CENTRAL VALLEY FLOOD MANAGEMENT PLANNING PROGRAM

FloodSAFE CALIFORNIA

Public Draft

2012 Central Valley Flood Protection Plan

Attachment 8K: Climate Change Analysis

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section provides the purpose of this attachment, background information (including planning areas and goals), an overview of potential climate change effects on the Central Valley flood management system, and report organization.

1.1 Purpose of this Attachment

The State of California's (State) climate is dynamic. Traditionally, flood management agencies have used past experience and historical climate records to make decisions and develop investment strategies. Advances in climate science over the past decade have produced several new techniques that can allow flood management issues to be considered using future projections of climate. Climate change already affects California, and the potential future consequences of climate change are significant (Resources Agency, 2009). Therefore, California recognizes that the time to act is now. In response to the need for action, State legislation requires consideration of climate change conditions in plan development. According to Senate Bill 5 (Statutes of 2008), the Central Valley Flood Protection Plan (CVFPP) should include the following:

> *A description of the probable impacts of projected climate change, projected land use patterns, and other potential flood management challenges on the ability of the system to provide adequate levels of flood protection (California Water Code Section 9614).*

Potential impacts could result from changing location and timing of precipitation, sea level rise, increased temperatures, and extreme weather events. Similarly, the California Department of Water Resources (DWR) is currently assessing the likely extent of climate change over the foreseeable future and the potential changes to regional and statewide water resources conditions consistent with Executive Order S-13-08 and related State policies. CVFPP development is in coordination with other ongoing projects and programs.

Executive Order S-13-08

Tasks State agencies with developing California's first strategy to identify and prepare for expected climate impacts.

This report documents an assessment of probable impacts of projected climate change on the ability of the flood management system to provide adequate levels of flood protection. It includes a description of potential climate change effects on flood management, a discussion of the unique

Climate Change Threshold Analysis Approach, and presents the results of a pilot study demonstrating the Climate Change Threshold Analysis Approach.

1.2 Background

As authorized by Senate Bill 5, also known as the Central Valley Flood Protection Act of 2008, DWR has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the State Plan of Flood Control (SPFC), and will be updated every 5 years.

As part of development of the CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Sacramento-San Joaquin Delta (Delta).

1.3 CVFPP Planning Areas

For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

- **SPFC Planning Area –** This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010)). The State of California's (State) flood management responsibility is limited to this area.

- **Systemwide Planning Area –** This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

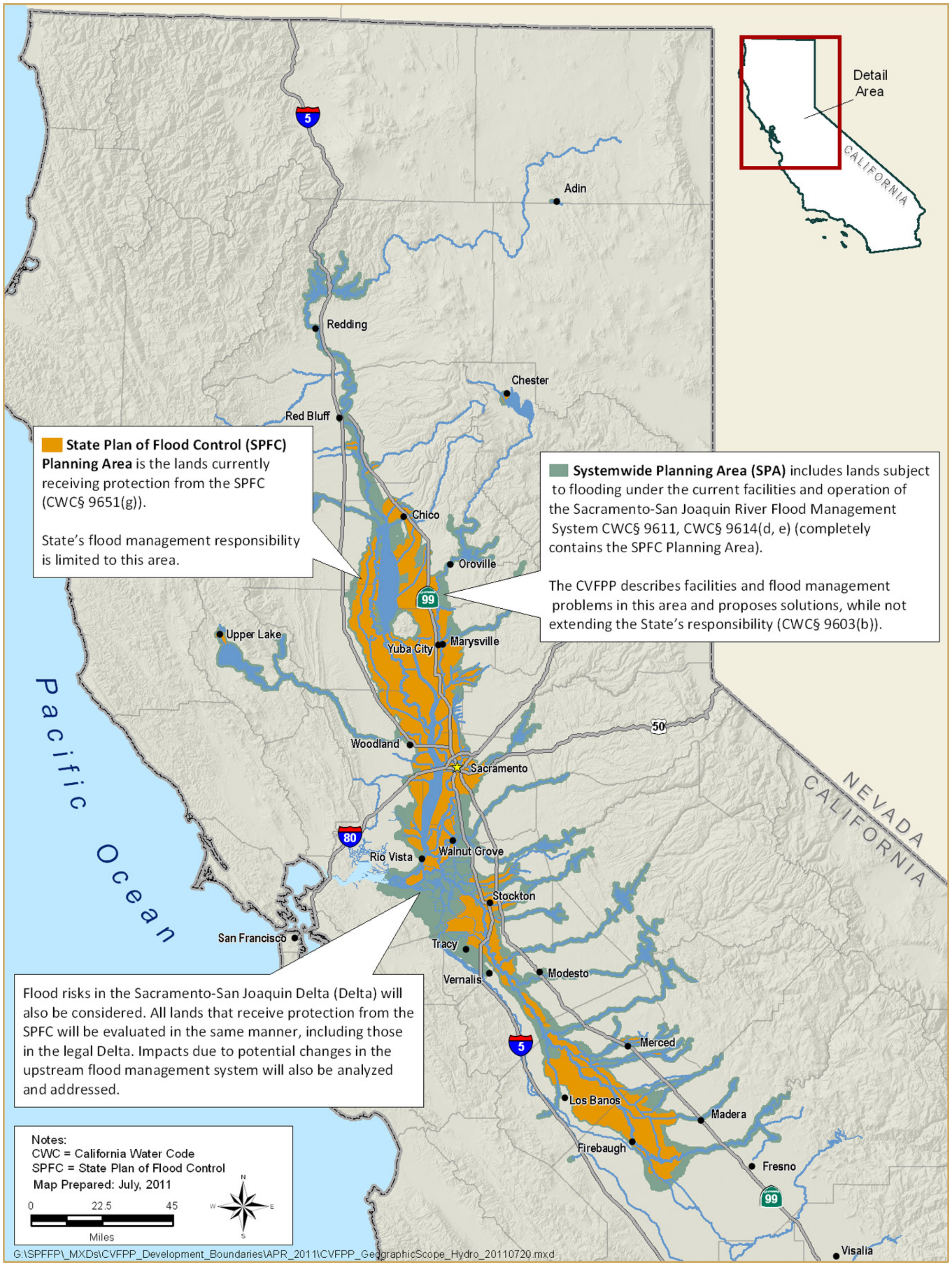


Figure 1-1. Central Valley Flood Protection Plan Planning Areas

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

The Climate Change Threshold Analysis Approach developed for the CVFPP is applicable throughout the Systemwide Planning Area. However, for the 2012 CVFPP, a pilot study demonstrating the Climate Change Threshold Analysis Approach focused on the Yuba-Feather river system.

1.4 2012 CVFPP Planning Goals

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal –** Improve Flood Risk Management
- **Supporting Goals**:
    - Improve Operations and Maintenance
    - Promote Ecosystem Functions
    - Improve Institutional Support
    - Promote Multi-Benefit Projects

Understanding how a changing climate may affect the flood management system is an important requirement for improving flood risk management in the Systemwide Planning Area.

1.5 2012 CVFPP Planning Approaches

In addition to **No Project**, three fundamentally different approaches to flood management were initially compared to explore potential improvements in the Central Valley. These approaches are not alternatives; rather, they bracket a range of potential actions and help explore trade-offs in costs, benefits, and other factors important in decision making. The approaches are as follows:

- **Achieve SPFC Design Flow Capacity –** Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.
- **Protect High Risk Communities –** Focus on protecting life safety for populations at highest risk, including urban areas and small communities.
- **Enhance Flood System Capacity –** Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

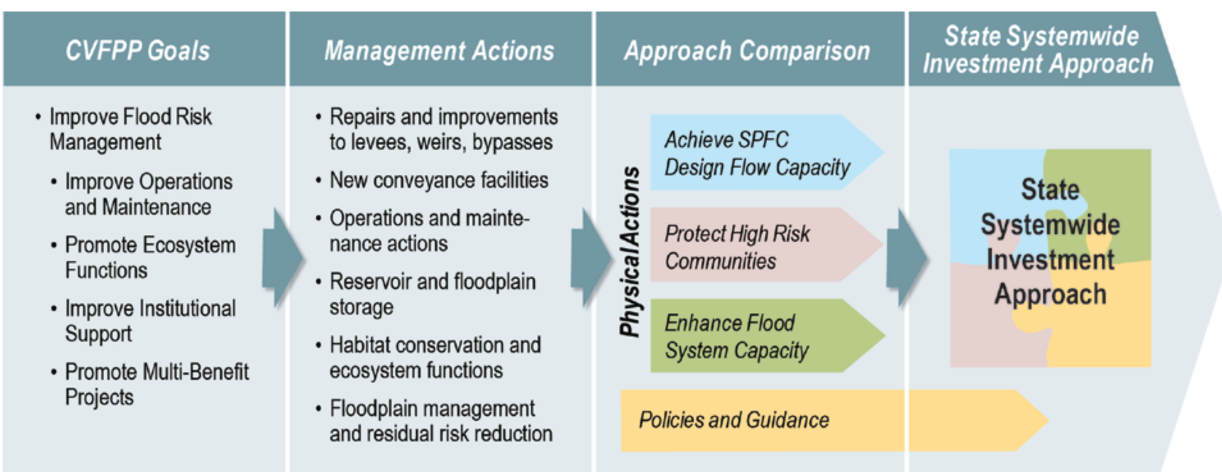


Figure 1-2. Formulation Process for State Systemwide Investment Approach

1.6 Climate Change and Flood Management

Three major categories of potential climate change effects are related to flood management; these include changes in precipitation and runoff patterns, sea level rise, and economic development. The first two categories of change relate to the chance of flooding, and the third category of change relates to consequences of flooding.

