical calibration dataset is comprehensive enough to provide a representative calibration for use in projecting the future.
- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and often viewed as effectively "random" for planning purposes.
- Projections of future conditions, including future land use, irrigated land estimates, and climate variables (step 3 in Figure 5-7).

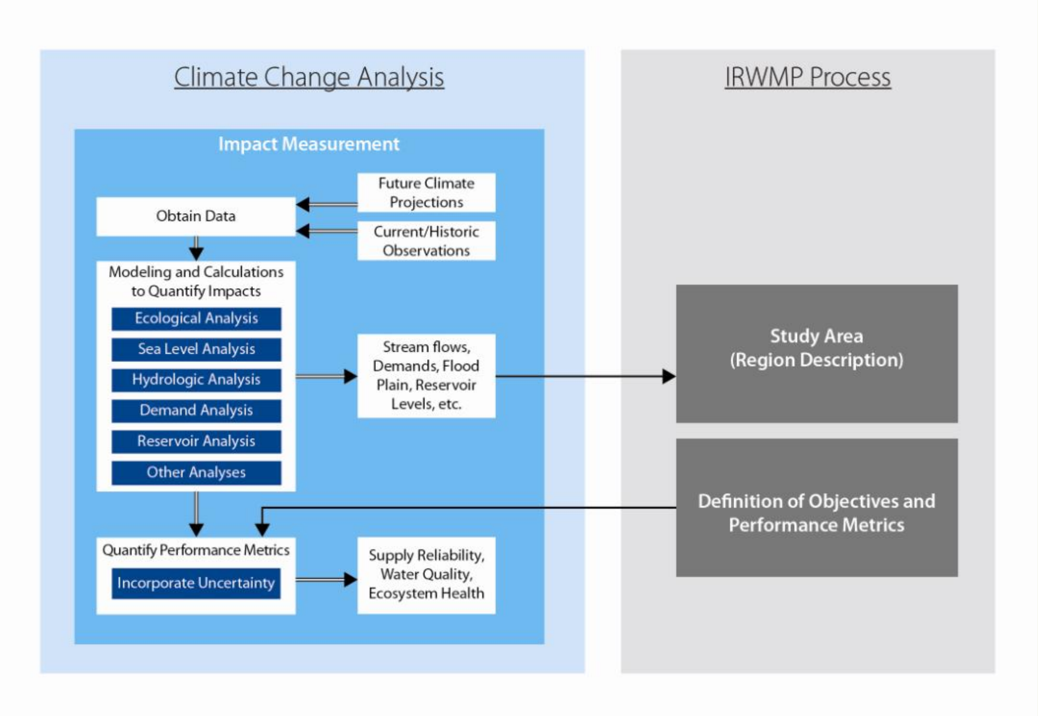
Two options for quantifying uncertainty in water supply analyses are probabilistic modeling and scenario planning. Both are described in detail in Appendix C. For example, hydrologic models could be used to simulate future conditions given a fixed number of discrete climate scenarios, representing dry, wet, and median conditions. These scenarios could be developed with guidance from climate model projections and/or available historical records. A sensitivity analyses to quantify the uncertainty associated with model calibration might also be appropriate to establish error bars for model projections.

Potential Performance Metrics

Performance metrics for water supply may include the probability of a water supply shortfall or unmet demand, or the maximum possible shortfall magnitude. Other potential metrics could include a minimum tolerable reservoir level or a maximum acceptable reliance on imported water. Metrics for water supply should include all water uses including environmental uses or instream flow needs. Evaluating performance metrics takes place in step 6 in Figure 5-7.

Case Study: Measure Impacts

Puget Sound Region – Water Supply Analysis



Background:

- The Water Supply Forum (WSF) was created in 1998 from both public water systems and local governments to address water supply issues. Members represent the King, Pierce and Snohomish Counties. The 2001 Central Puget Sound Regional Water Supply Outlook report developed by the WSF addressed regional water supplies and demands and included information on conservation and potential future supplies. The 2009 Outlook report is an update to the 2001 report which included climate change in the supply assessment and demand projection.

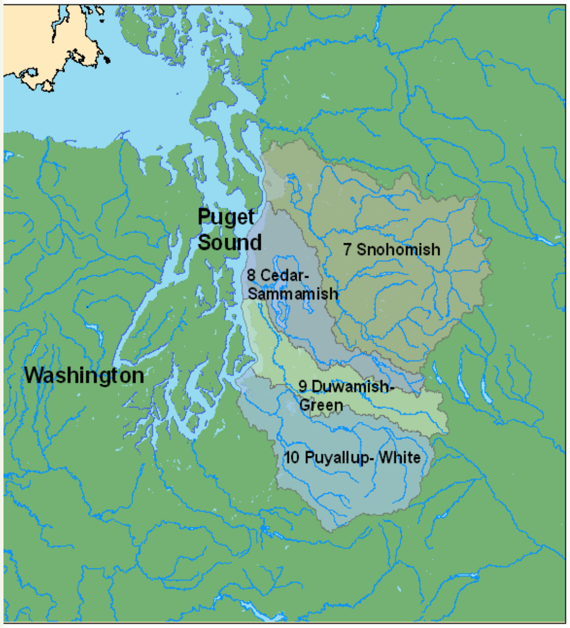


Figure 2: Basin 7: Snohomish, Basin 8: Cedar-Sammamish, Basin 9: Duwamish-Green, Basin 10: Puyallup-White. Source: http://www.climate.tag.washington.edu/regionalmap.html

Box 5-2

- The Climate Change Technical Committee (CCTC) was formed as part of a regional planning effort in 2005. Results from the CCTC analysis of climate change impacts on streamflows in the Central Puget Sound region were used to develop the WSF 2009 Outlook report and have also been used in local planning for Seattle Public Utilities, the City of Everett, and Tacoma Public Utilities.

- Central Puget Sound regional vulnerabilities to climate change:
  - Water supply (focus of this case study) snowpack, precipitation runoff
  - Water quality
  - Water demand

- Streamflow/Surface Water Supply: Four river basins provide roughly 66% of regional water supply (WSF, 2009)
  - Snohomish
  - Cedar-Sammamish
  - Duwamish-Green
  - Puyallup-White (fed by glaciers)

Step 1: Obtain Locally Applicable Data

Data Obtained:

- GCM Downscaled Data
- Historical Observation Data

1. **Select GCM/emissions scenario couples**
   - GISS_B1: "warm"
   - ECHAM5_A2: "warmer"
   - IPSL_A2: "warmest"
2. **Reasons for choosing these scenarios**
   - Good replication of Temperature and Precipitation for the Pacific Northwest (Mote, 2005)
   - Emissions Scenarios:
     - Two chosen out of six
     - Represents high (A2) and low (B1) emissions levels
   - GCMs:
     - Three chosen (out of "more than 20")
     - All three represent PNW temperature and precipitation well historically
3. **Obtain local historical/current data**
   - Maximum and minimum daily temperature
   - Local wind records
   - Total daily precipitation
   - Observation station elevation & geographic position
   - Soil characteristics (porosity, etc.)
   - Vegetation type

Step 2: Assessment and Analysis

Analyses Conducted:

- Watershed Modeling
- Water System Modeling

1. **Model Description - The Distributed Hydrology Soil Vegetation Model (DHSVM)**

Inputs:

- Air temperature
- Wind speed

Box 5-2 (Continued)

- Relative humidity
- Incoming shortwave radiation
- Outgoing longwave radiation
- Precipitation
- Temperature lapse rate

Other data needed:

- Soil porosity, type, thickness
- Vegetation cover
- Topography

Special Model Features:

- Glacier component
- Snowpack component

2. Calibration

Historical flows measured at USGS streamgages were reproduced with the model. Historical weather data was used as model input. Statistical properties of both measured and modeled streamflows were compared to verify model calibration. Values compared include:

- Daily flows –averaged from 1945-2004 (Figure 3)
- Monthly flows –averaged over various time periods
- Cumulative flows–totaled over several years
- Hydrograph comparisons–over several years – monthly, daily
- Annual Mass Accumulation Error
- Reservoir Storage level

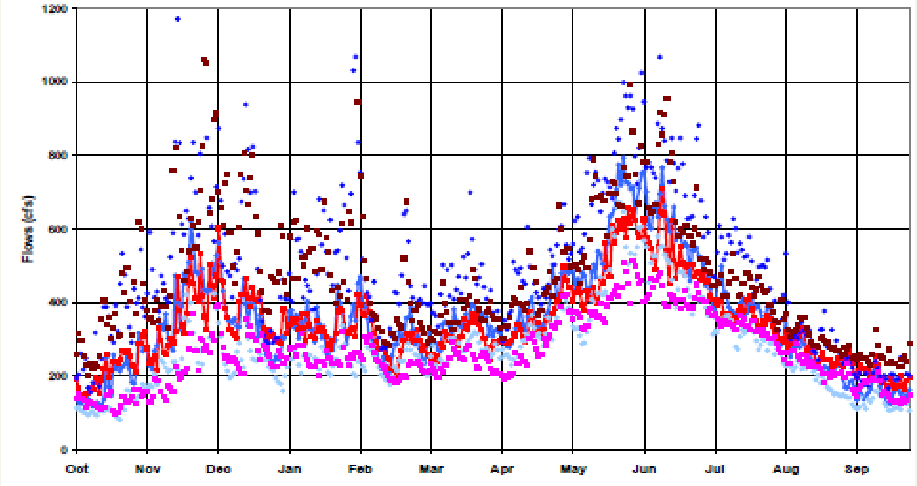


Figure 2: Annual streamflow calibration results at USGS Streamgage 12094000. (Source: CCTC 2007a)

3. Model Analysis and Results

Model Runs Based on:

- Historical Data
  - Year 2000
- GCM Downscaled Data
  - Years 2000-2075

Results Analysis:

- Bias check: Compared GCM-based watershed results for the year 2000 with

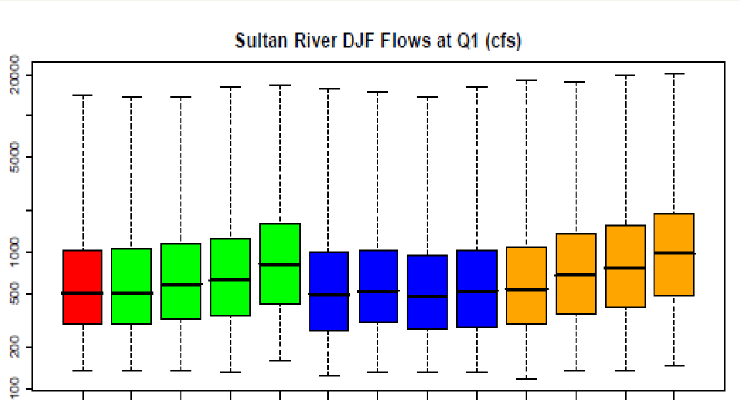


Figure 3: Model-predicted future flows compared among emissions scenarios and against the historical record (red). (Source: CCTC 2007a)

Box 5-2 (Continued)

historical data-based model runs to identify baseline biases that are a carry-over from the GCM data itself. The main variable used for this step was streamflow at various locations.

- Compared modeled average monthly flows with 2000 historic record for
  - each scenario
  - multiple years
- Box Plots of seasonal averages – There are significant levels of uncertainty in future climate data and significant variability in natural climate characteristics. Comparing statistical properties of the model results is therefore more informative than examining absolute numbers. Some of the box plots used for this analysis are shown in Figure 4.
- General Results
  - All basins, all three scenarios – earlier peak in spring, lower early summer flows (lower by 37% with all scenarios averaged) – higher winter flows by 48% on average
  - Least pronounced change: B1 scenario (driest scenario, but smallest temp increase)
  - Most pronounced change: basins with more snow

Step 3: Performance Metrics

Metric Used:

- System Yield

---

1. From Modeled Streamflows to Reservoir Levels

- Streamflows were input into water system models (for City of Everett, SPU, and Tacoma Water)
- Analysis used fixed reservoir operation rules

Water District	Projected Yield Impact in 2075
Everett	6-13% Decline
Seattle	13-25% Decline
Tacoma	4-8% Decline

Source: WSF, 2009

2. Planning-Level Performance Metric: *Yield vs Demand*

- Model results used for years 2020, 2040
- Ensemble average flows used for planning (average of all 3 scenarios)

Year	Flow Reduction	Projected Yield	Impact
2020	12 mgd	159 mgd	None, even accounting for uncertainties associated with demand calculations
2040	24 mgd	147 mgd	20% chance of demands exceeding supplies

Source: SPU, 2007

Box 5-2 (Continued)

Influence on Regional Water Management: Potential Management Strategies Being Considered to Increase Supply/Redundancy

SPU

- Seasonal reservoir operation/Operational protocol changes
- Conservation
- Infrastructure improvements
- Additional supply projects

City of Everett

- Seasonal reservoir operation/Operational protocol changes
- Snohomish River water
- Groundwater sources
- Enhanced conservation
- Reclaimed water
- Intertie with SPU

Tacoma Public Utilities

- Reservoir operational management changes
- Regional interties
- Aquifer recharge projects
- Additional storage projects

For More Information

City of Everett. 2007. City of Everett Comprehensive Water Plan. http://www.ci.everett.wa.us/Get_PDF.aspx?pdfID=3875

Climate Change Technical Committee. 2007a. Final Report of the Climate Change Technical Committee. http://www.govlink.org/regional-water-planning/tech-committees/climate-change/index.htm

Climate Change Technical Committee. 2007b. Technical Memorandum #4: Approach for Developing Climate Impacted Meteorological Data and its Quality Assurance/Quality Control. http://www.govlink.org/regional-water-planning/tech-committees/climate-change/index.htm

Climate Change Technical Committee. 2007c. Technical Memorandum #5: Approach for Developing Climate Impacted Streamflow Data and its Quality Assurance/Quality Control. http://www.govlink.org/regional-water-planning/tech-committees/climate-change/index.htm

Mote, Philip, Eric Salathé, and Cynthia Peacock. 2005. Scenarios of Future Climate for the Pacific Northwest. Climate Impacts Group, University of Washington. http://cses.washington.edu/db/pdf/kc05scenarios462.pdf

Seattle Public Utilities. 2007. Seattle Public Utilities Water System Plan. http://www.cityofseattle.net/util/About_SPU/Water_System/Plans/2007WaterSystemPlan/SPU01_002126.asp

University of Washington Climate Impacts Group. (n.d.). http://cses.washington.edu/cig/

Water Supply Forum. 2009. Water Supply Forum 2009 Water Supply Outlook. http://www.watersupplyforum.org/outlook

Box 5-2 (Continued)

5.3.2.2 Imported Water Reliability

More than 23 million people in California rely on water from either the CVP or from the SWP (Chung et al 2009). In addition, many people in Southern California also rely on water imported from the Colorado River Aqueduct (CRA) through MWD.

The three major imported water supplies in the State of California (SWP, CVP, and CRA) either have current reliability studies that account for climate change, or are in the process of conducting such a study. This handbook recommends that regions incorporate results from these reliability studies with respect to climate change in the planning process, rather than develop an independent assessment of imported water reliability. This recommendation is consistent with Urban Water Management Plan (UWMP) requirements.

Data Needed

Projected supplies from water purveyors and projected supplies from all other sources (or assumptions about availability from them).

State Water Project: "The State Water Project Delivery Reliability Report 2009" contains information on obtaining and using water reliability projections that take into account both climate change and environmental flow restrictions. The MWD and IRWD, among others, have conducted supply reliability studies based on data from the SWP Reliability Report (Rodrigo and Heiertz 2009, MWD 2010) (see also MWD case study, Box 7-1).

Central Valley Project: The California Climate Change Center 2009 report "Using Future Climate Projections to Support Water Resources Decision Making in California" (http://www.water.ca.gov/pubs/climate/using_future_climate_projections_to_support_water_resources_decision_making_in_california/usingfutureclimateprojtosuppwater_jun09_web.pdf) discusses impacts of climate change to both the Central Valley Project and the State Water Project.

Colorado River Aqueduct: Because MWD also obtains water from the Colorado River, MWD used data from the BOR's water supply model, CRSS, to estimate reliability from this source (see Appendix A-1 of MWD (2009), and the MWD case study). The USBR is currently conducting a Colorado River Basin Water Supply and Demand Study. The interim report is available at http://www.usbr.gov/lc/region/programs/crbstudy.html. Characterizing demand-supply imbalances resulting from climate change impacts is one of the objectives of the study, which is scheduled to be complete in July 2012.

Conducting the Analysis

"The State Water Project Delivery Reliability Report 2009" contains guidance on applying supply reliability projections to local and regional planning efforts. The SWP and CVP both provide delivery reliability in terms of an exceedence frequency. Projected deliveries can be combined with other regional water sources to estimate overall regional water supply reliability.

Incorporating Uncertainty

The SWP and CVP both provide delivery reliability estimates in the form of a cumulative probability distribution that reflects hydrologic variability. Other uncertainties are associated with climate change, future demands, environmental flow restrictions, and natural disasters, among others. Many of these uncertainty sources cannot be modeled probabilistically and scenario planning may be the best option for assessing uncertainty. Regions that rely on imported water are encouraged to read documentation associated with published delivery reliability and incorporate this uncertainty into regional supply reliability studies.

Potential Performance Metrics

Potential performance metrics for evaluating climate change impacts on imported water supply and reliability might include an agency's threshold of acceptable regional supply certainty, or a percent decrease from existing supplies. Projected future supply need, associated with the imported source, may also be a performance metric.

5.3.3 Surface Water Quality

Water quality is critical to both drinking water supplies and ecological needs. Near-coastal drinking water intakes and estuarine habitats are both susceptible to salt water intrusion. Fish in riverine environments are susceptible to higher temperatures. Rivers, reservoirs, lakes, and coastal areas are all susceptible to low dissolved oxygen that can easily accompany higher temperatures.

Surface water systems susceptible to water quality impacts from climate change vary in configuration and require analyses tailored to their unique features. The EPA Watershed and Water Quality Modeling Technical Support Center (http://www.epa.gov/athens/wwqtsc/index.html) contains information on several EPA-supported water flow and transport models that range in complexity from 1-Dimensional (1D) (e.g., the Storm Water Management Model (SWMM) model) to 3D (e.g., the Environmental Fluid Dynamics Computer Code (EFDC) model). Several of the watershed models discussed in Section 5.4.3 can also be used to study water quality. This section specifically discusses salinity studies, and generally refers to inland water quality studies. The methods discussed in this section can be applied to many other water quality studies.

As with other resources areas, in some instances a numerical model is not necessary to develop a complex model. For example, a regression relationship can be developed between air temperature and stream temperature to estimate future stream temperatures (Rehana and Mujumdar 2011). In addition, mass balance-based box models can be developed to estimate concentrations and loadings.

5.3.3.1 Coastal Surface Water: Hydrodynamic Studies of Salinity Infiltration and Sea Level Rise

For drinking water source intakes that are located upstream of estuarine systems, vulnerabilities to salinity intrusion from downstream may be a concern. Estuarine hydrodynamic modeling is a useful tool for evaluating water quality. In some instances, a simple 1 or 2D model will suffice. In the Delaware Estuary, a 3D hydrodynamic modeling study was conducted to assess impacts of climate change on the salt wedge in the Delaware River (Kreeger et al 2010). There are many hydrodynamic models that can be used to evaluate coastal systems. Some examples include:

- EFDC (http://www.epa.gov/athens/wwqtsc/html/efdc.html
- ELCOM (http://www.cwr.uwa.edu.au/software1/models1.php?mdid=5) and
- MIKE 3D (http://www.mikebydhi.com/Training/CourseTopics/CoastandSea.aspx).

Common 2D models include ADCIRC (http://www.adcirc.org/) and RMA2 (http://chl.erdc.usace.army.mil/rma2).

Because developing a hydrodynamic model is labor-intensive and requires a high level of technical expertise, regions should thoroughly evaluate the potential benefits of such an investment. Where resources are not available for a modeling study, more qualitative methods, such as surveying local experts, may provide useful information for guiding planning decisions. The EPA's Climate Ready Estuaries program (CRE, http://www.epa.gov/climatereadyestuaries/) provides several resources that may support this type of analysis. Where models are already developed, they can be useful tools for assessing impacts of sea level rise and other climate change impacts on a coastal system. Figure 5-8 depicts the steps to create an example coastal surface water impacts analysis.

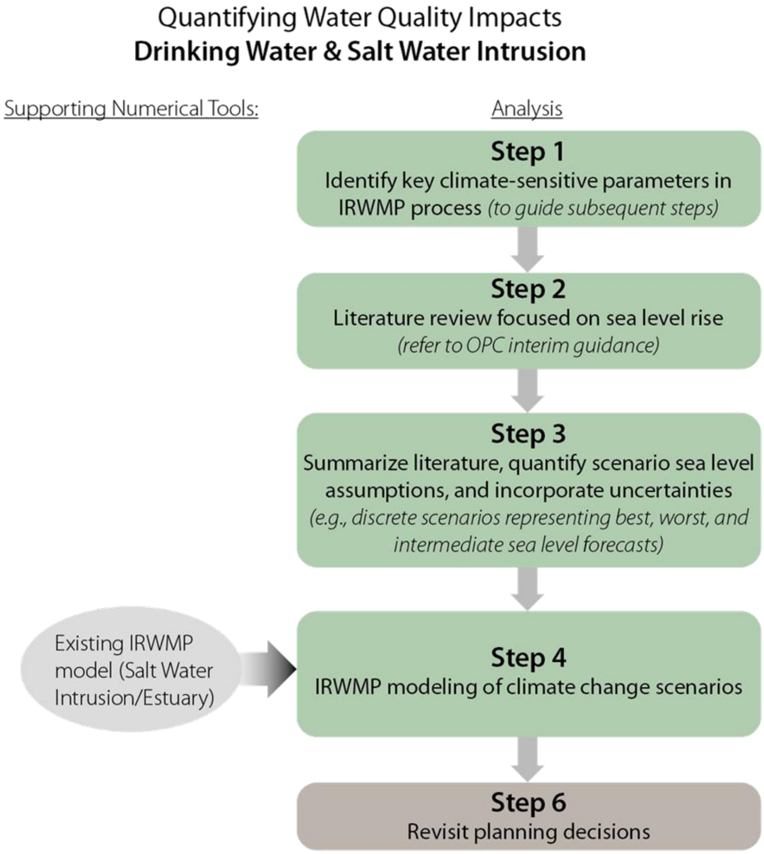


Figure 5-8: Water Quality Salt Intrusion Climate Change Analysis Process Flow Chart.

Data Needed

Regardless of the dimensions modeled, hydrodynamic modeling requires data that characterizes the estuary and points of concern upstream; such as bathymetry data (river and estuary topography), the coastline delineation, and streamflow data. Depending on the morphology of the estuary system, it can be necessary to include large spatial domains in the model set-up if multiple-dimensional modeling is used. In addition to data on the physical shape of the system, hydrodynamic modeling also requires variables, such as atmospheric data (including wind and precipitation), tidal data, historical streamflow data, and historical salinity data.

Other data required for taking climate change into account may include projected levels of sea level rise (see section 5.4.4), anticipated changes in streamflows (see Section 5.4.3), and atmospheric variables such as air temperature, possibly from downscaled GCM results. Determining which model input variables to alter to account for climate change, and obtaining relevant variable projections, involves steps 1 and 2 in Figure 5-8.

Conducting the Analysis

After gathering data, configuring a model for a region, and calibrating/validating it against observed field data; a hydrodynamic model's boundary conditions can be altered to reflect a warmer climate (step 4 in Figure 5-8). Where regions have existing hydrodynamic estuary models, they are encouraged to modify existing models to account for climate change. Variables reflecting climate change may include:

- Tidal elevations reflecting sea level rise;
- Streamflows reflecting seasonal flow patterns altered by climate change; and
- Atmospheric variables downscaled from GCM results; such as evaporation, temperature, wind, and atmospheric pressure).

Incorporating Uncertainty

Primary sources of uncertainty specific to hydrodynamic modeling of saltwater intrusion include:

- Our limited understanding of how the physical system responds to climate and other variables.
- Numerical accuracy of the hydrodynamic model. This uncertainty is associated with limitations of the underlying mathematical equations and the way the model solves these equations. Uncertainty is also associated with the assumption that the historical calibration dataset provides a representative calibration for use in projecting the future.
- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and often viewed as effectively "random" for planning purposes.
- Projections of future conditions, including climate variables (step 3 in Figure 5-8) and other boundary conditions influenced by climate, such as streamflows and sea levels. Future oceanic boundary conditions also serve as a source of uncertainty.

Two options for quantifying uncertainty in hydrodynamic modeling are probabilistic modeling and scenario planning; both described in detail in Appendix C. It is challenging to integrate complex hydrodynamic models into full probabilistic analyses. Therefore, scenario planning may be the better option than probabilistic modeling. A suite of model simulations could be developed assessing sea level rise and intrusion for a range of assumed climate projections. As with hydrologic models, sensitivity analyses are recommended to quantify uncertainty associated with model parameterization.

Potential Performance Metrics

Useful performance metrics for this type of study may include salinity levels relative to acceptable thresholds for drinking water or marine life, or storm surge flooding damage or extent. Various water quality performance metrics can also be addressed with surface water models; these are discussed in the next subsection. Evaluating performance metrics using a coastal water model is represented by step 6 in Figure 5-8.

5.3.3.2 Inland Surface Water Quality Modeling

Inland water systems are also vulnerable to water quality problems exacerbated by climate change. This section discusses water quality modeling generally, and can be relevant to watershed, riverine, or surface water body systems. A common water quality constituent of concern is Dissolved oxygen, which is critical to aquatic life. Dissolved oxygen levels generally decrease with increased water temperature, decreased flow velocity, increases in biologic activity and oxygen demand, and changes in re-aeration. Therefore, this parameter is particularly impacted by climate change in California. Figure 5-9 depicts the general steps for an inland surface water quality impacts assessment.

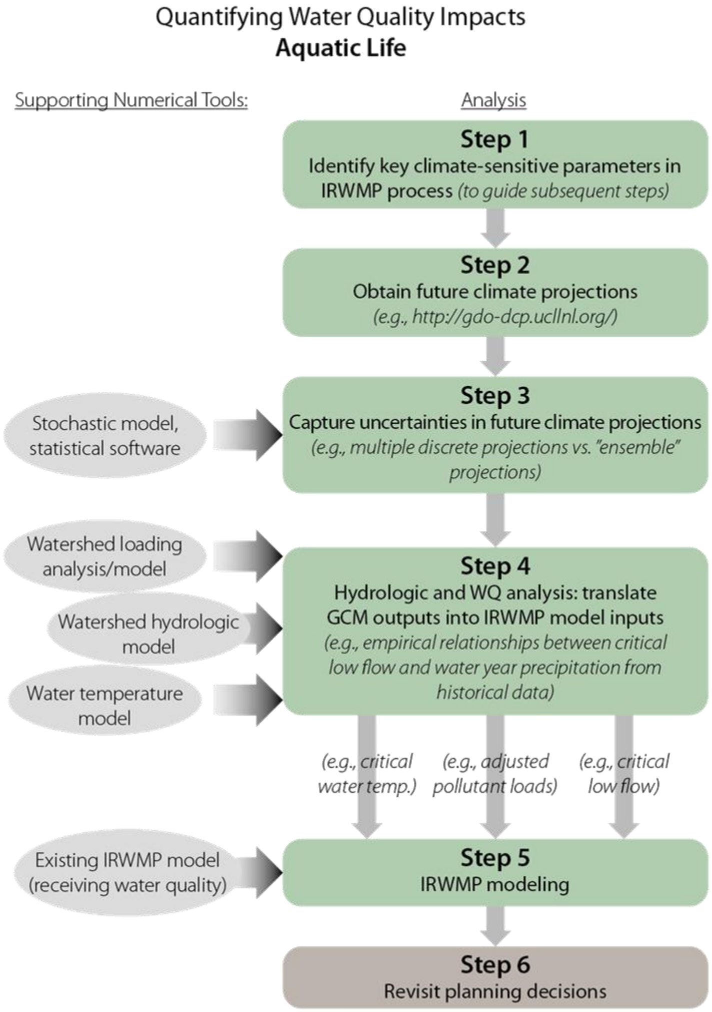


Figure 5-9: Water Quality Climate Change Impacts Process Flow Chart.

Other inland surface water quality concerns may include bacteria, temperature, and pollutants. Temperature lowers dissolved oxygen solubility, which can impact fish viability. Other pollutants may be identified from the State's 303(d) list of impacted waters, or from established total maximum daily loads (TMDLs) in a region's water bodies. Streamflow temperatures will be impacted by both snowmelt and ambient air temperature. Identifying water quality constituents to study is part of step 1 in Figure 5-9.

Data Needed

Flow and hydraulic data are critical to any surface water quality model. For the majority of dissolved oxygen studies, the critical condition corresponds to periods of low flows. Quantifying the low flows used in water quality modeling is often guided by regulatory mandate (e.g., 7Q10 low flow). Therefore, flow data acquisition can often focus on short-term low flows. Other data required to develop a water quality model depends on the system included in the model. Data needs for watershed models are discussed in Section 5.3.2, and may be applicable to a watershed scale surface water quality model. Data needs for a river/water body system also include:

- Watershed area and land use,
- River elevation and cross sectional data,
- Climate data (e.g., precipitation and temperature), and
- Pollutant loadings.

Values for all variables are needed both for current/historical conditions, for calibration purposes (for new models developed as part of the planning study), and for reflecting projected future conditions. Obtaining relevant data and future climate variable projections is represented by step 2 in Figure 5-9. Using GCM results to estimate extremes, such as low flows can be tenuous. Some statistical analyses have been used to estimate low flows from hydrologic studies directly using GCM results (Cox and Tummuri 2010).

Conducting the Analysis

Some well-known surface water quality models include:

- QUAL2K (http://www.epa.gov/athens/wwqtsc/html/qual2k.html),
- RMA4 (http://chl.erdc.usace.army.mil/rma4)
- WASP (http://www.epa.gov/athens/wwqtsc/html/wasp.html), and
- CAEDYM (http://www.cwr.uwa.edu.au/software1/models1.php?mdid=3).

As with most water system process models, it is necessary to calibrate a model to historical data before evaluating the impact of climate change on the system. After calibration, altering variables, such as streamflows and temperature, according to future climate projections provides an estimate of future water quality conditions. A link between climate projections and streamflow and water temperature will likely be required in this process. The watershed hydrologic models described in Section 5.3.2 can provide streamflow projections. External stream or lake temperature models may be required to simulate temperature impacts. Watersheds with snowpack may need to consider cold water releases from snowmelt. Steps 4 and 5 in Figure 5-9 include simulating future water quality impacts from climate change.

Incorporating Uncertainty

Primary sources of uncertainty specific to surface water quality modeling include:

- Our limited understanding of how the physical system responds to climate and other variables.
- Numerical accuracy of the water quality model. This uncertainty is associated with limitations of the underlying mathematical equations and the way the model solves these equations. There is also uncertainty associated with the assumption that the historical calibration dataset is comprehensive enough to provide a representative calibration for use in projecting the future.
- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and are often viewed as effectively “random” for planning purposes.
- Projections of future conditions, including pollutant loading, land use, climate variables (step 3 in Figure 5-9) and other boundary conditions influenced by climate, such as streamflows.

Two options for quantifying uncertainty in water quality modeling are probabilistic modeling and scenario planning. Both options are described in detail in Appendix C. It is challenging to integrate complex water quality models into full probabilistic analyses, although many new water quality modeling tools include probabilistic and/or stochastic simulation modes. Alternatively, scenario planning techniques could be applied. Under scenario planning, a suite of model simulations are developed for a range of assumed uncertain variables (like future climate conditions). For example, a range of critical low-flow and air temperature inputs might be used in the analysis of future dissolved oxygen conditions in a stream. Both of these inputs might be informed by site-specific climate change model projections. Sensitivity analyses are recommended to quantify uncertainty associated with model parameterization.

Potential Performance Metrics

Performance metrics may include comparing modeling results with thresholds of acceptable pollutant concentrations, such as water quality standards. Water quality standards will define minimum acceptable dissolved oxygen concentrations, or acceptable ranges of instream temperatures. Evaluating performance metrics is represented by step 6 in Figure 5-9.

5.3.4 Ecosystem and Habitat Vulnerability

Ecosystems and habitats are varied. The approaches to measuring potential impacts of climate change on these systems are equally varied. While more vulnerability metrics and methods for assessing them can be found in the literature, this section addresses stream water temperature, water quantity, estuarine salinity, coastal habitat loss from sea level rise, and threats to individual species.

5.3.4.1 Estuarine Salt Intrusion: Hydrodynamic Modeling

Just as salt intrusion into estuarine systems can impact drinking water supplies, it can also have a significant ecological impact. The approach described in Section 5.3.3 also applies to ecosystem habitat vulnerability.

5.3.4.2 Streamflow Water Quality and Quantity

Changes instream flow and water quality could have a significant impact on aquatic life. For streamflow estimation, the rainfall runoff modeling methods described in Section 5.3.2 and the water quality modeling methods described in Section 5.3.3 can be used to assess potential ecosystem impacts. In some cases, ecological response models can be used to further estimate more specific impacts on species, habitats and ecosystems (see NWF 2011).

5.3.4.3 Wetland Habitat Loss from Sea Level Rise

Coastal marsh habitats are particularly vulnerable to sea level rise. Where data is available, it may be advantageous to use modeling tools to estimate future marsh and wetland migration or loss. This information could be used to prioritize protection of land that could accommodate wetland migration. Where these modeling tools and/or data are not available, it is also possible to compare existing coastal habitat with projected sea level rise impacts. Figure 5-10 depicts the steps for a wetland habitat loss/migration study.

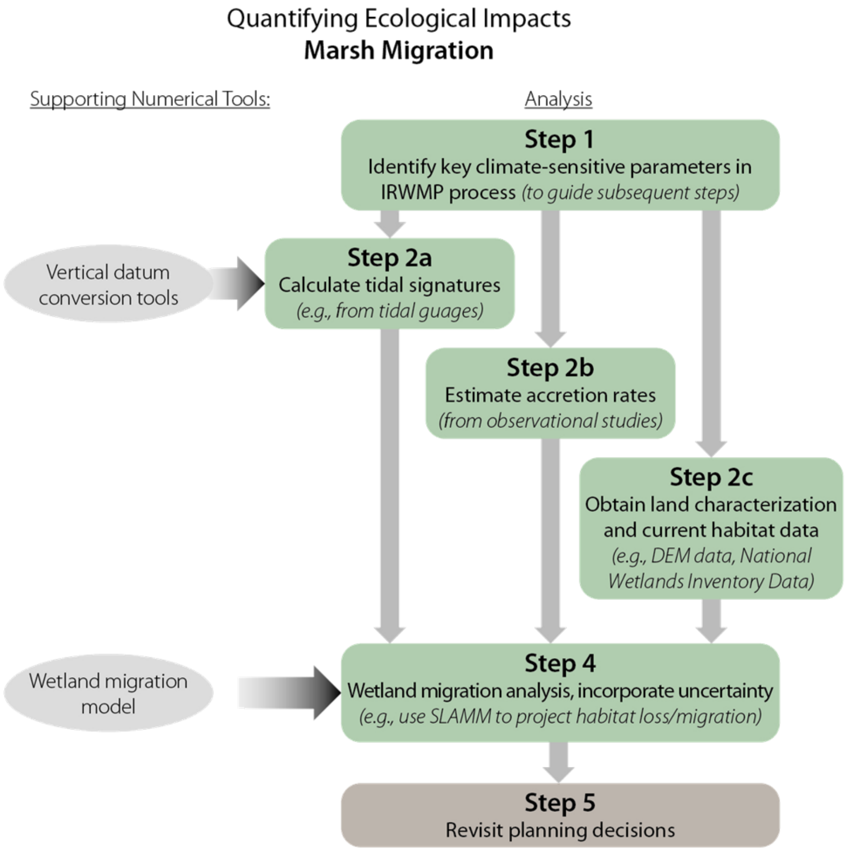


Figure 5-10: Marsh Migration Process Flow-chart

Marsh Migration Modeling

The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (http://www.csc.noaa.gov/digitalcoast/index.html) provides several tools for coastal data management, calculations, and decision making. Among these tools is the Sea Level Affecting Marshes Model (SLAMM). SLAMM allows the user to estimate impacts of long-term sea level rise on wetlands, including factors such as erosion and sedimentation.

