Section 4
Assessing Regional Vulnerability to Climate Change

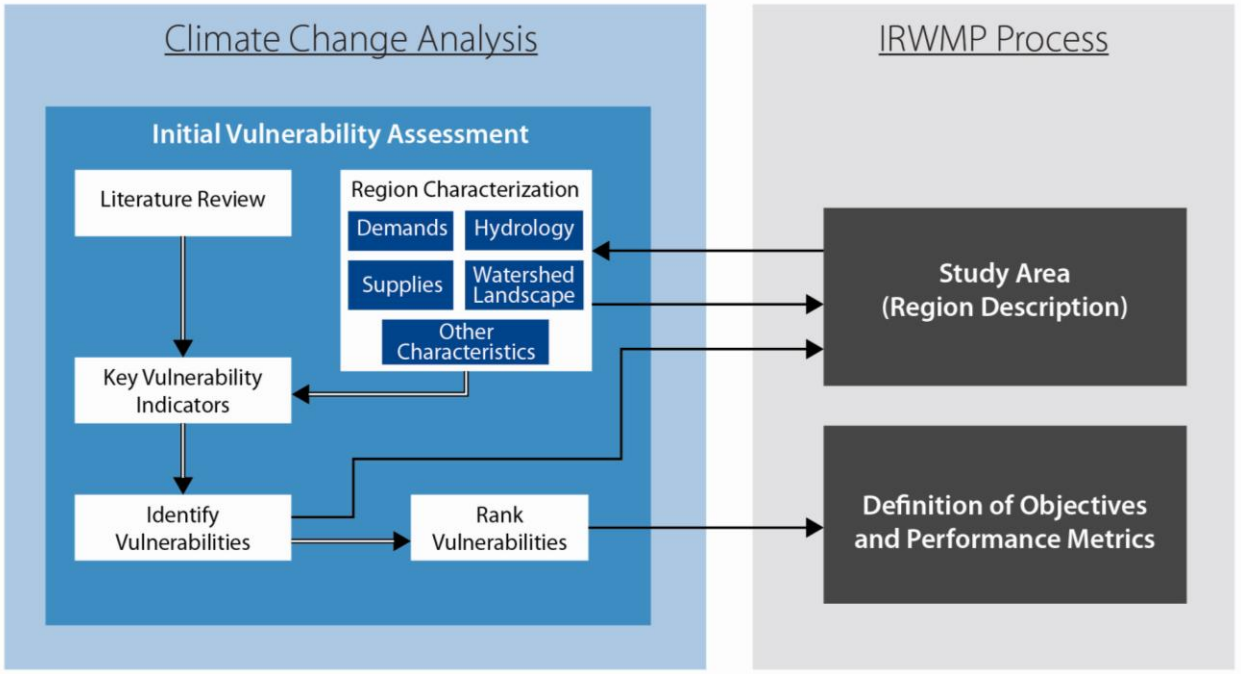


Figure 4-1. Process for Assessing Vulnerability to Climate Change as part of an IRWMP.

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.

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

> ***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*

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.

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

4.3 Identifying Key Indicators of Potential Vulnerability

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.

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

    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.

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

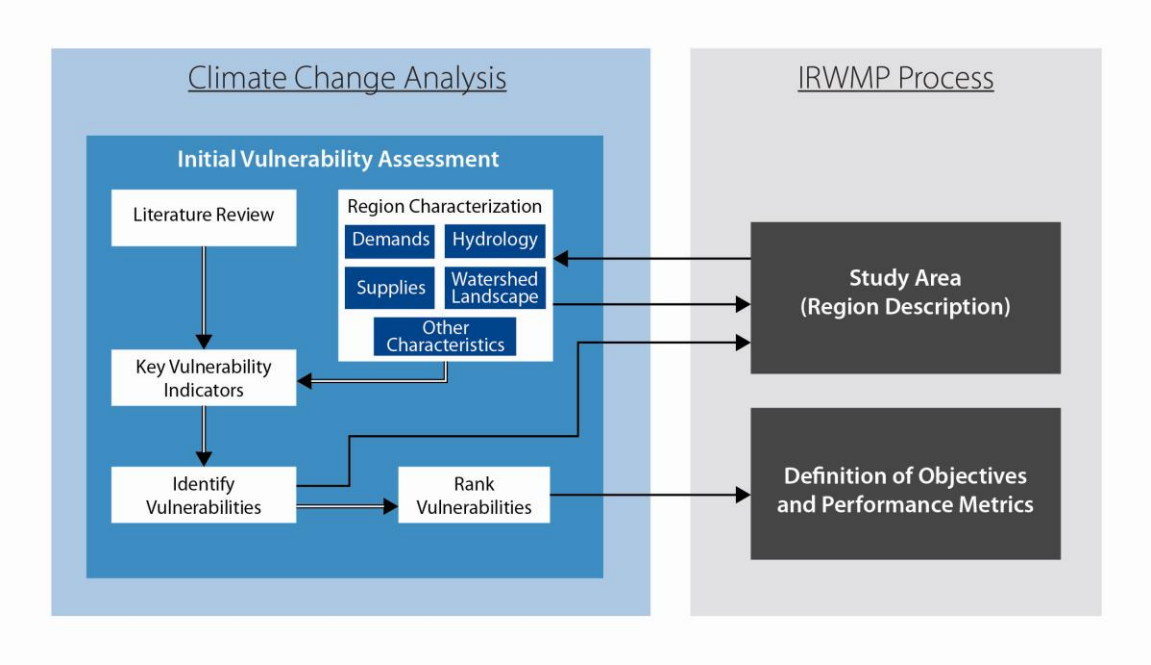
This section provides guidance for finding key references and literature that describe expected and potential impacts of climate change in a planning region. It also guides identification of important water resources and aspects of water resource management that are vulnerable to anticipated climate 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.