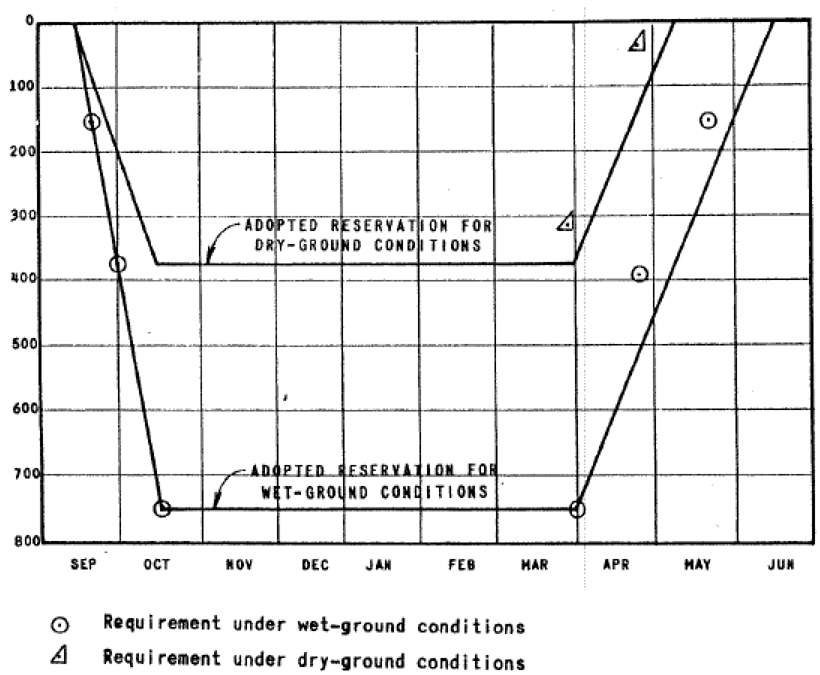
1.6.1 Change in Precipitation and Runoff Patterns

Historically, about 15 million acre-feet of runoff in California (with about 14 million acre-feet estimated in the Central Valley) originated from snowpack that accumulated in winter and melted gradually from April through July (DWR, 2008). About two-thirds of the runoff in the Central Valley originated in the Sacramento Valley (DWR, 2006). California's water storage and conveyance infrastructure gathers this melting snow in the spring and delivers it for use during the drier summer and fall months.

Increased temperatures may alter precipitation and runoff patterns, such as a rise in snow-line elevations, earlier snowmelt occurrence, more precipitation falling as rain instead of snow, and reductions in the volume of overall snowpack. Knowles and Cayan (2002) found that the combination of warmer storms and earlier snowmelt may cause April watershed total snow accumulation to drop by 5 percent of present levels by 2030, 36 percent by 2060, and 52 percent by 2090. Already, a greater proportion of annual runoff has been occurring earlier in a water year (Knowles et al., 2006). The combination of earlier snowmelt and shifts from snowfall to rainfall seem likely to increase flood peak flows and flood volumes (Miller et al., 2003; Fissekis, 2008; Dettinger et al., 2009), which is likely to affect associated flood risk. Higher snow lines could increase flood risk because more watershed area contributes to direct runoff. From an O&M viewpoint, these higher snow lines could increase erosion rates that would result in greater sediment loads and turbidity, altering channel shapes and depths, and possibly increasing sedimentation behind dams and affecting habitat and water quality (DWR, 2008).

Just as climate change is expected to change the magnitude and frequency of flooding, the same is expected of forest fires because of drier warm-season fuel conditions. For 70 years, the 220,000-acre Matilija fire of 1932 stood as California's largest wildfire. It has been surpassed twice in the past 6 years. Of the 10 largest California wildfires since 1932, 7 have occurred since 2003. Increased frequency and severity of wildfires (Resources Agency, 2009) reduces the availability of vegetation that absorbs runoff, which results in further increased runoff, erosion, and sedimentation.

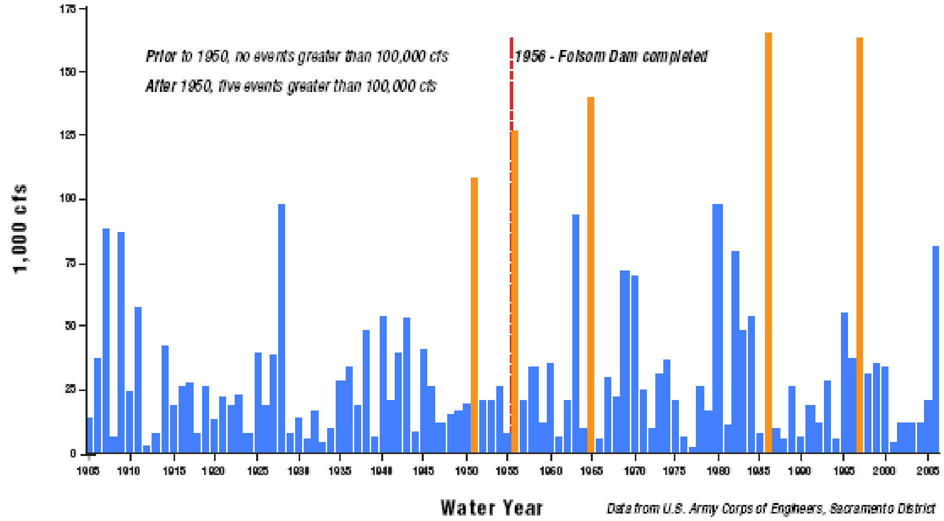
For reservoirs downstream from significant mountain snowpack, the resulting temporal shift in reservoir inflows could pose major challenges for managing flood storage capacity and water supply, particularly if reservoir operations are not modified to accommodate the new conditions (DWR, 2006; Medellin-Azuara et al., 2008; Fissekis, 2008). Flood control space requirements are generally specified using reservoir rule curves as a function of accumulated snowpack forecasts, measured rainfall, and the seasonality of precipitation. Existing rule curves for major flood control reservoirs were mostly based on characterization of local watershed hydrology while a dam was under construction. For example, Lake Oroville, the only major flood control reservoir in the SPFC, requires a seasonal flood control storage range of 375 to 750 thousand acre-feet based on soil moisture conditions (see Figure 1-3) (USACE, 1970). Changes in precipitation form (snow versus rain) associated with temporal shifts in runoff, and potential increases in flood frequencies and magnitudes, are likely to require reevaluation of existing operational rules developed based on previously accepted historical conditions.



Source: USACE 1970

Figure 1-3. Lake Oroville Seasonal Flood Control Space Requirement

Figure 1-4 shows 3-day peak flows of American River runoff in the past century (DWR, 2008). Five events with 3-day peak flows greater than 100,000 cubic feet per second (cfs) have been observed since 1950. These high peak flow volumes have resulted in a recharacterization of the level of flood protection offered by Folsom Dam, which was designed in the 1940s (DWR, 2008).