Data Needed

SLAMM incorporates several options for sea level rise estimates. Other data required include:

- National Wetlands Inventory data (http://www.csc.noaa.gov/digitalcoast/data/nwi/index.html),
- Digital elevation data for the region of interest (http://www.csc.noaa.gov/digitalcoast/data/ned/index.html),
- Local tidal data,
- Local accretion data, and
- Local erosion rates.

Assembling data may take some processing and datum conversion. The tool VDatum is useful for datum conversion (http://vdatum.noaa.gov/). Data processing is also simplified by using Geographic Information Systems (GIS). Step 2 in Figure 5-10 illustrates some components of assembling necessary data.

Conducting the Analysis

SLAMM allows model simulations far into the future. The Delaware Estuary Wetland Work Group used SLAMM to assess tidal wetland habitat loss (Kreeger et al 2010), estimating effects going out to 2100. This analysis is represented by step 4 in Figure 5-10.

Incorporating Uncertainty

Primary sources of uncertainty specific to marsh migration modeling include:

- Our limited understanding of how the physical system responds to climate and other variables.
- Numerical accuracy of the marsh migration model. This uncertainty is associated with limitations of the underlying mathematical equations and the way the model solves these equations. There is also uncertainty associated with the assumption that the historical calibration dataset is comprehensive enough to provide a representative calibration for use in projecting the future.

- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and often viewed as effectively “random” for planning purposes.
- Projections of future conditions, including pollutant loading, land use, climate variables (step 3 in Figure 5-10) and other boundary conditions influenced by climate, such as streamflows.

Due to the complexity of the SLAMM model, scenario planning is likely a better fit for quantifying uncertainty compared to full probabilistic modeling. Scenario planning should be coupled with sensitivity analyses to quantify the uncertainty attributable to model parameterization.

Potential Performance Metrics

Performance metrics for wetland habitat loss may include estimates, such as the percent of the total existing habitat that is at risk, or the total acreage of habitat that may be lost (or preserved). As SLAMM estimates shifts from one marsh type to another, metrics may be qualified by conversion to specific classes of similar wetlands.

Qualitative Land Footprint Comparison

A simpler method than using SLAMM may involve a qualitative analysis, such as comparing projected coastlines under future conditions based upon previous studies with the existing location of wetlands. For this analysis, the descriptions in Section 5.3.5 may apply.

5.3.4.4 Individual Species

Endangered and threatened species can be especially vulnerable to climate change. Figure 5-11 depicts the steps for an individual species impact analysis. While projecting impacts for some species is necessarily qualitative, the US EPA Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change (EPA 2009b) (“Framework”) provides comprehensive guidance in evaluating the projected impacts of climate change on a species. The Framework takes into account “baseline” vulnerability, irrespective of climate change, and accounts for variables specifically related to climate change. The Framework is included in the Literature Review in Appendix A.

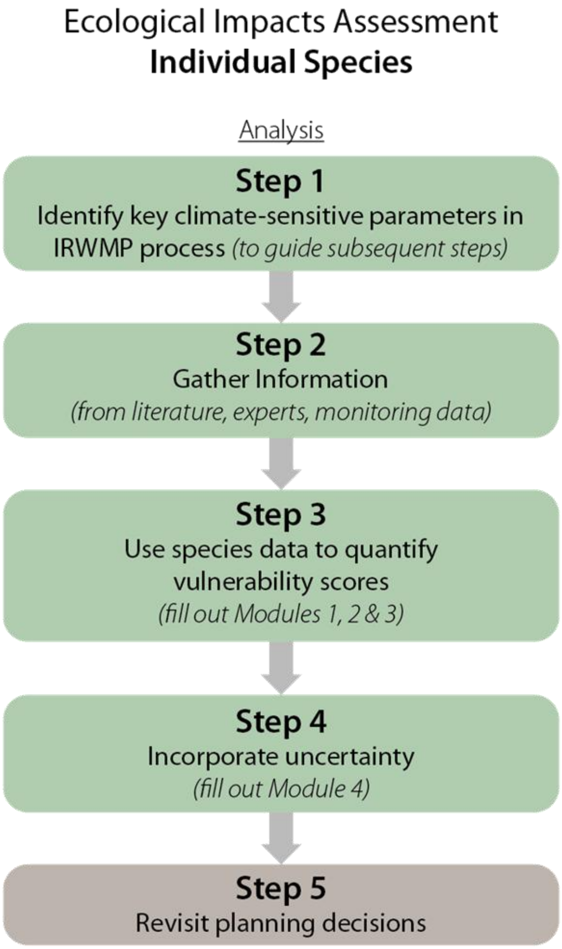


Figure 5-11: Species Process Flow-chart

The Framework analysis includes four modules that assess:

- Background vulnerability,
- Species vulnerability to climate change,
- Overall vulnerability, and
- Uncertainty associated with the vulnerability assessment.

The Framework includes example cases where the modules have been applied to threatened and endangered species.

Other qualitative and quantitative methods can be used for evaluating climate change impacts on individual species. The Southwest Climate Change Initiative (SWCCI) uses a conceptual model to evaluate relationships between climate factors and ecological processes (see case study, Box 5-3). The National Wildlife Federation (NWF) report "Scanning the Conservation Horizon" provides information on other ecological response models and uncertainty associated with them (NWF 2011).

Data Needed

The modules included in the Framework require the user to make qualitative assessments of many variables related to physiological requirements and behavioral characteristics of the species being assessed. If this data is not readily available, and experts are not readily available for consultation, a thorough literature review may be required (see step 2 in Figure 5-11). Implicit in the data required is a qualitative understanding of projected temperature and precipitation changes due to climate change. This assessment is not based on a specific future scenario, rather the planner's judgment about the direction and magnitude of the future under climate change. Information needed to complete the assessment includes:

- Species population size and range, and trends of both;
- Vulnerability to external (non-climate change-related) variables, such as policy and management decisions, stochastic events, and other stressors;
- Species attributes, such as individual replacement time, dispersive capacity, dependence on other species, and dependence on temporal inter-relationships;
- Habitat resiliency; and
- Vulnerability to changes in temperature and precipitation and extreme weather events.

Conducting the Analysis

Use of the EPA Framework involves of filling out a one-page form for modules 1-3. Modules 1 and 2 require data entry. Module 3 requires analyzing the data provided in Modules 1 and 2 to categorize the species as "critically vulnerable", "highly vulnerable", "less vulnerable", "least vulnerable", or "likely to benefit from climate change".

Incorporating Uncertainty

Module 4 of the Framework consists of approximating the certainty of the Module 3 assessment as high, medium, or low. Because the assessment is qualitative in nature, the uncertainty is also qualitatively assessed. This uncertainty is weighed against the severity of potential climate impacts to determine overall climate impacts. Uncertainties are associated with:

- Our limited understanding of how species will respond to climate and other variables.
- Natural hydrologic and climatologic variability.
- Projections of future conditions, including habitat land availability and connectivity, climate variables and other boundary conditions influenced by climate, such as streamflows and water quality.

Scenario planning could be applied through the use of variable climate and hydrologic condition assumptions within the EPA framework.

Potential Performance Metrics

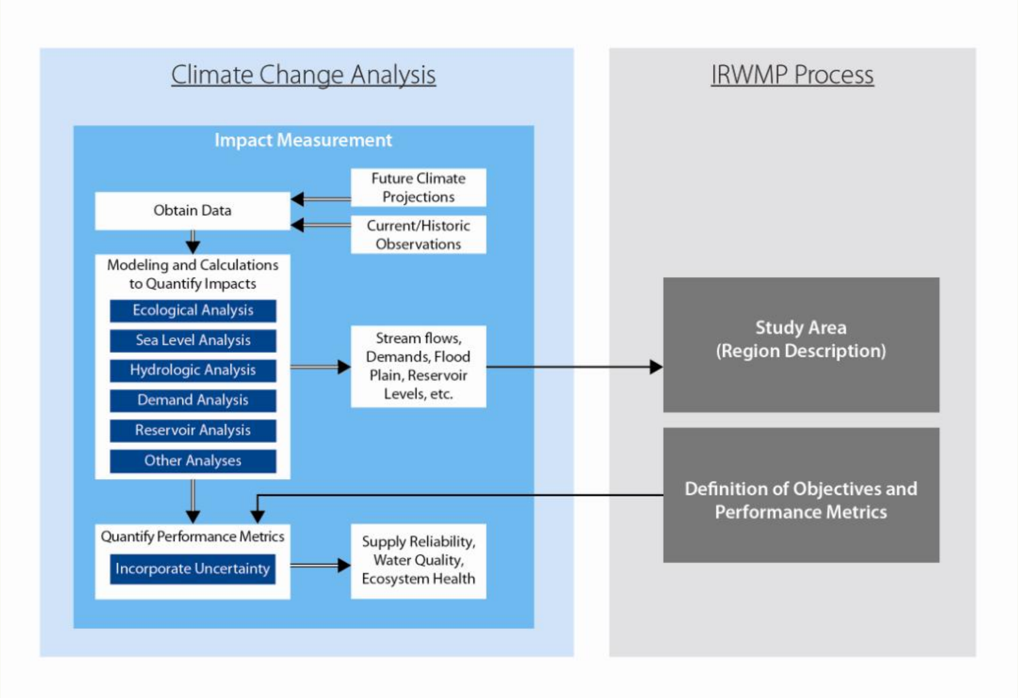
Uncertainty is explicitly included in module 4 of the Framework, which facilitates evaluation of Framework results. A comparison of module 1 and module 2 results facilitates identification of climate-related vulnerability.

The results of this analysis are qualitative, which simplifies performance metrics. Metrics may be set to overall vulnerability ratings. For example, a region could determine to use a “medium” vulnerability as a threshold of performance acceptability. Alternatively, the score from an individual module or question within the Framework may be of particular importance to a region. For example, a region could use a projected habitat availability under climate change of “medium” with a high level of certainty as a threshold of performance acceptability.

Case Study: Measure Impacts

Bonneville Cutthroat Trout – Ecological Impacts Analysis

Southwest Climate Change Initiative



Background:

- The Southwest Climate Change Initiative (SWCCI) was launched in 2009 to provide tools to assess the impacts of climate change on conservation objectives, and build partnerships between scientists and managers for adaptation planning. SWCCI is a partnership of The Nature Conservancy, the Wildlife Conservation Society, the Climate Assessment for the Southwest at the University of Arizona, the National Center for Atmospheric Research, and the Western Water Assessment at the University of Colorado.
- The Bear River Basin spans parts of Utah, Idaho and Wyoming, and is the largest tributary to the Great Salt Lake. Figure 1 shows a map of the Bear River watershed.
- The Bonneville Cutthroat Trout's (BCT) last large river habitat is the Bear River. The BCT is affected by irrigation diversions and hydropower facilities, and is a focus of

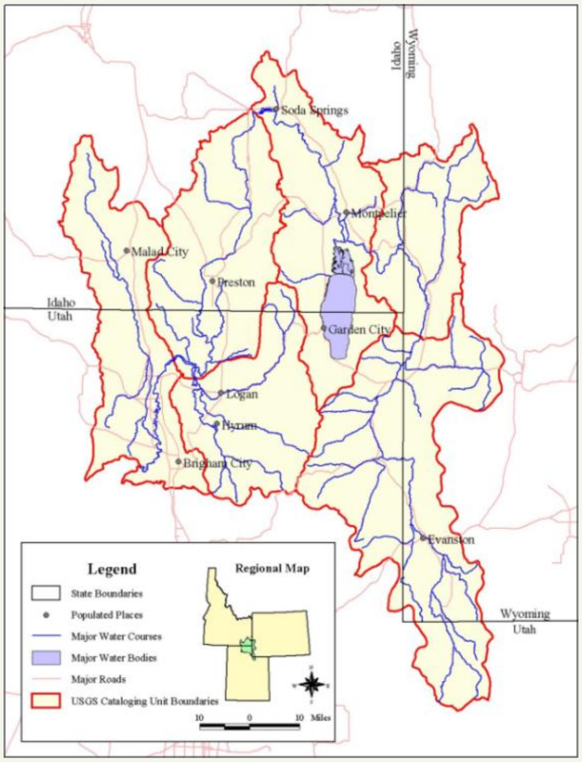


Figure 1: Bear River Watershed. (Source: BRWIS 2011). For larger image please see http://www.bearriverinfo.org/mapping/images/watershedmap.jpg

Box 5-3

conservation efforts through the Utah State Wildlife Action Plan (Utah Division of Wildlife Services 2010). Water temperatures in the main stem of the river are already close to the BCT's tolerance level, raising concern about the potential effects of climate change.

Key Questions:

1. What temperature and moisture changes are likely in the future?
    - The analysis approach included hydrologic modeling with GCM downscaled climate projections
2. How will climate change impact systems of interest in the Bear River?
    - The analysis approach include developing a conceptual ecological model

The Nature Conservancy (TNC) held a 2-day workshop in 2010 to identify climate adaptation strategies for species and ecosystems in the Bear River. The workshop focused on both the Bear River wetlands ecosystem and the BCT subspecies. This case study focuses on BCT-related analyses.

Step 1: Obtain Locally Applicable Data and Preliminary Analysis

Data Obtained:

- *Develop future climate scenarios*
- *Develop future streamflow projections (hydrologic modeling)*

---

1) Develop future climate scenarios

- A2 emissions scenario
- Examine distribution of model results for Bear River area, select two model results
    - NCAR CCSM GCM (model results represent more moderate climate change in the Bear River area)
    - CRCM GCM (model results represent more challenging climate change in the Bear River area)
- GCM results obtained from CMIP3 archive

2) Run a hydrologic model:

a. Variable Infiltration Capacity Model (VIC).
    i. Obtain historical and current data needed for runoff modeling
    ii. GCM results used to adjust historical record

b. Results: streamflow conditions 2041-2070
    i. Earlier springmelt
    ii. Lower summer low flows
    iii. Lower summer high flows
    iv. Higher winter flows

Box 5-3 (Continued)

Step 2: Assessment and Analysis

Analyses Conducted at the workshop:

- *Conceptual model*
- *Workshop discussion*

Workshop Details

- 13 participants examining BCT:
  - Public agencies
  - Private organizations
  - Academic institutions
- Two days long

Develop BCT Conceptual Model

Start with draft developed before workshop

Elements included in the final conceptual model (Figure 2):

- Relationships among key features:
  - Habitat
  - Biological agents
  - Ecological processes
  - Climate parameters
  - Human management
- Elements critical for BCT viability
  - Genetic diversity/gene flow
  - Population demography
  - Habitat connectivity
- Critical habitat elements
  - Flow regime
  - Water quality regime
  - Physical habitat characteristics

Box 5-3 (Continued)

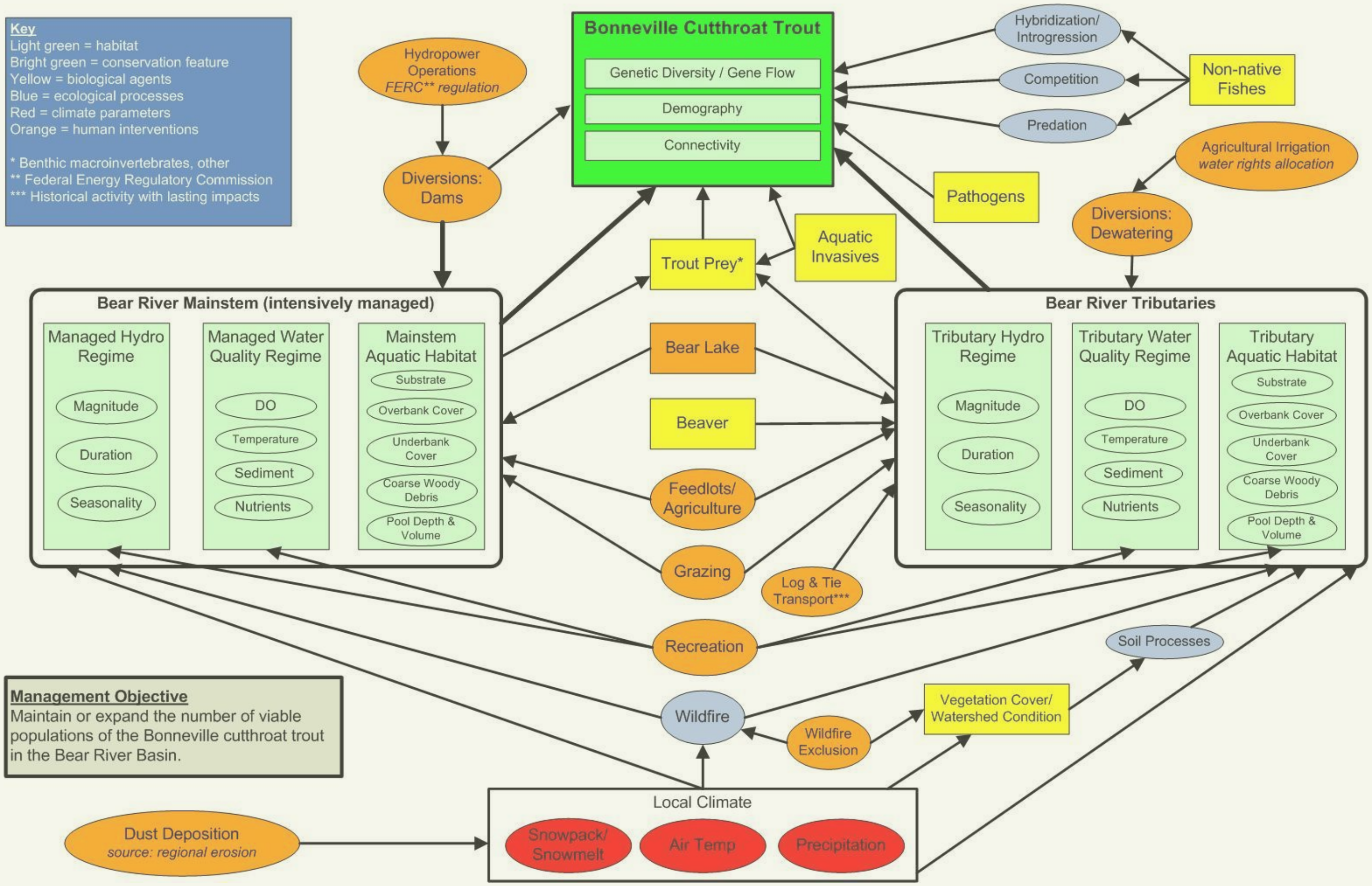


Figure 2: Bonneville Cutthroat Trout Conceptual Ecological Model. (Source: SWCCI 2010).

Box 5-3 (Continued)

Using conceptual model, identify climate change impacts and drivers (direct and indirect)

Physical climate change impacts and their effects on the BCT (modified from SWCCI 2010 Appendix 5) include:

Climate Change Impact	Effect on Bonneville Cutthroat Trout
Increased sediment loading, changes in channel morphology	Decrease in viability
Decreased dissolved oxygen	Physiological stress
Flow regime changes (due to shifts in vegetation)	Decrease in viability
Increased agricultural water demands	Water quantity, stranding
Increased water temperatures	Physiological stress Increase in pathogens Increase in non-native fish species
Less stream ice	Expanded habitat Fewer thermal refugia
Lower base flows, changes in riparian zone	Decreased water quantity Habitat loss Increased water temperature Stranding
Earlier snowmelt runoff	Phenological changes Stranding
Decreased infiltration to soil layers	Decreased water quantity Habitat loss Physiological stress
Increased droughts	Habitat loss Physiological stress Decreased viability
Cattle migration to riparian zones during drought	Habitat loss Physiological stress Decreased viability

---

Step 3: Relation to Management Objectives

Metric Used:
Challenges posed for accomplishing management objectives

The workshop was not a part of a formal planning process and no performance metrics were formalized or evaluated. However, the management objectives were used as a basis for identifying climate change impacts and potential management strategies.

1) 5-10 year Management Objective:
   "Maintain or expand the number of viable populations of the Bonneville cutthroat trout in the Bear River Basin." (SWCCI 2010)

   Subobjectives were to maintain or restore:
   - Connectivity between mainstream and tributaries
   - Flows in actual and potential habitat
   - Habitat quality
   - Genetic diversity
   - Aquatic community
   - Water quality

Impacts posing the largest threat relate to habitat loss:

- Fewer thermal winter refugia
- Loss of ice bridges in tributary streams
- Fewer summer-time streams within the BCT thermal tolerance
- Tributary dewatering/decreases in flows

Box 5-3 (Continued)

Potential Adaptation Measures and Research/Data Needs

The workshop identified potential management strategies that would address the climate change impacts identified for the BCT. This provided steps for moving forward.

Recommended Strategies

- Reducing/removing non-native fish
- Maintaining and creating cool water refugia and connectivity among refugia
- Improving riparian and aquatic habitat
- Removing physical barriers in priority reaches

Data/Research Needs

- River hydrology and fluvial morphology
- BCT biology
    - Demography
    - Life history
    - Phenology
    - Genetics
    - Habitat requirements
- Watershed condition
- Habitat

For More Information

BRWIS. 2011. Bear River Watershed Information System website. http://www.bearriverinfo.org/mapping/images/watershedmap.jpg

SWCCI. 2010. Bear River Climate Change Adaptation Workshop Summary. May 26 and 27, 2010. Salt Lake City, Utah. http://conserveonline.org/workspaces/climateadaptation/documents/southwestern-us-pilot-sites/view.html

Utah Comprehensive Wildlife Conservation Strategy http://wildlife.utah.gov/cwcs/

VIC model website http://www.hydro.washington.edu/Lettenmaier/Models/VIC/

Box 5-3 (Continued)

5.3.5 Sea Level Rise

Sea level rise impacts many water resources; including wildlife habitats, water quality, and coastal infrastructure. Coastal estuaries, wetlands, and marshes will be impacted by changing freshwater-ocean water balances; and may also migrate inland where unimpeded. Estuarine and river delta modeling methods are discussed in Section 5.3.3, along with coastal habitat migration modeling techniques. As sea level rises, coastal flood plains will also move inland; which has impacts for local infrastructure and coastal property. Rising sea levels are necessary inputs to many of the models discussed in these sections.

Planners are encouraged to familiarize themselves with coastal data. Bathymetry and coastal elevation data is available through the NOAA Coastal Inundation Toolkit (http://www.csc.noaa.gov/digitalcoast/inundation/index.html).

5.3.5.1 Future Sea Level Estimates

Studies have been conducted on future sea level rise estimates encompassing the California coast and beyond, reducing the burden on individual planning entities to assess predicted levels of sea level rise. Planners should take advantage of existing studies where possible. The NAS is developing a Sea Level Rise Assessment Report, which is expected to be released in the spring of 2012. The CO-CAT has developed interim guidance on taking sea level rise into account (http://www.water.ca.gov/climatechange/docs/SLR_GuidanceDocument_SAT_Responses.pdf), which the OPC supports (http://www.opc.ca.gov/2011/04/resolution-of-the-california-ocean-protection-council-on-sea-level-rise/). The CO-CAT guidance recommends following the Vermeer and Rahmstorf (2009) method for projecting sea level rise (http://www.pnas.org/content/106/51/21527.full.pdf+html). All future guidance updates will be available at the OPC web site (www.opc.ca.gov).

The CO-CAT guidance document provides sea level rise estimates that are applicable to the California Coast for the years 2030, 2050, 2070 and 2100. Planners are encouraged to utilize these existing projections, which are supported by the OPC.

In California, the OPC guidance supersedes other sea level rise guidance documents. More nationally applicable guidance, such as the USACE sea level rise guidance, refers back to an approach developed for the 1987 NRC report (NRC 1987). Since this report was published, models and approaches have improved. However, the “medium” and “high” sea level rise projection methods outlined in the USACE guidance result in sea level rise projections that are very similar to the CO-CAT guidance.

The CO-CAT guidance document provides sea level rise estimates that are applicable to the California coast for the years 2030, 2050, 2070 and 2100. However, planners may need to calculate projected rises for other time frames.

Data Needed

The Vermeer and Rahmstorf method requires globally averaged GCM temperature projections extending through the planning period. Local mean sea level in the years 1990 or 2000 are also needed. Using sea level rise estimates to project inundation also requires local elevation data for the coast.

Conducting the Analysis

The Vermeer and Rahmstorf method empirically relates global mean temperature to sea level rise. Because California's projected sea level rise is expected to be similar to the global average sea level rise, no regional adjustments needs to be made in the parameters used by Vermeer and Rahmstorf (CO-CAT 2010). Planners using the year 2000 as a baseline should subtract 3.4 cm from resulting sea level rise projections, however, because the reference year used in the Vermeer and Rahmstorf study is 1990. Projected sea level increases can be compared with digital elevation data to identify land at risk to either inundation due to sea level rise or potential coastal flooding.

Incorporating Uncertainty

Uncertainties in using the Vermeer and Rahmstorf method are associated with:

- Our understanding and characterization of climate and other variables in general and how sea levels will respond to changes in the future.
- Projections of future climate variables and other boundary conditions influenced by climate, such as streamflows and water quality.

Given the empirical nature of the Vermeer and Rahmstorf method, and the direct use of GCM temperature projections, a probabilistic framework might be appropriate for quantifying uncertainty associated with the climate projections. As discussed in Appendix C, results of this type of analyses should not be strictly viewed as likelihood of occurrence probabilities, but rather are more representative of levels of consensus of the best available projections.

Potential Performance Metrics

Possible performance metrics for sea level rise include differences in the amount of infrastructure at risk before and after considering sea level rise. This comparison could be quantified by the potential cost for repairs in a flood event, or it could be quantified by the critical nature of the vulnerable infrastructure (e.g., influencing regional ability to respond in an emergency).

5.3.5.2 Erosion

Erosion and sediment deposition rates will change as sea levels rise. The Pacific Institute completed a study of California Coastal Erosion in 2009 (http://www.pwa-ltd.com/about/news-CoastalErosion/PWA_OPC_Methods_final.pdf) that maps projected potential hazard zones along much of the California coast. The CO-CAT guidance document refers to parts 3 and 4 of the U. S.

Geological Survey National Assessment of Shoreline Change for additional guidance on future erosion and accretion rates:

- U.S. Geological Survey report on shoreline changes for California's beach habitat http://pubs.usgs.gov/of/2006/1219/, and
- U.S. Geological Survey report on shoreline changes for California's bluff habitat http://pubs.usgs.gov/of/2007/1133/.

5.3.5.3 The Sacramento-San Joaquin Delta

The Delta is the largest estuary on the west coast of North America. Sub-sea level Delta islands, protected by aging levees, are particularly vulnerable to sea level rise, levee collapse, and flooding. Analysis of the impacts of sea level rise in the Delta should rely on recent work by DWR as part of the Delta Risk Management Study (DRMS) (http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/phase1_information.cfm). Phase 1 of DRMS was completed in 2009 and provides a comprehensive risk analysis that considers the potential effects of climate change including sea level rise. The DRMS also considers the likelihood of occurrence of earthquakes, island subsidence, and flooding resulting from the increased magnitude and frequency of storms due to climate change.

5.3.5.4 100-year Coastal Flood Plains

One method for quantifying climate change impacts is to superimpose projected sea level rise onto elevations for existing coastal floodplains. For example, the Pacific Institute conducted a study on potential impacts of 1.4 m of sea level rise on coastal floodplains. This rise in sea level corresponds to the high estimate for the year 2100 in the CO-CAT guidance mentioned above. The results from this study are available at http://www.pacinst.org/reports/sea_level_rise/ as GIS shapefiles delineating new floodplains. With new floodplains mapped, it is possible to compare existing infrastructure and resource locations with these flood plains. For example, the Santa Monica Bay Restoration Commission (SMBRC) State of the Bay 2010 report (SMBRC 2010) includes such a comparison for the LA area (using the Pacific Institute's shapefiles), as does the initial Pacific Institute report (Herberger et al 2009). The Pacific Institute analysis does not strictly follow the CO-CAT guidance, as it was developed before the guidance was released; however, the Pacific Institute provides coastal flooding and erosion projections based on a 1.4 m sea level rise "high" projection by 2100, which is consistent with the CO-CAT guidance. Figure 5-12 depicts the steps for a coastal flood plain impacts analysis.

Data Needed

The data necessary for this exercise includes the floodplain model results that are available from the Pacific Institute, along with digital information on the location of various pieces of infrastructure in coastal areas for comparison. Assembling this data is represented by step 2 in Figure 5-12.

Conducting the Analysis

Comparing the Pacific Institute model results with existing infrastructure could be done by overlaying the infrastructure and floodplains from the Pacific Institute and taking an inventory of at-risk infrastructure. Conducting a "what-if" analysis of how vulnerable each facility would be in a flooding event may also be useful. This exercise is represented by steps 3 and 4 in Figure 5-12.

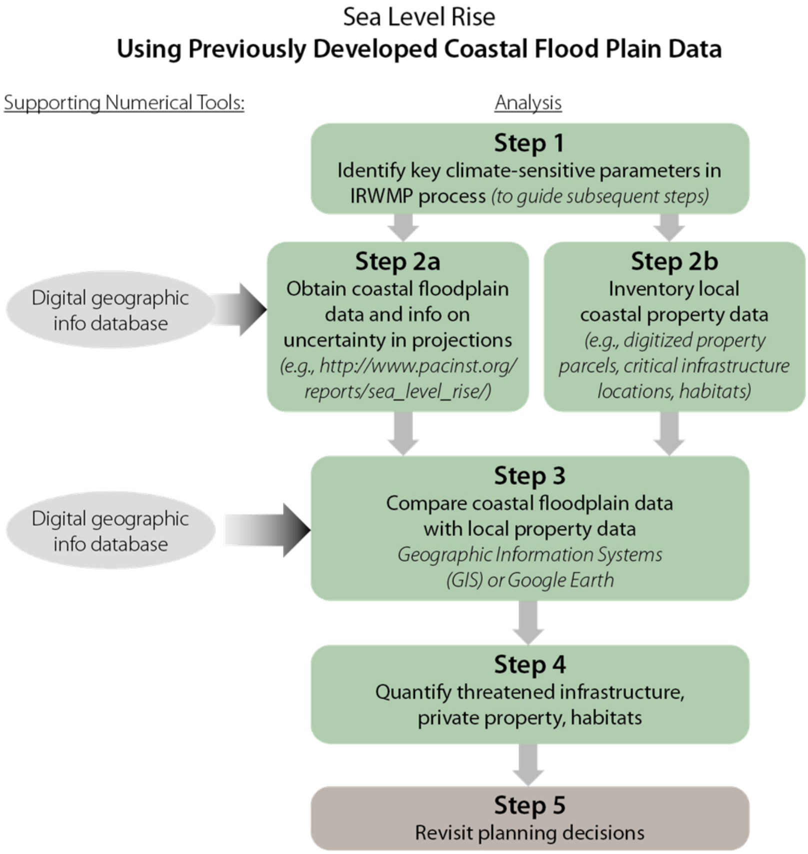


Figure 5-12: Coastal Flooding from Sea Level Rise Process Flow-chart.

Incorporating Uncertainty

The dominant source of uncertainty in this type of analysis is that associated with the sea level rise estimates used to make the floodplain maps. For documentation of uncertainties associated with the Pacific Institute study, see the original report developed by the Pacific Institute (Herberger et al 2009).

Other uncertainties are associated with assumptions made regarding what coastal infrastructure will be present in the planning horizon. Step 4 in Figure 5-12 includes incorporating uncertainty.

The use of multiple projections of sea level rise and shoreline changes from multiple expert sources might be an appropriate technique for addressing uncertainty in this type of planning analysis.

Potential Performance Metrics

Possible performance metrics for sea level rise include differences in the amount of infrastructure contained in the present 100-year floodplain and the 100-year floodplain with sea level rise. This comparison could be quantified by the potential cost for repairs in a flood event; or it could be quantified by the critical nature of the vulnerable infrastructure (influencing regional ability to respond in an emergency). Step 6 of Figure 5-12 represents quantifying performance metrics.

5.3.6 Flooding

The current suite of GCMs are not designed to project future extreme weather events and may not be the appropriate tools for evaluating these impacts. While the current suite of GCMs provides the best available information on long-term global climate trends at a monthly time step, extreme precipitation events that cause flooding occur at hourly and daily time steps. In addition, precipitation patterns are strongly influenced by regional and subregional geography, especially in mountainous areas. GCMs are not designed to provide information at these scales or time steps, and downscaling methods may not provide adequate accuracy or precision for making flood planning decisions. Therefore, the tools and strategies described for other planning activities that rely on GCM data are likely not appropriate for incorporating climate change into flood planning decisions.

Unfortunately, there are few examples of alternative tools and methods specifically tailored to incorporating climate change considerations into flood planning (DWR 2010c). Despite a lack of analysis methods, assessment of climate change impacts on future flooding is still an important aspect of regional water planning.

Given the difficulty in quantitatively assessing the frequency and severity of future storms, regional planners may need to take more qualitative approaches to assessing future flood risks, such as a threshold analysis, sensitivity analysis, or relative change analysis. An example threshold analysis method (described below) has been used by DWR as part of the Central Valley Flood Protection Plan (CVFPP). Other possible methods for planning for increased flood severity include applying a large uncertainty buffer to existing floodplain analyses. For example, one CWP recommendation is to refrain from placing critical infrastructure within 200-year floodplains (DWR 2009). DWR maintains the best available floodplain mapping throughout the state at: http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/best_available_maps/. This data is a useful starting point for any flood planning exercise.

DWR's FloodSAFE is an integrated system-wide approach for sustainable flood risk management (http://www.water.ca.gov/floodsafe/). FloodSAFE manages several projects, including the Central Valley Flood Protection Plan (CVFPP), which is scheduled to be adopted by July, 2012 by the Central Valley Flood Protection Board. The FloodSAFE web site contains resources for many flooding topics, including progress on the CVFPP.

5.3.6.1 Threshold Analysis

A threshold analysis approach is being developed by DWR. The CVFPP will describe a system-wide approach for implementing possible future flood management improvements in the Central Valley, with a focus on lands currently protected by the State Plan of Flood Control. Planners may choose to tailor the threshold analysis approach described in the CVFPP Threshold Analysis Work Plan (DWR 2010d) (Work Plan) to their region. This subsection's methodology is based closely on the CVFPP Work Plan.

Data Needed

This analysis requires knowledge of current water systems in the region, including existing floodplains and flood control infrastructure. If an existing regional hydrologic model exists, the process of obtaining data and assessing the current regional flood control systems may be facilitated. Historical data relating past flooding events to hydrologic and atmospheric conditions is also needed.