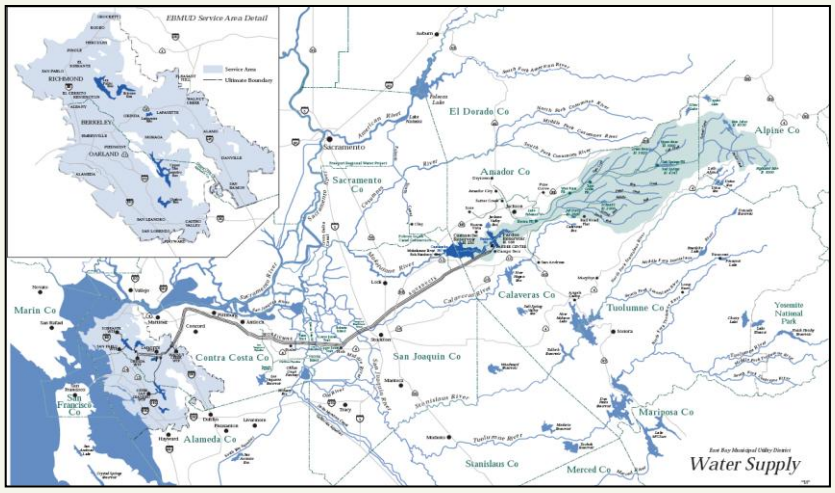


Figure 1: EBMUD Water Supply System (For a high resolution map, please see http://portal.ebmud.com/our-water/water-supply/current-water-supply-outlook/water-system-map)

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.

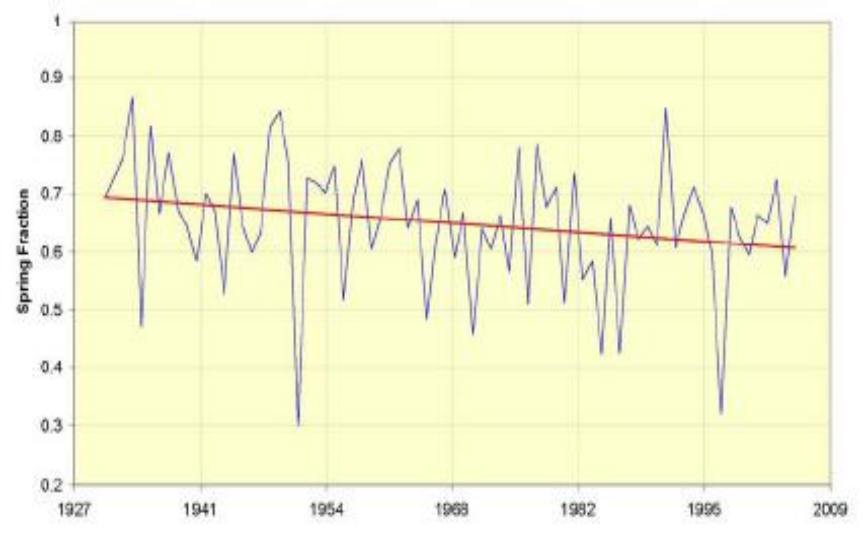


Figure 2: "April-July Flow as Fraction of Water Year – Mokelumne River". Source: Figure 1-2 in EBMUD, 2009a, page 4.

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

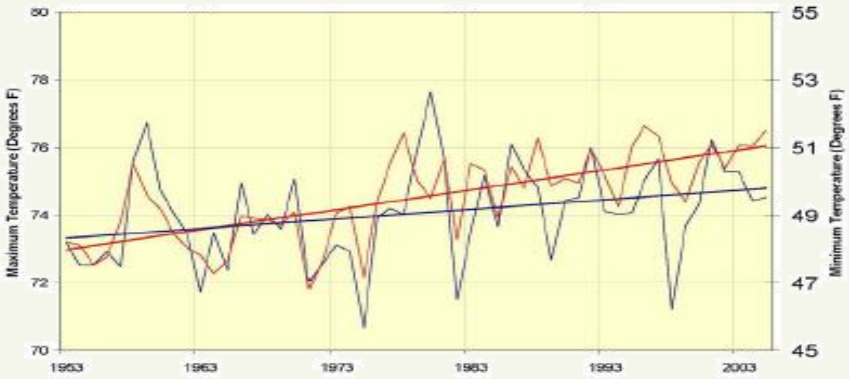


Figure 3: "Camp Pardee Average Annual Temperature". Source: Figure 1-1 in EBMUD, 2009a, page 4.

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.