Source: DWR 2008 (with top five annual maximum 3-day flows highlighted)

Figure 1-4. American River Runoff, Annual Maximum 3-Day Flow

Sea Level Rise

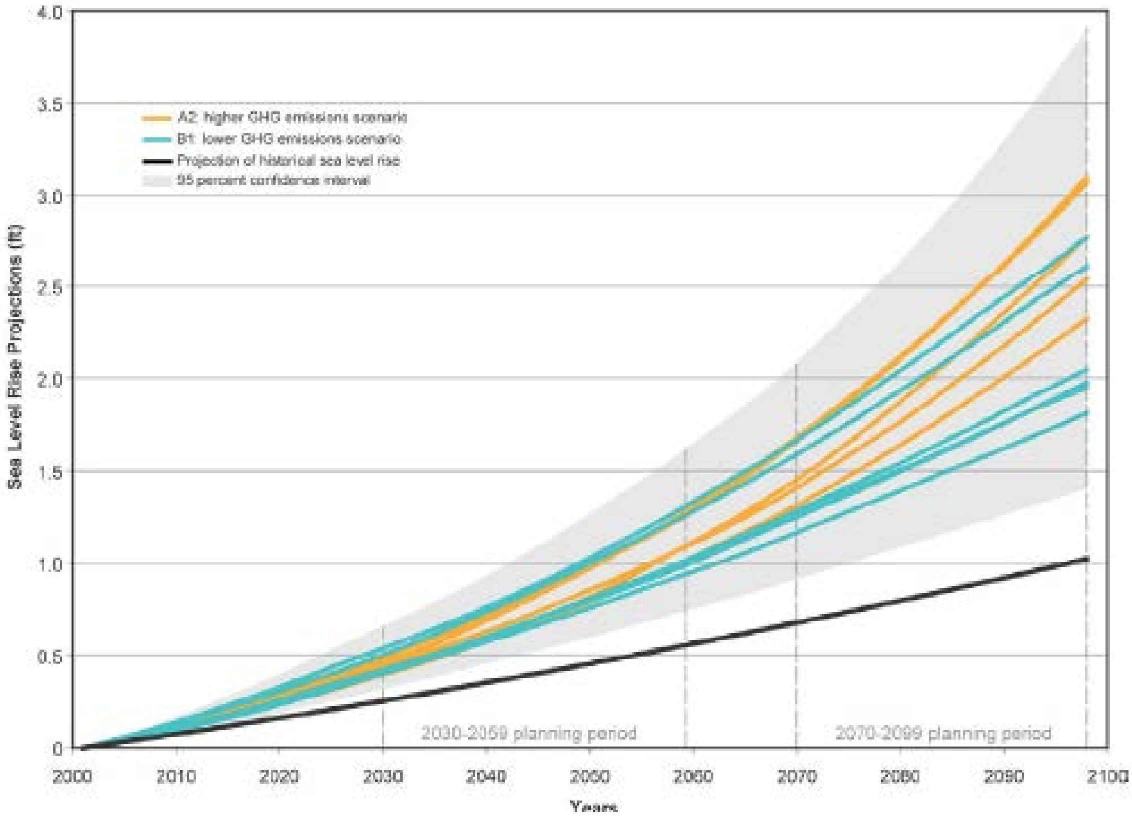
Increasing temperature also results in sea level rise due to the melting of land-based glaciers, snowfields, and ice sheets, along with thermal expansion of the ocean as the surface layer warms (DWR, 2008). In the last century, sea level has risen about 20 centimeters (cm) (7 inches) along California's coast (DWR, 2008). Recent studies suggest that since 1990, the global sea level has been rising at a rate of approximately 3.5 millimeters per year (mm/year) (0.14 inches per year (inches/yr)) (CALFED, 2007). Continuation or acceleration of this sea level rise, in combination with changes in precipitation and runoff patterns, would significantly augment flood problems in the Central Valley (Knox, 1993; Florsheim and Dettinger, 2007).

Sea level rise is likely to produce more frequent and potentially more damaging floods, increasing risks for those already at risk, and increasing the size of the coastal floodplain, placing new areas at risk (CEC, 2009a). Increased risk of storm surge and flooding is expected to increase risks for California's coastal residents and infrastructure, including wastewater treatment plants (DWR, 2008).

In the Systemwide Planning Area, sea level rise impacts would be most significant for the Delta, where a rise in sea level would increase hydrostatic pressure on levees currently protecting low-lying land, much of which is already below sea level. These effects threaten to cause potentially catastrophic levee failures that could inundate communities, damage infrastructure, and interrupt water supplies throughout the State (Hanak and Lund, 2008). Roos (2005) found that a 1-foot rise in sea level could increase the frequency of the 100-year peak high tide to a 10-year event in the western Delta at Antioch. The resulting higher tides, in combination with increases in storm intensity and flood volumes, would likely aggravate existing flood problems in upstream areas along the Sacramento and San Joaquin rivers.

Although it is generally accepted that sea levels will continue to rise on a global scale, the exact rate of rise remains unknown. Recent peer-reviewed studies estimate a rise of between 0.6 and 4.6 feet by 2100 along California's coast (DWR, 2008). Another set of projections, shown in Figure 1-5 based on 12 future climate scenarios selected by the California Climate Action Team (CAT), indicates a 1.8- to 3.1-foot rise in sea level by 2100. In addition to the CAT projections, even historical trends in sea level rise would indicate an approximately 1-foot increase in San Francisco Bay (CEC, 2009b). A California Energy Commission (CEC) report prepared by The Pacific Institute on sea level rise along the California coast estimated that a 5.6-foot sea level rise would put 480,000 more people at risk of a 1-percent annual exceedence probability (AEP) flood event, given the existing population (CEC, 2009a). One additional set of projections, developed for the State of California by the Ocean Protection Council[1] (OPC), indicates a 3.3- to 4.6-foot rise in sea level by 2100 (OPC, 2010).

[1] OPC used IPCC emissions scenarios and GCMS to develop these projections.



Source: CEC 2009b

Figure 1-5. Sea level Rise Projections Based on Air Temperatures from 12 Future Climate Scenarios

Economic Activities

California has 76,000 farms and 26.3 million acres in production, making agriculture an important component to the State's economy. Much of California's $36 billion agricultural industry is concentrated in the Central Valley (CDFA, 2009). More frequent and larger flood events are likely to damage structures, threaten livestock, contaminate croplands, cause increased erosion and sedimentation, take croplands out of production for extended periods as fields dry and recover, threaten levees that protect cropland and, in conjunction with sea level rise, increase farmland vulnerability in coastal areas and the Delta. Notably, despite decades of construction of flood management structures and levees in the Central Valley and its tributaries, levees continue to fail under existing flood conditions (Florsheim and Dettinger, 2007; Florsheim and Dettinger, 2005).

Currently, there is a trend toward converting annual crops to perennial crops with higher economic value. Because it takes longer for perennial crops to recover from flood damage, potential increased flooding resulting from climate change would likely have even greater economic impacts on the agricultural industry.

The Central Valley is also under pressure to urbanize, yet future floods could be of a greater volume and intensity under climate change. Much is at stake because California has $4 trillion in real estate assets, of which $2.5 trillion are exposed to potential climate change effects (Kahrl and Roland-Holst, 2008). Increasing populations in high-risk areas means more flood damage can occur and additional flood protection is required. Increasing costs of providing greater flood protection hinder local economic development by constraining growth and limiting money available for other community needs.

1.6.2 Related Effects on Other Aspects of Water Resources Management

Climate change is also likely to impact water supply and ecosystem management in ways that affect flood management.

Water Supply

California's current major water systems are designed and operated to store water and regulate floodflows in winter and early spring and supply water in late spring, summer, and fall. Water supplies are provided to serve statewide demands for municipal and industrial (M&I), agricultural, and environmental water. More than 20 million (of about 37 million) Californians rely partially on two large water projects: the State Water Project (SWP) and federal Central Valley Project (CVP). The effects of climate change on SWP and CVP operations are expected to include changes in reservoir inflows, delivery reliability, and annual average carryover storage (DWR, 2006). In particular, higher snow elevation, early snowmelt, more precipitation as rainfall instead of snow, and reductions in overall snowpack are likely to contribute to reductions in water supply reliability. Accommodating higher flood volumes may require more flood storage in the winter and early spring, making it more difficult to refill reservoirs during the traditional April-through-July snowmelt runoff period.

In addition to overall changes in water volumes, water supplies will likely be affected by changes in water quality as a result of climate change. For example, higher temperatures are likely to increase the rates of chemical reactions in water generally, increasing biological oxygen demand through algal growth and decay. Broader areas of watersheds receiving rain rather than snow may see an increase in erosion and thus downstream turbidity and sediment transports. M&I water supply may also be compromised because water treatment processes are affected by water temperature, although this may not be a significant problem, as demonstrated by the ability of many other communities around the world to adapt treatment processes to higher temperatures (Hanak and Lund, 2008).

Sea level rise is likely to increase seawater intrusion into the Delta, which, by increasing salinity, will further degrade water quality for those who use Delta water (DWR, 2006). More freshwater releases from upstream reservoirs could be required to maintain compliance with existing Delta water quality standards, resulting in further stress to available water supplies in upstream reservoirs.

In an average year, groundwater meets about 30 percent of California's applied urban and agricultural water demands, and this can increase to more than 60 percent during drought years (DWR, 2003). This important component of the State's water supply is likely to be affected by climate change because of reduced ability to replenish groundwater, increasing demand, and expanding areas of saltwater intrusion in coastal aquifers (CEC, 2008).

Aquatic species are likely to be affected by an increase in water temperatures throughout the system, including inflows into reservoirs, water stored within reservoirs, and water flowing downstream. The rising water temperature in river stretches serving as aquatic habitats would increase the demand for temperature management, using already limited cold-water reserve in major reservoirs, creating additional competing needs of limited stored water.