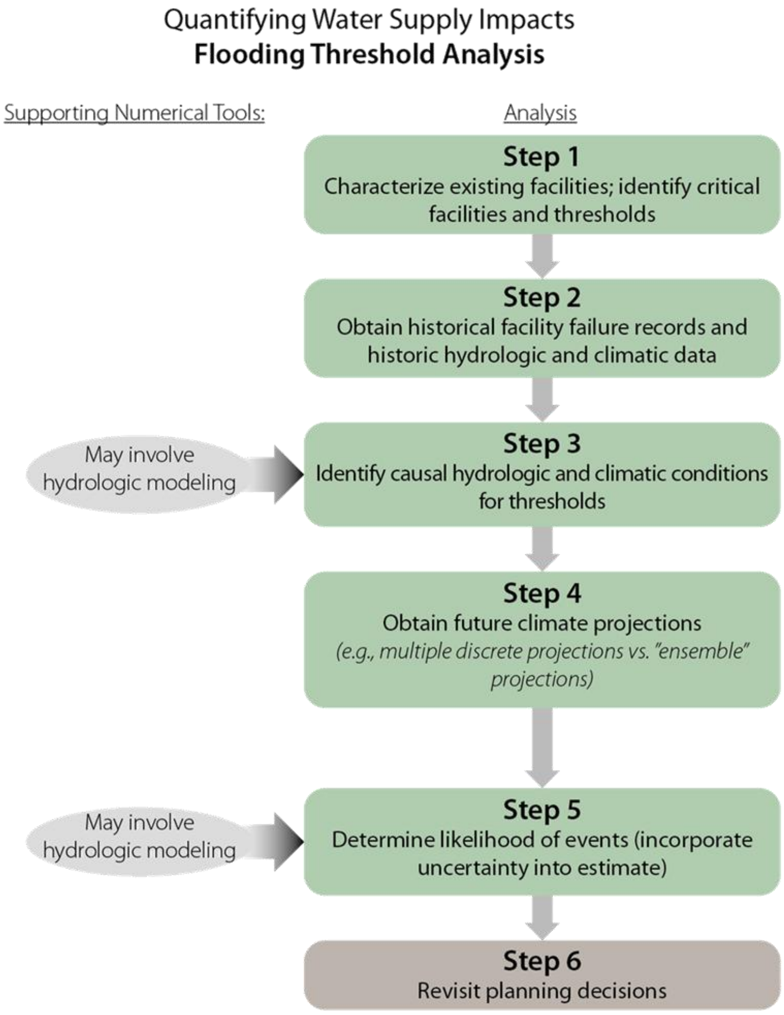


Figure 5-13: Flooding Threshold Analysis Process Flow-chart.

Conducting the Analysis

The threshold analysis approach developed by DWR follows the following components:

- Identify critical components (e.g., levees), thresholds (e.g., conditions for levee failure), and consequences (e.g., flooding, resulting in property damage and economic losses);
- Identify climatic and hydrologic conditions that will result in crossing thresholds; and
- Characterize likelihood of conditions that result in undesirable consequences.

Thresholds

Characterizing and describing the regional flood management system and operations is an important first step to assessing thresholds. Of the many critical components and thresholds identified in the Central Valley system, examples include levee failure, objective reservoir release exceedence, and uncontrolled releases from major flood control reservoirs. This process of identifying particularly vulnerable facilities is similar to the vulnerability assessment described in Section 4 of this handbook. Thresholds can be framed in terms of performance metrics identified in an IRWMP.

Causal conditions

Once key thresholds have been identified, the hydrologic and climatic conditions that could lead to approaching thresholds are identified. The CVFPP Work Plan Identifies hydrologic and atmospheric metrics that help characterize causal conditions. Hydrologic metrics discussed in the Work Plan include:

- 3-day and instantaneous peak flow,
- Flow volumes over several-day increments (1-day through 30-day),
- Flow duration,
- Inundation duration,
- Seasonal flow timing, and
- Time to peak flow.

Atmospheric metrics discussed in the Work Plan include:

- Atmospheric river index,
- Freezing elevation, and
- Rain-on-snow events.

Likelihood

Estimating the likelihood of specific atmospheric metrics may be difficult to do using GCM results, though it is possible to follow extreme event sampling (the CVFPP Work Plan describes a methodology for extreme event GCM sampling). However, because the GCMs are not designed to represent extreme events, qualitative methods may also be used to develop scenarios or assumptions about future extreme weather events. Qualitative assumptions and expert opinions may be used to develop likelihood brackets. Sensitivity analyses can also be used to assess the climatic conditions that would result in thresholds being crossed.

Incorporating Uncertainty

Uncertainty in threshold flooding analyses has several sources:

- Our limited understanding of existing facilities. A threshold analysis relies on an accurate assessment of thresholds that would result in undesirable consequences. It also relies on a solid understanding of the consequences that would result from a critical facility failure.
- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and often are viewed as effectively “random” for planning purposes.

- Our estimates of how likely certain events are. While it is likely that severe storm events will become more frequent as the climate warms (CCSP 2009), assessing likelihood of specific precipitation events and resulting hydrologic responses is difficult to do using available science.

Potential Performance Metrics

The various consequences identified with threshold exceedences may include undesirable events, such as casualties and economic damage. The risk associated with these events may be a metric used to evaluate potential flooding impacts under various project alternatives. Exceedance thresholds such as 100-year protection might be an appropriate performance metric; however, such metrics may be moving targets if climate change alters the recurrence interval for extreme flooding events.

5.3.6.2 Flood Assessment in the Central Valley

Within the Central Valley, the 200-year floodplain is the standard for planning purposes. These maps are available from the DWR database. The CVFPP has completed a draft scope report that identifies methods for taking climate change into account in future work (DWR 2009). Following recommendations in the scoping report, the Climate Change Threshold Analysis Workgroup developed the Work Plan (DWR 2010d) discussed above. The results from the Flood Protection Plan will require cities and counties in the Central Valley to modify their general plans and zoning accordingly, and comply with the required level of flood protection.

Regions within the Central Valley will be able to make use of CVFPP results and materials for planning purposes. FloodSAFE is an excellent resource for up to date information (http://www.water.ca.gov/floodsafe/).

5.3.7 Hydropower

Hydropower production could be impacted by shifts in streamflow timing that result from climate change. To quantify this loss in power production, it is possible to incorporate climate change into a power production model (Vicuña et al 2009, Chung et al 2009). The steps for this type of analysis are similar to the steps for a watershed model created for water supply analysis (see Section 5.3.2, Figure 5-7).

Data Needed

The information required to calibrate a dam operation model to an existing system includes:

- Historical streamflows entering the reservoir;
- Historical precipitation and evaporation rates for the reservoir;
- Historical and anticipated future dam operations rules , including:
    - Environmental flow release requirements,
    - Downstream water demand requirements,

  - Power production objective,
  - Any other flow-related constraint or objective,
  - Weighting of flow requirements and objectives, and
  - Flood protection rule curves (required flood storage space),
- Future streamflows impacted by climate change.

Future streamflows under climate change conditions may be obtained from a hydrologic model (see Section 5.3.2), or by adjusting historical flows, according to general trends projected in the literature for streamflow, as climate change becomes more evident (i.e., earlier snowmelt).

Conducting the Analysis

A model that has been calibrated to accurately represent historical dam operations can be used to assess impacts of climate change by using the model to analyze potential future streamflow scenarios that incorporate the likely impacts of climate change.

Incorporating Uncertainty

Uncertainties associated with future hydropower projections include:

- Our limited understanding of how the physical system responds to climate and other variables (i.e., gaps in the science of the hydraulic and hydroclimate system).
- Numerical accuracy of the hydrologic models. This uncertainty is associated with limitations of the underlying mathematical equations and the way the model solves these equations. There is also uncertainty associated with the assumption that the historical calibration dataset is comprehensive enough to provide a representative calibration for use in projecting the future.
- Hydrologic and climate variability. Fluctuations in climate and hydrology at annual or sub-annual time scales are not predictable and are often viewed as effectively “random” for planning purposes.
- Operational changes that may take place in the future.
- Water use changes in the future with diversions from, and return flows to, streams.
- Future changes in regulations and instream flow requirements.
- Projections of future conditions, including future land use and land cover, infrastructure development, and climate variables (step 3 in Figure 5-7).

As above, a suite of model simulations might be developed based on different assumed future climate conditions. These climate scenarios might be combined with a range of operational assumptions to arrive at a set of model projections that capture a degree of the uncertainty inherent in the analysis.

Potential Performance Metrics

Potential performance metrics include loss in power production or shifts in timing of power production.

Using the information and resources provided in this section, the reader should now be able to:

- Select an analytical approach for measuring the impacts associated with each of the vulnerabilities identified in the Vulnerability Assessment step,
- Gather the necessary data required as input for the analysis,
- Decide on a set of assumptions or scenarios that will represent how the region characterizes future climate, and
- Conduct the analysis.

  The result of these activities will be: 1) a set of projected future conditions that assume some level of climate change occurring over the planning period, and 2) a performance metric for each sector or resource identifying how well that sector is projected to perform. The performance metrics should directly reflect a project's contribution toward meeting the objectives of an IRWMP.

5.4 Summary

This section provides information on:

- Determining the level of sophistication appropriate for a region's highly prioritized climate vulnerabilities,
- Resources available for defining future climate variables to use to conduct many types of quantitative and/or qualitative analyses of many types of water resource vulnerabilities, and
- Resources available for conducting various types of quantitative and qualitative analyses for many types of water resource vulnerabilities.

While this section discusses many analysis tools and methods, it is not comprehensive. Planners are encouraged to ensure that the analysis methods they use for planning purposes are both appropriate to their needs and current to scientific advances. The data sources and tools in Appendix D may also be a useful resource for this exercise.

Results from the analyses conducted in this section are useful in quantifying performance metrics to help planners evaluate projects and identify the need for additional projects in a planning portfolio. This process is discussed in Section 6.

Section 6

Evaluating Projects, Resource Management Strategies, and IRWM Plan Benefits with Climate Change

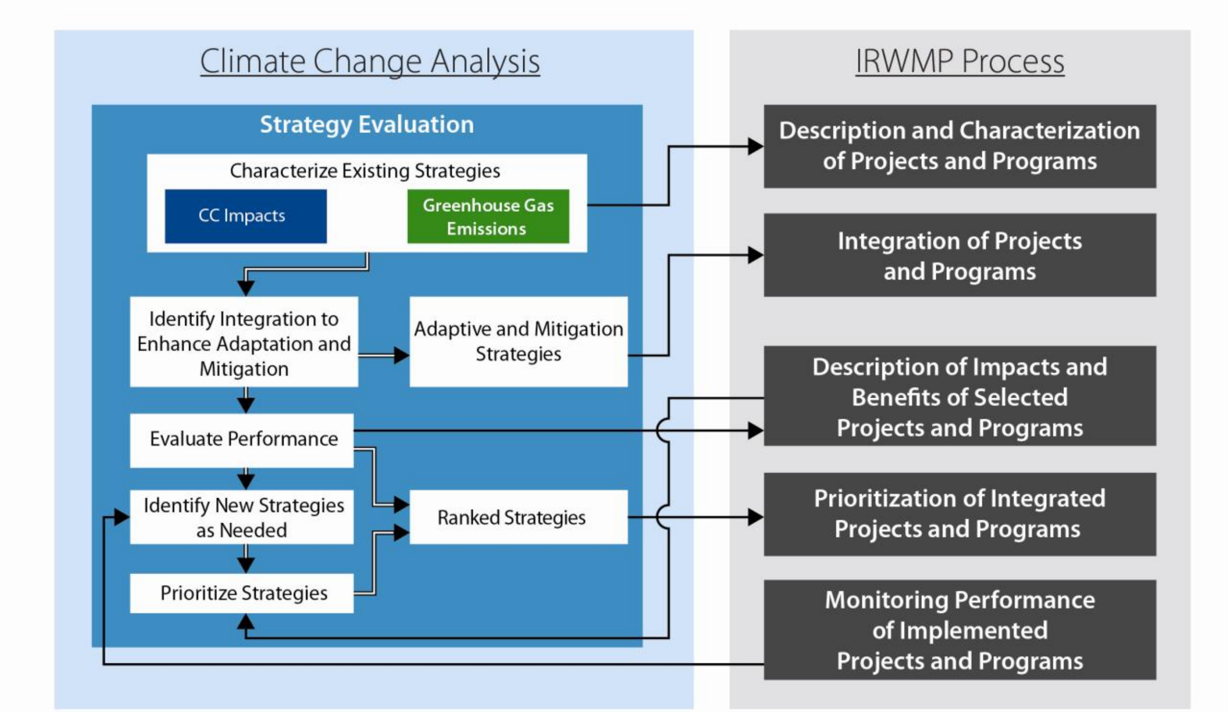


Figure 6-1. Process for Evaluating Strategies as part of an IRWMP.

The analytical methods discussed in Section 5 provide information about projected future conditions in a region that can be used to evaluate IRWM projects, assess strategies, and estimate project and strategy benefits. Many IRWM projects and strategies can provide climate change mitigation, such as projects with lower energy requirements than the status quo. IRWM projects may also enhance climate change adaptation, such as a project that increases water supply flexibility. This section describes the evaluation and comparison of projects and project portfolios for climate change mitigation and adaptation performance. The basic elements associated with evaluating strategies and their resulting projects and programs in the presence of climate change are depicted in Figure 6-1.

***Project Integration**: Combining or refining individual (and likely local) projects into a single, regional project.*

In addition to the evaluation of individual projects, this section describes how a climate change evaluation should also address projects collectively (e.g., as a “portfolio” of projects). Project portfolio evaluation is necessary to describe the potential impacts and benefits of an IRWMP. Project portfolio evaluation often requires a separate analysis for two main reasons:

1) The planner may integrate some of the selected projects to achieve synergies and increase cost-effectiveness. Integration can alter individual project characterizations so that portfolio performance is not simply a combination of individual project performances; and

2) The portfolio of projects included in the IRWMP may have benefits that are not equal to the sum of benefits of the individual projects in the plan.

Figure 6-2 presents a potential/typical path for the projects in an IRWMP and where the climate change evaluation takes place. The steps use terminology specific to IRWMPs but common to most regional and watershed-based planning efforts.

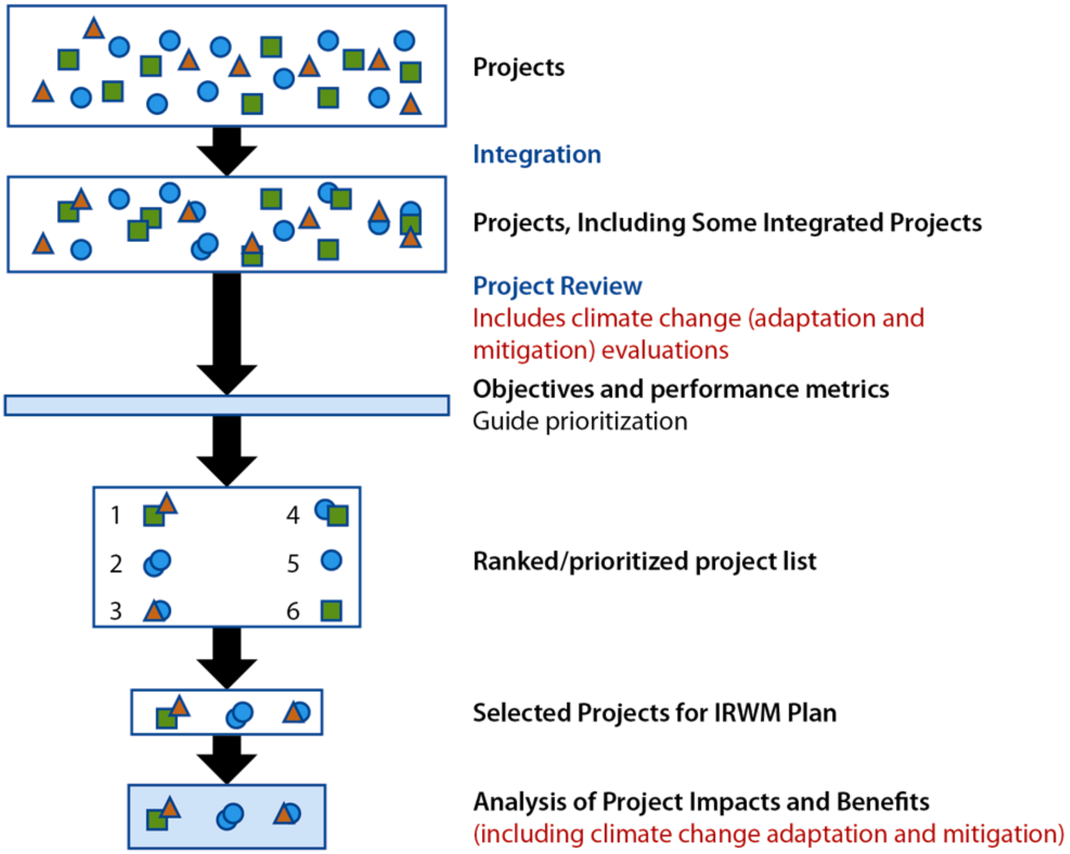


Figure 6-2. Typical Process Leading from Projects to IRWMP Plan.

This section focuses on the importance of incorporating climate change into project performance metrics which includes:

- Quantifying a “baseline” for climate change impact analysis,
- Applying performance metrics that incorporate climate change mitigation and adaptation goals to evaluate projects, integrated projects, and project portfolios,
- Considering Resource Management Strategies in identifying and evaluating projects, and
- Options for weighting and combining performance metrics related to climate change in the evaluation process.

6.1 Climate Vulnerabilities, Objectives, and Performance Metrics

6.1.1 Transition from Vulnerabilities to Performance Metrics

The objectives in an IRWMP dictate the analysis needed to characterize projects in the IRWM planning process. A project or program in any regional plan can be characterized in terms of how much it costs, how much water it supplies, how much water it treats, how it may impact a Disadvantaged Community (DAC), or how it enhances habitat. If a plan does not include objectives related to, for example, managing salinity, the planner does not need to evaluate the salinity management benefits of a given project. The objectives and resulting performance metrics dictate the analysis required to evaluate all projects. Climate change adaptation and mitigation goals must be incorporated into the objectives and performance metrics in order to have an influence on a plan’s outcome. Figure 6-3 illustrates potential progression from vulnerabilities identified in Section 4 of this handbook, to performance metrics measured in Section 5 of the handbook, to evaluating projects based on their performance in Section 6 of the handbook.

A single performance metric for climate change adaptation is not appropriate or adequate.

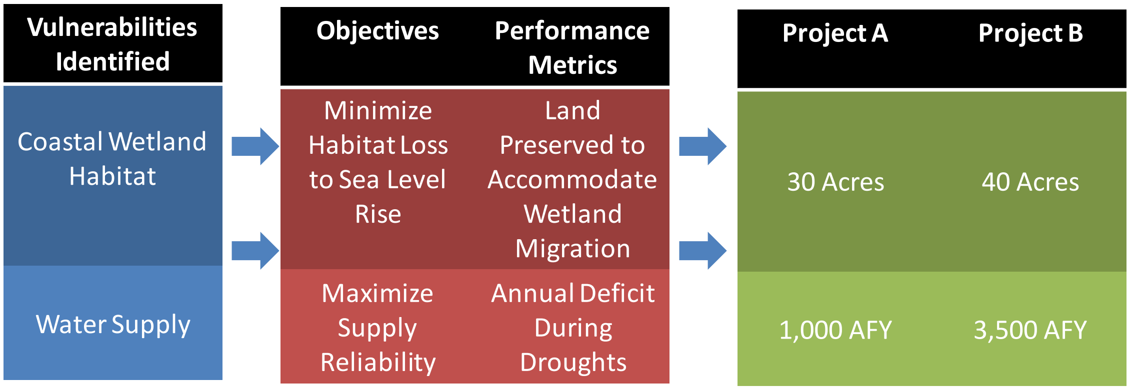


Figure 6-3: Example of Project Contributions to Climate Change Adaptation.

6.1.2 Incorporating Climate Change Objectives with Other Planning Objectives

California's IRWMP standards describe relevant attributes for plan objectives and introduce the concept of a hierarchy of objectives. Table 6-1 illustrates an example of the hierarchy of objectives, sub-objectives, and performance metrics. It also demonstrates how climate change adaptation may be included with other objectives and performance metrics; some of the items in the table are not directly (or even indirectly) related to climate change.

Table 6-1. Example of One Objective, One Sub-Objective with Two Performance Measures (Qualitative and Quantitative)

Objective	Sub-Objective	Performance Metrics
Develop A Reliable Water Supply	Increase water supplied by sources that are not vulnerable to climate change.	Number of sources not vulnerable
		Amount of annual supply with reduced vulnerability
	Develop water supplies that are resistant to earthquakes	Increase in seismically resistant water supplies.

If climate change is incorporated into objectives and performance metrics, the contributions of a project to adapt to and/or mitigate climate change are considered in project development and evaluation, along with other planning objectives. While climate change mitigation is limited to GHG emissions reduction (from a baseline) and GHG sequestration opportunities, adaptation benefits can be found in many watershed and regional functions. Because of this, a single performance metric for climate change adaptation is not appropriate or adequate. Instead, the extent to which a project, a strategy, and the IRWMP as a whole, helps the region adapt to climate change is better described by a series of performance metrics related to more general objectives (as shown in Table 6-1).

When evaluating a project in any planning process (with or without climate change), the combined numerical or qualitative values for performance measures, should reflect the benefits of that project. If climate change is added to the planning process, the climate change adaptation benefits of projects should also be measurable by performance measures. Figure 6-3 illustrates this concept. In the figure, both projects contribute to climate change adaptation. Project B preserves more habitat area than Project A, but Project A is better than Project B in maximizing drought reliability. The planner may chose to create a composite index of climate change adaptation performance using the performance metrics values for each project, as well as information on the weight or priority of the planning objectives. Section 6.6 presents an example of a method to generate a composite index using objective weights. This type of composite evaluation and weighting helps planners evaluate and incorporate tradeoffs involved with various project alternatives.

6.2 Evaluating Project Performance Using Climate Change-Related Performance Metrics

Performance metric evaluation in an IRWMP occurs at three stages: the baseline level, the project level (individual or integrated), and at the IRWMP level for a portfolio of projects. Evaluation at each of these stages is summarized in this section. Climate change considerations are incorporated into this evaluation process in three ways:

1. Any performance metric that may be *influenced by* climate change impacts needs to be quantified in a manner that accounts for this possible influence, as described in Section 5. An example would be the annual yield of a storage project, which is an important metric to characterize such a project, but can be impacted by climate change. Methods discussed in Section 5 can be used to incorporate climate change into evaluating these performance metrics.

2. Some performance metrics may *explicitly address* climate change adaptation. These performance metrics must be quantified and added to the mix of performance metrics that contribute to overall project portfolio ranking and weighting. Examples of performance metrics that explicitly address climate change are included in Figure 6-3. Methods discussed in Section 5 can be used to evaluate these performance metrics.

3. At least one performance metric should *explicitly address* climate change mitigation. These performance metrics must be quantified and added to the mix of performance metrics that contribute to overall project portfolio ranking and weighting. An example of a performance metric explicitly addressing mitigation is emissions of CO_2 equivalent in metric tons per year. Methods discussed in Section 3 can be used to evaluate these performance metrics.

The analyses discussed in Section 5 can also be used to quantify climate change impacts for a "baseline future", which is the existing set of projects and programs in the region. Climate change impacts on the baseline future system contribute to the regional description in an IRWMP, and should influence regional objectives. Baseline performance metrics also provide a basis of comparison for potential projects, project portfolios, and programs.

6.2.1 Baseline (Climate Change Conditions and No New Projects)

The "baseline" conditions are the existing set of environmental conditions and the existing set of regional or local projects and programs. For planning purposes, projecting baseline conditions into the future provides a "no action" alternative analysis. This future baseline identifies how the current set of projects, programs, and infrastructure would perform over the planning period; which is 20 years for IRWMPs (DWR 2010a). Thus, this includes analysis of how changes in population, demographics, land use, economic conditions, and climate are likely to affect conditions in the region. The baseline conditions will help identify both problems that already challenge the region, and problems that will likely challenge the region in the future. Therefore, this analysis helps inform the development of additional objectives aimed at meeting the challenges. The baseline performance also serves as a benchmark from which to compare impacts and benefits of the final plan.

When the baseline conditions are analyzed, all relevant aspects of the regional environment should be incorporated into the analysis. For example, this might include:

- Existing regional characteristics, such as water supplies and demands,
- Ongoing projects and existing institutional programs, such as river or wetland restoration efforts,
- Existing operational policies, such as dam release rules, and
- Existing population, land use, and cropping patterns.

Comparing results from the analyses discussed in Section 5, conducted with and without accounting for climate change, allows planners to quantify climate change impacts. Evaluating the performance of the baseline, however, should *not* include analysis results without climate change considerations. The distinction between quantifying climate change impacts and evaluating baseline performance is depicted in Figure 6-4.

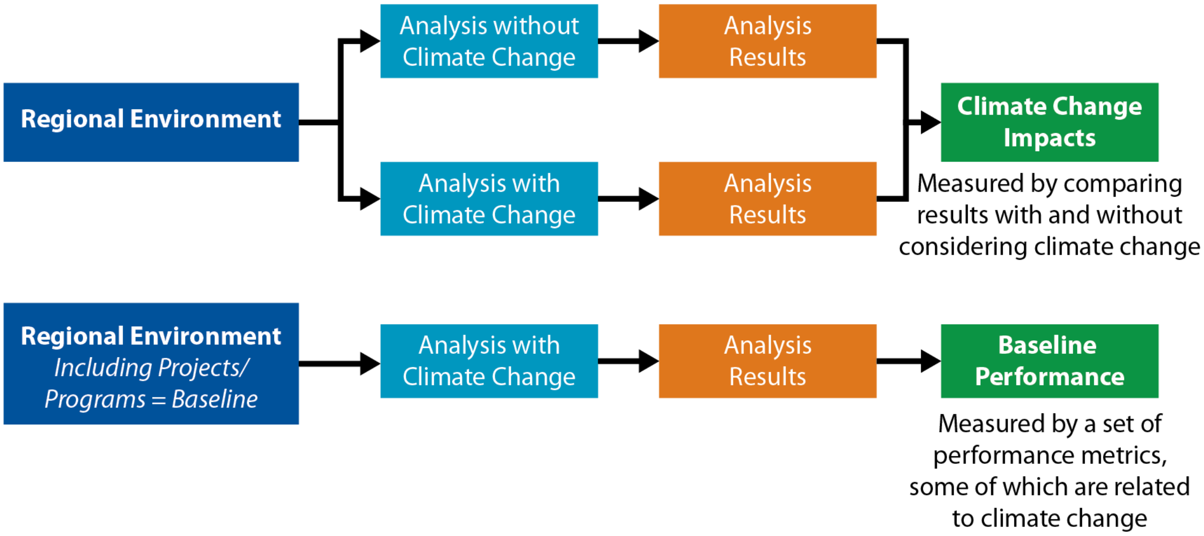


Figure 6-4: Baseline Conditions Performance Metric Evaluation.

Baseline analysis results are translated into performance metrics for comparison with the portfolio of projects and programs included in the IRWMP. Planners can describe the benefits of the plan by comparing the baseline with the portfolio of projects and programs.

6.2.2 Evaluating Individual Projects

Climate change will not impact every project. Planners must evaluate each project to determine if its expected performance might be impacted by climate change. The project then needs to be evaluated using the same assumptions about future climate change (i.e., planning scenarios) that were used to evaluate the baseline future conditions.

In many cases, project performance can be measured by adjusting the baseline analysis to represent inclusion of the project. For example, the change in water supply that would result from a project to raise a reservoir's capacity may require adjustment of a regional water system operational model (such as WEAP or an equivalent – see Section 5 and Appendix D.2). The performance metrics resulting from this new analysis would reflect the adaptation inherent in the project. The process of re-visiting the baseline and adjusting to account for a potential project is depicted in Figure 6-5.

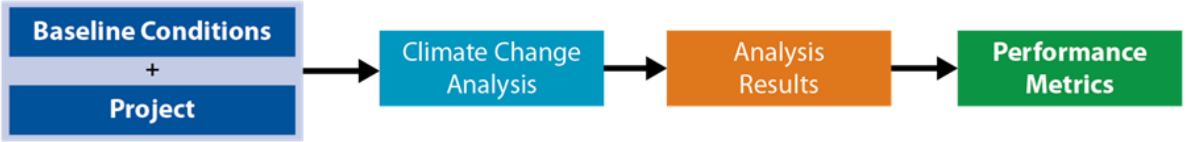


Figure 6-5: Project Performance Metric Evaluation.

6.2.2.1 Project Integration

Project integration can serve as a way to maximize project performance and synergies among projects and minimize conflicts and tradeoffs . Because climate change impacts on various water resources are interrelated, compound effects from integrating projects has the potential to greatly increase adaptation. For example, if habitat preservation projects are integrated with floodplain management projects, both projects are likely to see increased climate adaptation, as many floodplain management strategies involve habitat conservation. Examples of such synergies are discussed throughout this section of the handbook.

6.2.3 Evaluating Project Portfolios

As discussed above, integrated and grouped projects and programs may not have the same benefits and performance as the sum of their individual projects and programs. Portfolios of projects and programs (the list of projects included in the IRWMP) are evaluated against planning performance metrics in the IRWMP process. Portfolio performance evaluation is similar to individual project evaluation. In portfolio evaluation, the baseline conditions are adjusted to reflect all selected projects and programs after integration. The process of adjusting baseline analyses to reflect project portfolios is depicted in Figure 6-6.

***Project Portfolio**: a collection of projects selected in an IRWMP.*

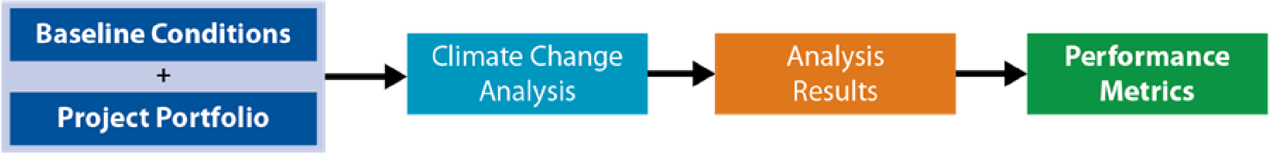


Figure 6-6: Project Portfolio Performance Metric Evaluation.

6.3 Resource Management Strategies

As existing and proposed projects are evaluated, gaps in performance objectives may indicate the need for additional projects. The IRWMP guidelines require consideration of the CWP 2009 Update's Resource Management Strategies (RMSs) in identifying projects for IRWMPs. The CWP dedicates Volume II to discussing these RMSs. Because the CWP discussion is comprehensive and includes strategies that apply to most climate change adaptation and/or mitigation projects, this handbook uses the CWP RMSs as a basis for RMS discussion. The CWP also includes many region-specific RMSs, which regions should consider in project development. In addition, many regions have their own priorities and strategies. Many other sources provide detailed information on adaptation strategies, and are included in Appendix A of this handbook. The general CWP RMSs include:

1. Reduce Water Demand:
    - Agricultural Water Use Efficiency, and
    - Urban Water Use Efficiency.
2. Improve Operational Efficiency and Transfers:
    - Conveyance – Delta,
    - Conveyance – Regional/local,
    - System Reoperation, and
    - Water Transfers.
3. Increase Water Supply:
    - Conjunctive Management and Groundwater Storage.
    - Desalination,
    - Precipitation Enhancement,
    - Recycled Municipal Water,
    - Surface Storage – CALFED, and
    - Surface Storage – Regional/local.
4. Improve Water Quality:
    - Drinking Water Treatment and Distribution,
    - Groundwater Remediation/Aquifer Remediation,
    - Matching Quality to Use,
    - Pollution Prevention, and
    - Salt and Salinity Management.

5. Urban Runoff Management (including Low Impact Development[1])
6. Practice Resource Stewardship:
    - Agricultural Lands Stewardship,
    - Economic Incentives (Loans, Grants, and Water Pricing),
    - Ecosystem Restoration,
    - Forest Management,
    - Land Use Planning and Management,
    - Recharge Area Protection,
    - Water-dependent Recreation, and
    - Watershed Management.
7. Improve Flood Management:
    - Flood Risk Management.
8. Other Strategies:
    - Crop Idling for Water Transfers,
    - Dewvaporation or Atmospheric Pressure Desalination,
    - Fog Collection,
    - Irrigated Land Retirement,
    - Rainfed Agriculture, and
    - Waterbag Transport/Storage Technology.

The California Climate Adaptation Strategy provides another set of adaptation strategies that are targeted at specific sectors (e.g., water, agriculture, health). Adaptation strategies from the California Climate Adaptation Strategy that are specifically applicable to IRWMPs are listed below (CNRA 2009):

- Aggressively increase water use efficiency, targeting:
    - Water efficiency,
    - Energy efficiency, and
    - Water conservation.
- Practice and promote integrated flood management by improving:
    - Flood management,
    - System reoperation, and
    - Land use policies.

---

[1] Low Impact Development is an increasingly important RMS that enhances pollution prevention, aquifer recharge, and overall watershed health. For more information, visit the Low Impact Development Center: http://www.lowimpactdevelopment.org/

- Enhance and sustain ecosystems, targeting:
    - Species migration and movement corridors,
    - Floodplain corridors,
    - Anadromous fish,
    - Tidal wetlands as buffers,
    - Reversal of Delta island subsidence, and
    - Upper watershed services.
- Expand water storage and conjunctive management of surface and groundwater resources by:
    - Expanding water storage,
    - Conducting surface storage feasibility studies,
    - Developing conjunctive use management plans and groundwater management plans, and
    - Implementing local ordinances.
- Fix Delta water supply:
    - Participate in Delta adaptation planning.
- Preserve, upgrade, and increase monitoring, data analysis, and management, targeting:
    - Climate monitoring,
    - Atmospheric observations,
    - Water use feasibility studies, and
    - Water use accountability.
- Plan for and adapt to sea level rise.

The set of RMSs appropriate for a region depends on regional needs, vulnerabilities, and priorities. If a region's list of potential projects and programs does not meet the region's objectives regarding climate change adaptation, additional projects may be added that incorporate additional climate change adaptation strategies. In addition, launching or augmenting a comprehensive data collection and monitoring program may be needed, especially in cases where data availability limits comprehensive analysis. Section 6.3.1 discusses ways in which various RMSs can be applied to climate change adaptation and/or mitigation, and some performance metrics that could quantify any adaptation/mitigation.

Not all of the CWP RMSs directly apply to climate change adaptation or mitigation efforts. Instead, many are directed at overall system resiliency, which also improves resilience to climate change impacts.

> ***Resilience**: The ability of a system to absorb some amount of change, including shocks from extreme events, bounce back and recover from them, and, if necessary, transform itself in order to continue to be able to function and provide essential services and amenities that it has evolved or been designed to provide.*
>
> *--- IPCC 2001*

6.3.1 Adaptation Strategies

This section discusses ways in which each of the CWP RMSs can be used to adapt to climate change. It also discusses some ways that the RMS performance can be impacted by climate change. All discussions in this section are necessarily generic given that the applicability of any RMS to climate change adaptation is specific to the project, the specific climate change impact, and the region.

Table 6-2 summarizes the CWP strategies and their potential ability to aid in climate change adaptation. Many strategies have multiple potential benefits, indicating potential synergies among projects that result from these strategies.

6.3.1.1 Reduce Water Demand

The Reduce Water Demand strategy includes water use efficiency measures for urban and agricultural water use. California has made progress in encouraging water conservation and water use efficiency. The state's 20x2020 Water Conservation Plan (20x2020 Plan) (http://www.swrcb.ca.gov/water_issues/hot_topics/20x2020/index.shtml) includes measures that can, and should, be taken to conserve urban water use. Many of the strategies discussed in the 20x2020 Plan could potentially be expanded to further increase conservation efforts. In water demand/supply projections, however, it is important that regions not "double count" water conservation measures – if demand projections already account for 20x2020 Plan conservation targets, only strategies that expand on the 20x2020 Plan conservation measures should be considered additional demand reductions.

Municipal and irrigation demands are both potential sources of water conservation. According to the 20x2020 Plan, landscape water use has the greatest potential for reduction of any urban water use sector.

Table 6-2. Applicability of CWP Resource Management Strategies to Climate Change Adaptation

Resource Management Strategies	Climate Change Adaptation							
	Habitat Protection	Flood Control	Water Supply Reliability	Additional Water Supply	Water Demand Reduction	Sea Level Rise	Water Quality Protection	Hydropower
Reduce Water Demand								
Agricultural Use Efficiency			✓		✓		✓	
Urban Water Use Efficiency			✓		✓		✓	
Improve Operational Efficiency and Transfers								
Conveyance – Delta	✓	✓	✓	✓		✓	✓	
Conveyance – Regional/local	✓	✓	✓	✓			✓	
System Reoperation		✓	✓	✓				✓
Water Transfers			✓	✓				
Increase Water Supply								
Conjunctive Management and Groundwater Storage		✓	✓	✓			✓	
Desalination			✓	✓				
Precipitation Enhancement				✓				✓
Recycled Municipal Water			✓	✓				
Surface Storage – CALFED	✓	✓	✓	✓			✓	✓
Surface Storage – Regional/local	✓	✓	✓	✓			✓	✓
Improve Water Quality								
Drinking Water Treatment and Distribution			✓	✓			✓	
Groundwater Remediation/Aquifer Remediation			✓	✓			✓	
Matching Quality to Use			✓	✓			✓	
Pollution Prevention	✓		✓				✓	
Salt and Salinity Management	✓		✓	✓			✓	
Urban Runoff Management	✓	✓					✓	
Practice Resource Stewardship								
Agricultural Lands Stewardship	✓	✓			✓		✓	
Economic Incentives (Loans, Grants and Water Pricing)	✓	✓	✓	✓	✓	✓	✓	✓
Ecosystem Restoration	✓	✓	✓			✓	✓	
Forest Management	✓	✓	✓				✓	
Land Use Planning and Management	✓	✓				✓	✓	
Recharge Area Protection		✓	✓	✓			✓	
Water-dependent Recreation	✓	✓	✓				✓	
Watershed Management	✓	✓	✓	✓		✓	✓	✓
Improve Flood Management								
Flood Risk Management	✓	✓				✓	✓	✓
Other Strategies								
Crop Idling for Water Transfers			✓	✓	✓			
Dewvaporation or Atmospheric Pressure Desalination				✓				
Fog Collection				✓				
Irrigated Land Retirement			✓		✓			
Rainfed Agriculture					✓			
Waterbag Transport/Storage Technology	✓		✓	✓		✓	✓	

The Agricultural Water Management Council (www.agwatercouncil.org) promotes several efficient water management practices (EWMPs). EWMPs include infrastructure and operational improvements, such as canal lining and pump operation optimization. EWMPS also include district level management activities, such as facilitating recycled urban water use and other supporting efforts.

Performance metrics that could quantify water use efficiency project adaptation include:

- Average (annual) water demand reduction, and
- Peak (seasonal, monthly) water demand reduction.

6.3.1.2 Improve Operational Efficiency and Transfers

The Improve Operational Efficiency and Transfers strategy includes optimizing system operations to maximize efficiency. It also includes maintaining and improving existing infrastructure for regional and local conveyance, including facilities in the Delta and throughout the SWP and CVP.

Through system reoperation, regions may be able to adapt to climate change impacts on hydropower production. Regions may also be able to adapt to lower or less reliable water supplies and/or increased water demands by maintaining conveyance infrastructure. Well maintained conveyance infrastructure can also improve regional adaptation to climate change impacts on flooding, habitats, and water quality. Water transfers can help adapt to climate change by providing a region with additional water supply.

Performance metrics that could quantify operational efficiency or transfer project adaptation include:

- Additional supply, and
- Supply reliability.

6.3.1.3 Increase Water Supply

Potential additional supply sources include increased storage in ground and surface facilities, precipitation enhancement, recycled water use, and desalination. The California Recycled Water Policy (http://www.swrcb.ca.gov/water_issues/programs/water_recycling_policy/docs/recycledwaterpolicy_approved.pdf) goals include substituting as much recycled water for potable water as possible by 2030. Increased storage and conjunctive use may also increase resilience to shifting runoff patterns, providing more storage for early runoff. This strategy is an adaptation measure for increased demands and/or decreased supplies or supply reliability.

Performance metrics that could quantify water supply project adaptation include:

- Additional supply,
- Potable demand offset, and
- Supply reliability.

6.3.1.4 Improve Water Quality

Improving water quality includes improving drinking water treatment and distribution, groundwater remediation, matching water quality to use, pollution prevention, salinity management, and urban runoff management. These strategies may help a region adapt to not only water quality impacts from climate change, but ecosystem impacts from sea level rise, and other climate stressors as well. They may also contribute to providing additional supplies. For example, stormwater capture can provide a seasonal source of irrigation water for urban landscaping.

Performance metrics that could quantify water quality project adaptation include:

- Salt line migration,
- Stream temperature,
- Dissolved oxygen,
- Turbidity, and
- Pollutant concentrations.

6.3.1.5 Practice Resource Stewardship

Resource stewardship includes stewardship of land, wildlife, and water by way of conservation and preservation, ecosystem restoration and forest management, watershed management, flood attenuation, and water-dependent recreation. Restoring and preserving habitat and wetlands has multiple benefits. In addition to promoting biodiversity and habitat enhancement, riparian habitat restoration can be a key aspect of integrated flood management, as the natural storage provided by riparian wetlands can serve as buffers that absorb peak flows and provide slow releases after storm events (DWR 2008). Because the scope of resource stewardship includes all resources, these strategies can help adapt to climate change impacts in various ways, depending on project-specific details.

Because resource stewardship is so broad, performance metrics that could quantify resource stewardship project adaptation are also broad. Some examples include:

- Presence/absence of key indicator species,
- Acres of a certain habitat or floodplain function restored/protected, and
- Volume of natural flood storage provided.

6.3.1.6 Improve Flood Management

Flood management involves emergency planning, general planning activities (e.g., infrastructure improvements), and policy changes (e.g., defining new hazard zones). Flood management strategies can help a region adapt to many other climate change impacts, including ecosystem vulnerabilities and water quality. Performance metrics that could quantify flood management project adaptations include:

- Acres of a certain habitat or floodplain function restored/protected,
- Volume of natural flood storage provided,
- Storm return period used for planning, and
- Expected damage resulting from a certain return period storm.

6.3.1.7 Other Strategies

Other resource management strategies in the CWP include obtaining additional water supplies, such as fog capturing and waterbag transport technology. Additional conservation and demand reduction measures, such as crop idling, irrigated land retirement, and rainfed agriculture are also discussed. Waterbag transport could be used to target water quality and ecosystem protection, for instance to supplement freshwater inflows in estuaries. Fog capture, and other supply/conservation measures, could be used to adapt to climate change-induced demand increases or decreases in supply/supply-reliability.

6.3.2 Strategies for Climate Change Mitigation

Implementation of mitigation strategies can reduce GHG emissions from the baseline, or minimize increases in GHG emissions as much as possible. This can be done by:

- Carbon sequestration through vegetation growth,
- GHG emission reductions, accomplished by:
    - *Energy use efficiency*. Implementing green infrastructure and utilizing Leadership in Energy and Environmental Design (LEED) certified building technologies can save energy by reducing emissions from carbon-based energy sources.
    - *Use of renewable energy sources*. Installing roof-mounted solar panels and optimizing hydropower generation reduces reliance on carbon-based fuels which can reduce emissions.
    - *Energy-efficient water demand reduction*. While some water conservation strategies are energy-intensive, many strategies help reduce energy consumption; lowering water demands also lowers energy requirements associated with water conveyance, treatment, and distribution.

The CWP strategies presented in this section could help increase energy-use efficiency or reduce emissions. Table 6-3 also summarizes strategies assist to mitigation efforts.

Table 6-3. Applicability of CWP Resource Management Strategies to Greenhouse Gas Mitigation

Resource Management Strategies	Greenhouse Gas Mitigation		
	Energy Efficiency	Emissions Reduction	Carbon Sequestration
Reduce Water Demand			
Agricultural Use Efficiency	✓	✓	
Urban Water Use Efficiency	✓	✓	
Improve Operational Efficiency and Transfers			
Conveyance – Delta	✓	✓	
Conveyance – Regional/local	✓	✓	
System Reoperation	✓	✓	
Water Transfers[1]	X		
Increase Water Supply			
Conjunctive Management and Groundwater Storage[1]	X		
Desalination[1]	X	X	
Precipitation Enhancement		✓	
Recycled Municipal Water	✓	✓	
Surface Storage – CALFED		✓	
Surface Storage – Regional/local		✓	
Improve Water Quality			
Drinking Water Treatment and Distribution			
Groundwater Remediation/Aquifer Remediation			
Matching Quality to Use	✓		
Pollution Prevention		✓	
Salt and Salinity Management		✓	
Urban Runoff Management	✓	✓	
Practice Resource Stewardship			
Agricultural Lands Stewardship	✓	✓	✓
Economic Incentives (Loans, Grants and Water Pricing)	✓	✓	✓
Ecosystem Restoration			✓
Forest Management			✓
Land Use Planning and Management	✓	✓	✓
Recharge Area Protection			✓
Water-dependent Recreation		✓	
Watershed Management			✓
Improve Flood Management			
Flood Risk Management			✓
Other Strategies			
Crop Idling for Water Transfers		✓	
Dewvaporation or Atmospheric Pressure Desalination	✓	✓	
Fog Collection			
Irrigated Land Retirement			
Rainfed Agriculture	✓	✓	✓
Waterbag Transport/Storage Technology	X	X	

Key:

✓ Indicates that in general this will provide a beneficial effect

X Indicates that in general this will provide an adverse effect

[1] The net effect may be positive or negative, depending on the source of water that is offset by implementing the strategy

The California Climate Change Scoping Plan (CARB 2008) has several recommendations for increasing energy efficiency, reducing GHG emissions, and increasing reliance on renewable energy. Among these recommendations are the use of energy efficient and alternate fuel vehicles, reliance on solar panels and other renewable energy sources, and energy-efficient buildings. These recommendations can be worked into several of the CWP strategy elements, especially the strategies that include higher energy consumptions.

Performance metrics that quantify mitigation-related characteristics for the RMSs include:

- Project-related GHG emissions, relative to baseline (no project) emissions if appropriate (Section 3 discusses GHG emissions inventories),
- Carbon sequestered per year, and
- Energy savings (including savings from water use conservation/efficiency).

6.3.2.1 Reduce Water Demand

The Reduce Water Demand strategy includes water use efficiency measures for urban and agricultural water use. Conservation is an ideal way to reduce emissions by saving water and energy. Municipal and irrigation demands are both potential sources of water conservation.

6.3.2.2 Improve Operational Efficiency and Transfers

The strategy to Improve Operational Efficiency and Transfers includes optimizing water system operations to maximize efficiency. Maintaining and improving existing regional and local conveyance infrastructure is critical for regional and local conveyance, including facilities in the SWP and CVP.

Improving operational efficiency can indirectly reduce emissions by reducing system losses. However, many water transfers are relatively high in energy costs. As for all projects, the potential carbon footprint needs to be compared with other supply alternative projects.

6.3.2.3 Increase Water Supply

Potential additional supply sources include increased storage in ground and surface facilities, precipitation enhancement, recycled water use, and desalination. This strategy is an adaptation measure for increased demands and/or decreased supply or supply reliability.

The carbon footprint associated with increasing water supply depends a great deal on the individual strategies selected. Desalinated water and water imported from distant regions with high pumping requirements have very high carbon footprints. The high energy requirements also translate into a high cost per acre-foot of yield. Pumping requirements associated with groundwater projects may also be high. Other options, such as increasing water storage, may increase GHG emissions (i.e., via additional pumping and emissions) associated with project construction, but may have relatively low operational GHG emissions.

6.3.2.4 Improve Water Quality

The strategy to Improve Water Quality includes improving drinking water treatment and distribution, groundwater remediation, matching water quality to use, pollution prevention, salinity management, and urban runoff management. GHG emissions and energy requirements associated with the project depend on project-specific details, but matching water quality to use is generally lower in energy costs than the potable water provision that it replaces. Pollution prevention also saves money and effort that would be dedicated to treatment in the longer term.

6.3.2.5 Practice Resource Stewardship

The strategy of Resource Stewardship includes practices that improve the stewardship of land, wildlife, and water by way of conservation and preservation, ecosystem restoration and forestand watershed management, and water-dependent recreation. These strategies can help reduce carbon emissions by reducing the treatment requirements. Stewardship practices can decrease the total emissions by contributing to carbon sequestration in cases where vegetation growth is enhanced by projects.

6.3.2.6 Improve Flood Management

Flood management involves emergency planning, general planning activities (e.g., infrastructure improvements), and policy changes (e.g., defining new hazard zones). Flood management touches on many other categories, such as ecosystem protection and water quality. Where flood management projects encourage vegetation growth, carbon sequestration can potentially reduce net carbon emissions.

Flood management requirements on dam operation can compete with hydroelectric energy production, which may increase overall project, and regional, GHG emissions.

6.3.2.7 Other Strategies

Other climate change mitigation strategies in the CWP include obtaining additional water supplies, such as fog capture and waterbag transport technology. These strategies are varied and often involve emerging and innovative technologies.

Rainfed agriculture, irrigated land retirement, and crop idling may all reduce GHG emissions by conservation. Dewvaporization is less energy intensive than traditional desalination, but the method is still under development. Other methods, such as fog capture and waterbag technologies, may require more intensive energy inputs for transportation or conveyance.

6.4 Climate Change Impacts on RMSs

Some projects, including projects that can be used as part of strategies to adapt to climate change, can provide different results in the presence of climate change. These climate change impacts on adaptation/mitigation projects can be thought of as "residual" climate change impacts, or impacts that may occur even with adaptation measures present. Figure 6-7 depicts the relationship by which climate change impacts can be reduced by implementing some projects while the projects' performance can be impacted, in turn, by climate change.

To illustrate implementation of the tools discussed in Section 5 and other portions of Section 6 for project evaluation, this section provides example project evaluation methodologies that may apply to the CWP RMSs. The following subsections discuss a sample project for each overall RMS from the CWP (except "Other Strategies"). Items discussed for each project include:

- How the project may help the region *adapt* to climate change,
- Potential performance metrics and ways that they could be *influenced by* climate change, and
- Methods to account for the impacts in performance metric calculation.

Table 6-4 summarizes climate change impact measurement methods for the CWP RMS. Project evaluations resulting from the analyses discussed in this section contribute to project ranking for the development of IRWMP implementation strategies.

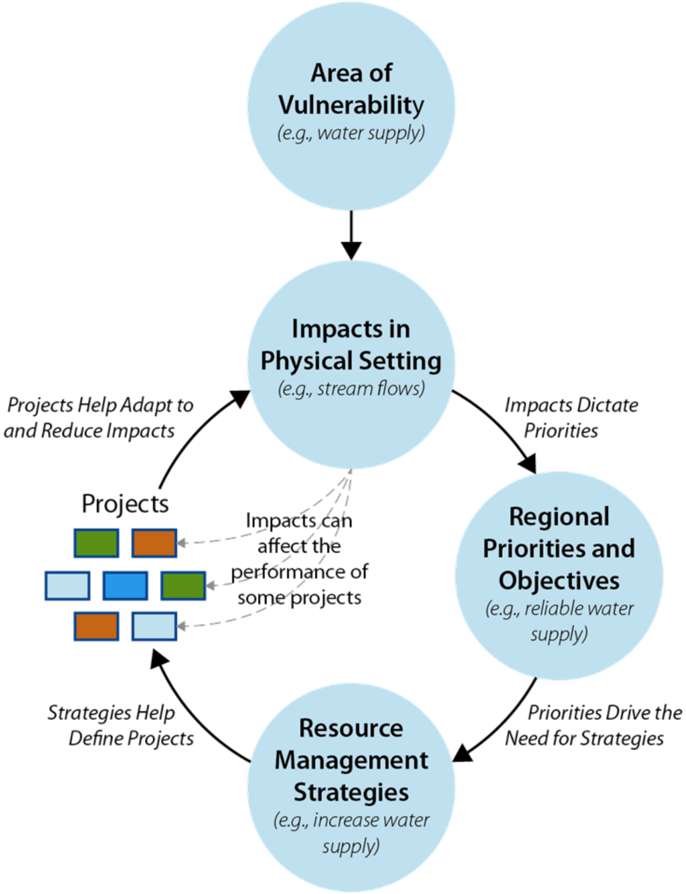


Figure 6-7: Climate Change Impacts on Physical Setting and Projects.

Table 6-4. Examples of the Types of Technical Analysis to Assess Potential Impacts of Climate Change on Performance of RMSs

Resource Management Strategies	Type of Technical Analysis to Assess Impact	Potential Climate Change Impact
Reduce Water Demand		
Agricultural Use Efficiency	Evaluation of ET impacts and demand elasticity to weather	Water Demand
Urban Water Use Efficiency	Evaluation of demand elasticity to weather	Water Demand
Improve Operational Efficiency and Transfers		
Conveyance – Delta	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Storm intensity and/or snow-line migration - streamflows	Flooding
	Inundation analysis	Sea Level Rise
Conveyance – Regional/local	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Storm intensity and/or snow-line migration - streamflows	Flooding
System Reoperation	Watershed, streamflows and water system analysis	Water Supply
	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
Water Transfers	Watershed Analysis - streamflow projections and water availability	Water Supply
Increase Water Supply		
Conjunctive Management and Groundwater Storage[1]	NA	NA
Desalination	Salt intrusion analysis (if open coastal intake or coastal discharge)	Water Quality
Precipitation Enhancement	Analysis of future climate (temperature, cloud cover, e.g.) on project functionality	Project-specific
Recycled Municipal Water	Agricultural (ET) and/or urban RW demand elasticity to weather	Water Demand Analysis
Surface Storage – CALFED	Temperature, dissolved oxygen, pollutant loading analysis	Water Quality
	Watershed Analysis - Streamflow projections	Water Supply
Surface Storage – Regional/local	Temperature, dissolved oxygen, pollutant loading analysis	Water Quality
	Watershed Analysis - Streamflow projections	Water Supply
Improve Water Quality		
Drinking Water Treatment and Distribution	Raw water stream/reservoir water quality analysis	Water Quality
Groundwater Remediation/Aquifer Remediation[1]	NA	NA

Table 6-4. Examples of the Types of Technical Analysis to Assess Potential Impacts of Climate Change on Performance of RMSs

Resource Management Strategies	Type of Technical Analysis to Assess Impact	Potential Climate Change Impact
Matching Quality to Use	Agricultural (ET) and/or urban irrigation and other urban demand elasticity to weather	Water Demand
	For untreated water use: temperature, dissolved oxygen, pollutant loading analysis	Water Quality
	For untreated water use: streamflow analysis	Water Supply
Pollution Prevention	Streamflow analysis	Water Quality
	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	
Salt and Salinity Management	Watershed Analysis - Streamflow projections	Water Quality
	Salinity intrusion analysis	
Urban Runoff Management	Temperature, dissolved oxygen, pollutant loading analysis	Water Quality
	Urban Watershed Analysis – storm drain Streamflow analysis	Flooding
Practice Resource Stewardship		
Agricultural Lands Stewardship	Storm Intensity Analysis	Flooding
	Temperature, dissolved oxygen, pollutant loading analysis	Water Quality
Economic Incentives (Loans, Grants and Water Pricing)[1]	NA	NA
Ecosystem Restoration	Storm intensity and/or snow-line migration - streamflows and wetland inflows	Flooding
	Sea Level Rise-induced marsh migration	Sea Level Rise
	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
Forest Management	Temperature, dissolved oxygen, pollutant loading analysis	Water Quality
	Watershed Analysis - streamflow projections and water availability	Water Supply
Land Use Planning and Management	Storm intensity and/or snow-line migration - streamflows	Flooding
	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Evaluation of ET impacts and demand elasticity to weather	Water Demand
Recharge Area Protection	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Watershed Analysis - streamflow projections and water availability	Streamflow
	Storm intensity and/or snow-line migration - streamflows	Flooding

Table 6-4. Examples of the Types of Technical Analysis to Assess Potential Impacts of Climate Change on Performance of RMSs

Resource Management Strategies	Type of Technical Analysis to Assess Impact	Potential Climate Change Impact
Water-dependent Recreation	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Watershed and streamflow analysis, water system analysis (for reservoir level estimates, e.g.)	Streamflow
	Storm intensity and/or snow-line migration - streamflows	Flooding
	Coastal inundation and erosion analysis	Sea Level Rise
Watershed Management	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Watershed Analysis - streamflow projections and water availability	Streamflow
	Storm intensity and/or snow-line migration - streamflows	Flooding
	Coastal inundation and erosion analysis	Sea Level Rise
Improve Flood Management		
Flood Risk Management	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Storm intensity and/or snow-line migration - streamflows	Flooding
Other Strategies		
Crop Idling for Water Transfers	Evaluation of ET impacts and demand elasticity to weather	Water Demand
Dewvaporation or Atmospheric Pressure Desalination	Analysis of future climate (temperature, cloud cover, e.g.) on project functionality	project-specific
Fog Collection	Analysis of future climate (temperature, cloud cover, e.g.) on project functionality	project-specific
Irrigated Land Retirement	Evaluation of ET impacts and demand elasticity to weather	Water Demand
Rainfed Agriculture	Evaluation of ET impacts and demand elasticity to weather	Water Demand
Waterbag Transport/Storage Technology	Salinity intrusion and/or temperature, dissolved oxygen, pollutant transport analysis	Water Quality
	Watershed Analysis - streamflow projections and water availability	Water Supply

[1] Some RMSs are related to resources that are not associated with an accepted analysis method that addressed climate change. For these RMSs, the "Type of Analysis" and "Potential Climate Change Impact" are designated "NA", or "Not Available".

6.4.1 Reduce Water Demand

One of the Agricultural Water Management Council EWMPs is to convert irrigation canals and ditches to piping. This water conservation method prevents evaporative losses, especially as temperatures rise. Thus, this could help a region adapt to climate change by expanding water supplies and making existing water supplies less vulnerable to evaporative losses.

A potential performance metric that specifically applies to this project could be water demand reduction. This metric could be influenced by climate change because evaporation from irrigation ditches and canals is a function of temperature and other climate variables that are altered by climate change. Considering climate change would influence the total demand reduction accomplished by the project.

Methods for measuring the impact of climate change on evaporative water losses could include developing a regression model between historical temperature and historical evaporation rates, then applying this relationship to projected temperatures. Alternatively, projected evaporative losses could be estimated from the suite of climate variables projected by GCM data. Regression versus process-based climate change analysis is discussed in Section 5.2.2.

6.4.2 Improve Operational Efficiency and Transfers

Water transfers can serve as an alternate water supply for some regions. This can improve supply reliability when other supplies are projected to have lowered reliability due to climate change impacts.

A performance metric that potentially applies to this project is the additional water supply provided. Depending on the source of the transferred water, this metric could be influenced by climate change.

Methods for incorporating climate change into performance metric calculations for this example, include developing or adjusting a watershed modeling analysis, such as those described in Section 5.3.2.

6.4.3 Increase Water Supply

Developing a project to provide additional local surface storage is a possible adaptation strategy for climate change impacts on water supply or water supply reliability. Storage provides a way of adjusting a water system to altered peak streamflow timing resulting from earlier snowpack melting. Additional storage capacity can help regions to adapt to larger precipitation variability.

The ability for additional storage to provide additional supply reliability depends on both evaporative losses exiting the storage facility and on streamflows (or other source flows) entering the facility. Methods for evaluating potential evaporative losses include those discussed in section 6.3.1. However, if the storage facility is included in a larger watershed model (such as those discussed in Section 5.3.2) that has been adjusted for climate change, evaporative losses may be adjusted within the model's calculations. Methods for evaluating potential flows into the storage facility can be calculated using watershed models, such as those discussed in Section 5.3.2.

6.4.4 Improve Water Quality

Stormwater capture and reuse projects can reduce the burden on treatment plants and potable water supplies, helping a region adjust to climate change impacts on water quality.

A performance metric that applies to stormwater capture could be the reduction in pollutant loading to receiving waters. Climate change could influence this metric for a stormwater capture project, due to an altered hydrograph or precipitation pattern. Measuring demand offset for this project would, therefore need to incorporate precipitation projections from climate models. Any existing urban runoff water quality models would also need to be adjusted for climate change. Water quality models are discussed in Section 5.3.3.

6.4.5 Practice Resource Stewardship

Projects that include coastal restoration elements can help regions adjust to climate change by creating a water quality and flooding buffer against sea level rise or storm surges. Potential performance metrics for this type of project could be the estimated changes in salinity intrusion into groundwater wells or expected damages from storm surges. Climate change impacts on coastal ecosystems can be assessed in a variety of ways including qualitatively by surveying local experts, as discussed in Section 5.2.3.

6.4.6 Improve Flood Management

Restoring, managing, and protecting wetlands can improve flood control by retaining, and slowly releasing, stormwater. Wetlands can also improve runoff water quality. This can help a region adapt to anticipated increased storm intensity as the climate changes. A potential performance metric for a wetland restoration project could be stormwater retention volume, or measureable water quality improvements of runoff directed to wetlands.

The capacity of a wetland to retain stormwater is a function of ecosystem health. Climate change can influence wetland health by changes in overall stream inflows and precipitation, and also by climate change impacts on water quality parameters (e.g., dissolved oxygen). Streamflows into wetlands can be calculated using watershed models as described in Section 5.3.2.Water quality can be assessed using models such as those described in Section 5.3.3.

6.5 Prioritizing Projects

After the project evaluation process, the evaluation results can be used for prioritization. The IRWMP can include all of the projects evaluated, a prioritized list of projects, or a limited list of projects that are more likely to provide the benefits to the region.

There are a number of methods for prioritization of projects which regions should already be familiar with from past planning process. Each region must decide on a method to short-list or rank projects. In every method, the performance metrics will be useful in providing objective information for a defensible prioritization.

If the planner considers that a relevant criterion for project evaluation is the overall contribution of a project to climate change adaptation, a composite index can be estimated. This section presents a sample method to develop such a composite index. This method, the Multi-Attribute Rating Technique (MART), utilizes the performance values for each performance metric of interest. The weight of the objectives is associated with each performance measure.

6.5.1 Developing a Composite Index

In order to use MART, a numerical value is required for each performance metric. Thus, if some qualitative performance metrics exist, they must be converted into numerical values. For example, if the qualitative scores are “high”, “medium”, and “low”; they can be replaced with a scale of 1, 2, and 3; or -1, 0, and 1. These numeric values can then be used in MART to develop the index.

Similarly, the plan objectives need to be prioritized, and a numerical value needs to be provided to reflect the objective’s relative importance. A number between 0% and 100% is required for MART.

Since different performance metrics have different units, the development of a composite index requires a unitless score that can then be added for all performance metrics. For every performance metric, a normalization scale is required. In the example below, a normalization has been performed with normalized scores between 0 and 1. A linear scale has been used giving the best value (0 acre-feet per year (AFY) in deficit) a score of 1, and the worst value (5,000 AFY deficit) a score of 0.

Normalized scores are multiplied by the weight of the objective associated with the performance metric. The weighted score is all metrics added together. In the example shown in Table 6-5 and Figure 6-8, below (continued from Figure 6-2), the best normalized weighted score is 0.785 for Project A, whereas Project B has a normalized weighted score of 0.51. In this example, Project A would be more effective at achieving the objectives, given its performance, and the weight of the planning objectives.

This composite index is not a requirement for project prioritization, but it can help interpret the technical analysis performed for the projects, and can support the planner in making decisions about which projects would merit inclusion in the IRWMP. In the example, a tradeoff between two objectives is compared by looking at an overall composite project score.

Table 6-5: Example of Performance Metric Scoring Using a Composite Index.

		Performance Metrics		Total Score
		Annual Deficit During Droughts	Habitat Area Preserved	
Parameters	Objective Weights	0.7	0.3	
	Best Possible Performance by a Project	0 AF	40 acres	
	Worst Possible by a Project	5,000 AF	0 acres	
Performance	Project A	1,000 AFY	30 acres	
	Project B	3,500 AFY	40 acres	
Normalized Performance for each Metric	Project A	0.8	0.75	
	Project B	0.3	1	
Weighted Performance for each Metric	Project A	0.56	0.225	0.785
	Project B	0.21	0.3	0.51

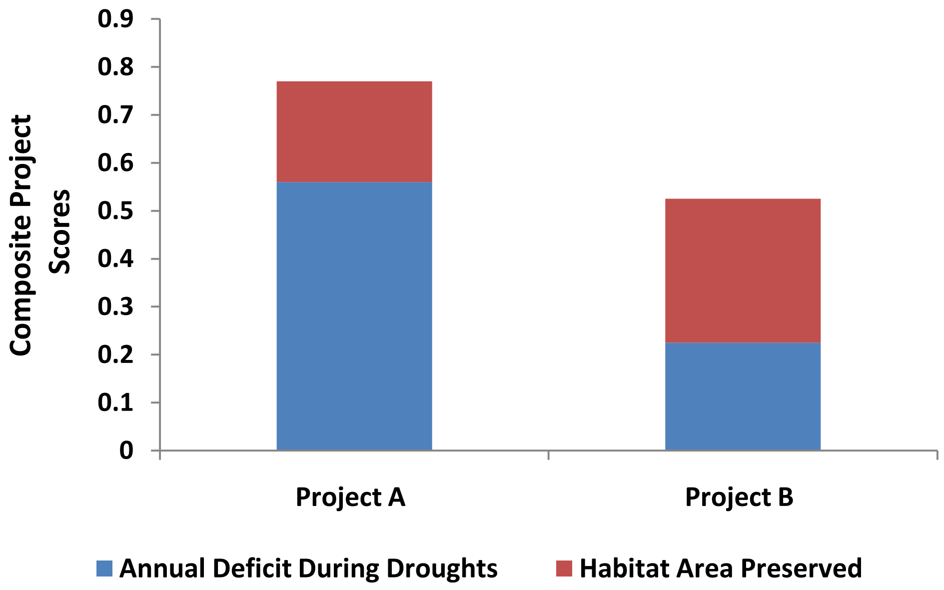


Figure 6-8: Example Composite Climate Change Adaptation Index Calculation.

6.6 Preferred Project Portfolio – Planning for Uncertainty

Evaluating and prioritizing projects is a process that needs to consider uncertainty. Final project selection necessarily includes consideration of time frames for implementation, and the uncertainty involved in planning assumptions. Approaches for incorporating this uncertainty into final project selection are varied, and include:

- Adaptive management,
- Robust decision making, and
- Decision-scaling.

The IRWMP guidelines (DWR 2010a) strongly encourage IRWMPs to incorporate principles of adaptive management in the planning process. Principles from all three of these approaches are woven into this handbook, and are discussed in detail in Section 7.

This page intentionally left blank.

Section 7

Implementing Under Uncertainty

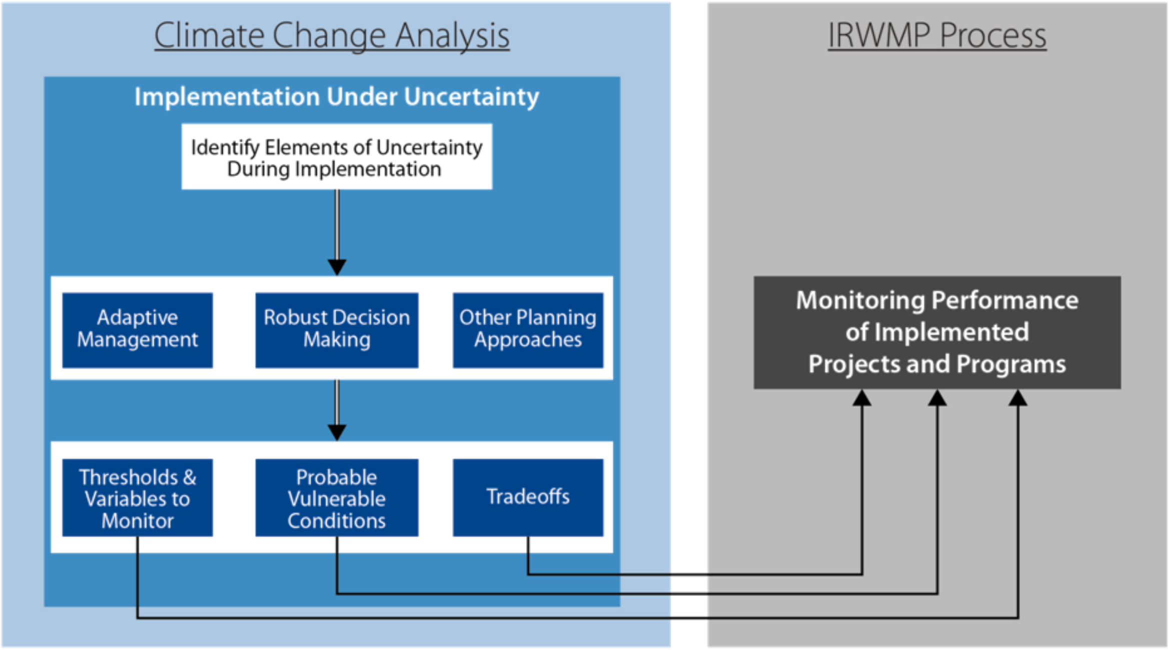


Figure 7-1. Process for Implementing Under Uncertainty as part of an IRWMP.

Section 7 focuses on relating overall decision making strategies with the handbook's decision-support framework. As uncertainty permeates every aspect of the planning process, the overall planning strategies discussed in this section apply to each section in the handbook. Figure 7-1 depicts options for incorporating uncertainties into climate change planning and the ways that uncertainty is linked into the IRWM planning process. This section describes Adaptive Management, Robust Decision Making (RDM), and other related approaches including Decision-Scaling. There are other approaches described in the literature, and planners are encouraged to use planning strategies that fit their regional priorities.

This section focuses on the following areas:

- The steps necessary to apply each approach.
- The relative strengths and limitations of using each approach in the IRWM process.
- Relevant case studies or example applications from the literature.

The approaches discussed in this section influence activities in all other sections of this handbook, as they constitute overarching themes in incorporating uncertainty, including climate change, into the planning process.

Uncertainty is not a new concept, but the uncertainty associated with climate change is often large and difficult to quantify. This fact, however, should not be considered an insurmountable obstacle that forces planners to use a simplistic qualitative analysis. The approaches discussed in this section are especially applicable for systems where uncertainty is high, and sometimes ambiguous, and are useful to develop plans that are still sufficiently quantitative and technically well supported.

Uncertainties in planning are driven by different aspects of the planning process. Some uncertainties are associated with the future state of some variables for which historical records are not a guide or not sufficient (such as GHGs in the atmosphere). Other uncertainties are associated with the future value of a probabilistic variable (e.g., precipitation or temperature). Yet, another type of uncertainty is associated with the ability of planners, scientists, and engineers to accurately model or simulate the environmental variables of interest (i.e., model uncertainties). Appendix C discusses these kinds of uncertainties and presents a discussion on probabilistic methods to address them.

Uncertainty associated with projecting future conditions is expressed in different ways, depending on the variable: assigning a probability to a potential future conditions, or developing a set of scenarios. Both of these approaches are discussed below and in Appendix B.