Ecosystem Management

While ecosystems have always naturally changed over time, ecosystem effects of climate change are likely to be exacerbated by the dramatic loss of natural areas experienced in the last 50 years (CEC, 2009c) and by the relatively rapid rate at which climate change and other stresses are advancing. The abundance, production, distribution, and quality of ecosystems throughout California are likely to be dramatically affected during this century by a combination of climate-change-associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g., land use change, pollution, fragmentation of natural systems, overexploitation of resources) (IPCC, 2007a). Most vulnerable to climate change are endangered and threatened species, plants and animals living within confined geographic ranges with limited abilities to move rapidly, and species migrating to new areas where they meet increased competition for habitat or food (IPCC, 2007a).

Climate change effects on ecosystem land management include both the geographic loss of habitat and the loss of habitat connectivity. Sea level rise is expected to cause increased seawater intrusion into California's coastal marshes and estuaries. Increased intrusion will likely disrupt marsh and estuary ecosystems, especially at the higher projections of sea level rise. The loss of natural areas in turn reduces opportunities to use ecological systems and functions within flood management systems.

Higher water temperatures resulting from climate change are likely to negatively impact aquatic and terrestrial resources. Warmer temperatures can compromise the health and resilience of existing aquatic and terrestrial species and, thus, make it more challenging for them to compete with nonnative species for survival. Of specific concern to Central Valley aquatic habitats, Chinook salmon and steelhead prefer temperatures of less than 64.4 to 68 degrees Fahrenheit (°F) (18 to 20 degrees Celsius (°C)) in mountain streams, although these anadromous fish may tolerate higher temperatures for short periods (Bennett, 2005). Increased water temperatures could reduce the habitat suitability of California rivers for these species. Impacts on terrestrial ecosystems have also been observed in North America, including changes in the timing and length of growing seasons, timing of species life cycles, primary production, and species distributions and diversity (CEC, 2009c).

Competition for habitat and food will intensify with climate change. For example, climate change is expected to decrease suitable summer habitat of delta smelt, a federally listed endangered species, because waters in the lower Delta may be too saline and lack food, and freshwater in the upper Delta may be too warm. Climate change could combine with nonclimate stressors, such as land use changes, wildfire, and agriculture and cause habitat fragmentation at increasing rates, thus contributing to species extinction (USFWS, 2009).

1.7 Report Organization

Organization of this document is as follows:

- Section 1 introduces and describes the purpose of this report and provides background on climate change and flood management.
- Section 2 summarizes results and findings for the Climate Change Threshold Analysis Approach.
- Section 3 describes methodology and results for the Threshold Analysis Approach Pilot Study.
- Section 4 contains references for the sources cited in this report.

- Section 5 lists abbreviations and acronyms used in this report.
- Appendix A contains supplemental pilot study figures.

2.0 Methodology

The CVFPP has a unique approach to climate change, developed through extensive engagement with the public and the scientific research community. As part of development of the CVFPP, two topic work groups addressing climate change developed, recommended, and described a unique approach for analyzing climate change in the context of flood management.

A Climate Change Scope Definition Work Group (CCSDWG) was formed in the first phase of the CVFPP planning process to provide recommendations to DWR on the scope of climate change considerations to be addressed in the 2012 CVFPP and subsequent updates. (Topic-specific work groups are used in CVFPP development to develop recommended contents for inclusion considerations (DWR, 2009a)). Outcomes from the CCSDWG are summarized in a CCSDWG summary report (DWR, 2009b) that presents the following:

- Key aspects of climate change that may affect flood management
- Existing problems and expected future challenges within the CVFPP project area related to climate change
- Checklist of climate change considerations for the CVFPP
- Summary of related climate change projects and programs
- Climate change references for the CVFPP

Input from the CCSDWG for the first two items above is incorporated into Section 1.5 of this report. Work group input for the third item was instrumental in guiding subsequent development of the CVFPP climate change approach. Input on projects and programs is incorporated into overall coordination efforts, and references are contained in a master compilation for the CVFPP reference library.

The CCSDWG proposed a unique approach for incorporating considerations of climate change into the CVFPP planning process. A subsequent Climate Change Threshold Analysis Work Group (CCTAWG) further identified the need for a unique approach and developed the framework for the Climate Change Threshold Analysis Approach.

2.1 Considerations in Methodology Design

This section describes the need for a unique climate change analysis approach and outlines the overall methodology for the CVFPP climate change analysis.

2.1.1 Need for a Unique Approach

For any planning project or program, the methodology, tools, and data should align with the purpose(s) of the study, intended decision making, and information available to inform the decision.

Climate change impacts and considerations have been incorporated into many recent and ongoing California resources planning studies, using various methods. Much of the current analysis of climate and water impacts considers how changes in various mean conditions (e.g., mean temperatures, average precipitation patterns, mean sea level) will affect water resources, water supply in particular. Although many water resource factors are affected by such average conditions, some of the most important impacts, including flooding, will result not from changes in averages, but from changes in local extremes (DWR, 2006). Because of the focuses of other ongoing studies, the resulting methodology, resolution, data, and results of these studies are not directly relevant to flooding risk assessment and flood management.

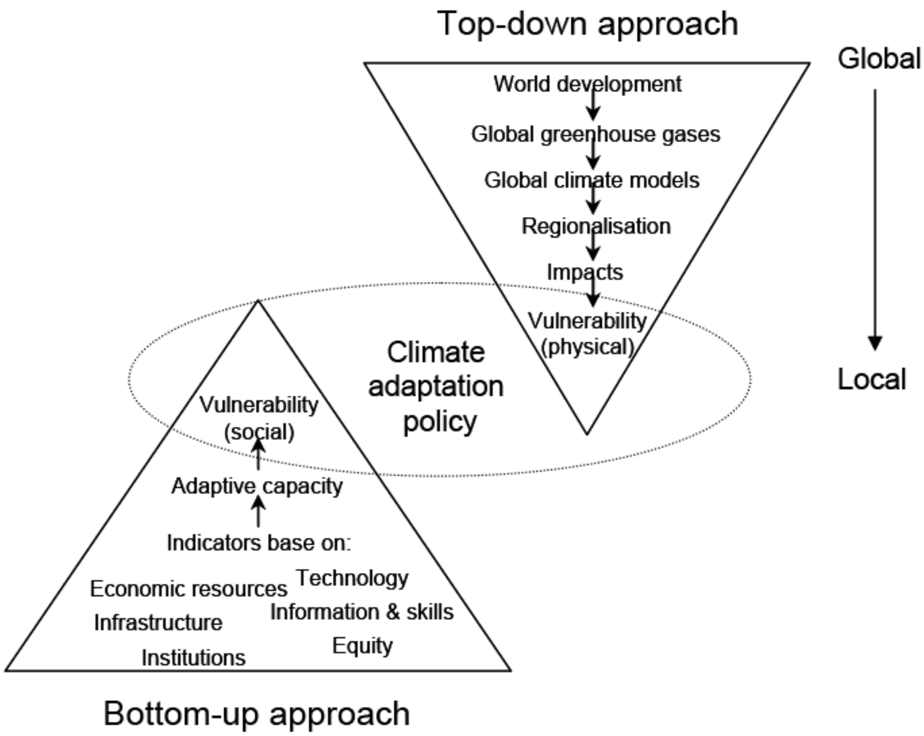
Climate change impacts to extreme events, such as flooding and droughts, will result not from changes in averages, but from changes in local extremes.

CVFPP will be the first major policy-level study with broad applications that addresses climate change for flood management in California. Flood management requires consideration of extreme precipitation and runoff events. An extreme weather event is defined by the Intergovernmental Panel on Climate Change (IPCC) as an “event that is rare at a particular place and time of year,” where rare is defined as having a magnitude below 10 percent or above 90 percent of observations (Ray et al., 2008).These extremes are difficult to project for the future because climate projections from global climate models (GCM) have difficulty representing regional- and local-scale precipitation patterns and processes that drive extreme events. GCM climate projections also generally provide data at time-steps that are not useful for analysis of flooding. In addition, the substantial influence of both human settlement patterns and water-management choices impact overall flood risk (DWR, 2005).

Therefore, the approach needed for CVFPP development can be discussed in at least three aspects: (1) perspectives of climate change vulnerability assessment, (2) analytical focus for flood management, and (3) the decision-making process, with uncertainties. These three aspects are interrelated in designing the appropriate approach for CVFPP climate change considerations.

Perspectives for Climate Change Vulnerability Analysis

The purpose of climate change vulnerability analysis is to inform climate adaptation policy development. Vulnerability analysis includes “top-down” and “bottom-up” approaches. Figure 2-1 shows the concept of these two approaches.