7.1 Techniques for Managing Climate Change Uncertainty

Uncertainty should be a key consideration of most IRWMP activities, from defining and prioritizing objectives to evaluating projects and project portfolios. There are several strategies for planning under uncertainty, and many are not mutually exclusive. This section discusses the following strategies:

- **Robust Decision Making:** This method involves using performance metric evaluations to identify tradeoffs associated with the various project options and objectives. With the tradeoff information, hedges can be developed from which realistic portfolios can be identified. Iterations are often involved in which portfolios are reevaluated collectively, fine-tuned, and evaluated again (Water Utility Climate Alliance (WUCA), 2010).
- **Adaptive Management:** This method consists of identifying and monitoring the most important uncertainties and translating them into risk triggers or early warning indicators. The values of the variables that constitute early warning indicators can be established deterministically (e.g., a threshold) or probabilistically (e.g., frequency by which a level is exceeded). Adaptive management constructs a flexible path with actions to take when specific triggers occur. This approach is gaining more popularity because the future cannot be accurately predicted (MWD 2010, CDM 2007, DWR 2010a).
- **Other Approaches:** There are many methods for incorporating large uncertainty into the planning process, some of which are variants of RDM and adaptive management. Traditional scenario planning and decision-scaling are among the other methods discussed.

7.2 Robust Decision Making

The main focus of RDM is to select options that are resilient, or that achieve desired results in multiple future scenarios. A RDM strategy can sometimes be in contrast with classic decision analysis, where the set of options that performs most optimally under the most probable future scenario is selected (WUCA 2010). Contrasts may result where alternatives that are optimal for the most probable scenario can perform poorly in other future scenarios (CCSP 2009). Therefore, RDM is ideal for conditions with large, and often unquantified, uncertainty. The CWP includes RDM as a way of managing risk (DWR 2010a).

RDM consists of using project performance metric values, evaluated under several climate scenarios, to identify vulnerable conditions and tradeoffs between alternatives. By plotting the performance of different project portfolios under multiple future climate conditions RDM helps identify project portfolios that perform well under expected or average future conditions, but also perform well under unexpected future conditions. This information is then used to select a set of preferred projects that perform well under several future scenarios i.e., “no regrets” strategies.

7.2.1 Elements of RDM

The RDM process helps select among well-performing projects and programs, and can be incorporated into Strategy Evaluation (Section 6 of the handbook).

7.2.1.1 Identifying Vulnerable Conditions

RDM consists of identifying conditions where the best-performing project alternatives do not perform well. Portfolios of preferred project combinations are subjected to scrutiny for potential vulnerabilities. This analysis would fit well in the evaluations process discussed in Section 6 of this handbook.

RDM relies on performance metrics to determine the most “vulnerable” scenarios. This process is made easier by selecting:

- A wide variety of future scenarios that includes as many potential future conditions as possible, and
- Combinations of initial projects, and project portfolios, which push the boundaries of planning objectives.

After performance metrics have been evaluated for individual potential projects and integrated projects, it is useful to then group the better-performing projects into portfolios, as discussed in Section 6. Initial portfolios can be developed for evaluation in RDM, as a means of identifying vulnerable conditions and tradeoffs between meeting various performance metrics. These initial project portfolios need not be final sets of selected projects. Pasadena Water and Power

(PWP) developed an initial round of portfolios with the goal of "pushing the boundaries" of specific planning objectives in their Integrated Resources Plan (CDM 2011).

Performance metrics are evaluated on preferred project portfolios, typically using a large number of scenarios (WUCA 2010, NAS 2010b, Brekke et al 2009). Scenarios are identified that yield the worst performance for the generally best performing strategies. For example, IEUA worked with RAND Corporation to identify specific events that would cause their existing plans to fail (i.e., not provide enough water). This process involved using a WEAP model developed for the IEUA water supply system, and applying several future climate scenarios in order to identify specific vulnerable conditions. Conditions included combinations of factors like simultaneous decreases in precipitation, groundwater infiltration, and imported water supply (NAS 2010b).

7.2.1.2 Identifying Tradeoffs

If the scenarios yielding poor results (i.e., "vulnerable" conditions) are considered probable, then additional strategies and projects may need to be considered. At this point, tradeoffs need to be identified and iteration may take place. Identifying tradeoffs is the best way to prepare for multiple futures simultaneously (NAS 2010a). Tradeoffs are essential for addressing multiple stressors, which prevents "maladaptation" (i.e., adaptation that results in more harm than good).

RDM evaluates projects that perform well under "vulnerable" conditions for tradeoffs. Some projects that perform well under stressful conditions do not perform the best in "expected" future conditions. This tradeoff needs to be quantified to inform option selection. Where possible, identifying a probability associated with the "vulnerable" scenario helps this decision process. Listing advantages and disadvantages for project alternatives also helps identify the tradeoffs involved with their selection (CDM 2011).

Stakeholder involvement is a critical component of selecting final preferred project portfolios, as minimizing some vulnerabilities may involve sacrificing good performance of other performance metrics. Evaluating these tradeoffs does not require a consensus among planners of what the future will look like, but does require a consensus of priorities (NAS 2011). This type of prioritization is consistent with the IRWMP concept of assigning weights to performance metrics.

7.2.1.3 Selecting Optimal Projects and Planning Strategies

There is no formula for selecting final preferred project alternatives in RDM. Decision makers ultimately need to rely on their own set of priorities, combined with their professional opinions of how likely the previously-identified "vulnerable" scenarios are (WUCA 2010). In cases where formal probabilities can be assigned to scenarios, RDM is less subjective. In this way, RDM is useful for uncertainty analysis where some probabilities are known, if not all (WUCA 2010).

RDM is well-suited to planning under climate change because of its flexibility. Probabilistic information can be incorporated in a way that will improve decision making, but is not required for successful planning. RDM is scenario-based, which allows planners to address climate uncertainty through climate scenarios (WUCA 2010).

7.2.2 Strengths and Weaknesses

RDM 's strengths include:

- RDM is useful for systems where uncertainty is difficult to quantify (NAS 2011). It also helps address multiple stressors (NAS 2010a), and promotes portfolio diversification (NAS 2011).
- Robust strategies help prepare for surprises, or unexpected events (Brekke et al 2009).
- RDM is able to maximize any uncertainty information that is available, without requiring information that is not available. For scenarios with combinations of uncertainty types, RDM allows uncertainty associated with individual events, such as population increasing by a certain amount over a given time period, to be evaluated. (WUCA 2010).
- RDM's flexibility in addressing uncertainty is well suited for collaboration among stakeholders, as it does not require agreement regarding the exact likelihood of future events. In addition, it has been shown to help decision makers feel more comfortable with their decisions regarding climate change (Feifel 2010).

There are also limitations to using the RDM technique:

- If quantitative probabilities are not associated with the scenarios used in RDM, choosing vulnerable scenarios to plan for is a subjective decision, and is largely influenced by individual perceptions of risk (CCSP 2009). This subjectiveness is complicated by uncertainties that are difficult to quantify.
- Another limitation is the need for resources to conduct the in-depth analysis. Identification of tradeoffs is greatly facilitated by having a large number of scenarios. For example, RAND Corporation used four scenarios in an initial RDM analysis and expanded their analysis to include over 200 scenarios (Feifel 2010). This type of in-depth analysis may not be practical for regions with limited resources.
- Not necessarily a limitation, but an important consideration in the application of this approach, is the fact that the technical analysis needs to be supported by a well-defined and robust decision-making process and, potentially, a decision-support tool. As the number of scenarios increases, the information available to make better decisions increases but the *ability* to make decisions decreases, given the difficulty of interpreting all the data. A decision-support tool can help organize and interpret data, but the development of such a tool requires additional resources.

7.3 Adaptive Management Planning

The adaptive management concept is well-known among water resources practitioners and frequently applied, at some level, in water resources projects. The adaptive management process generally includes elements of either scenario planning or probabilities analyses, or both. The key to the process is a formalization of a plan for performance monitoring and project reevaluation in the future. In other words, the process recognizes the inherent uncertainties in water resources planning, and structures an adaptive strategy that responds to new information. For this reason, adaptive management is particularly well-suited for projects that include climate change considerations, where uncertainties are great. As new climate data and model projections become available, adaptive management projects will be able to respond accordingly. The IRWMP Guidelines encourage regions to adopt "policies and procedures that promote adaptive management" (DWR 2010a).

While many variations of adaptive management exist, the fundamental steps related to IRWMP projects, can be summarized as:

1. Identify risk triggers associated with important vulnerabilities or uncertainties,
2. Quantify impacts and uncertainties (this step corresponds to Section 5 and Appendix C of the handbook),
3. Evaluate strategies and define an implementation path that allows for multiple options at specific triggers,
4. Monitor performance and critical variables in the system, and
5. Implement or reevaluate strategies when triggers are reached and monitor system reaction. (Figure 7-2).

Step 2 above is not unique to adaptive management projects; it is a major piece of all IRWMP projects, and has been described elsewhere. Steps 1, 3, 4 and 5 comprise the key elements of adaptive management. Step 1 involves identifying the most important uncertainties and vulnerabilities early in the process, which are then translated into risk triggers or early warning indicators. These triggers are quantified in Step 2 and serve as the basis for the definition of a path for plan implementation in Step 3. The monitoring provides the impetus for project implementation and system reevaluation (Step 5). The reevaluation component of adaptive management has been traditionally the focus of academic work, while in professional practice the project implementation has taken a greater emphasis. Both elements are important in adaptive management: when new knowledge about the state of the system is obtained, actions can be taken in terms of project implementation, but technical analyses can also be conducted or updated based on the new information. The main premise of adaptive management is that over time, we learn more about the water resources system in which the strategies are being implemented. Key to the adaptive management process is continued active participation by stakeholders and a clear understanding of project objectives.

For further details on the adaptive management process, the reader is referred to the proceedings of the American Water Resources Association (AWRA)'s 2009 Summer Specialty Conference focusing on adaptive management. Example applications include Rodrigo and Heiertz (2009) and Adams (2009). The MWD case study at the end of this section (Box 7-1) also provides an example application of adaptive management. The focus of this section is on the use of adaptive management techniques to address uncertainties in climate change studies. Each step of the general process is described further below with particular attention to addressing climate change uncertainties.

7.3.1 Conducting the Adaptive Management Analysis

System vulnerabilities should be identified prior to the adaptive management process. This step is described in detail in Section 4. An identified vulnerability might include instream concentration of a specific pollutant or specific fish species with sensitivity to changes in water temperature. A risk trigger needs to be established for each identified vulnerability to monitor the system's response. Risk triggers can be established deterministically (e.g., a threshold) or probabilistically (e.g., frequency by which a level is exceeded). Risk triggers might include, for example, threshold mean temperatures or annual precipitation levels that fall outside of the historical record used in previous analyses. These new data might allow for recalibration of models describing system response to extreme conditions. Reevaluation efforts would be based on the results of the updated models. Development of a new technology that may implement a strategy in the plan can also be a trigger.

Performance monitoring is critical to the adaptive management process. Monitoring should focus on observed climate fluctuations, how these compare to historical records, and how the targeted system responds to such fluctuations. Monitoring of the state of climate change science should also be an important part of the process. Monitoring should be guided by the identified risk triggers described above.

In setting the risk triggers, it is important that decision makers set them at levels where policies and projects can be implemented before a crisis develops. Reacting to a crisis is not adaptive management. On the contrary, the times for action and reevaluation in adaptive management are set conservatively to avoid the development of crisis.

When and if reevaluation is initiated, all available new information is incorporated into existing tools, and strategies are reanalyzed. This may include an expanded baseline dataset, new climate projections, or changes in uncertainty levels for specific parameters. For example, an existing hydrologic model might be recalibrated for extreme drought conditions if such conditions are observed in the future. This recalibration then might change the results of strategy evaluation and ultimately planning decisions.

Central to adaptive management is the definition of a path with specific actions that managers can take when triggers, or early warning signals, are reached. This is done with quantitative information from the technical analysis of the plan concerning the performance and characteristics of projects. An iterative process may be necessary to define the path. In such a process, the system is quantified (e.g., simulated with models, if available) under different paths to identify the impacts that a given project can have on the system. Figure 7-2 shows an example of an adaptive management path for a typical integrated resources plan.

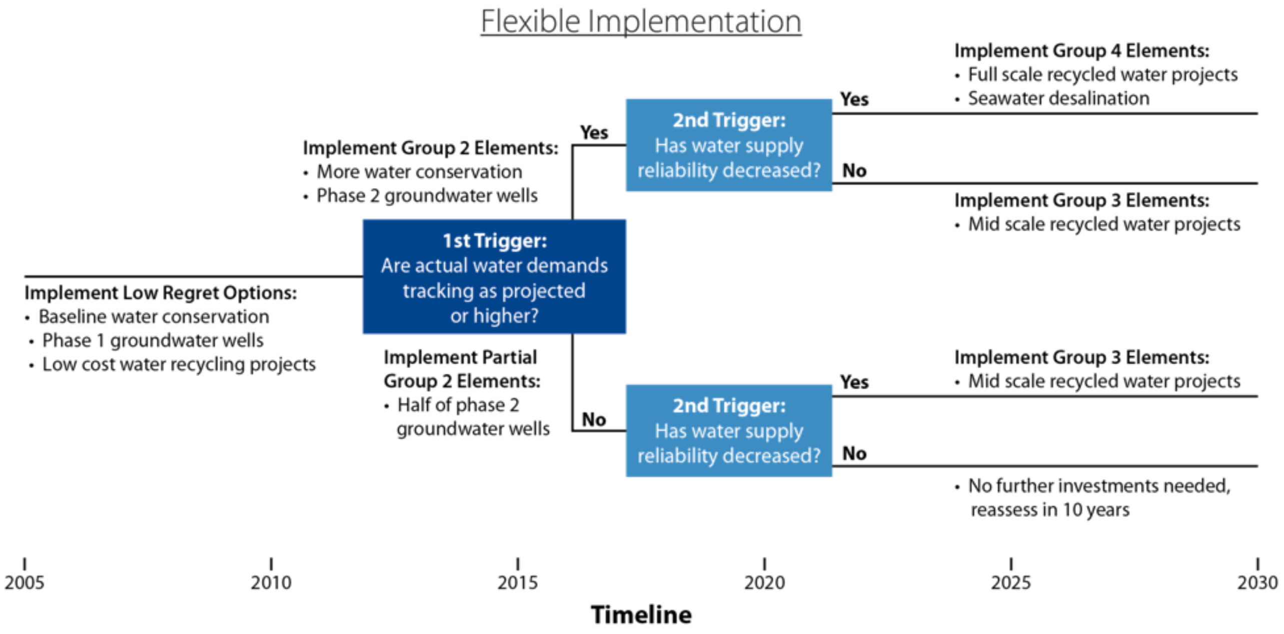


Figure 7-2. Diversity of Options in an Adaptive Management Plan.

7.3.2 Strengths and Weaknesses

The greatest strength of the adaptive management approach lies in its flexible, rather than prescriptive, approach to planning, given large uncertainties. The approach recognizes that all of the information needed to make optimal decisions may not be available now, but may be in the future. As described above, given the evolving science of climate change, adaptive management is a particularly appealing approach for IRWMP projects.

The primary weakness of the adaptive management approach is that it can be more labor intensive and expensive to execute properly compared to traditional implementation processes. It also may require a certain continuum of stakeholder involvement and political support for periods of many years into the future. If such a continuum is not maintained, the process can be compromised.

Two areas that are a challenge in implementing adaptive management, which do not necessarily represent a weakness but can represent obstacles in implementation, are the need for implementation steps that are flexible and "modular," and the difficulty in determining if a trigger has been reached.

Modular implementation: Adaptive management implementation methods are useful under high uncertainty, but adaptive management is harder to implement when the scale of the projects is large, and the magnitude of the actions required to implement the plan is significant. When a diversified portfolio of projects is part of the IRWMP, adaptive management can be more effective. For example, adaptive management would be appropriate if the projects in the plan include decentralized treatment facilities, small scale habitat restoration projects, expandable conjunctive use projects, or reservoir releases.

The strategy in Figure 7-2 shows the great diversity of options included in the plan, which allows managers to take different actions that do not commit the district to any single individual project. Instead, a portfolio of projects is being implemented in phases according to the identified triggers.

Identifying thresholds: The concept of monitoring a variable and identifying the time when that variable reaches a certain threshold is simple and intuitive. In the real world, however, significant challenges exist in defining the state of variables that have uncertainty and natural variability, such as temperature and precipitation. Hydrologic variability presents the same variability characteristics that make it difficult to determine. For example, it is difficult to know whether a drought is beginning or there is just a short dry period that will end soon. Even water demand presents variability from year to year, and a snapshot of water consumption at one moment in time may not be representative of a longer term trend.

Data collection, management, and interpretation need to be part of the IRWMP implementation process in order to be able to identify thresholds for variables that undergo significant inherent natural perturbations. The governance structure defined in a regional plan needs to accommodate the significant task that performance monitoring represents. In the case of climate change, coordination with agencies outside the region (e.g., NOAA) that are better positioned to identify trends and make conclusions about the state of some variables, will be crucial. Access to information from, and communication with, Federal and international agencies and academic institutions that monitor the global climate trends should be a component of IRWMP implementation.

7.4 Other Planning Approaches

There are many decision-making frameworks that incorporate variations of robust and adaptive strategies, including iterative risk management (NAS 2011), decision-scaling (Brown, n.d.), and traditional scenario planning (WUCA 2010). All frameworks rely on stakeholder involvement and engagement. All methods are limited by estimates of uncertainty; planners need to be aware of assumptions made in developing scenario likelihood estimates and the shortcomings of subjective estimates of uncertainty (CCSP 2009).

7.4.1 Decision-Scaling

Decision-scaling applies specific bottom-up planning and analysis methods with concepts from robust planning methodologies. Decision-scaling includes three main steps (Brown, n.d.):

- Bottom-up Analysis: Identification of key concerns and decision thresholds,
- Developing a decision-based climate response function, and
- Estimating relative probability of changing climate conditions.

This type of bottom-up analysis is ideal for adapting to vulnerabilities that are difficult to quantify, such as extreme events like flooding (Cromwell and McGuckin 2010). Many of the general aspects of decision-scaling are incorporated into other parts of this handbook.

7.4.1.1 Bottom-up Vulnerability Assessment

Decision-scaling involves a bottom-up analysis that begins with a decision-driven prioritization of potential climate vulnerabilities, as they relate to planning objectives. The preliminary vulnerability assessment discussed in Section 4 of this handbook involves a similar stakeholder-driven prioritization of climate vulnerabilities and the resulting formation of performance metrics. This assessment could feed into a decision-scaling framework.

Decision-scaling involves developing a "climate-response function" as part of a climate change impact analysis. This is done by conducting a sensitivity analysis (see Section 5) to evaluate a range of conditions that cross a region's tolerance thresholds. This process is similar to the identification of vulnerabilities described in RDM; however, there are two differences: 1) rather than examining a wide array of scenarios, decision-scaling focuses on anticipated vulnerabilities, and 2) decision-scaling does not rely on future scenarios. This type of vulnerability prioritization relative to thresholds and user-based needs is a common aspect of planning (Association of Metropolitan Water Agency (AMWA) 2007, NAS 2010c).

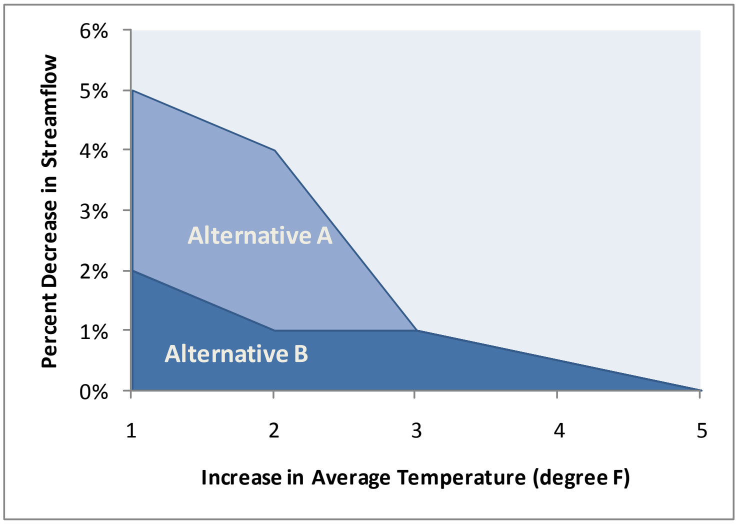


Figure 7-3: Sample Decision Space Showing the Conditions Where Project Alternatives Perform Well.

7.4.1.2 Decision-Based Climate Response Function

Section 5 of this handbook lists many options for system analysis methods. Using a sensitivity analysis, conditions where existing or potential plans perform well (or fail) can be identified (Brown, n.d., WERF 2009). Establishing conditions where projects would be preferable aids in the decision-making process. Figure 7-3 shows a sample decision space where Alternative

A performs well under more extreme decreases in streamflow, but not in cases where average temperature increases by more than 3 degrees. Alternative B performs well under most temperature conditions, but crosses a performance threshold where streamflows decrease by more than 2%.

7.4.1.3 Estimating Relative Probabilities

The probability of the selected scenarios is assessed and incorporated into performance metrics resulting from the selected scenarios. Identifying the probability of these scenarios helps planners weight the performance metrics. Appendix C of this handbook discusses ways of estimating probability based on GCM results. Decision-scaling also encourages consultation with local experts. CCSP (2009) recommends caution when basing probabilities solely on individual opinions, as there is inherent danger in being subjective.

7.4.2 Other Related Planning Approaches

Adaptive management, robust decision making, and decision-scaling are not mutually exclusive; as discussed in this section, in many ways they overlap with each other. There are many options for robust decision making and decision-scaling within the adaptive management framework. Similarly, decision-scaling could be used to direct robust decision making. Adaptive management is sometimes thought of as a robust strategy (CCSP 2009), as collectively the project portfolio selected in adaptive management will perform well under multiple future scenarios. The trigger and monitoring framework in adaptive management is a robust way to avoid surprises (NAS 2011).

Deliberation with analysis reflects elements of both adaptive management and robust decision making (NAS 2010c). Deliberation with analysis is similar to adaptive management; it is iterative, encourages stakeholder participation, and relies heavily on performance metrics and monitoring. Iterative risk management incorporates elements of both adaptive management and robust decision making (NAS 2011). It involves reevaluation of strategies as additional data becomes available, and also emphasizes diversification and selecting alternatives that perform well across multiple scenarios.

Robust decision making also overlaps with decision-scaling; the process of conducting a sensitivity analysis to identify thresholds of acceptable performance is similar to the RDM strategy of using a large number of scenarios to identify vulnerable conditions. In both cases, final decision making is facilitated where uncertainties are more easily quantified.

Traditional scenario planning is also similar to robust decision making. It focuses on identifying key uncertainties, and framing future scenarios specifically around these uncertainties. Assessing which projects perform well under more extreme scenarios allows planners to select more robust projects (WUCA 2010). Implications are that projects that perform well under extreme conditions will also perform well under normal conditions.

A general reference on decision-support planning methods that can be used in climate change analysis can be found in the Water Utility Climate Alliance's white paper "Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning" (WUCA 2010).

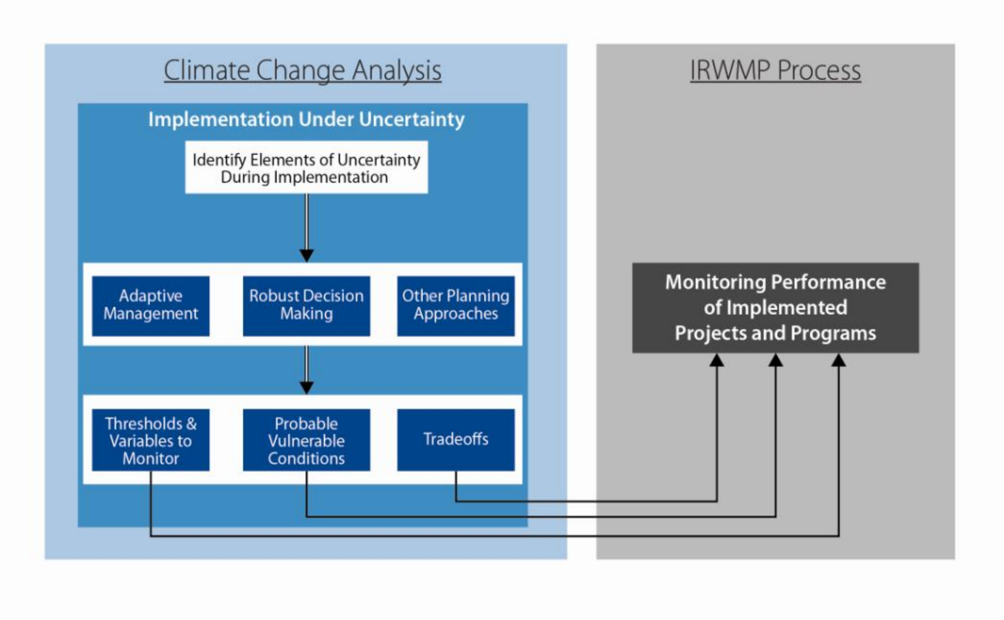
7.5 Planning Under Uncertainty

There are many ways to incorporate uncertainty into the planning process, and variants of these methods are implemented in planning projects regularly. This section focuses on RDM and adaptive management, and also discusses decision-scaling and other planning techniques. While climate change adds an additional layer of uncertainty to water resources planning, it does not necessarily alter the way uncertainty is addressed. The methods discussed in this section, and throughout most of this handbook, are applicable to any planning process. Regardless of which method is used for planning, all plans are limited by data availability and ability to project into the future. The general planning principles of flexibility and robustness are key to planning for climate change.

Case Study: Implement Under Uncertainty

Southern California – Adaptive Management

Metropolitan Water District of Southern California



Background:

- Metropolitan Water District of Southern California (MWD) is a consortium of 26 member agencies. MWD's service area includes portions of the counties of Los Angeles, Orange, San Diego, Riverside, San Bernardino and Ventura.
- Water Sources & Customers: MWD is a wholesale water supplier for 26 water utility districts in Southern California. MWD obtains its water primarily from the Colorado River Aqueduct (CRA) and from the Delta via the State Water Project (SWP).

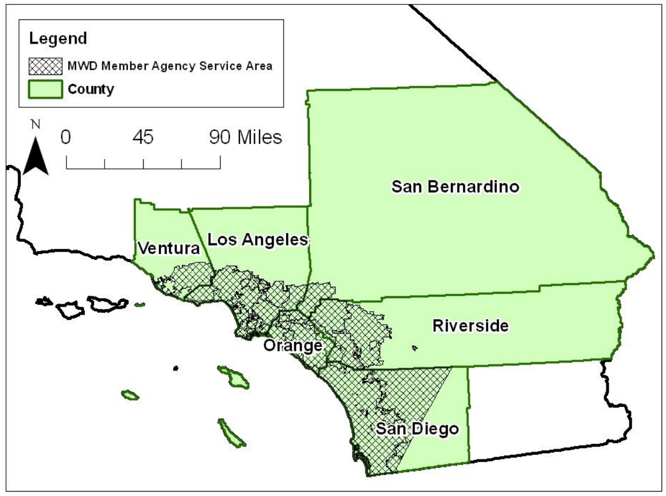


Figure 1: MWD Member Agency Service Areas.

- Planning Setting: MWD has been using adaptive management approaches for several years. MWD's first planning document using adaptive management is their 1996 Integrated Resources Plan (IRP). Updates were made in 2004 and 2010.
- Climate Change Analysis: As part of the 2010 update, MWD conducted a reliability analysis addressing potential climate change impacts along with other uncertainties, and used the results of their reliability study to evaluate and prioritize several management programs.

Box 7-1

- Adaptive Management: Adaptive Management makes sense for the MWD system for the following reasons:
  - Subject to multiple sources of uncertainty
  - High reliance on imported water
  - Desire to keep costs down and reliability up

Adaptive Management involves every step of the climate change analysis process in a cyclical manner. This Case Study summarizes every step of the climate change analysis as outlined in the handbook that MWD has undertaken for the 2010 update of the IRP, in the broader context of Adaptive Management. Because adaptive management is also a cyclical process (Figure 2), this case study refers to work done for the 2010 plan as an *update* from the work done for the 2004 plan.

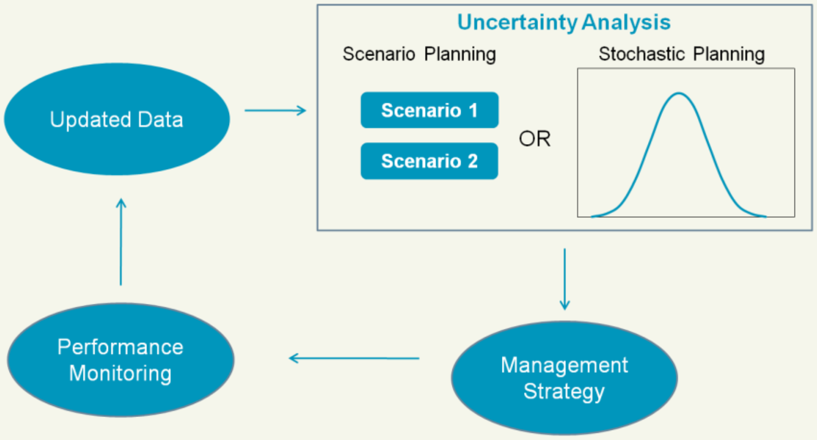


Figure 2: Adaptive Management Framework.

Step 1: Vulnerability Assessment

- Previously identified areas of vulnerability
- Review new literature/data
- Update key sources of reliability uncertainty

Previously identified vulnerabilities (from 2004 update):

- Water quality regulatory compliance risk
- Resource implementation risk
- Increased water demand projections

Update of data/information available for vulnerability assessment:

- Current and projected SWP supplies - CALSIM II model results (including climate change impacts, used 2007 reliability report)
- Current and projected CRA water supplies - CRSS supply model (including climate change impacts)
- Demand projections
- Economy
- Climate change literature

Key Sources of Uncertainty for 2010 update:

- Climate change (impacts on demand and supply)
- Policy/permitting restrictions
- Ongoing drought in Colorado River Basin
- Endangered species protection in the Delta
- Demographic and economic variables

Climate Change potential impacts of concern (from Regional Urban Water Management Plan 2010):

- Demand – increased outdoor residential/agricultural use
- Supply – snowpack reductions
- Supply – sea level rise in the Delta, which could result in pumping cutbacks for SWP, CVP
- Water quality impairments
- Extreme weather events such as drought
- Loss of hydroelectric power generation capacity

Box 7-1 (Continued)

Step 2: Impacts Analysis

- Demand modeling
- Supply gap modeling: IRPSIM Water Balance
- Probability analysis

Updated Data and Model Projections Since 2004 Analysis:

- Regional economic, demographic data from Southern California Area Governments (SCAG)
- Water use records
- Supply projections from SWP
- Supply projections from CRA
- Updated Demand data from records and updated projections

Statistical Demand Modeling: MWD-MAIN

- Uses historical water use records: trends
- Incorporates economic and demographic projections from SCAG and San Diego Association of Governments (SANDAG)
- Incorporates climate

Water Supply Modeling: IRPSIM

- Supplies from SWP
- Supplies from CRA
- Demands
- System Configuration - Current Management Strategy

Supply Gap Year 2035: Demand - (SWP + CRA + Local Supplies)

- With Current Resources: maximum shortage of 1.7 MAF
- With Current Resources and Reserve Storage (0.4 MAF storage available for single-year use): maximum shortage of 1.3 MAF

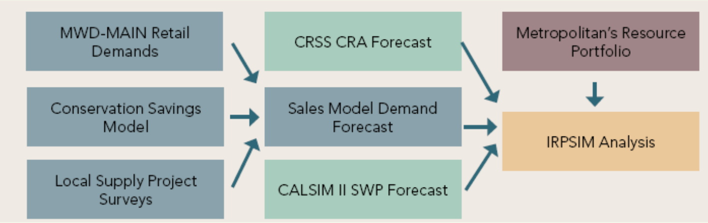


Figure 3: MWD Modeling Suite. Source: MWD, 2010.

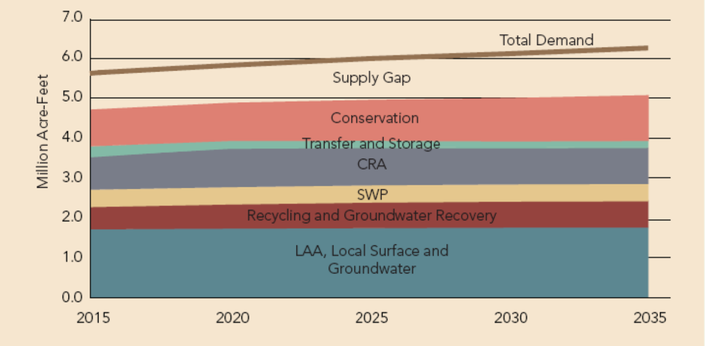


Figure 4: IRPSIM Results: Dry-Year Supply Gap under Existing MWD Resources. Source: MWD, 2010.

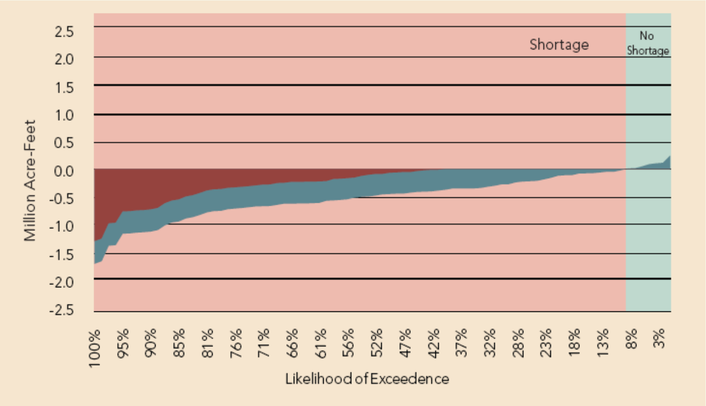


Figure 5: IRPSIM Results: Dry-Year Supply Gap under Existing MWD Resources. Red represents use of storage. Source: MWD IRP 2010.

Uncertainty Analysis

Run IRPSIM several times with slight hydrologic condition variations based on historical record – generate probability distributions

- With Current Resources: shortage 91% of the time in year 2035
- With Existing Storage Resources (not sustainable source for multi-year use): shortage 59% of the time in year 2035

Box 7-1 (Continued)

Step 3: Evaluate Strategies

- Examine supply gap resulting from different strategies
- Rank strategies

Strategies included in the 2004 plan were evaluated against criteria to create a water portfolio of three tiers: Core Resources, an Uncertainty Buffer, and Foundational Actions. Core Resources comprise "baseline" management programs and activities to prevent the future gap between demands and available supplies. The Uncertainty Buffer is composed of projects that may be implemented should the need arise in the future. Foundational Actions are larger-investment, longer term projects that can be started on an investigative level without incurring extensive costs.

Evaluation Criteria:

1) Flexibility: projects that could be (or need to be) adjusted at a later date are ideal for all 3 tiers in the Water Portfolio below.
2) Cost: higher cost supply projects implemented in more certain needs
3) Time Required to implement:
    a. strategies taking longer to produce supplies were moved to Foundation
    b. strategies that can be implemented immediately were put in the Buffer
4) Current Progress: Strategies already in progress were kept in the Core Strategies
5) Certainty of success: projects with less issues/complications are higher priority project in the final portfolio.

Water Project Portfolio:

Core Resources: "Baseline" Management Portfolio

- Similar to "Preferred Resource Mix" developed in 2004 update
- Resource areas:
    - CRA dry-year programs
    - Mid- and long-term Bay-Delta improvements
    - Facilitate 20x2020 in service area
    - Facilitate additional local supply projects

Uncertainty Buffer

- Minimize costs – only implement when needed
- Monitoring and reevaluation of need is built into plan
- Resource areas:
    - Collaboration with member agencies to achieve 20x2020
    - Local resource programs to be implemented on an *as needed* basis

Foundational Actions: Long-term Planning Actions

- Low cost at first – initial investigative actions are low-investment
- *Prepare* to implement later steps if needed – feasibility studies, research, etc.
    - Monitoring and reevaluation of need is built into plan
- Long-term: timeline for actions going 10+ years into the future before supply is available
- Resource areas:
    - Recycled water
    - Seawater desalination
    - Stormwater
    - Greywater

Box 7-1 (Continued)

Step 4: Implement Preferred Strategies & Perform Monitoring

- Update plan every 4-5 years

MWD developed an Integrated Resources Plan in 1996, which was updated in 2004 and 2010. This plan will continue to be updated as new information, data, and tools are available, and as conditions and needs change. The uncertainty buffer and foundational actions laid out in the water project portfolio require periodic reevaluation.

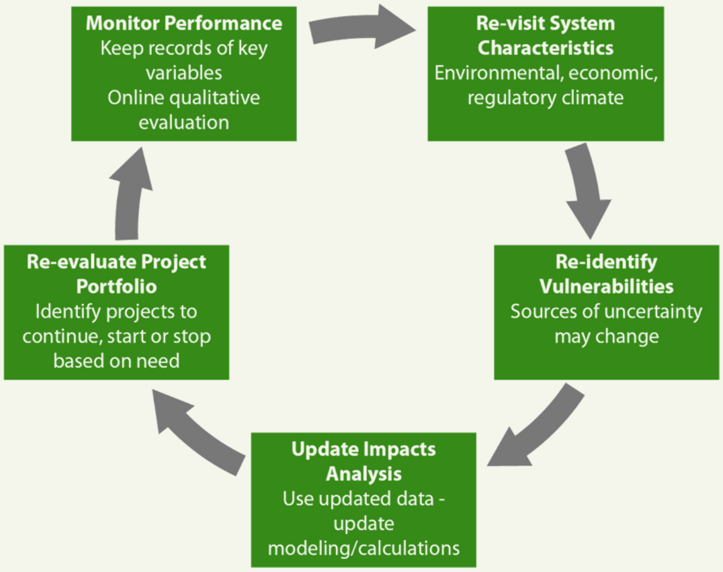


Figure 6: Adaptive Management Cycle Applied by MWD.

For More Information

Metropolitan Water District of Southern California (MWD). 2004. Integrated Water Resources Plan 2004 Update.

MWD. 2010. Integrated Water Resources Plan 2010 Update. http://www.mwdh2o.com/mwdh2o/pages/yourwater/irp/IRP2010Report.pdf.

MWD. 2010. Regional Urban Water Management Plan. November, 2010. http://www.mwdh2o.com/mwdh2o/pages/yourwater/RUWMP/RUWMP_2010.pdf.

MWD. 2011. The Metropolitan Water District of Southern California. http://www.mwdh2o.com/index.htm.

Miller and Yates. 2006. Climate Change and Water Resources: A Primer for Municipal Water Providers. Awwa Research Foundation, Denver, CO and UCAR, Boulder, CO.

Water Utilities Climate Alliance. 2011. http://www.wucaonline.org/html/.

Water Utilities Climate Alliance. 2010. Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning. http://www.wucaonline.org/assets/pdf/actions_whitepaper_012110.pdf.

Box 7-1 (Continued)

This page intentionally left blank.

Section 8
References

Adams, Alison. 2009. Enhancing Reliability through Adaptive Management Strategies: A Water Utility Perspective. AWRA Summer Specialty Conference. Snowbird, UT. June 29-July 1, 2009.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva. Available: http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Brekke, L.D., Kiang, J.E., Olsen, J.R., Pulwarty, R.S., Raff, D.A., Turnipseed, D.P., Webb, R.S., and White, K.D. 2009. Climate change and water resources management—A federal perspective: U.S. Geological Survey Circular 1331. (Also available online at http://pubs.usgs.gov/circ/1331/.)

Brown, Casey. Not Dated. Decision-scaling for Robust Planning and Policy under Climate Uncertainty. World Resources Report, Washington, DC. Available: http://www.worldresourcesreport.org/files/wrr/papers/wrr_brown_uncertainty.pdf

California Air Pollution Control Officers Association (CAPCOA). 2010. Quantifying Greenhouse Gas Mitigation Measures. Available: http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf)

California Air Resources Board (CARB). 2008. Climate Change Scoping Plan: a framework for change. Available: http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm

California Climate Action Team (CAT). 2008. Water-Energy Sector Write-up for Public Distribution. http://www.climatechange.ca.gov/climate_action_team/reports/CAT_subgroup_reports/Water_Sector_Summary_and_Analyses.pdf

CAT. 2010. 2009 Climate Action Team Biennial Report. Accessed May 24, 2011. Available: http://www.energy.ca.gov/2010publications/CAT-1000-2010-004/CAT-1000-2010-004.PDF

California Climate Action Team Coastal and Ocean Working Group (CO-CAT). 2010. State of California Sea-Level Rise Interim Guidance Document. Available: http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20100911/14.%20SLR/1011_COPC_SLR_Interim_Guidance.pdf

California Department of Water Resources (DWR). 2006. Progress on Incorporating Climate Change into Management of California's Water Resources. Technical Memorandum Report. Accessed April 24, 2011. Available: http://www.climatechange.ca.gov/climate_action_team/reports/2006report/2006-07_DWR_CLIMATE_CHANGE_FINAL.PDF

DWR. 2008. Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water. Available: http://www.water.ca.gov/climatechange/docs/ClimateChangeWhitePaper.pdf

DWR. 2009. California Water Plan Update 2009 - Integrated Water Management. DWR Bulletin 160-09. Accessed May 31, 2011. Available: http://www.waterplan.water.ca.gov/cwpu2009/index.cfm.

DWR. 2010a. Proposition 84 & 1E Integrated Regional water Management Guidelines. August 2010. Available: http://www.water.ca.gov/irwm/docs/Guidelines/Prop84/GL_Final_07_20_10.pdf

DWR. 2010b. State Water Project Delivery Reliability Report 2009. Available: http://baydeltaoffice.water.ca.gov/swpreliability/Reliability2010final101210.pdf

DWR. 2010c. Climate Change Characterization and Analysis in California Water Resources Planning Studies. California Department of Water Resources Report. Available: http://www.water.ca.gov/climatechange/docs/DWR_CCCStudy_FinalReport_Dec23.pdf

DWR. 2010d. Climate Change Threshold Analysis Work Plan. Draft Technical Memorandum, Central Valley Flood Management Planning Program, FloodSAFE California. Available: http://www.water.ca.gov/cvfmp/docs/ThresholdAnalysisWorkPlan-DRAFT-20100930.pdf

California Energy Commission (CEC) Public Interest Energy Research Program (PIER). 2008. The Future Is Now: An Update on Climate Change Science, Impacts, and Response Options for California. Publication # CEC-500-2008-077. Available: http://www.energy.ca.gov/2008publications/CEC-500-2008-077/CEC-500-2008-077.PDF

CEC. 2005. California's Water-Energy Relationship. Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding (04-IEPR-01E). Final Staff Report (CEC-700-2005-011-SF). Available: http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF

California Natural Resources Agency (CNRA). 2009. 2009 California Climate Adaptation Strategy. Available: http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

California Ocean Protection Council (OPC). 2010. Resolution of the California Ocean Protection Council on Sea-Level Rise. Available: http://www.opc.ca.gov/webmaster/ftp/project_pages/Climate/1011_COPC_SLR_Draft%20Resolution.pdf

California State Assembly. 2006. Assembly Bill No. 32 (Chapter 488). http://www.climatechange.ca.gov/publications/legislation/ab_32_bill_20060927_chaptered.pdf

California State Senate. 2007. Senate Bill No. 97 (Chapter 185). http://www.climatechange.ca.gov/publications/legislation/SB_97_bill_20070824_chaptered.pdf

Cayan, Dan. Amy Lynd Luers, Michael Hanemann, Guido Franco, Bart Croes. 2006. Scenarios of Climate Change in California: An Overview. California Energy Commission publication CEC-500-2005-186-SF. Available: http://www.energy.ca.gov/2005publications/CEC-500-2005-186/CEC-500-2005-186-SF.PDF

Cayan, Dan, Mary Tyree, Mike Dettinger, Hugo Hidalgo, Tapash Das, Ed Maurer3, Peter Bromirski, Nicholas Graham, and Reinhard Flick. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment. California Energy Commission publication CEC-500-2009-014-F. Available: http://www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-F.PDF

CDM. 2007. Integrated Regional Water Management Plan for the Upper Santa Margarita Watershed Planning Region. Prepared for Rancho California Water District and Riverside County Administration Center. Available: https://www.ranchowater.com/irwmp.aspx

CDM. 2008. City of San Diego Water Department Update of Long-term Water Demand Forecast. Prepared for the City of San Diego Water Department.

CDM. 2011. Water Integrated Resources Plan. City of Pasadena Water and Power. Available: http://ww2.cityofpasadena.net/waterandpower/WaterPlan/default.asp

Central Puget Sound Water Supply Forum (WSF). 2009. 2009 Regional Water Supply Outlook. Available: http://www.watersupplyforum.org/home/outlook/

Chung, F., J. Anderson, S. Arora, M. Ejeta, J. Galef, T. Kadir, K. Kao, A. Olson, C. Quan, E. Reyes, M. Roos, S. Seneviratne, J. Wang, H. Yin. 2009. Using Future Climate Projections to Support Water Decision Making in California. California Energy Commission publication CEC-500-2009-52-F. Available: http://www.energy.ca.gov/2009publications/CEC-500-2009-052/CEC-500-2009-052-F.PDF

Congressional Budget Office (CBO). 2009. Potential Impacts of Climate Change in the United States. Congress of the United States. Available: http://www.cbo.gov/ftpdocs/101xx/doc10107/05-04-ClimateChange_forWeb.pdf

Ecosystem Sciences Foundation. 2006. Cosumnes, American, Bear & Yuba Watersheds Integrated Regional Water Management Plan. Available: http://www.cabyregion.org/plan/the-plan/

The Climate Ready Water Utilities (CRU). 2010. Climate Ready Adaptive Response Framework. Available: http://water.epa.gov/drink/ndwac/climatechange/upload/CRWU-NDWAC-Final-Report-12-09-10-2.pdf

Consumnes, American, Bear & Yuba (CABY). 2006. Consumnes, American, Bear and Yuba Watersheds Integrated Regional Water Management Plan. Accessed June 27, 2011. Available: http://www.cabyregion.org/plan/the-plan/

Cox, Timothy, Enrique Lopezcalva and William Davis. 2009. Incorporating Climate Change into Water Supply Planning Models. AWRA Summer Specialty Conference. Snowbird, UT. June 29-July 1, 2009.

Cox, Timothy and Spandana Tummuri. 2010. Investigating Regulatory Low Flows in the Face of Climate Uncertainty. WEFTEC 2010. New Orleans, LA. October 2-6, 2010.

Cox, T. J., E. Lopez Calva, A.P. Navato. 2011. Quantifying Climate Change in Water Supply Planning for a Snowpack-Driven Watershed. AWRA 2011 Spring Specialty Conference. Baltimore, MD. April 18-20, 2011.

Cromwell, John and Robyn McGuckin. 2010. Implications of Climate Change for Adaptation by Wastewater and Stormwater Agencies. WEFTEC 2010. New Orleans, LA. October 2-6, 2010.

Dettinger, Michael. 2011. Climate change, atmospheric rivers, and floods in California – A multimodel analysis of storm frequency and magnitude changes. Journal of the American Water Resources Association. 47(3): 514-523.

EBMUD. 2009. Climate change analysis TM. In East Bay Municipal Utility District Water Supply Management Program 2040 Plan, Appendix C. http://www.ebmud.com/our-water/water-supply/projects-and-long-term-planning/water-supply-management-program/water-supply-0

Feifel, K. 2010. Using Robust Decisionmaking as a Tool for Water Resources Planning in Southern California [Case study on a project of the RAND Corporation]. Product of EcoAdapt's State of Adaptation Program. Retrieved from CAKE: http://www.cakex.org/case-studies/1029 (Last updated April 2010).

Heberger, M., H. Cooley, P. Herrera, P. Gleick, and E. Moore. 2009. *The Impacts of Sea Level Rise on the California Coast*. California Energy Commission publication CEC-500-2009-024-F. Available: http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF

Howat, Ian M. and Slawek Tulaczyk. 2005. Climate sensitivity of spring snowpack in the Sierra Nevada. Journal of Geophysical Research. 110:F04021.

Industrial Economics, Incorporated. 2010. Application of Ecological and Economic Models of the Impacts of Sea-Level Rise to the Delaware Estuary. prepared for U.S. Environmental Protection Agency, Climate Change Division, Climate Science Impacts Branch and Partnership for the Delaware Estuary. Available: http://www.delawareestuary.org/pdf/Climate/IEc-%20Delaware%20Estuary%20SLAMM%20HEA%20-%20June%202010.pdf

Intergovernmental Panel on Climate Change (IPCC). 2000. Emissions Scenarios. Available: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

IPCC. 2001. Climate Change 2001: Synthesis Report and Glossary of Terms. IPCC Third Assessment Report. Available: http://www.grida.no/publications/other/ipcc_tar/

IPCC. 2007a. Climate Change 2007 Synthesis Report: Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Pachauri, R.K. and Reisinger, A. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

IPCC. 2007b. Summary for Policymakers. In: 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. Available: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

IPCC. 2010. The IPCC Fifth Assessment Report (AR5) Leaflet. Available: http://www.ipcc.ch/pdf/press/ipcc_leaflets_2010/ipcc_ar5_leaflet.pdf

IPCC. 2011. IPCC Intergovernmental Panel on Climate Change web site: Organization Page. http://www.ipcc.ch/organization/organization.shtml

Johnson, T., and C. Weaver, 2009. A Framework for Assessing Climate Change Impacts on Water and Watershed Systems. *Environmental Management* 43: 118-134.

Kreeger, D., J. Adkins, P. Cole, R. Najjar, D. Velinsky, P. Conolly, and J. Kraeuter. 2010. Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning. Available: http://www.delawareestuary.org/science_projects_climate_ready_products.asp

Maurer, E.P. and H.G. Hidalgo. 2008. Utility of daily vs. monthly large-scale climate data: an intercomparison of two statistical downscaling methods, *Hydrology and Earth System Sciences* Vol. 12, 551-563.

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy. 2007. 'Fine-resolution climate projections enhance regional climate change impact studies'. Eos Trans. AGU, 88(47):504.

Medellín-Azuara, J., J. Harou, M. Olivares, K. Madani, J. Lund, R. Howitt, S. Tanaka, M. Jenkins, T. Zhu, 2008. "Adaptability and Adaptations of California's Water Supply System to Dry Climate Warming." Climatic Change 87: 75-90.

Metropolitan Water District of Southern California (MWD). 2010. Integrated Resources Plan. Available: http://www.mwdh2o.com/mwdh2o/pages/yourwater/irp/.

National Academy of Sciences (NAS). 1987. Responding to Changes in Sea Level. Engineering Implications. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Available: http://www.nap.edu/openbook.php?isbn=0309037816.

NAS. 2010a. Adapting to the Impacts of Climate Change. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Available: http://www.nap.edu/catalog.php?record_id=12783

NAS. 2010b. Informing an Effective Response to Climate Change. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Available: http://www.nap.edu/catalog.php?record_id=12784

NAS. 2010c. Advancing the Science of Climate Change. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Available: http://www.nap.edu/catalog.php?record_id=12782

NAS. 2011. America's Climate Choices. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Available: http://www.nap.edu/catalog.php?record_id=12781

National Wildlife Foundation (NWF). 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Available: http://www.nwf.org/News-and-Magazines/Media-Center/Reports/Archive/2011/Scanning-the-Horizon.aspx.

Natural Resources Defense Council (NRDC). 2007. In hot water. Available: http://www.nrdc.org/globalwarming/hotwater/hotwater.pdf.

Nawaz, N.R., and A.J. Adeloye. 1999. Evaluation of monthly runoff estimated by a rainfall-runoff regression model for reservoir yield assessment. Hydrologic Sciences 44(1): 113-134.

Orang, Morteza N., Richard L. Snyder, and J. Scott Matyac. 2008. Consumptive Use Program Plus Version 1.0. California Land and Water Use, Department of Water Resources and Department of Air, Land and Water Resources, University of California, Davis. Available: http://www.water.ca.gov/landwateruse/models.cfm

PEW Center on Global Climate Change. 2011. Climate Change 101: Science and Impacts. Part of "Climate Change 101: Understanding and Responding to Global Climate Change." http://www.pewclimate.org/global-warming-basics/climate_change_101

Phillip, Williams & Associates, Ltd. 2009. California Coastal Erosion Response to Sea Level Rise – Analysis and Mapping. Prepared for the Pacific Institute. Available: http://www.pwa-ltd.com/about/news-CoastalErosion/PWA_OPC_Methods_final.pdf

Public Policy Institute of California (PPIC). 2008. Adapting California's Water Management to Climate Change. Available: http://www.ppic.org/main/publication.asp?i=851

Rehana, S. and P. P. Mujumdar. 2011. River water quality response under hypothetical climate change scenarios in Tunga-Bhadra river, India. Hydrologic Processes. Published online in Wiley Online Library. DOI: 10.1002/hyp.8057. Available: http://onlinelibrary.wiley.com/doi/10.1002/hyp.8057/abstract

Rodrigo, Dan and Greg Heiertz. 2009. Planning of Reliable Water Supply in the Face of Climate Change and Uncertainty. AWRA Summer Specialty Conference. Snowbird, UT. June 29-July 1, 2009.

Santa Monica Bay Restoration Commission (SMBRC). 2010. Bay Restoration Plan Update: State of the Bay 2010 analysis of the environmental conditions of Santa Monica Bay. Available: http://www.santamonicabay.org/smbay/NewsEvents/StateoftheBay/StateoftheBayReport/tabid/176/Default.aspx

Sierra Nevada Alliance. 2010. Sierra Climate Change Toolkit, 3rd Ed. Available: http://www.sierranevadaalliance.org/publications/db/pics/1303760072_12034.f_pdf.pdf

State of California, Office of the Governor, 2005. Executive Order S-3-05. Available: http://www.dot.ca.gov/hq/energy/ExecOrderS-3-05.htm

Stewart, I.T., Cayan, D.R., and M. Dettinger, 2003. Changes in snowmelt runoff timing in western North America under a "business as usual" climate change scenario. Climate Change 62:217-232.

United States Bureau of Reclamation (BOR). 2010. Climate Change and Hydrology Scenarios for Oklahoma Yield Studies, Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver Colorado.

BOR. 2011a. West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections. Technical Memorandum No. 86-68210-2011-01. Available: http://www.usbr.gov/WaterSMART/docs/west-wide-climate-risk-assessments.pdf.

BOR. 2011b. Secure Water Act Section 9503(c) – Reclamation Climate Change and Water 2011. Report to Congress. Available: http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf

United Nations Development Programme. 2005. Adaptation Policy Frameworks for Climate Change. Developing Strategies, Policies and Measures, Ed. Bo Lim, Erika Spanger-Siegfried, Co-authors Ian Burton, Elizabeth Malone, Saleemul Huq.

US Climate Change Science Program (CCSP). 2008. Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C. Available: http://www.climatescience.gov/Library/sap/sap3-3/final-report/default.htm

CCSP. 2009. Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decisionmaking. [M. Granger Morgan, Hadi Dowlatabadi, Max Henrion, David Keith, Robert Lempert, Sandra McBride, Mitchell Small, and Thomas Wilbanks (eds.)]. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. National Oceanic and Atmospheric Administration, Washington, DC. Available: http://www.climatescience.gov/Library/sap/sap5-2/final-report/default.htm.

U.S. Environmental Protection Agency (EPA). 2009a. Synthesis of Adaptation Options for Coastal Areas. Washington, DC, U.S. Environmental Protection Agency, Climate Ready Estuaries Program. EPA 430-F-08-024. Available: http://www.epa.gov/climatereadyestuaries/downloads/CRE_Synthesis_1.09.pdf

EPA. 2009b. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/011. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

EPA. 2011. High Global Warming Potential Gases, on the US EPA web site. Accessed July 12, 2011: http://www.epa.gov/highgwp/scientific.html.

U. S. Global Change Research Program/Climate Change Science Program. 2009. Climate Literacy: the Essential Principles of Climate Sciences. Available: http://www.climatescience.gov/Library/Literacy/

Vermeer and Rahmstorf. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences of the United States of America. 106(51): 21527-21532. Available: http://www.pnas.org/content/106/51/21527.full.pdf+html

Vicuña, S., J. Dracup, L. Dale. 2009. Climate Change Impacts on the Operation of Two High-Elevation Hydropower Systems in California. California Energy Commission. CEC-500-2009-019-F. Available: http://www.energy.ca.gov/2009publications/CEC-500-2009-019/CEC-500-2009-019-F.PDF.

Water Utility Climate Alliance (WUCA). 2010. Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning. Available: http://www.wucaonline.org/assets/pdf/pubs_whitepaper_012110.pdf

Appendix A

Climate Change Literature Review Summary

This appendix reviews current literature (as of November 2011), web content, and existing summary tables provided by EPA and California Department of Water Resources (DWR) that relate to addressing climate change impacts on water resources. This search and review of available documents is summarized into the following summary table that identifies climate change documents specifically linked to regional water planning standards. The table is intended to provide guidance for regional water planners and stakeholders to address climate change at key stages within their planning process. The literature summary table is not intended to be a comprehensive survey of the vast amount of scientific literature regarding climate change; rather a targeted survey which identifies the body of literature directly applicable to the regional water planning process.

Organization of the Literature Search Summary Table

The six main categories of the table include:

- General Information,
- General Introduction to Climate Change and Water Resources,
- Climate Change Research,
- Climate Change Implications and Impacts,
- Resource Management Strategies (Adaptation),
- Planning Under Uncertainty, and
- Climate Change Mitigation.

These main categories generally follow the process of addressing climate change issues over the course of a water resource planning process. The summary table provides a "roadmap" indicating the specific aspect of climate change covered by each document reviewed. The literature was screened to identify the presence (or absence) of information useful for preparation of regional water plans. The type of information provided under each category is described below.

General Information

This category contains general citation information for each document. This section of the literature review includes:

- Source Title,
- Author(s),
- Journal/Agency Information, and
- Publication Date.

The literature review summary also includes the following information:

- Index Number: This is an arbitrary number assigned for bookkeeping purposes. A unique index is assigned to each source.
- DWR Reference Information: The Department of Water Resources has produced a Climate Change Clearinghouse (http://www.water.ca.gov/irwm/docs/drftIRWMPlanningClrhs3_041210.pdf) containing reference information that points to many useful documents in climate change and Water Resources Planning. Items in the Summary Table that are also contained in the clearinghouse are indicated in the "DWR Reference Information" column with a "CH"; items that are also contained in the large DWR index are indicated with the index number from the DWR list.
- Document Type: Most documents in this table are in text form; however, several PowerPoint presentations and a video have also been included.
- Geographic Scope: the tabulated literature references are categorized by location in the "Geographic Scope" column, beginning with California (denoted "CA"), followed by the Pacific Northwest ("PNW") and documents that either focus on a region of the United States outside of the PNW or contain nationwide information. Finally, the notation "NA", referring to Not Applicable, is assigned to documents addressing global-scale phenomena, local-scale phenomena external to the United States, and topics that are not region-specific (such as Adaptive Management). In addition to California, the Pacific Northwest was a selected region due to the similarities in topography and coastal environments. Furthermore, a large amount of climate change research related to water resources has been conducted in this region. Associated with the grouping by location, the table may be sorted chronologically, with the most recent documents for each location shown at the top.
- General Introduction to Climate Change and Water Resources: This category represents literature which provides general overviews or summaries of climate change. These may be useful to serve as a "primer" on climate change or to provide general overview information for presentation in a non-technical setting. A "Y" indicates that the document addresses this category.

Climate Change Research

This category identifies literature which addresses the scientific understanding of climate change as well as its trends and processes. This is an area in which there is a vast amount of prior and ongoing research, so the literature summary table is not intended to be comprehensive. Five subcategories which are intended to indicate the relevance of the research to regional water plans have been identified. These include:

- Global Climate Change Trends,
- General Overview of Climate Change Processes,
- Regional Climate Change Trends (targeting West Coast of the U.S.), Global Climate Model (GCM) modeling, Downscaling, and
- Hydrology Trends and Models.

A "Y" indicates that the document addresses each subcategory and provides useful information for a regional planner.

Climate Change Implications and Impacts

The category represents literature which is directly relevant to assessment of climate change vulnerability and impacts to various sectors applicable to a regional water plan. Ten subcategories were identified to cover the suite of water resource management sectors including:

- Flood Management,
- Groundwater,
- Habitat/Ecosystem,
- Hydropower,
- Sea Level Rise,
- Stormwater Management,
- Surface Water Supply,
- Water Quality,
- Urban Water Demand, and
- Agricultural Water Demand.

These categories reflect a combination of the Integrated Regional Water Management (IRWM) plan minimum requirements, the Statewide Priorities for the IRWM Grant Program, the DWR Proposition 84 and Proposition 1E Guidelines Project Definition, and the typical categories of climate change study. A "G" or "S" is used to designate whether each document provides General information or Specific information. "General" indicates literature which is typically more descriptive and qualitative while "Specific" provides a higher level of detail and technical basis.

Resource Management Strategies (Adaptation)

This category represents literature relevant to the IRWM plan minimum requirements, Statewide Priorities for the IRWM Grant Program, and the DWR Proposition 84 and Proposition 1E Guideline Project Definition. Twelve subcategories are identified which generally overlap with the Implications and Impact category above but also include Conservation, Reuse, and Recycling. A "G" or "S" is used to designate whether each document provides General information or Specific information. "General" indicates literature which is typically more descriptive and qualitative while "Specific" provides a higher level of detail and technical basis.

Planning Under Uncertainty

This category represents a departure from prior regional water planning processes and represents one of the unique features of the Handbook. The DWR IRWM Plan Guidelines require that technical analysis consider uncertainty and how the uncertainty is applied to the planning horizon. Three subcategories are identified: Decision Support/Alternative Evaluation, Analysis of Uncertainty, and Adaptive Management. A "G" or "S" is used to designate whether each document provides General information or Specific information. "General" indicates literature which is typically more descriptive and qualitative while "Specific" provides a higher level of detail and technical basis.

Climate Change Mitigation

This category represents literature which addresses greenhouse gas emissions inventories and emission reduction strategies. This is an area where there is a vast amount of prior and ongoing research and the literature summary table is not intended to be comprehensive. A "Y" indicates that the document addresses mitigation.

The "G" and "S" classifications allow a user to filter the abundant reference information available in these subcategories between general overviews of the subject material—denoted as "G" resources, or specific case studies, examples, or guidelines on the approach, implementation and monitoring of climate change elements within the planning process—denoted as "S" resources. For example, DWR's "Managing an Uncertain Future" is assigned a "G" in the table for all Implications and Impacts and Adaptation categories. This is because the document provides an introductory overview of general state-wide trends and management strategies. However, AWWA's "Climate Change and Water: International Perspectives on Mitigation and Adaptation" is assigned several "S" categorizations because it contains many case studies where specific management strategies were evaluated.

The other tabs included in the Excel file for this table include general notes, a list of acronyms, and a companion table containing web links where files are publicly available. An effort was made to concentrate on publicly available literature, but in some instances journal publications and other private documents containing valuable information were included.

How to Use the Literature Search Summary Table

This literature review table is intended to be used in conjunction with the Handbook to allow regional water planners and stakeholders to identify the climate change references most useful to them as they incorporate climate change into the regional water planning process. The literature summary table is provided in electronic format to allow a user search and sort capabilities. The most effective method is to use the **Filter** option and the **Sort** option, both found in the **Data** menu of Microsoft Excel. These options allow a user to produce a short list of documents that have both general and specific information related to the planning category, or group of select planning categories, and will allow limiting the list further to those documents showing only specific information. These data filtering options were applied after the initial round of literature review to determine where information gaps existed and to focus on filling these gaps during subsequent rounds.

General Findings of the Literature Search

During development of the literature review, it became apparent that a significant amount of climate change literature related to water resources has been produced over the last five years. To address this, an additional table is included to show references that have yet to be reviewed and determined useful for the regional water planners. This table also includes some website links for additional information and documentation related to climate change. Other key findings from the literature review and tabulation were as follows:

- There is a significant amount of general climate change information, but much less of the specific/procedural guidelines necessary for a regional water planner to follow through a regional water planning process.
- There is an information gap on specific strategies for water agencies or utilities to adapt to climate change impacts.
- Limited information exists in the integration of strategies and how they might impact other sectors and/or other strategies.
- A lack of information related to climate change implications on potential vulnerabilities and impacts on Groundwater and Water Quality.
- Much of the available literature presents general information, but there is relatively little which presents specific tools and guidelines on how to apply impacts to sectors for regional water planners and the regional water planning project prioritization and evaluation process.
- There is an abundant amount of documentation on mitigation, but the documents primarily describe this category in general terms as it relates to preventive measures (emissions

reduction). Less information is available on how a participant can use and integrate mitigation to offset an impact associated with a specific water resource strategy.

- There is very limited information and guidance on the use of decision-support tools as used by regional water planners in the context of evaluating strategies to address climate change impacts.
- There are many examples of planning and decision support in preparing for climate change, but there is very little material describing ways in which climate change planning can be incorporated into a larger planning process such as a regional water plan, which has a separate structure for project prioritization and evaluation. The limited number of regional water plans that take climate change into account include climate change in the project weighting process or include climate change as a specific objective. These regional water plans are included in the Literature Summary.

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
1	Sierra Climate Change Toolkit	-	Sierra Nevada Alliance	2007	text (pdf)	CA		Y	Y	Y		Y											S	S		S	G				S						S	Y
2	California Water Plan Update 2005 - Climate Change and California Water Resources: A Survey and Summary of the Literature	Michael Kiparsky Peter Gleick	CEC (Pacific Institute)	Jul-03	text (pdf)	CA				Y	Y	Y	G	G	G	G	G		G	G		G	G					G			G		G	G			G	
3	Progress on Incorporating Climate Change into Management of California's Water Resources	Anderson et al.	Climatic Change	2008	text (pdf)	CA				Y	Y	Y	S						S	S											S					S		
4	Using Future Climate Projections to Support Water Resources Decision Making in California	Chung et al.	CA CCC	Jun-09	text (pdf)	CA				Y	Y	Y	G				S		S			G																
5	DWR Presentation to the Regional Advisory Committee for the San Diego Integrated Regional Water Management Plan	John T. Andrew	DWR	Oct-09	ppt (pdf)	CA	Y												G	G																		Y
6	Framework for the Implementation of Water Management Planning	California Water Institute - Fresno State	California Partnership for the San Joaquin Valley	Mar-09	text (pdf)	CA																									S							
7	The Future is Now: An Update on Climate Change Science Impacts and the Response Options for California	Moser et al.	CEC PIER	Sep-08	text (pdf)	CA	Y			Y					G																							
8	The State of Climate Science for Water Resources Operations, Planning and Management	Michael Anderson	DWR	Jan-09	text (pdf)	CA		Y			Y																											
9	Water Management Adaptation with Climate Change	Medellin-Azuara et al.	CA CCC	Aug-09	text (pdf)	CA					Y	Y				S			S		S	S					S				S				S			
10	Adapting California's Water Management to Climate Change	Elen Hanak Jay Lund	PPIC	Nov-08	text (pdf)	CA							G				G		G	G				G	G		G				S	G	G	G		G	G	Y
11	Managing Water in the West: Literature Synthesis on Climate Change Implications for Reclamation's Water Resources	Spears et al.	BOR	Sep-09	text (pdf)	CA				Y	Y	Y	G	G	G	G	G		G	G	G																	
12	The Impact of Climate Change on California's Ecosystem Services	Shaw et al.	CA CCC	Mar-09	text (pdf)	CA					Y	Y			S																							
13	Adopted Text of the CEQA Guidelines Amendments	-	CEQA	Dec-09	text (pdf)	CA																																Y
14	Climate Change Scoping Plan: A Framework for Change	-	California Air Resources Board	Dec-08	text (pdf)	CA																																Y
15	Preparing California for a Changing Climate	Louise Bedsworth Ellen Hanak	Public Policy Institute of CA	NA	text (pdf)	CA				Y																												
16	Planning for Reliable Water Supply in the Face of Climate Change and Uncertainty	Dan Rodrigo Greg Heiertz	AWRA Specialty Conference on Adaptive Management (CDM)	Jun-09	text (pdf)	CA						Y							S		S															S	S	
17	Our Changing Climate: Assessing the Risk to California	Guido Franco Daniel C. Cayan Amy Linde Luers	CA CCC	Jul-06	text (pdf)	CA						Y			G	G	G		G																			
18	Climate Change and California Water Management: First Western Forum on Energy and Water Sustainability	John T. Andrew	DWR	Mar-07	ppt (pdf)	CA	Y			Y							G		S																			
19	Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water	-	DWR	Oct-08	text (pdf)	CA				Y			G	G	G	G	G		G	G			G	G	G	G		G	G		G							
20	Progress on Incorporating Climate Change into Management of California's Water Resources: July 2006 Technical Memorandum Report	-	DWR	Jul-06	text (pdf)	CA		Y	Y	Y	Y	Y	S	G			S		S		S	S													G	G		Y
21	2009 California Climate Adaptation Strategy	-	California Natural Resources Agency (CNRA)	2009	text (pdf)	CA		Y	Y	Y	Y		S	G	S	G	S	G	S	G	S	S	G	G	G	G	G	G	G	G	G		S	G			S	Y
22	A Report on Sea Level Rise Preparedness	Herberger et al.	California State Lands Commission CA CCC	May-09	text (pdf)	CA									S		S									S		S							S	S		