Source: Dessai and Hulme, 2003

Figure 2-1. “Top-Down” and “Bottom-Up” Approaches Used to Inform Climate Adaptation Policy

Most of the existing climate change impacts analysis uses a projection-oriented “top-down” approach that considers a range of scenarios of world development. These scenarios include greenhouse gas emissions that serve as input to GCMs. GCM output serves as input to impact models (with or without inclusion of adaptive actions). Under this approach, analysis of the probability of certain impacts could largely depend on the ability of the GCMs to characterize that probability, which may be more subjective than the level of rigor required to support a risk-based analysis (Dessai and Hulme, 2003). In flood management, risk-based analysis is often based on probabilities derived from event frequency documented in historical records. However, the extreme events and their corresponding climate signals are the most uncertain elements of the climate change research. As a result, additional consideration is necessary of an appropriate approach for a climate change vulnerability analysis in the context of flood management.

Another approach, the "bottom-up" approach, has seen greater development and application in recent years. The bottom-up approach reflects a focus on the underlying adaptive capacity of the system under study, emphasizing broader social impacts. It is place-based and deals with specific resources of interest. Flood managers could start with existing knowledge of the system and use evaluation tools to identify changes in climate that may be most threatening to long-term management goals and practices – critical system vulnerabilities. GCM outputs are then used as a reference to assess the likelihood of such system-critical vulnerabilities (Ray et al, 2008; Dessai and Hulme, 2003). This approach may ease concerns for policy makers who are hesitant to move forward with policy decisions while climate uncertainties remain.

Analytical Focus for Flood Management

Many climate change analyses, including ongoing studies by DWR for various California water planning and management purposes, are based on the most readily available climate change signals in GCMs, such as changes in temperature and precipitation. Analytical time steps are often monthly for water supply and other resources management purposes. As previously mentioned, these climate change signals may be sufficient to assess longer term average conditions, especially in the case of temperature, but provide little information for extreme events. Furthermore, challenges with projecting precipitation are only amplified when focusing on shorter time-scale events.

For flood management, hydrographs (e.g., volume, peak) and corresponding antecedent conditions are key factors for flood damage assessment. Perturbation of these properties from historical storm patterns may be helpful for early investigation, but may not relate well to climate change conditions and, thus, leave decision makers unable to assess the level of urgency for specific adaptive actions. Therefore, it is critical to establish proper types of climate change signals (in terms of time scale and physical representation) that could be more appropriate for linking to storm hydrologic properties, allowing more meaningful vulnerability analysis.

Decision-Making Considerations

The CVFPP focuses specifically on improving flood protection for areas protected by SPFC facilities. The CVFPP is a systemwide assessment of the Sacramento-San Joaquin Flood management system that includes elements of SPFC facilities and local projects (that may or may not have federal partnership). The State Systemwide Investment Approach included in the CVFPP represents policy and investment priority and objectives for improving flood management in the Central Valley. The investment approach reflects the State's policy directives for providing appropriate flood protection (and, thus, sustainable maintenance) for urban areas, small communities, and rural areas in an economic, environmentally and socially sustainable manner. Implementation of the State System Investment Approach defines the roles and responsibilities of State, federal, and local entities, a timeline for implementation, and a financial strategy for sustaining long-term flood management improvements and maintenance.

Several studies have reviewed various decision support planning methods for water resources management (Brekke et al., 2009; Western Utility Climate Alliance, 2010). These studies identify potential limitations on applying traditional decision support analysis, with recognition that the cited limitations have a greater influence if extreme events are the metric of interest. One example is traditional risk-based decision support analysis, which manages uncertainties through analysis of well-characterized probabilities, and recommends optimal strategies. This type of analysis uses tools such as decision trees or influence diagrams. Application of risk-based decision support analysis to flood management would inherit challenges because of the uncertainties of climate change with respect to extreme events, as previously mentioned.

Another traditional decision planning method is scenario planning, which focuses on a set of critical uncertainties to form various scenarios that managers agree are plausible and reasonable to describe the decision space. While scenario planning can be beneficial in identifying a range of potential strategies, obtaining consensus on which climate change projections to use for extreme events is challenging.

A third traditional decision support planning method is adaptive management, which "promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood" (NRC, 2004). However, adaptive management is more suited to guiding operational or institutional changes rather than construction of new water facilities. Structural solutions may be hard to reverse unless they are designed to anticipate alternative future conditions with planned upgrades (Brekke, et al., 2009).

Identified by the CCSDWG as a useful decision support planning method, robust decision making combines portions of traditional decision analysis and scenario planning (Western Utility Climate Alliance, 2010). Robust decision-making identifies options that perform well over a wide range of possible future scenarios, rather than optimizing for a single scenario. The goal of this method is to reduce the potential to be "surprised" by unexpected events (Brekke et al., 2009). Robust decision making uses a large ensemble of scenarios for simulations to avoid the need to prioritize uncertainties and agreements about future conditions.

Brekke et al. (2009) emphasize the need for planning frameworks to be flexible enough to incorporate uncertainties related to climate change in managing risks. Planning approaches that incorporate climate change probabilities, robust decision making, and adaptive management are all adaptation strategy options that allow decisions to be more flexible. These approaches also consider future advances in scientific understanding as they become available.

The purpose of this discussion is not to identify the optimal decision support planning method for making flood management decisions for the CVFPP under climate change. Rather, it is to identify potential problems and opportunities associated with various decision support planning method options. While the robust decision making method recommended by the CCSDWG could be an appropriate decision tool, as currently performed it could be very time consuming for the CVFPP, which addresses a large, complex system and has broad management objectives.

2.2 Methodology Design

The climate change approach needs for flood management described previously were considered in development of the Climate Change Threshold Analysis Approach for the CVFPP. This climate change approach is based on the bottom-up approach for vulnerability assessment; however, it has been expanded to include causal relationships among metrics for communities, hydrology, and atmospheric factors to provide a framework allowing a qualitative comparison of the likelihood of exceedence of critical thresholds of vulnerability. The concept of robust decision criteria could be included in the Climate Change Threshold Analysis Approach, as it is applied across various sets of management actions. However, the CVFPP Threshold Analysis Approach does not follow the common execution of the robust decision-making method, which uses a large number of simulations.

Climate Change Threshold Analysis Approach is an analytical framework to identify vulnerability thresholds that may be exceeded in the next 50 years, given the expected, although uncertain, effects of climate change, warranting changes in investment strategy and priority for improving regional and/or systemwide flood management in the Central Valley.

The CCTAWG was instrumental in developing the Climate Change Threshold Analysis Approach. The following section provides preliminary details of this approach; the approach will be further developed and refined for the 2017 CVFPP.

2.2.1 Definition of Threshold Analysis Approach

Climate is the prevailing condition of temperature, winds, precipitation, and runoff in a location over the long term (classically defined as 30 years by the World Meteorological Association (2003)). Changing climate may significantly alter the magnitude, timing, and frequency of extreme precipitation events and resulting runoff in the Central Valley. It could also alter the distribution and type of winter precipitation and the timing of annual snowmelt processes that generate runoff. Taken together, these changes could significantly alter the profile of floods in the Central Valley.

A conceptual diagram of the Climate Change Threshold Analysis Approach is shown in Figure 2-2.

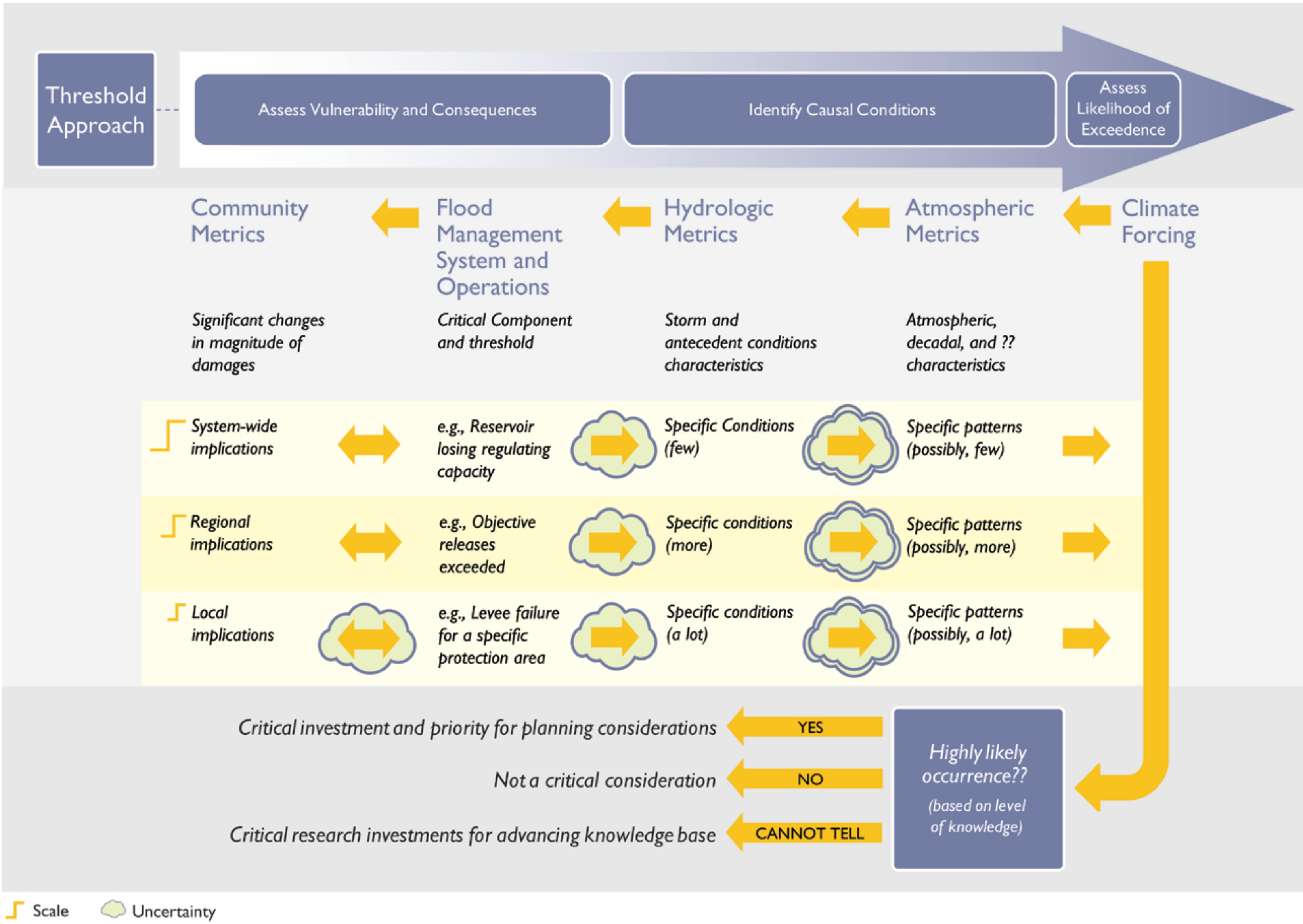


Figure 2-2. Conceptual Diagram of Climate Change Threshold Analysis Approach

The arrow along the top of the diagram shows the general work flow. The Threshold Analysis begins with an assessment of vulnerability thresholds at critical system components, and the resulting consequences of crossing those thresholds. Subsequently, an assessment of the conditions that would cause the thresholds to be exceeded would be conducted, followed by an assessment of the likelihood of exceedence.

The second row of the diagram shows the individual pieces of the analysis and the work flow for a more top-down impacts analysis. Below the second row are illustrations of three possible scales at which the Threshold Analysis may be applied. The clouds surrounding connecting arrows indicate increasing levels of uncertainty. Finally, the long arrow on the right shows that all of this information is aggregated into a decision framework, identifying needed investment in the flood system or in additional research.

As mentioned, major steps of the Threshold Analysis are assessing vulnerability, identifying causal conditions, and assessing likelihood of threshold exceedence.

Assess Vulnerability

Vulnerability can be assessed from various different levels and with different focus. Critical components of the flood management system have associated thresholds of vulnerability, the crossing of which can cause undesirable consequences. The first step is to identify components and thresholds that exist on several spatial scales. Examples include a reservoir losing capacity to regulate flows downstream, a reservoir (or a system of reservoirs) exceeding its objective release, or an infrastructure (e.g., dam, levee) failure.

Once thresholds for critical system components are identified, the consequences of exceeding the thresholds on a community level can be quantified. For example, a reservoir losing its capacity to regulate downstream flows would have large-scale, systemwide consequences. The effects of crossing a systemwide threshold would likely cascade through the system, causing other thresholds to be crossed. Other critical thresholds would have more moderate, regional consequences, such as a reservoir exceeding its objective release. At the smallest, most local scale, a levee failure may have severe impacts to a specific protection area, but less impact on other parts of the flood management system and operations.

Defining critical thresholds that will need analysis requires a level of agreement among the various State, federal, and local entities with flood risk management responsibilities. It is conceivable that components with potential broader damages to communities (including natural communities) would be easier for broad agreement for CVFPP systemwide application. However, for local flood management studies with a more finite project scope, the local critical thresholds could be used without exhausting available resources.

Identify Causal Conditions

The next step is to define the hydrologic conditions required for a given threshold to be exceeded. These conditions can be described by a set of hydrologic metrics. Critical thresholds for large-scale, systemwide components will be affected by relatively fewer sets of hydrologic matrices. In contrast, critical thresholds for local components will be influenced by significantly more sets of hydrologic metrics at various locations throughout the flood management system.

Hydrologic conditions leading to threshold exceedence are linked to atmospheric patterns that can be affected by climate change. These patterns can be described by a set of atmospheric metrics that can be sampled from a future projection of climate and translated into hydrologic metrics for planning purposes. Subject to additional investigation, it is anticipated that for systemwide components, relatively fewer sets of atmospheric metrics will correspond to the hydrologic metrics, which in turn, correspond to critical thresholds, and more sets for critical thresholds for local components.

Assess Likelihood of Exceedence

The final step in the approach is to assess the likelihood of threshold exceedence. It is anticipated that this would be an assessment against baseline conditions or other base of comparison, and would be conducted qualitatively based on available GCMs. It remains to be determined whether current climate change science can provide adequate information to inform the process. If so, an analysis of the likelihood of crossing critical thresholds can be performed, and the results will inform planning analysis for further investment in the flood management system. If not, identification of vulnerabilities will help identify areas of needed climate science investment to obtain adequate information.

2.2.2 Vulnerability Assessment

The vulnerability assessment includes a description of the critical component and its associated threshold, and a description of the consequences of exceeding the threshold.

Critical Components and Thresholds

The Climate Change Threshold Analysis will be applied to the SPFC, which includes flood management facilities, lands, programs, conditions, and modes of O&M. More details on the specific definition of each of these terms are included in the *State Plan of Flood Control Descriptive Document* (DWR, 2010). Major facilities for each of the two basins are listed below.

Major SPFC facilities along the Sacramento River and tributaries are shown in Figure 2-3 and include the following:

- About 440 miles of river, canal, and stream channels (including an enlarged channel of the Sacramento River from Cache Slough to Collinsville)
- About 1,000 miles of levees (along the Sacramento River channel, Sutter and Yolo basins, and Feather, Yuba, Bear, and American rivers)
- One major flood management reservoir (Lake Oroville)
- Four relief bypasses (Sutter, Tisdale, Sacramento, and Yolo bypasses)
- Knights Landing Ridge Cut, connecting the Colusa Basin to the Yolo Bypass
- Five major weirs (Sacramento Weir, built in 1916; Fremont Weir, built in 1924; and Moulton, Tisdale, and Colusa weirs, built in 1932 and 1933)
- Two sets of outfall gates
- Five major drainage pumping plants
- Cache Creek Settling Basin, maintaining the flood conveyance integrity of the Yolo Bypass
- Numerous appurtenant structures such as minor weirs and control structures, bridges, and gaging stations.