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
23	Incorporating Climate Change into Water Supply Planning Models	Timothy Cox Enrique Loezcalva William Davis	AWRA Specialty Conference on Adaptive Management (CDM)	Jun-09	text (pdf)	CA						Y							S												S						S	
24	CEQA and Climate Change	-	CAPCOA	Jan-08	text (pdf)	CA																																Y
25	CEQA and Climate Change: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review	-	Governor's Office of Planning and Research	Jun-08	text (pdf)	CA																																Y
26	Vulnerability in the Water Sector: Drought and Climate Change	David Behar	San Fracnsico Public Utility Commission WUCA	Apr-10	ppt (pdf)	CA	Y												G												G							
27	California Climate Risk and Response	Fredrich Kahrl David Roland-Holst	UC Berkeley Department of Agricultural and Resource Economics	Nov-08	text (pdf)	CA					Y	Y							S						G		G				G							
28	DRAFT Biennial Climate Action Team Report	-	CAT	Mar-09	text (pdf)	CA				Y	Y	Y	G		G	S	S		S							G		G			G							Y
29	Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation	Andrea J. Ray Joseph J. Barsugli Kristen B. Averyt	Colorado Conservation Board	2008	text (pdf)	US		Y		Y	Y	Y																										
30	The Copenhagen Diagnosis: Updating the World on the Latest Climate Science	-	UNSW	2009	text (pdf)	NA		Y	Y																													
31	Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making: Synthesis and Assessment Product 5.2	-	US Global Change Research Program, Climate Change Science Program	Jan-09	text (pdf)	NA					Y	Y																							S	S	S	
32	Climate Change 2007 Synthesis Report: Summary for Policymakers	-	IPCC	2007	text (pdf)	NA		Y	Y																													
33	Climate Change and Water: IPCC Technical Paper VI	-	IPCC	Jun-08	text (pdf)	NA		Y			Y	Y	S		S	S	S	S	S	S	S	S	G	G		G	G	G		G	G		G	G				Y
34	Climate Change and Water: International Perspectives on Mitigation and Adaptation	-	AWWA IWA Publishing	2010	text (pdf)	NA		Y				Y	S	S	G	G	S	S	G	S	S	S	S	S	S		G	S		S	S		S	S	S	S	S	Y
35	California's Water-Energy Relationship	Gary Klein	CEC	Nov-05	text (pdf)	NA										S						G	G				G											Y
36	Refining Estimates of Water-Related Energy Use in California	-	CEC PIER (Navigant Consulting)	Dec-06	text (pdf)	NA																	G															Y
37	Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits through Integrated Water-Energy Efficiency Measures	-	University of California Santa Barbara	Jan-00	text (pdf)	NA																	S						G									Y
38	Flood Protection in the Netherlands: Framing Long-Term Challenges and Options for a Climate-Resilient Delta	Ligtvoet et al.	Netherlands Environmental Assessment Agency	Dec-09	text (pdf)	NA							G				S							S				S										
39	Before the Deluge: Coping with Floods in a Changing Climate	Patrick McCully	International Rivers Network	May-07	text (pdf)	NA							S											S														
40	Setting the Record Straight: Responses to Common Challenges to Climate Science	Doppelt et al.	University of Oregon Climate Leadership Initiative University of Washington Climate Impacts Group	2009	text (pdf)	NA		Y	Y																													
41	Climate Change 101: Understanding and Responding to Global Climate Change	-	PEW Center on Climate Change	Jan-09	text (pdf)	NA	Y	Y	Y																												G	

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
42	Identifying Adaptation Options	UK Climate Impacts Programme	UK Climate Impacts Programme	2006	text (pdf)	NA																													S	S	S	
43	Climate Adaptation: Risk, Uncertainty, and Decision Making	UK Climate Impacts Programme	UK Climate Impacts Programme	2003	text (pdf)	NA																													S	S	S	
44	Cities Preparing for Climate Change	Eva Ligeti Jennifer Penney Ireen Wieditz	The Clean Air Partnership	2007	text (pdf)	NA		Y		Y			G		G		G	G	G		G	G	G	G		G		G	G	G	G			G	G	G	S	Y
45	Enhancing Reliability Through Adaptive Management Strategies: A Water Utility Perspective	Alison Adams	AWRA Specialty Conference on Adaptive Management	Jun-09	text (pdf)	NA													S						S						S						S	
46	A Framework for Incorporating Streamflow Forecasts into Reservoir Management	Lucien Wang Gavin Gong Upmanu Lall	AWRA Specialty Conference on Adaptive Management	Jun-09	text (pdf)	NA													S												S				S		S	
47	Climate Change and Water Resources Management: A Federal Perspective	Brekke et al.	USGS	2009	text (pdf)	US		Y	Y			Y	S		G		G		G	G		G									G		G	G		G	G	
48	National Water Program Strategy Response to Climate Change	-	EPA	Sep-08	text (pdf)	US		Y	Y								G		G				G	G		G				G								Y
49	Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change	Barsugli et al.	Water Utility Climate Alliance (WUCA) (Stratus Consulting) (University of Colorado at Boulder) (Iowa State University Climate Science Initiative)	Dec-09	text (pdf)	US					Y	Y																										
50	Global Climate Change Impacts in the United States	Karl et al.	US Global Change Research Program	June-09		US		Y	Y	Y		Y	G		S		G		G	G																		
51	Ecological Impacts of Climate Change	-	The National Academies	2009	text (pdf)	US	Y	Y	Y						S																							
52	Implications of Climate Change for Urban Water Utilities	John E. Cromwell Joel B. Smith Robert S. Raucher	Association of Metropolitan Water Agencies (AMWA) (Stratus Consulting)	2007	text (pdf)	US	Y	Y	Y		Y	Y	G		G		G	G	G	G	G	G													G	G		Y
53	Climate Change and Water Resources: A Primer for Municipal Providers	Kathleen Miller David Yates	AWWARF UCAR	2006	text (pdf)	US		Y	Y		Y	Y	G	S			S	G	S	S	G	G	S	S						S	S	S		S	G	G	S	
54	Implications of Climate Change for Adaptation by Wastewater and Stormwater Agencies	Cromwell et al.	WERF (Stratus Consulting) (MWH Global)	Dec-09	text (pdf)	US		Y	Y		Y	Y	G				G		G																S	G	S	
55	Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning	Means et al.	Water Utility Climate Alliance (WUCA) (Malcolm Pirnie)	Jan-10	text (pdf)	US																													S	S	S	
56	Climate Literacy	-	US Global Change Research Program, Climate Change Science Program	Mar-09	text (pdf)	US	Y		Y																													
57	Thresholds of Climate Change in Ecosystems: Final Report, Synthesis and Assessment Product 4.2	-	US Global Change Research Program, Climate Change Science Program	Jan-09	text (pdf)	US									S											G											S	
58	Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis	-	EPA	Mar-08	text (pdf)	US		Y		Y		Y			S																							
59	A Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change (DRAFT)	Hector Galbraith Jeff Price	US EPA Global Change Research Program National Center for Environmental Assessment	Feb-09	text (pdf)	US									S																							
60	Synthesis of Adaptation Options for Coastal Areas	-	US EPA Climate Ready Estuaries	Jan-09	text (pdf)	US							G		G		G							G		G		G										
61	Preliminary Review of Adaptation Options for Climate Sensitive Ecosystems and Resources	Julius et al.	US Climate Change Science Program	2008	text (pdf)	US		Y	Y	Y			G		S		G	G	G	G						S									S	S	S	Y

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
62	The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States: Final Report, Synthesis and Assessment Product 4.3	Peter Backlund Anthony Janetos David Schimel	US Climate Change Science Program	May-08	text (pdf)	US		Y	Y			Y		G	S		G		S	G																		
63	Adapting to climate change in United States National Forests	Blate et al.	Unasylva	2009	text (pdf)	US																				S												
64	Final Report from the Technical Committee on Climate Change	R. N. Palmer	Department of Civil and Environmental Engineering, University of Washington The Climate Impacts Group	2006	ppt (pdf)	PNW					Y	Y		G					S																			
65	2009 Regional Supply Outlook	Central Puget Sound Water Supply Forum	Central Puget Sound Water Supply Forum (CDM)	2009	text (pdf)	PNW			Y	Y	Y								S		S		S		S				S		S			S	S	S	S	
66	Everett Comprehensive Water Plan 2006; Appendix 6-2 - Climate Change Technical Memorandum Evaluation of Climate Change on Everett's Yield	Amie Hansen	City of Everett Public Works Department (HDR)	2006	text (pdf)	PNW					Y	Y				S			S								S				S				S	S	S	
67	Preparing for Climate Change: A Guide for Local, Regional and State Governments	Climate Impacts Group (UW), King County, Wa	Center for Science in the Earth System (Climate Impacts Group), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington King County ICLEI - Local Governments for Sustainability	2007	text (pdf)	PNW		Y	Y	Y			G	G	G	G	S	S	S	G	G	G	G	G	G	G	G	G	G	G	G		G	G	S	S	S	Y
68	SPU 2007 Water System Plan - Part I, Chapter 2: Water Resources	-	Seattle Public Utilities	2007	text (pdf)	PNW				Y	Y								S		S		S	G	S	G			S		S			S	G	S	S	
69	Climate Impacts on Washington's Hydropower, Water Supply, Forests, Fish and Agriculture	Casola et al.	Center for Science in the Earth System (Climate Impacts Group), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington Climate Impacts Group	2005	text (pdf)	PNW		Y	Y	Y			S		S	S		S	S		S	S																
70	Climate Change Building Blocks	Palmer et al.	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2006	text (pdf)	PNW		Y	Y	Y					G		G		G																			
71	Technical Memorandum #1: Literature Review of Research Incorporating Climate Change into Water Resources Planning	D. Alexander R.N. Palmer A. Polebitski	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW					Y	Y																										
72	Technical Memorandum #2: Methodology for Downscaling Meteorological Data for Evaluating Climate Change	A. Polebitski M.W. Wiley R.N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW					Y																											
73	Technical Memorandum #3: Online Database Functionality and Design for Climate Impacted Data	C. O'Neill R.N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW					Y	Y																										

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
74	Technical Memorandum #4: Approach for Developing Climate Impacted Meteorological Data and its Quality Assurance/Quality Control	Polebitski A., L. Traynham R.N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW				Y	Y	Y																										
75	Technical Memorandum #5: Approach for Developing Climate Impacted Streamflow Data and its Quality Assurance/Quality Control	Polebitski A., L. Traynham R.N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW				Y		Y																										
76	Technical Memorandum #6: Framework for Incorporating Climate Change into Water Resources Planning	R. N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW		Y	Y		Y	Y	G	G	G			G	G		G																	
77	Technical Memorandum #8: Impacts of Climate Change on Groundwater Resources- A Literature Review	D. Alexander R.N. Palmer	Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.	2007	text (pdf)	PNW								S																								
78	Climate Change Impacts on Columbia River Basin Fish and Wildlife	Independent Science Advisory Board	Independent Science Advisory Board	2007	text (pdf)	PNW		Y	Y	Y			G		S				G							G											G	Y
79	HB 1303 Interim Report: A Comprehensive Assessment of the Impacts of Climate Change on the State of Washington	Climate Impacts Group	Climate Impacts Group	2007	text (pdf)	PNW		Y		Y			G		G		G	G				G															G	Y
80	Adapting to climate change on Olympic National Forest	D. L. Peterson J.S. Littell O'Halloran	Mountain Views	2008	text (pdf)	PNW																				G											G	Y
81	Sea Level Rise in the Coastal Waters of Washington State	Mote et al.	University of Washington Climate impacts Group Washington Department of Ecology	2008	text (pdf)	PNW				Y																												
82	The Washington Climate Change Impacts Assessment	Climate Impacts Group	Climate Impacts Group	2009	text (pdf)	PNW		Y		Y	Y	Y	S		S	S	S	S	S		S	S	G	G	G	G	G	G		G	G		G	G			G	
83	California Water Plan Update 2009 Volume I: Strategic Plan	-	DWR	2009	text (pdf)	CA				Y			S	G	G	G	G		S	G	S	S	S	S	S	S			S	S	S	S	G	G		S	S	Y
84	Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems	-	The H. John Heinz III Center For Science, Economics and the Environment	no date!!	text (pdf)	NA																				S									S		S	
85	Understanding and Responding to Climate Change: Highlights of National Academies Reports 2008 Edition	-	National Academy of Science National Academy of Engineering Institute of Medicine National Research Council	2008	text (pdf)	US	Y	Y	Y																													
86	The Impacts of Sea-Level Rise on the California Coast	Herberger et al.	CA CCC	May-09	text (pdf)	CA					Y		G	G	S		S							G		G		S								S		
87	Climate Change in California: Scenarios for Adaptation	Amy Luers Michael D. Mastrandrea	PPIC	Nov-08	text (pdf)	CA				Y	Y						G																			G		
88	California Water Plan Update 2009 Volume II: Resource Management Strategies	-	DWR	2009	text (pdf)	CA																	S	S	S	S		S	S	S	S	S	S	S				
89	A Climate of Change	-	DWR	NA	video	CA	Y		Y	Y	Y	Y	G	G		G	S		S						S		G	S										
90	The Potential Consequences of Climate Variability and Change for California	Wilkinson et al.	California Regional Assessment Group	2002	text (pdf)	CA		Y	Y		Y	Y	G	G	S	G	S		S	G						G					G				G		G	Y
91	Report of the World Climate Conference-3: Better Climate Information for a Better Future	-	World Meteorological Organization (WMO) and United Nations Educational, Scientific and Cultural Organization (UNESCO)	Sep-09	text (pdf)	NA																																

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
92	Climate Change and Water Management	-	California Environmental Dialoque	Sep-09	text (pdf)	CA																	G		G				G	G								Y
93	Bird Species and Climate Change	Janice Wormworth Karl Mallon	WWF-Australia	2006	text (pdf)	NA																																
94	Observed Changes in the Sierra Nevada Snowpack: Potential Causes and Concerns	Sarah Kapnick Alex Hall	CA CCC	Aug-09	text (pdf)	CA						Y																										
95	An Enhanced California Climate Monitoring System	Kelly T. Redmond David B. Simeral Greg D. McCurdy	CEC PIER	Aug-09	text (pdf)	CA				Y																												
96	Preparing for the Impacts of Climate Change in California: Opportunities and Constraints for Adaptation	Amy Lynd Luers Susanne C. Moser	CA CCC	Mar-06	text (pdf)	CA																													S		G	
97	Climate Scenarios for California	Cayan et al.	CA CCC	Mar-06	text (pdf)	CA				Y	Y	Y																										
98	Scenarios of Climate Change in California	Cayan et al.	CA CCC	Feb-06	text (pdf)	CA					Y	Y				S	S		S																			
99	In Hot Water: Water Management Strategies to Weather the Effects of Global Warming	Nelson et al.	NRDC	Jul-07	text (pdf)	US		Y	Y	Y		Y	G		G	G	G		G	G	S	G	S	G	G	G				G	S	G	G	G			G	Y
100	Climate Change Scenarios and Sea Level Rise Estimates for the CA 2008 Climate Change Scenarios Assessment	Cayan et al.	CA CCC	Mar-09	text (pdf)	CA				Y	Y	Y					S																					
101	Planning for Climate Change in the West	Rebecca Carter Susan Culp	Lincoln Institute of Land Policy	2010	text (pdf)	US				Y																												
102	California Water Myths	Hanak et al.	PPIC	Dec-09	text (pdf)	CA	Y																															
103	Why Climate Change Makes Riparian Restoration More Important than Ever: Recommendations for Practice and Research	Seavy et al.	Ecological Restoration	Sep-09	text (pdf)	NA																				S												
104	Bay Delta Conservation Plan Chapter 3: Working Draft Conservation Strategy	-	BDCP	Aug-09	text (pdf)	CA																	S			S		S			S	S					S	
105	Bay Delta Conservation Plan: Independent Science Advisor's Report on Adaptive Management	Dahm et al	BDCP Steering Committee	Feb-09	text (pdf)	NA																															S	
106	Surface Temperature Reconstructions for the Last 2,000 Years	-	National Academy of Sciences	2006	text (pdf)	NA																																
107	Water World: Why the Global Climate Challenge is a Global Water Challenge	Stoddart et al.	Global Public Policy Network on Water Management	Dec-09	text (pdf)	NA	Y								G	G											G				G							
108	Incorporating Climate Change in Water Planning	Freas et al.	Journal of the American Water Works Association	Jun-08	text (pdf)	US																													S	S		
109	Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change	Secretariat of the Convention on Biological Diversity	Convention on Biological Diversity UNEP	2009	text (pdf)	NA									S											S												Y
110	Potential Inundation due to Rising Sea Levels in the San Francisco Bay Region	Noah Knowles	CA CCC USGS	Mar-09	text (pdf)	CA											S																					
111	Taking the Heat: Bay Area Ecosystems in the Age of Climate Change	Glen martin	Bay Nature	Apr-10	text (pdf)	CA									S		S																					Y
112	Institutional Adaptation of Water Resource Infrastructures to Climate Change in Eastern Ontario	P. Crabbe M. Robin	Climatic Change (University of Ottowa)	2006	text (pdf)	NA								S						S										G					S		S	
113	Inverse Flood Risk Modeling Under Changing Climatic Conditions	Juraj M. Cunderlik Slobodan P. Simonovic	Hydrological Processes (University of Western Ontario)	2007	text (pdf)	NA					Y	Y	S																									
114	Forecasting Water Demand	William Davis	CDM	2009	ppt (pdf)	NA															S		S											S				

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
115	Qualitative Assessment of Municipal Water Resource Management Strategies Under Climate Impacts: The Case of the Northern Cape, South Africa	Pierre Mukheibir	Water SA (University of Cape Town)	2007	text (pdf)	NA								G																					S			
116	Water Supply Risk on the Colorado River: Can Management Mitigate?	Rajagopalan et al	Water Resources Research (University of Colorado at Boulder, NOAA, BOR, AMEC, Inc)	2009	text (pdf)	US				Y	Y	Y							S												S				S	S		
117	National Security and the Threat of Climate Change	-	CNA Corporation	2007	text (pdf)	NA		Y					G		G		G		G																			
118	Risk-Based Climate-Change Impact Assessment for the Water Industry	O. M. Thorne R. A. Fenner	Water Science and Technology (Cambridge University)	2009	text (pdf)	NA					Y	Y							S	S																		
119	Identification of Major Sources of Uncertainty in Current IWRM Practice. Illustrated for the Rhine Basin	van der Keur et al	Water Resources Management (Geological Survey of Denmark and Greenland, University of Osnabrück, Wageningen University, Rijkswaterstaat Centre for Water Management)	2008	text (pdf)	NA																													S	S	S	
120	Multi-Objective Water System Operations Optimization to Address Supply Uncertainty	Bill Fernandez Kirk Westphal Alek Cannan	AWRA Specialty Conference on Adaptive Management (CDM)	2009	text (pdf)	CA						Y							S																	S		
121	City of San Diego Water Department Update of Long-term Water Demand Forecast	-	CDM	2008	text (pdf)	CA					Y										S		S											S		S		
122	Assessing Climate Change Impacts on Water Supply Planning	Enrique Lopez Calva Gordon McCurry Tim Cox	CDM	2009	ppt (pdf)	US		Y	Y	Y	Y										S													S	G	S		
123	Integrated Resources Planning: A Path to Sustainability	Dan Rodrigo	CDM	2008	ppt (pdf)	NA									G			G	G	G	G		G		G	G			G	G	G	G			S	S		
124	Irvine Ranch Water District Water Supply Reliability Study	-	CDM	2008	text (pdf)	CA								S					S		S													S		S		
125	New York City Department of Environmental Protection Greenhouse Gas Management Feasibility Study	-	CDM	2007	text (pdf)	US																																Y
126	Climate Change Impacts on Recharge in a Semi-Arid Irrigated Watershed	Gordon N. McCurry Kenneth M. Strzepek	CDM	2008	text (pdf)	US						Y		G					S			S																
127	Climate Change and the Water/Wastewater Industry: Challenges and Opportunities	Alexandra Doody Lynne Moss Gordon McCurry	CDM	2008	text (pdf)	US																																Y
128	The Role of Low-Impact Redevelopment/Development in Integrated Watershed Management Planning: Turning Theory Into Practice	Mark Maimone	CDM, PWID	2007	ppt (pdf)	US																								S		S						
129	Green Infrastructure in CSO Long Term Control Planning	Marty Umberg Samantha Doering	MSD Greater Cincinnati CDM	2008	ppt (pdf)	US																								S		S						
130	Water Supply Reliability Planning in the Face of Uncertainty: A Case Study of the Irvine Ranch Water District	Dan Rodrigo	CDM	2008	ppt (pdf)	CA								S					S		S															S		
131	The City of West Palm Beach Wetlands-Based Water Reclamation and Water Supply Augmentation Program	Lee Wiseman, Larry Schwartz	CDM	2008	ppt (pdf)	US								S											S				S			S					S	
132	Cosumnes, American, Bear & Yuba River Integrated Water Management Plan	-	Cosumnes, American, Bear & Yuba River Watersheds Group (Ecosystem Sciences Foundation)	Dec-06	text (pdf)	CA						Y			G				S																S		G	

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
133	The Future of Sustainability	W. M. Adams	International Union for the Conservation of Nature (IUCN)	Jan-06	text (pdf)	NA																																
134	Adapting to Climate Change in Australia: An Australian Government Position Paper	-	Commonwealth of Australia Department of Climate Change	2010	text (pdf)	NA																																
135	Integrated Regional Water Management Plan for the Upper Santa Margarita Watershed Planning Region	-	Rancho California Water District Riverside County (CDM)	2007	text (pdf)	CA																												S			Y
136	Solano Agencies Integrated Regional Water Management Plan and Strategic Plan	-	Solano County Water Agency Solano Agencies	2005	text (pdf)	CA																												S			
137	Climate Change Risks to Australia's Coast	-	Commonwealth of Australia Department of Climate Change	Nov-09	text (pdf)	NA						Y			S		S																	S	S	S	
138	Climate Change in Australia: Regional Impacts and Adaptation - Managing the Risk for Australia	-	Australian Prima Minister's Science, Engineering and Innovation Council	2007	text (pdf)	NA																			G						G							
139	Climate Change Science Compendium		United Nations Environment Programme	Sep-09	text (pdf)	NA	Y	Y	Y						S		S																			G	
140	Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs		CH2MHill; Association of Metropolitan Water Agencies	October-09	text (pdf)	US	Y			Y	Y	Y	S				S	S	S					S				S	S	S	S					G	G	
141	Climate Change Indicators in the United States		US EPA	April-10	text (pdf)	US	Y	Y	Y	Y							G																					
142	Advancing the Science of Climate Change		National Research Council of the National Academies	May-10	text (pdf)	US	Y	Y	Y	Y	Y		S	G	S		S	G	S	G	G	G	G					G									G	
143	Adapting to the Impacts of Climate Change		National Research Council of the National Academies	May-10	text (pdf)	US	Y	Y		Y	Y	Y			S		S					G	S	S	G	S	G	S	S	S	S	S	S	S	S	S	S	
144	Climate Adaptation Priorities for the Western States: Scoping Report		Western Governer's Association	June-10	text (pdf)	US	Y		Y																													
145	Water, Climate Change, and Forests - Watershed stewardship for a changing climate		US Forest Service	June-10	text (pdf)	US	Y	Y		Y	Y	Y	G	G	S	G		G	S	G			S	S	S	S			G	G	S	S				G	S	
146	Evaluating Sustainability of Projected Water Demands in 2050 under Climate Change Scenarios		Tetra Tech/NRDC	July-10	text (pdf)	US	Y	Y		Y	Y	Y	G	G		S		G	S	G	G	G																
147	The State Water Project Delivery Reliability Report 2009		CA Department of Water Resources	August-10	text (pdf)	CA	Y					Y	G			G	S	G	S																	G		
148	Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change		US Fish and Wildlife Service	September-10	text (pdf)	NA		Y	Y						G				G							G											G	Y
149	Myths of California Water - Implications and Reality	Hanak, Lund, Dinar, Howitt, Mount, Moyle, Thompson		Winter 2010	text (pdf)	CA	Y					Y							S																		G	
150	Sierra Climate Change Toolkit - 3rd Edition		Sierra Nevada Alliance	XX 2010	text (pdf)	CA	Y	Y	Y	Y		Y											S	S		S	G				S						S	Y
151	Framework for Cooperative Conservation and Climate Adaptation for the Southern Sierra Nevada and Tehachapi Mountains		Southern Sierra Partnership	October-10	text (pdf)	CA				Y	Y				S				S				S			S											G	
152	Preparing for the Effects of Climate Change - A Strategy for California		Pacific Council on International Policy`	November-10	text (pdf)	CA	Y								G		S		S				S	G	S	G		S		S	S		G	S			S	
153	Climate Action Team Report to Governor Schwarzenegger and the California Legislature		Cal EPA and the Climate Action Team	December-10	text (pdf)	CA																															G	Y
154	Climate Change Characterization and Analysis in California Water Resources Planning Studies	Abdul Kahn and Andrew Schwarz	California Department of Water Resources	December-10	text (pdf)	CA					S	S	G				G	G	G																G	G		
155	The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas		EcoAdapt	January-11	text (pdf)	NA	Y	Y		Y					S		S	S	S	S			S	S	G	S		S	G	S	S	S				G	S	Y

Literature Review Summary Relevant to Climate Change - Integrated Regional Water Management Planning

General Information								Climate Change Research					Climate Change Implications and Impacts										Resource Management Strategies (Adaptation)												Planning for Uncertainty			
Index	Source Title	Author(s)	Journal Title/Agency(ies) Prepared for Institution(s)/ Agency(ies) Prepared by)	Date	Document Type	Geographic Scope	General Introduction To Climate Change and Water Resources	Global Climate Change Trends	General Overview of CC Processes	Regional CC Trends	GCM Modeling and Downscaling	Hydrology Trends and Models	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Stormwater Management	Surface Water Supply	Water Quality	Urban Water Demand	Agricultural Water Demand	Conservation	Flood Management	Groundwater	Habitats, Ecosystems and Biodiversity	Hydropower Generation	Sea Level Rise	Reuse and Recycling	Stormwater Management	Surface Water Supply	Water Quality	Agricultural Water Demand	Urban Water Demand	Decision Support Alternatives Evaluation	Analysis of Uncertainty	Adaptive Management	CC Mitigation
156	Managing Water in the West - Literature Synthesis on Climate Change Implications for Water and Environmental Resources (Second Edition)	Mark Spears, Levi Brekke, Alan Harrison, and Joe Lyons	BOR	January-11	text (pdf)	US	Y			Y	Y	Y	G		G	G	G		G		G																	
157	West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections		BOR	March-11	text (pdf)	US	Y			Y	Y	Y																							G	G		
158	Ready...Or Not? An Assessment of California Agricuture's Readiness for Climate Change		California Climate and Agricultural Network	March-11	text (pdf)	CA				Y									G				G								G		G					Y
159	Climate Change Vulnerability Assessments: Four Case Studies of Water Utility Practices		US EPA	March-11	text (pdf)	CA	Y			Y	Y	Y	S			S	S	S	S	S	S			G				G			G				G	S	G	
160	SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water 2011		US Bureau of Reclamation	April-11	text (pdf)	NA	Y			Y	Y	Y	S	S	S	S		S	S	S	S	S														G		
161	Drops of Energy: Conserving Urban Water in California to Reduce Greenhouse Gas Emissions		UC Berkeley School of Law's Center for Law, Energy & the Environment (CLEE); UCLA School of Law's Environmental Law Center & Emmett Center on Climate Change and the Environment; Bank of America	May-11	text (pdf)	CA	Y			Y							G		G				S								S			S				Y
162	Extreme Weather and Climate Change - Understanding the Link, Managing the Risk		Pew Center on Global Climate Change	June-11	text (pdf)	NA	Y	Y																													G	G
163	The Economic Costs of Sea-Level Rise to California Beach Communities		California Dept of Boating and Waterways	September-11	text (pdf)	CA	Y	Y	Y	Y	Y		S				S							S				S									G	
164	Water, Energy and Climate Change - A contribution from the business community		World Business Council for Sustainable Development	no date	text (pdf)	NA	Y												G				S								S					G		Y
165	Adapting Urban Water Systems to Climate Change		ICLEI	xx 2011	text (pdf)	NA	Y			Y			G	G			G	S	S	G									S		S		S	S	G	G	S	Y
166	America's Climate Choices		National Research Council of the National Academies	XX 2011	text (pdf)	US		Y	Y																													
167	Informing an Effective Response to Climate Change		National Research Council of the National Academies	XX 2011	text (pdf)	US		Y			Y																								S	S	S	Y

This page intentionally left blank.

Appendix B

Vulnerability Assessment Checklist

I. Water Demand

☐ *Are there major industries that require cooling/process water in your planning region?*

- As average temperatures increase, cooling water needs may also increase.
- Identify major industrial water users in your region and assess their current and projected needs for cooling and process water.

☐ *Does water use vary by more than 50% seasonally in parts of your region?*

- Seasonal water use, which is primarily outdoor water use, is expected to increase as average temperatures increase and droughts become more frequent.
- Where water use records are available, look at total monthly water uses averaged over the last five years (if available). If maximum and minimum monthly water uses vary by more than 25%, then the answer to this question is "yes".
- Where no water use records exist, is crop irrigation responsible for a significant (say >50%) percentage of water demand in parts of your region?

☐ *Are crops grown in your region climate-sensitive? Would shifts in daily heat patterns, such as how long heat lingers before night-time cooling, be prohibitive for some crops?*

- Fruit and nut crops are climate-sensitive and may require additional water as the climate warms.

☐ *Do groundwater supplies in your region lack resiliency after drought events?*

- Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be particularly vulnerable to droughts and may become more dependent on groundwater pumping.

☐ *Are water use curtailment measures effective in your region?*

- Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be particularly vulnerable to droughts.

☐ *Are some instream flow requirements in your region either currently insufficient to support aquatic life, or occasionally unmet?*

- Changes in snowmelt patterns in the future may make it difficult to balance water demands. Vulnerabilities for ecosystems and municipal/agricultural water needs may be exacerbated by instream flow requirements that are:
    1. not quantified,
    2. not accurate for ecosystem needs under multiple environmental conditions including droughts, and
    3. not met by regional water managers.

II. Water Supply

☐ *Does a portion of the water supply in your region come from snowmelt?*

- Snowmelt is expected to decrease as the climate warms. Water systems supplied by snowmelt are therefore potentially vulnerable to climate change.
- Where watershed planning documents are available, refer to these in identifying parts of your region that rely on surface water for supplies; if your region contains surface water supplies originating in watersheds where snowpack accumulates, the answer to this question is "Yes."

  - Where planning documents are not available, identify major rivers in your region with large users. Identify whether the river's headwaters are fed by snowpack.

☐ *Does part of your region rely on water diverted from the Delta, imported from the Colorado River, or imported from other climate-sensitive systems outside your region?*

  - Some imported or transferred water supplies are sources from climate-sensitive watersheds, such as water imported from the Delta and the Colorado River.

☐ *Does part of your region rely on coastal aquifers? Has salt intrusion been a problem in the past?*

  - Coastal aquifers are susceptible to salt intrusion as sea levels rise, and many have already observed salt intrusion due to over-extraction, such as the West Coast Basin in southern California.

☐ *Would your region have difficulty in storing carryover supply surpluses from year to year?*

  - Droughts are expected to become more severe in the future. Systems that can store more water may be more resilient to droughts.

☐ *Has your region faced a drought in the past during which it failed to meet local water demands?*

  - Droughts are expected to become more severe in the future. Systems that have already come close to their supply thresholds may be especially vulnerable to droughts in the future.

☐ *Does your region have invasive species management issues at your facilities, along conveyance structures, or in habitat areas?*

  - As invasive species are expected to become more prevalent with climate change, existing invasive species issues may indicate an ecological vulnerability to climate change.

III. Water Quality

☐ *Are increased wildfires a threat in your region? If so, does your region include reservoirs with fire-susceptible vegetation nearby which could pose a water quality concern from increased erosion?*

  - Some areas are expected to become more vulnerable to wildfires over time. To identify whether this is the case for parts of your region, the California Public Interest Energy Research (PIER) Program has posted wildfire susceptibility projections as a Google Earth application at: http://cal-adapt.org/fire/. These projections are only the results of a single study and are not intended for analysis, but can aid in qualitatively answering this question. Read the application's disclaimers carefully to be aware of its limitations.

☐ *Does part of your region rely on surface water bodies with current or recurrent water quality issues related to eutrophication, such as low dissolved oxygen or algal blooms? Are there other water quality constituents potentially exacerbated by climate change?*

  - Warming temperatures will result in lower dissolved oxygen levels in water bodies, which are exacerbated by algal blooms and in turn enhance eutrophication. Changes in streamflows may alter pollutant concentrations in water bodies.

☐ *Are seasonal low flows decreasing for some waterbodies in your region? If so, are the reduced low flows limiting the waterbodies' assimilative capacity?*

  - In the future, low flow conditions are expected to be more extreme and last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

☐ *Are there beneficial uses designated for some water bodies in your region that cannot always be met due to water quality issues?*

- In the future, low flows are expected decrease, and to last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

☐ *Does part of your region currently observe water quality shifts during rain events that impact treatment facility operation?*

- While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to increased erosion, which will increase turbidity in surface waters. Areas that already observe water quality responses to rainstorm intensity may be especially vulnerable.

IV. Sea Level Rise

☐ *Has coastal erosion already been observed in your region?*

- Coastal erosion is expected to occur over the next century as sea levels rise.

☐ *Are there coastal structures, such as levees or breakwaters, in your region?*

- Coastal structures designed for a specific mean sea level may be impacted by sea level rise.

☐ *Is there significant coastal infrastructure, such as residences, recreation, water and wastewater treatment, tourism, and transportation) at less than six feet above mean sea level in your region?*

- Coastal flooding will become more common, and will impact a greater extent of property, as sea levels rise. Critical infrastructure in the coastal floodplain may be at risk.
- Digital elevation maps should be compared with locations of coastal infrastructure.

☐ *Are there climate-sensitive low-lying coastal habitats in your region?*

- Low-lying coastal habitats that are particularly vulnerable to climate change include estuaries and coastal wetlands that rely on a delicate balance of freshwater and salt water.

☐ *Are there areas in your region that currently flood during extreme high tides or storm surges?*

- Areas that are already experiencing flooding during storm surges and very high tides, are more likely to experience increased flooding as sea levels rise.

☐ *Is there land subsidence in the coastal areas of your region?*

- Land subsidence may compound the impacts of sea level rise.

☐ *Do tidal gauges along the coastal parts of your region show an increase over the past several decades?*

- Local sea level rise may be higher or lower than state, national, or continental projections.
- Planners can find information on local tidal gauges at http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca.

V. Flooding

☐ *Does critical infrastructure in your region lie within the 200-year floodplain? DWR's best available floodplain maps are available at: http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/best_available_maps/.*

- While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to higher peak flows and more severe floods.
- Refer to FEMA floodplain maps and any recent FEMA, US Army Corps of Engineers, or DWR studies that might help identify specific local vulnerabilities for your region. Other follow-up questions that might help answer this question:
    1. What public safety issues could be affected by increased flooding events or intensity? For example, evacuation routes, emergency personnel access, hospitals, water treatment and wastewater treatment plants, power generation plants and fire stations should be considered.
    2. Could key regional or economic functions be impacted from more frequent and/or intense flooding?

☐ *Does part of your region lie within the Sacramento-San Joaquin Drainage District?*

- The SSJDD contains lands that are susceptible to overflows from the Sacramento and San Joaquin Rivers, and are a key focus of the Central Valley Flood Protection Plan. (http://www.water.ca.gov/cvfmp/program.cfm).

☐ *Does aging critical flood protection infrastructure exist in your region?*

- Levees and other flood protection facilities across the state of California are aging and in need of repair. Due to their overall lowered resiliency, these facilities may be particularly vulnerable to climate change impacts.
- DWR is evaluating more than 300 miles of levees in the San Joaquin and Sacramento Rivers Valleys and the Delta (http://www.water.ca.gov/levees/).

☐ *Have flood control facilities (such as impoundment structures) been insufficient in the past?*

- Reservoirs and other facilities with impoundment capacity may be insufficient for severe storms in the future. Facilities that have been insufficient in the past may be particularly vulnerable.

☐ *Are wildfires a concern in parts of your region?*

- Wildfires alter the landscape and soil conditions, increasing the risk of flooding within the burn and downstream areas. Some areas are expected to become more vulnerable to wildfires over time. To identify whether this is the case for parts of your region, the California Public Interest Energy Research Program (PIER) has posted wildfire susceptibility projections as a Google Earth application at: http://cal-adapt.org/fire/. These projections are the results of only a single study and are not intended for analysis, but can aid in qualitatively answering this question. Read the application's disclaimers carefully to be aware of its limitations.