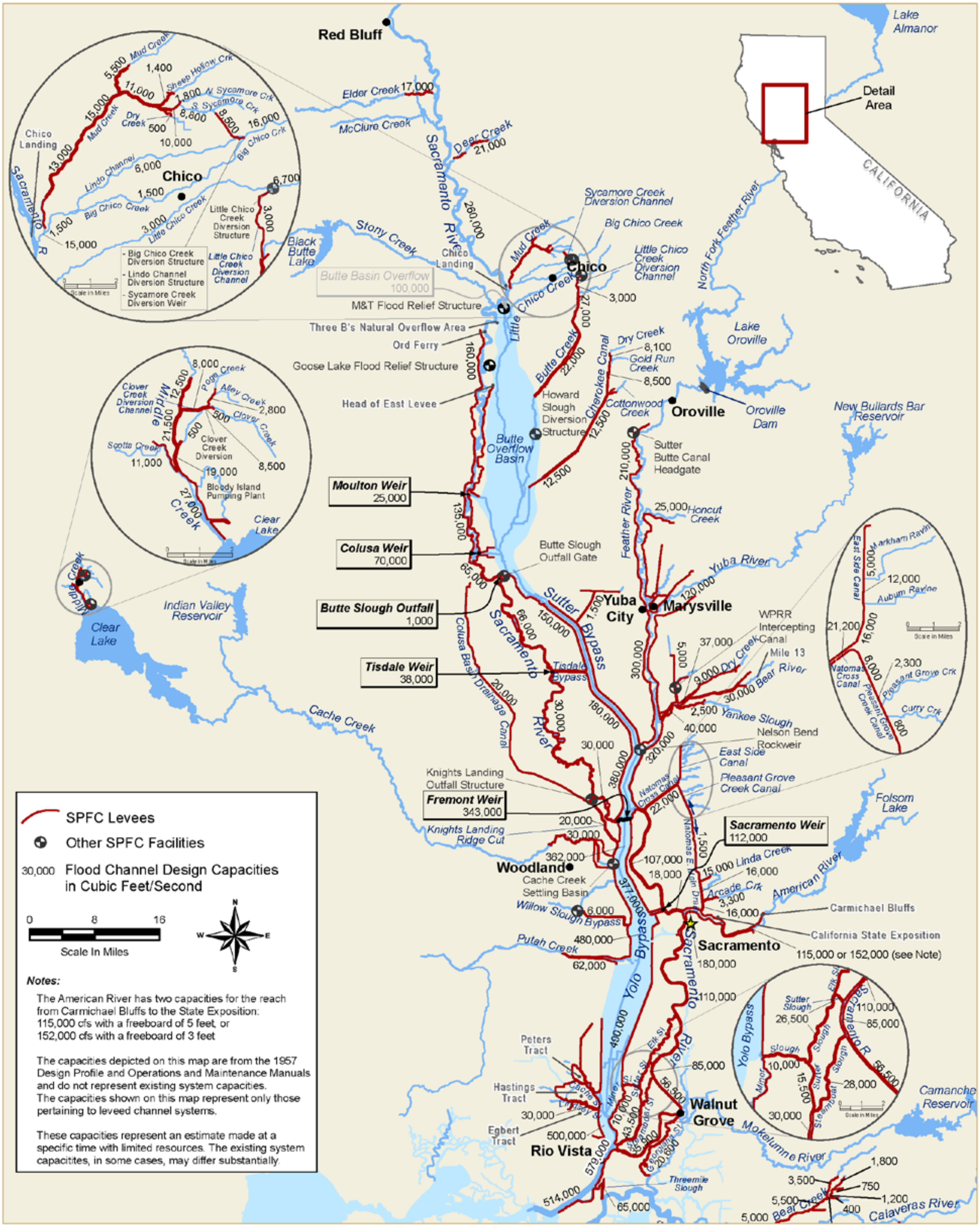


Figure 2-3. Design Flood Flow Capacities For Sacramento River, Bypasses, and Major Tributaries and Distributaries in Sacramento River Basin

Major SPFC facilities along the San Joaquin River and tributaries are shown in Figure 2-4 and include the following:

- Chowchilla Canal Bypass (and levees), which begins at the San Joaquin River downstream from Gravelly Ford, diverts San Joaquin River flows, and discharges the flows into the Eastside Bypass
- Eastside Bypass (and levees), which begins at the Fresno River, collects drainage from the east, and discharges to the San Joaquin River between Fremont Ford and Bear Creek
- Mariposa Bypass, which begins at the Eastside Bypass and discharges to the San Joaquin River (and levees)
- Approximately 99 miles of levees along the San Joaquin River
- Approximately 135 miles of levees along San Joaquin River tributaries and distributaries
- Six instream control structures (Chowchilla Bypass Control Structure, San Joaquin River Control Structure, Mariposa Bypass Control Structure, Eastside Bypass Control Structure, Sand Slough Control Structure, and San Joaquin River Structure)
- Two major pumping plants

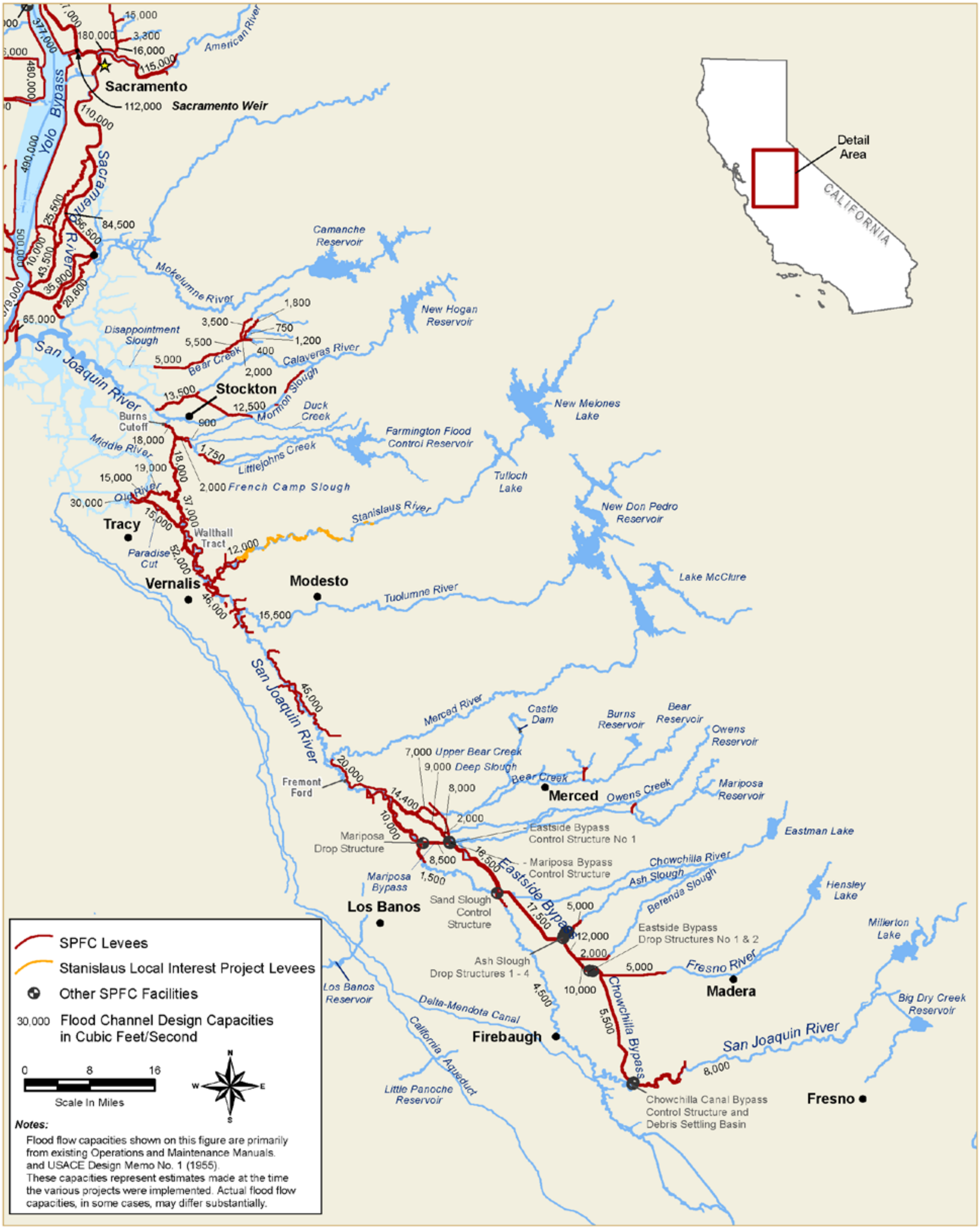


Figure 2-4. Design Flood Flow Capacities For San Joaquin River, Bypasses, and Major Tributaries and Distributaries of the San Joaquin River Basin

Many of the multipurpose storage facilities that contribute to flood management in the Sacramento and San Joaquin river basins are also operated for other purposes, such as water supply and power generation, but are not part of the SPFC because they include no State assurances to the federal government. Major multipurpose storage facilities are shown in Figure 2-5. Note that Oroville Dam is the only major multipurpose project listed that is part of the SPFC.

Figure 2-5. Locations of Multipurpose (Including Flood Management) Dams and Reservoirs in Sacramento and San Joaquin River Basins

While the functions of SPFC will be impacted by climate change, some critical functions have the potential to greatly impact other components of the system, if lost. These functions generally fit into a hierarchy of consequences, with systemwide, regional, or local implications. An example of each is below.

- **Systemwide example: uncontrolled release from a major flood management reservoir –** Reservoir operation is a key for flood management to regulate outflows for downstream safety. If a major flood control reservoir were to lose its regulatory capacity, the potential effects on downstream flood protection could be significant and widespread.

- **Regional example: objective release exceedence –** Objective releases from a reservoir or a jointly operated reservoir complex reflect the original plan of these facilities and associated downstream levees or floodwalls to provide desirable flood management function. If the threshold were to be exceeded, the flood risk downstream would increase significantly.

- **Local example: levee failure –** Levee integrity is an important threshold for local economic activities and communities protected by levees, and the consequences of exceeding this threshold are better understood than the previous two categories. However, the exact threshold for levee failure is not well defined. DWR currently conducts geotechnical exploration to identify potential levee failure modes, and associated risks.