VI. Ecosystem and Habitat Vulnerability

☐ *Does your region include inland or coastal aquatic habitats vulnerable to erosion and sedimentation issues?*

- Erosion is expected to increase with climate change, and sedimentation is expected to shift. Habitats sensitive to these events may be particularly vulnerable to climate change.

☐ *Does your region include estuarine habitats which rely on seasonal freshwater flow patterns?*

- Seasonal high and low flows, especially those originating from snowmelt, are already shifting in many locations.

☐ *Do climate-sensitive fauna or flora populations live in your region?*

- Some specific species are more sensitive to climate variations than others.

☐ *Do endangered or threatened species exist in your region? Are changes in species distribution already being observed in parts of your region?*

- Species that are already threatened or endangered may have a lowered capacity to adapt to climate change.

☐ *Does the region rely on aquatic or water-dependent habitats for recreation or other economic activities?*

- Economic values associated with natural habitat can influence prioritization.

☐ *Are there rivers in your region with quantified environmental flow requirements or known water quality/quantity stressors to aquatic life?*

- Constrained water quality and quantity requirements may be difficult to meet in the future.

☐ *Do estuaries, coastal dunes, wetlands, marshes, or exposed beaches exist in your region? If so, are coastal storms possible/frequent in your region?*

- Storm surges are expected to result in greater damage in the future due to sea level rise. This makes fragile coastal ecosystems vulnerable.

☐ *Does your region include one or more of the habitats described in the Endangered Species Coalition's Top 10 habitats vulnerable to climate change (http://www.itsgettinghotoutthere.org/)?*

- These ecosystems are particularly vulnerable to climate change.

☐ *Are there areas of fragmented estuarine, aquatic, or wetland wildlife habitat within your region? Are there movement corridors for species to naturally migrate? Are there infrastructure projects planned that might preclude species movement***?**

- These ecosystems are particularly vulnerable to climate change.

VII. Hydropower

☐ *Is hydropower a source of electricity in your region?*

- As seasonal river flows shift, hydropower is expected to become less reliable in the future.

☐ *Are energy needs in your region expected to increase in the future? If so, are there future plans for hydropower generation facilities or conditions for hydropower generation in your region?*

- Energy needs are expected to increase in many locations as the climate warms. This increase in electricity demand may compound decreases in hydropower production, increasing its priority for a region.

This page intentionally left blank.

Appendix C

Quantifying Uncertainty in Climate Change Analyses

This appendix discusses the sources of uncertainty in climate change analyses and methods for addressing and quantifying uncertainty in planning studies. Probabilistic methods and scenario planning are two common methods for incorporating uncertainty into planning analyses.

Uncertainty is a feature of any planning study, whether climate change is explicitly included or not. Accounting for and disclosing uncertainty is an established component of good planning practices. In water resources planning this has traditionally included uncertainties associated with natural climate and hydrologic variability, future population and economic conditions, and future technological advances and social trends. Climate change involves added uncertainties associated with future GHG emissions conditions and the hydroclimatic response to current and future emissions as projected by numerical models. This appendix describes the sources of climate change-related uncertainty and methods for quantifying uncertainty in planning.

Types of Uncertainty in Planning

Traditional Water Resources Planning Uncertainties

Uncertainty can be a significant part of any planning study that attempts to project future conditions that are subject to random processes using tools and understanding that are imperfect. In water resources planning, traditional sources of uncertainty have included natural hydroclimate variability, imprecision in measured model input parameters, model numerical error and inaccuracies, demographic projections, technological advances and performance, and human operational decision making.

Natural hydroclimate variability is defined here as the seasonal and yearly variations in climate (precipitation and temperature) and streamflow that has been observed in historical records. This variability includes the occurrence of droughts and floods. In water resources planning, the anticipated availability of water supply, for example, is often quantified using historical records or subsets of the available record. The assumption that a limited snapshot of the past is adequate for projecting the full range of potential future conditions is clearly imperfect and therefore introduces uncertainty in the projections.

Uncertainty is also introduced to planning studies through the use of data that are inherently imperfect due to inaccuracies and/or imprecision in measurement. For example, water quality modeling studies can be particularly sensitive to error in laboratory or field measurements upon which model parameterization and calibration are based. These sensitivities lead to uncertainty in projections. Similarly, uncertainties may be introduced in hydrologic studies through the use of imperfect stage-volume or stage-flow relationships. These forms of uncertainty are generally unavoidable and may or may not warrant explicit consideration in a planning study.

Process-based numerical models are typically based on simplified mathematical representations of complex natural or anthropogenic processes. As such, they are never completely accurate and their projections of the future are not certain. For example, a watershed hydrologic model might be constructed as a series of lumped-parameter "buckets" to represent the complex surface and sub-surface physical systems. This is a simplification of the real system and many potentially important processes are neglected. Consequently, simulations of runoff response to rainfall will be uncertain, particularly for conditions that fall outside the range of typical values seen in the past. This type of uncertainty can be reduced, but not eliminated, through calibration and/or verification exercises. Additionally, an element of uncertainty can be introduced in modeling studies due to numerical error: the error associated with the numerical approximations of underlying fundamental mathematical equations. This error, and consequently the resulting uncertainty, can often be reduced through model input parameter manipulations given appropriate user expertise.

Water resources planning studies often require projections of social parameters and demographics. For example, water demand projections typically rely on population projections. Demand modeling may also include projections of economic parameters, consumptive patterns, and land use change. Clearly uncertainty exists in all of these projections of the future and must be acknowledged in a planning study.

Technology changes with time. Uncertainty over how technology will advance in the future or how existing technology will perform in the future can play a significant role in water resources planning studies. For example, water quality planning studies often assume a certain level of treatment for wastewater treatment plant effluent entering a water body. If treatment technologies improve over time, water quality could be significantly impacted.

Finally, uncertainty associated with human operational decision making on a day-to-day basis can be significant in some planning studies. For example, reservoir releases may be managed based on a variety of objective and subjective criteria. This makes it challenging to model such dynamics and adds uncertainty to estimates of future reservoir conditions.

Climate Change Uncertainties

In the science of climate change, there are uncertainties associated with the climate models themselves (sometimes called epistemic uncertainty), and uncertainties associated with how the planet will respond to future conditions (sometimes called aleatory uncertainty or variability). Both kinds of uncertainty are relevant for regional water plan decision making.

With respect to the former, upwards of 20 different general circulation models (GCMs), each from different modeling centers located around the world, are widely accepted and used in climate change studies. Each of these has multiple versions based on varying input assumptions. Differences in regional downscaling techniques applied to each of these models also add to the volume of climate model projection information available for any given location. The fact that such volume exists, representing a range of projection values, for the same projected parameter (e.g., temperature or precipitation at a given location and time horizon) is indicative of the large epistemic uncertainty in GCM projections. This uncertainty arises due to differences in both model structure (i.e., underlying mathematical equations) and input assumptions (e.g., greenhouse gas emissions or cloud cover dynamics). There is simply not enough knowledge to arrive at a consensus. We can surmise that this type of uncertainty will be reduced over time as the climate change science advances.

Aleatory uncertainty in climate change studies is attributable to the randomness of many of the critical components of the system under study and is thus not reducible. In climate change studies, the “system” starts with the global climate system. There is large uncertainty in how the global climate will respond to the accumulation of greenhouse gases in the atmosphere. There is particular uncertainty with respect to precipitation impacts and annual and seasonal variability that is effectively random. In other words, for the purposes of this document, this type of uncertainty is attributable to the unpredictability of the planet’s natural system response to greenhouse gas accumulation.

Techniques for Addressing Uncertainty in Water Resources Planning Studies (With or Without Climate Change)

Addressing uncertainty, either quantitively or qualitatively, in water resources planning studies aids in the decision making process. For example, a planner may make decisions based on a worst case scenario quantified as part of uncertainty analyses. Similarly, a “margin of safety” might be implemented based on knowledge of the uncertainty in model projections. Given the significant additional uncertainty associated with climate change, addressing uncertainty in water resources planning studies is even more important now than it was in the past.

There are several techniques for incorporating uncertainty into the regional water planning process, with two categories of techniques that appear particularly well-suited for quantifying climate change uncertainty:

- **Probabilistic Methods**. These methods involve defining specific input variables in terms of probability functions. Traditionally, in water resources planning studies, probability distributions might be used to represent parameters that vary randomly in nature (or are effectively random due to the complexity of the process), such as wildlife bacterial loadings to a stream or climate fluctuations on a short time scale (e.g., daily). Additionally, probability distributions might be used to quantify a model input parameter whose value is unknown but for which a realistic range of potential values can be constructed by expert opinion. In climate change studies, this approach can be extended to address the uncertainties associated with climate change projections and capture the variability of available projections. This method can be applied at different stages of the plan development. It can be applied at the earliest stages to define temperature, precipitation and sea level rise data (described in Sections 2 and 5), and can also be applied to assess climate change impacts (described in Sections 5 and 6). The performance of a climate change strategy or group of strategies is measured in terms of joint probability functions based on the input distributions. The result of this analysis can be viewed as an overall assessment of risk and is useful for decision making.

- **Scenario Planning.** This method is widely used and simple to understand. First, several plausible scenarios of potential future conditions are defined. Then projects within a regional water plan are evaluated under these different scenarios to determine the most robust strategies.

A general description of each of these two categories of techniques is presented in the sections below. Information is provided on the data requirements and the steps necessary to complete each method. The relative strengths and limitations of incorporating each method into a regional water planning process are presented. Relevant example applications from the literature are provided. A general reference on planning methods that can be used in climate change analysis can be found in the Water Utility Climate Alliance's white paper "Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning" (WUCA 2010).

Probabilistic Methods

Probabilistic models provide a range of output, characterized by probabilities of occurrence, rather than the single projections provided by deterministic models. They require key inputs to be provided either as a range of possible discrete values or as continuous probability distribution functions, rather than as single values. Generally, output probabilities can be thought of as the "risk" of achieving a certain threshold. For example, probabilistic models could be used to quantify the risk of a water supply shortfall in a given planning horizon given past observed hydrologic conditions. This type of information can be very valuable to any decision making process.

As described in Section 5.1, combining GCM model results available in the CMIP3 dataset within a probabilistic framework, in which the projection of each GCM is given equal probability, is one method for addressing climate model uncertainty (Brown 2011). However, it is important to realize that probability distributions fit to these datasets do not strictly represent probabilities of occurrence. The data are model projections, not real observations, and (as discussed above) are subject to their own large uncertainties. Rather, the probabilities, and consequently the final planning model outcomes, represent *levels of consensus* in projective modeling (Mote et al 2011). We propose that this framework may be as useful as true risk assessment to planning decision making in the face of climate change.

The probabilistic method is prescriptive rather than adaptive—meaning once a decision is made about a strategy or group of strategies, they are fully implemented under the assumption that the strategy is the best (e.g., measured risk under a predefined threshold of acceptable risk to the decision maker) under varying future conditions. This probabilistic approach to decision making requires an explicit definition of risk tolerance. Decisions will be made based on the level of risk that different strategies represent; as such, decision makers need to be able to discriminate between different levels of risk.

Climate-Related Risk*: The possibility of interaction of physically defined hazards with the exposed systems. Risk is commonly considered to be the combination of the likelihood of an event and its consequences – i.e., risk equals the probability of climate hazard occurring multiplied by the consequences a given system may experience. (Sometimes risk is defined as hazard exposure times 'vulnerability', where vulnerability is merely the sensitivity and adaptive capacity of the exposed system.)*

--- United Nations Development Programme 2005

Conducting the Probabilistic Analysis

Numerical probabilistic models often incorporate random, or "stochastic", sampling in the analysis. This approach can be either "parametric" or "non-parametric" in nature. For the former, continuous probability distribution functions (PDFs) are fit to input data, such as the GCM climate data (ensemble or individual model projections). The PDFs would then be sampled over multiple iterations within the analysis process. For the latter, the actual data would be sampled, without assuming an underlying distribution. This type of iterative "bootstrap" sampling with replacement is a common modeling approach for capturing variability and uncertainty in projections.

In any stochastic sampling scheme, the number of sampling iterations must be set to ensure that the output properly reflects the full range of input statistical characteristics. Additionally, it may be necessary to incorporate input data couplings or correlations in the sampling. For example, there may be an identified correlation between monthly mean temperature and monthly precipitation. In such a case, these two parameters cannot be sampled independently of each other but rather must be sampled in a way that retains the quantified correlations. Multiple software tools exist for both PDF curve fitting and stochastic sampling, including @RISK (Palisade Inc., www.palisade.com/risk/), Crystal Ball (Oracle, www.oracle.com), and Excel (Microsoft Inc.). All of these tools also allow for the presentation of results probabilistically, often as cumulative distribution functions (CDFs).

The probabilistic approach described above for sampling climate data must ultimately be linked with the final regional water plan analyses. In some cases, it may be possible to incorporate regional water plan calculations and/or models directly into a probabilistic analysis. For example, a simple regression model describing changes in demand as a function of climate parameters could be built directly into spreadsheet calculations that include probabilistic sampling of climate data. In other cases, particularly for more complicated regions, the final analysis must be performed as a separate step or series of separate steps. In this case, intermediate output may need to be generated that are then able to serve as input to the regional water plan analyses. These intermediate outputs would need to reflect the collective results of the stochastic sampling. For example, an extended (e.g., 1,000 years) stochastic time series dataset might be developed using the techniques described above, in order to serve as input to a time series planning model.

In line with the goal of probabilistic modeling, final output and/or performance metrics should be presented as a range of numbers with quantified probabilities of occurrence (or levels of model consensus, as described above). These final outputs should then support decision making in the regional planning process.

An example of a parametric probabilistic approach to quantifying climate change uncertainty can be found in the Seattle Puget Sound demand study described in Section 5 (Box 5-1). In this study, probability distribution functions were fitted to historical demand data and modified to reflect climate change based on quantified regression "elasticities" that isolate the relationship between demand and climate variables. Future climate conditions were quantified using an ensemble of multiple GCM projections. Monte Carlo sampling of the input distributions were used to generate output cumulative probability distribution functions (CDFs).

An example of a non-parametric probabilistic analysis to address climate change uncertainty can be found in Cox et al. 2011. In this water supply study for the City of Santa Fe (NM), output from six different GCM models were pooled for two different emission scenarios. All of the GCM data corresponded to a single future planning horizon (2050 – 2070). The combined climate data were sampled randomly as two sets of pooled discrete data, rather than fitting a continuous PDF to the data. Significant month to month correlations in temperature were identified and incorporated into the random sampling. The results of the sampling were two sets (for each of the two emission scenarios) of 1000 year synthetic timeseries of monthly precipitation and temperature data that captured a large range of GCM projection variability. These data were used to seed hydrologic models that ultimately provided performance metrics (e.g., annual surface water supply delivery) in the form of probabilistic percentile curves.

Strengths and Weaknesses of Probability Analysis

The strengths of probabilistic modeling relate to the direct handling of model uncertainties and in the presentation of risk-based results. The structure of probabilistic models allows the user to input a range of values for a given parameter, with associated confidence levels, to reflect the uncertainty surrounding the parameter. These uncertainties are then compounded in the analysis with final output reflecting the combined impact of the individual parameter uncertainties. The compounded uncertainties are presented as risk levels associated with a specific performance metric, an appealing framework for both planners and regulators.

The primary weakness of the approach is that it often requires a significantly higher level of expertise compared to deterministic modeling and may require additional analytical tools and software. Additionally, data requirements are generally greater than deterministic methods, in order to support the parameterization of probabilistic inputs.

Finally, the fact that the output of the analysis is probabilistic requires the ability to interpret probabilistic information not only by the analyst but also by decision makers. In order to facilitate the interpretation of probabilistic results by decision makers, some output simplification may be required and the use of some interpretive charts and tables will be necessary. The technical analysts need to pay particular attention in these simplification steps to still preserve the relevant uncertainty in the output and the key characteristics of it. Usually, relevant information for decision makers is presented in the shape of a distribution, or its tail ends (extreme conditions).

The use of only an average to characterize the probabilistic value of an output of interest (e.g., water supply deficit) runs the risk oversimplifying the problem and making it look deterministic, with important implications for decision making.

Scenario Planning

Scenario planning is widely used and simple to understand, and it is similar to Robust Decision Making, described in Section 7. This method fully defines several potential “futures” (i.e., scenarios). Strategies are then evaluated under these different scenarios to determine the most robust strategy. For instance, one scenario might consist of future conditions that are warmer and wetter than current conditions, while another might consist of future conditions that are much warmer and drier than current conditions. The strategies’ performance is compared under all scenarios. Then each strategy can be evaluated for its performance under different climate conditions. A strategy that performs well under all scenarios would likely be preferred. Scenario analysis also provides good information for choosing “no regrets” strategies, meaning strategies that provide benefits across all scenarios of future conditions.

With this method, there typically is no quantitative assessment of probability for the selected scenarios, but in many cases a weight can be assigned to different scenarios representing the collective professional judgment about the credibility of the scenarios.

Section 5.2.2 describes how climate change scenarios can be developed using discrete climate model projections or an ensemble of climate projections.

Conducting the Scenario Planning Analysis

Scenario planning requires the planner to conduct a series of workshops with stakeholders and decision makers in addition to technical analysts. Developing the planning scenarios is typically a group exercise that takes place over a number of working sessions. Generally, the scenario definition process involves the following steps:

1. Understanding the system (e.g., watershed or region) and driving forces behind the variables of interests;
2. Identifying the key uncertain variables (e.g., future atmospheric temperature and precipitation) that define the range of unexpected future conditions that stakeholders wish to explore and ranking these variables in order to define a manageable number of scenarios;
3. Identifying the range of expected future conditions that stakeholders wish to explore;
4. Combining uncertainties to create a scenario table, and then describing these scenarios; and
5. Defining a pathway to each scenario.

The key elements of each step are described below:

1. <u>Understanding the system and driving forces</u>. Planners need to define those variables, independent of climate change, that drive the behavior of the region. For example, water demands for a region may be driven mostly by population growth and agricultural use. These driving forces are related to climate change but the climate change variables are not the emphasis of this scenario planning step. In this step of the process, brainstorming (often in interviews or stakeholder workshops) is commonly used to capture the full spectrum of driving forces before they are assessed.
2. <u>Identifying key uncertainty variables</u>. During this step of scenario planning, the key variables driving climate change uncertainty (e.g., sea level rise, temperature, or precipitation) are identified by the analysis team (experts) and presented to stakeholders. These key variables should be ranked and will be directly associated with the development of scenarios.
3. <u>Identifying the range of expected future conditions that stakeholders wish to explore</u>. Individual stakeholders may be acutely concerned about specific future conditions that could be detrimental to their interests. For instance, a salmon fisherman may be specifically concerned about extremely hot and dry future conditions that would stress salmon populations by decreasing streamflow and increasing the temperature of rivers. Alternatively, a floodplain manager maybe more concerned about future conditions that are cool and wet. Thus, the scenarios must incorporate a range of potential future conditions that meet the needs of stakeholders.
4. <u>Combining uncertainty to create scenarios</u>. Some of the literature recommends reducing the number of key variables to two, so that a 2 by 2 matrix of scenarios can be developed (WUCA 2009), which in traditional planning (including water resources planning) has proven to be adequate. This 2 by 2 matrix might consist of two scenarios for population growth (high and low) and two scenarios for land use trends (expansive development and compact development).

When climate change uncertainties are added to the analysis, another dimension is added to the matrix, significantly expanding the required analysis. In addition, it is difficult to adequately cover the range of uncertainty in climate change projections without analyzing multiple scenarios. Climate change projections typically output two important variables for water resource planning: temperature and precipitation. These two outputs vary independently, thus at least four scenarios are necessary to describe potential extreme results of climate change. A further scenario is necessary to describe a mean or median climate change scenario.

Combining variables of uncertainty in this case may be better represented by a tree than a two-dimensional matrix. Figure C-1 illustrates the difference between the 4-scenario matrix and the multiple scenario tree.

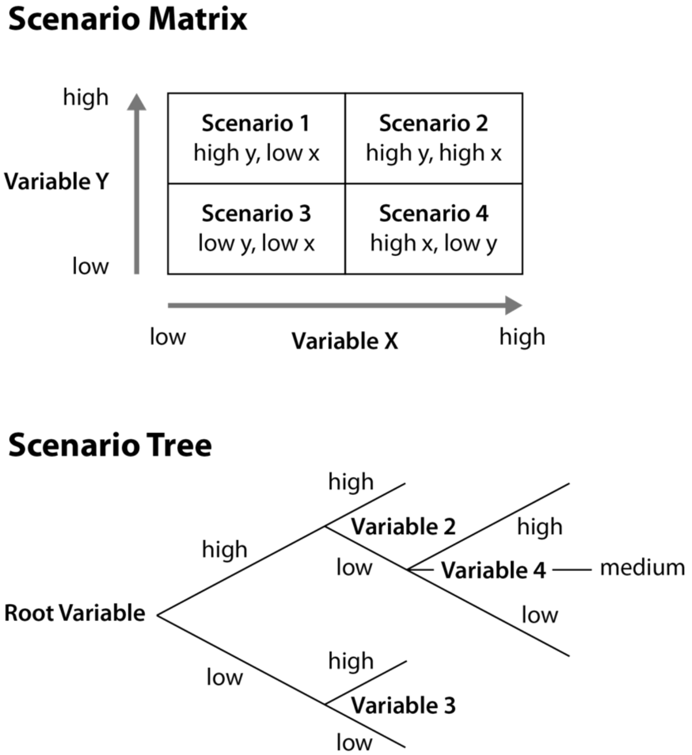


Figure C-1. Scenario Matrix vs Scenario Tree. Source: WUCA 2010.

Each branch of the tree needs to be thoroughly described by the planning group. A short document consisting of one or several paragraphs is typically written to describe each scenario, so that every decision maker is clear about them. A simple figure or table is usually insufficient to clearly describe a scenario and can result in different interpretations by different stakeholders.

5. <u>Defining Pathways</u>. The description of scenarios is followed by the definition of the pathway to each scenario (how the system transitions from today to the state described by the scenario, in the time frame included in the planning horizon). Defining pathways may be conducted in a workshop setting where the stakeholder group plots

independent pathways, each representing a sequence of strategies and projects, that would be necessary to realize each unique scenario based upon its specific characteristics and issues. Despite differences among the developed pathways, similarities and overlaps will occur; this commonality indicates which projects and programs would be most viable over time. This step is critical in decision making since it will provide the information necessary to define projects and strategies that can help change the outcome of the system performance under each scenario path.

6. Evaluating Alternative Plans. Once all scenarios are clearly defined, the different strategies and projects included in a regional water plan can be evaluated under each scenario. This evaluation is not a probabilistic evaluation; rather, it is a deterministic evaluation given that the uncertainty variables have been defined by a deterministic value for each scenario. That simplifies the analysis under each scenario, as compared to a probabilistic analysis. Depending on the number of scenarios, however, the overall effort of scenario planning compared to the effort in a probabilistic analysis may be similar or greater.

   The performance of alternative plans and strategies can be evaluated in two different ways under scenario planning: given a scenario, the performance metrics of the plan are better or worse compared to other plans and strategies. Alternatively, the path to arrive at a given scenario is modified after applying a set of plans and strategies, and the resulting potential future is transformed positively. In other words, the scenario itself is impacted by a strategy and the future that it describes is better than in the original scenario. These two different methods to evaluate performance are valid and will be dictated by the variables used to define the scenarios, and whether or not the analysis allows for feedback between variables and the strategies being tested.

   In most cases for regional water plans, the analysis will be more practical if strategies are analyzed in terms of the set of performance metrics under each scenario, without consideration to how a scenario could change based on the implementation of strategies. Various methodologies for performing this analysis are described in Section 5.

7. Decision Making. In the decision making step, consideration can be given to the different likelihood of the scenarios being used. In the scenario tree in Figure 7-2 (or the cells in the matrix in that figure), a weight for each tree branch can be assigned. The weight should not be confused with probability since probability implies a mathematical dimension that is not there in the simplified weight value. The weight of the scenarios can be valued to represent the professional judgment of the group in terms of the likelihood of the different scenarios. This weighted information can be then used in ranking the performance of the strategies and plans. Additional methodologies for performing this step are described in section 6.

   In the decision making step, projects and strategies are selected that work well under a range of scenarios. These projects and strategies are sometimes referred to as "no-regret solutions" or "co-benefit" solutions.

Strengths and Weaknesses of Scenario Planning

Some of the strengths of scenario planning are related to the amount of data required for the analysis, compared to the data required in the probability analysis. Given that no specific probabilities are necessary for the scenarios and that the variables of interest don't require a probabilistic output, the analysis can be conducted with less sophisticated tools.

Another significant strength of scenario planning is that the process to develop scenarios is very valuable as a learning process for stakeholders and decision makers. Stakeholders involved in the development of scenarios will learn about the key uncertain variables and better understand how uncertainties can play a role in shaping potential futures. When done correctly, scenario development is usually accompanied by some significant discussion about the system and the system's behavior to different triggers, so the learning for stakeholders and decision makers goes beyond the climate change impacts. They usually gain a greater understanding of the system structure and responses independent of climate change.

Scenario planning is useful when the management strategies and projects do not have great flexibility. For example, if the main options on the table to achieve regional objectives are related to large scale infrastructure, the phasing of that infrastructure may not be very flexible. When the actions that can be taken, or projects that can be implemented, are smaller or more flexible in nature (e.g., different levels of reservoir releases, or small scale best management practices for water quality management) adaptive management may be a stronger option.

One of the weaknesses of scenario planning is the heavy emphasis on the development of scenarios compared to the effort involved in evaluating the performance of the actual decisions under each scenario. In other words, scenario planning in some cases may fall short in the analytical elements necessary to make decisions in light of the scenarios developed. Another weakness of scenario planning, when resources are limited for it, is that the number of scenarios are reduced to just a handful. In these cases, the number of scenarios may be insufficient to adequately frame the universe of potential futures.

Combining Emissions Scenarios

A particular aspect of planning projects with climate change analysis where probabilistic methods can be combined with scenario planning is the handling of carbon emission scenarios in the technical analysis.

Several studies using GCM projections have developed ensemble GCM projections by combining projections that use different emissions scenarios (Chung et al 2009). However, some studies maintain the emission scenarios separate and avoid the ensemble averaging of them (Cox et al 2010). Combining scenarios inherently assumes that each scenario is equally likely. This can be appropriate as long as the assumption is understood by all decision makers. For planning horizons beyond 2050, planners may consider maintaining separation in the emission scenarios.

Appendix D

Climate Change Tools – Summary of Sources for Models, Data Analysis, and Decision Support

Table D-1: Data Sources

Data Type (e.g. Weather, hydrologic, geologic, etc.)	Repository Name	Agency	Web Link	Scope
Hydrologic, meteorologic, reservoir storage	California Data Exchange Center	DWR	http://cdec.water.ca.gov/	CA
Weather, agricultural	California Irrigation Management Information System (CIMIS)	CIMIS	http://wwwcimis.water.ca.gov/cimis/welcome.jsp	CA
Climate, snow pack, wildfire, sea level projections	Cal Adapt	PIER	http://cal-adapt.org/	CA
Weather – radar	NCDC NEXRAD Data Inventory	NOAA/NCDC	http://www.ncdc.noaa.gov/nexradinv/	US
Radar, model results, satellite	Unidata Program	UCAR	http://www.unidata.ucar.edu/	US
Hydrologic	National Hydrography Dataset	USGS	http://nhd.usgs.gov/data.html	US
Geologic, hydrologic, weather, imagery, geographic	USDA Natural Resources Conservation Service Geospatial Data Gateway	USDA	http://datagateway.nrcs.usda.gov/	US
Climate data and modeling ecosystem and water quality data sea level rise and elevation data, state-specific resources	Climate Ready Estuaries Coastal Toolkit	EPA	http://www.epa.gov/climatereadyestuaries/toolkit.html	US

Table D-1: Data Sources

Data Type (e.g. Weather, hydrologic, geologic, etc.)	Repository Name	Agency	Web Link	Scope
Geospatial wetland classification	National Wetlands Inventory	NOAA	http://www.csc.noaa.gov/digitalcoast/data/nwi/index.html	US
Elevation	Coastal Inundation Toolkit	NOAA	http://www.csc.noaa.gov/digitalcoast/inundation/index.html	US
Downscaled GCM climate projections	CMIP3 archive	Office of Science, US Department of Energy (via Lawrence Livermore National Laboratory, Reclamation, Santa Clara University, Climate Central	http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html	

Table D.2: Climate Change Analysis Tools

Tool Name	Description	Web Link	Public Domain (Y/N)?
Data Processing Tools			
CalAdapt	Synthesizes existing California climate change scenarios and climate impact research; provides interactive maps and charts, local profiles, community-based features, and background climate change information.	http://cal-adapt.org/	Y
Climate Wizard	Online tool that allows quick visualization of the CMIP3 downscaled dataset. Allows quick visual comparison among emissions scenarios and GCMs, and also visualizes ensemble results. Visualization of temperature and precipitation projections.	http://www.climatewizard.org/	Y
Pacific Institute Sea Level Rise GIS Data Downloads	Downloadable geographic data created or modified by Pacific Institute researchers for the project Impacts of Sea Level Rise on the California Coast	http://www.pacinst.org/reports/sea_level_rise/data/index.htm	Y
SimCLIM	GCM model/Scenario Comparison, Statistical Analysis. Interfaces with several other computational modeling tools.	http://www.climsystems.com/simclim/	N
Analytical Tools and Models			
ADCIRC	A system of computer programs for solving free surface water circulation and transport problems in 2D and 3D. Typical applications include: modeling tides and wind driven circulation, analysis of hurricane storm surge and flooding, dredging feasibility and material disposal studies, larval transport studies, near shore marine operations.	http://www.adcirc.org/	Y

Table D.2: Climate Change Analysis Tools

Tool Name	Description	Web Link	Public Domain (Y/N)?
BASINS	EPA tool for hydrologic and water quality data assessment and analysis. Contains tools for data extraction, processing, and evaluation. Contains several water quality models and interfaces with many other publicly available computational water models.	http://water.epa.gov/scitech/datait/models/basins/	Y
BASINS CAT	EPA tool for incorporating various climate change scenarios into BASINS analyses	http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203460	Y
CAEDYM	3D process-based model of the major biogeochemical processes influencing water quality.	http://www.cwr.uwa.edu.au/software1/models/caedym/caedym.php	N
Climate Ready Estuaries Coastal Toolkit	Resources for estuaries and coastal programs that are interested in learning more about climate change impacts and adaptation	http://www.epa.gov/climatereadyestuaries/toolkit.html	Y
CREAT	Assists in understanding potential climate change threats and in assessing the related risks for individual utilities. Evaluates potential impacts of climate change adaptation options to address these impacts using both traditional risk assessment and scenario-based decision making.	http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm	Y
CUP+	The CUP+ program is an MS-Excel application written to make accurate estimates of both crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw).	http://www.water.ca.gov/landwateruse/models.cfm	Y
DHSVM	Distributed hydrologic model that explicitly represents the effects of topography and vegetation on water fluxes through the landscape.	http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.shtml	Y
Digital Coast, NOAA Coastal Services Center	Provides tools, training, and information for conserving and protecting coastal communities and natural resources	http://www.csc.noaa.gov/digitalcoast/about/index.html	Y
DSM2	One-dimensional hydrodynamic, water quality, and particle-tracking model. Calculates stages, flows, velocities; many mass transport processes, including salts, multiple non-conservative constituents, temperature, THM formation potential and individual particles.		

Table D.2: Climate Change Analysis Tools

Tool Name	Description	Web Link	Public Domain (Y/N)?
	Environmental Fluid Dynamics Code (EFDC Hydro) is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions.	http://www.epa.gov/athens/wwqtsc/html/efdc.html	Y
ELCOM	3D hydrodynamics model used for simulating the velocity, temperature, and salinity distribution in natural water bodies subjected to external environmental forcing, such as wind stress, and surface heating or cooling.	http://www.cwr.uwa.edu.au/software1/models1.php?mdid=5	N
HEC-HMS	Computational rainfall runoff model	http://www.hec.usace.army.mil/software/hec-hms/	Y
HEC-RAS	1D River modeling, including temperature and sediment transport modeling	http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html	Y
HSPF	Simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.	http://water.usgs.gov/software/HSPF/	Y
MIKE 3	3D hydrodynamic model for simulating free surface flows and associated sediment or water quality processes.	http://www.mikebydhi.com/Products/CoastAndSea/MIKE3.aspx	N
NOAA Coastal Inundation Toolkit	Provides tools and information for understanding and addressing coastal flooding	http://www.csc.noaa.gov/digitalcoast/inundation/	Y
QUAL2K	I-dimensional steady state river and stream water quality model.	http://www.epa.gov/athens/wwqtsc/html/qual2k.html	Y
RMA2	Dynamic 2D depth-averaged model for computing water surface elevations and horizontal velocity components for subcritical, free-surface flow.	http://chl.erdc.usace.army.mil/rma2 http://www.aquaveo.com/rma2	N
RMA4	Water quality transport numerical model.	http://chl.erdc.usace.army.mil/rma4 http://www.aquaveo.com/rma4	N

Table D.2: Climate Change Analysis Tools

Tool Name	Description	Web Link	Public Domain (Y/N)?
SIMETAW/Cal-SIMETAW	Simulates many years of weather data from monthly climate data and to estimate reference evapotranspiration (ETo) and crop evapotranspiration (ETc) with the simulated data. Determines effective rainfall and ET of applied water (ETaw).	http://www.water.ca.gov/landwateruse/models.cfm	Y
SLAMM	Simulates potential impacts of long-term sea level rise on wetlands and shorelines.	http://www.csc.noaa.gov/digitalcoast/tools/slamm/index.html	Y
SWMM	Urban hydrology and conveyance system hydraulics software. Provides dynamic rainfall-runoff simulation of single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas.	http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/	Y
UNTRIM	3D hydrodynamics model used for simulating velocity, temperature and salinity distribution in natural water bodies.	N/A, model developed by Prof. Vincenzo Casulli of Trento University	Y
VIC	Macroscale hydrologic model that solves full water and energy balances	http://www.hydro.washington.edu/Lettenmaier/Models/VIC/	Y
WASP	Dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. Allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types	http://www.epa.gov/athens/wwqtsc/html/wasp.html	Y
WEAP	Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios.	http://www.weap21.org/	Y

Table D.2: Climate Change Analysis Tools

Tool Name	Description	Web Link	Public Domain (Y/N)?
Decision-Support Tools			
Criterium DecisionPlus	Used for complex decisions such as those found in regional water resources planning. CDP is especially useful for decisions that involve numerous competing objectives.	http://ebmtoolsdatabase.org/tools	N
@RISK	Performs risk analysis using Monte Carlo simulation to show you many possible outcomes in your Microsoft Excel spreadsheet—and tells you how likely they are to occur.	http://www.palisade.com/risk/	N
STELLA	Integrated systems model using use object-oriented programming. Provides a built-in graphical interfaces and output. Useful for comprehensive simulation of water, biological, or financial systems. Can demonstrate how many different types of systems respond dynamically.	http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx	N
Climate Ready Estuaries Coastal Toolkit	Resources for estuaries and coastal programs that are interested in learning more about climate change impacts and adaptation	http://www.epa.gov/climatereadyestuaries/toolkit.html	Y
CREAT	Assists in understanding potential climate change threats and in assessing the related risks for individual utilities. Evaluates potential impacts of climate change adaptation options to address these impacts using both traditional risk assessment and scenario-based decision making.	http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm	Y

This page intentionally left blank.