Community Metrics and Threshold

Community metrics measure the chance of flooding and/or consequences of flooding in an area and can be used as indices for vulnerability. These metrics result from flood management system operations and climate change scenarios; they are not influenced by operations alone. In other words, many combinations of upstream operations could result in a common outcome at the local level. These multiple-to-one relationships between the operation and reliability of the flood management system, and the thresholds of community metrics, require a significant level of effort to define. Developing community metrics requires customization for each community because each could have unique vulnerability or vulnerabilities. The following metrics are potential examples based on CCTAWG discussions regarding their potential applicability. However, no specific metric recommendations were formed because of the above recognition of the benefits of assigning thresholds to system component levels.

Two example sets of metrics for measuring community thresholds have been identified: metrics for chance of flooding and metrics for consequences of flooding. Examples of metrics for the potential chance of flooding include the following:

- **Level of Protection –** The level of protection is a legislatively mandated metric for measuring flood risk. It identifies the frequency of flooding from which an area is protected. For example, an area with a 200-year level of protection can withstand flooding that has a 1-in-200 chance of occurring in any given year. However, level of protection may be a problematic metric for vulnerability in the future because changing climate may alter the magnitude of a flood that occurs at a given frequency.

- **Upstream Flood Management Capacity –** This metric measures the total flood space in reservoirs, channels, bypasses, and detention basins upstream from a point in the system. This type of metric is problematic because of the challenge in defining upstream capacity in a consistent way.

Potential impact metrics include both upfront costs for adapting to climate change and the impacts themselves. Examples of potential impact metrics include, but are not limited to, the following:

- **Infrastructure Costs –** Altered hydrologic regimes because of climate change create the need for proactive investment in infrastructure, often at significant cost, to reduce the consequences of flooding. In addition to costs for resizing or reoperating flood management infrastructure, this metric would also include costs for relocating buildings, utilities, transportation corridors, water and wastewater treatment plants, and other public infrastructure.

- **Operations and Maintenance Costs –** O&M costs for the existing flood system represent a substantial fraction of current flood management costs. Climate change may alter these costs by changing the frequency, magnitude, or timing of floodflows. Climate change also may reduce the length of the construction and maintenance season, thereby limiting opportunities to gradually adapt to changes in the system.

- **Lives/Casualties –** Protecting public safety is a key component of the primary CVFPP goal to improve flood risk management. The number of casualties in a given year is an important metric for measuring flood impacts.

- **Economic Damages –** Flooding results in significant damages to State and local economies. Losses include lost jobs and income as well as damages to infrastructure, homes, and businesses.

- **Resilience/capacity to Recover –** Resilience describes the ability of a system to return to its pre-impact state. After a flood event, communities have different capacities to recover and resume economic growth. The time required for a community to recover from a flood event may be used as a metric.

- **Ecosystems/Natural Resources –** Potential metrics to measure loss of ecosystems and natural resources include acreage lost (e.g., critical habitat, wetlands, riparian woodlands), or the value of ecosystem services lost.

- **Permanent Loss/Concessions –** Flooding may result in irreparable cultural losses, as happened in portions of New Orleans after Hurricane Katrina. In addition, areas that are frequently inundated may need to be conceded as not able to be protected by the flood management system.

2.2.3 Identification of Causal Conditions

Subject to various potential flood management system configurations and operations, different hydrologic conditions and their corresponding atmospheric conditions could cause the critical threshold to be exceeded. In other words, the relationship between hydrologic metrics and system critical threshold are often multiple-to-one, and it is likely that the same kind of multiple-to-one relationship exists between hydrologic metrics and atmospheric metrics.

Hydrologic Metrics

Hydrologic metrics describe attributes of a flood moving through the flood management system. Typical characteristics of a flood hydrograph can be described by the following hydrologic metrics:

- **Peak Flow –** A 3-day peak flow is a widely used metric for measuring flood magnitude in reservoir operations. Instantaneous peak flow is another important metric, useful for assessing levee overtopping and unregulated flows.

- **Volume of Flow –** The volume of a flow has significant impacts on a flood management system, especially in increasing pressure on flood management reservoirs. Volume metrics should include flow volumes over 1, 3, 7, 15, and 30 days.

- **Duration of Flow –** Flow duration determines the amount of time a flood management system is engaged during a flood event. Longer duration high flows will create additional strain on a system. Duration of inundation is also an important metric for the health of natural floodplains.

- **Timing of Flow (seasonality) –** Flood risk in California occurs at specific times of year; therefore a metric measuring the timing of flows is necessary. Several methods are currently used to measure the seasonality of flow, including spring pulse onset, center of mass, date of maximum flow, and monthly seasonal fractional flows, among others. Seasonality is also an important factor in ecosystem health.

- **Time to Peak –** The time to peak furnishes important information on the rate at which a flood moves through the system.

Depending on system configuration and the particular component and its threshold of interest, one or more hydrologic metrics could be more relevant and better suited for the Climate Change Threshold Analysis Approach.

Atmospheric Metrics

Atmospheric metrics describe weather and climate patterns that influence hydrologic conditions. Atmospheric metrics need to be designed so that they can be sampled from GCMs or associated downscaled products and translated into a specific set of hydrologic metrics.

For flood events, examples of potential atmospheric metrics include the following:

- **Atmospheric River Index –** Atmospheric river (AR) events have been associated with the majority of major flood events in California (Dettinger et al., 2009). An AR Index to characterize the amplitude and frequency of AR events would be a useful metric for characterizing the potential for these high-impact events to affect flooding in the Central Valley. The index could potentially be related to the depth, width, and persistence of the atmospheric moisture plume.

- **Freezing Elevation –** Freezing elevation impacts the area contributing rainfall runoff to a river. A higher freezing elevation results in a larger catchment area contributing direct runoff. However, the magnitude of the effect of increased freezing elevation varies from watershed to watershed, based on local topography (Dettinger et al., 2009).

- **Rain-on-Snow Events –** A rain-on-snow event is defined as an event with both precipitation and snowmelt (i.e., decrease in snow depth) occurring (McCabe et al., 2007). The number of days per year with rain-on-snow conditions may be used as a metric. These conditions could relate to some most devastating California flood events in the past, and appear to correlate to climate signals such as the El Niño/Southern Oscillation (ENSO).

2.2.4 Assessment of Likelihood of Crossing Critical Thresholds Under Climate Change

The Climate Change Threshold Analysis Approach differs from a traditional climate change impact analysis, in which temperature and precipitation information sampled directly from downscaled GCM results are input into hydrologic, hydraulic, and operations models. In the Climate Change Threshold Analysis Approach, metrics representing general circulation features associated with extreme precipitation processes are sampled and related to identified atmospheric metrics that are important to flood-producing precipitation. The atmospheric metrics are subsequently related to the hydrologic metrics. Based on these relationships, potential impact of climate change on a flood management project or strategy can be qualitatively assessed. As the science underlying the estimation of climate change processes affecting flood events advances in the future, a quantitative assessment could be possible. It should be noted that many of the relationships between atmospheric hydrologic and flood management strategy metrics are not currently well defined and will require significant further development. Relationships between atmospheric and hydrologic metrics will likely to be on a many-to-one basis, which may require selecting appropriate models to better determine the metrics connections via sensitivity analyses.

The results of the overall analysis will be influenced by the technical methodologies used to assess the likelihood of crossing critical thresholds. These technical decisions will include the methodology used to sample GCMs, downscaling methodology, consideration of sea level rise, and choice of modeling tools. A brief discussion of each follows.

Extreme Event Sampling Methodology

This overall approach is proposed because extreme precipitation processes rely at least in part on processes that occur at too fine a spatial or temporal scale to be properly represented in the GCMs. Extreme events are, by definition, temporally rare. Thus, even a highly detailed simulation or downscaled version of high-temporal resolution twenty-first century climate change will not generally be sufficient to evaluate changes in extreme event frequencies. A potential solution to this problem could be to obtain multiple realizations of each combination of emissions scenario and GCM. This would result in realizations of multiple extreme events in the period of interest.

Because of the difficulties in sampling extreme precipitation events from GCMs, it may be necessary to carry out a sensitivity analysis on the method used to sample extreme precipitation metrics from a future climate distribution to determine a method that provides useful information but is not affected by the sampling strategy. Examples of two sampling strategies used in other DWR planning efforts include the scenario subset methodology employed for the CAT analyses and the ensemble informed approach used in the Bay-Delta Conservation Plan.

In the scenario subset approach, a selection of GCMs is sampled from the population of GCM runs. The selection criteria can include variables available to sample from the GCM run or runs with a metric matching a specified criterion. In the ensemble-informed approach, a small tractable set of realizations of future projection information is generated by segmenting the future projection distribution and creating ensemble projection information associated with each segment. While it is possible to sample the entire set of GCM runs, this is feasible only if the desired information to inform the atmospheric metrics of interest were available in all GCMs.[2]

Downscaling Methodology

Resolution of current climate models is too coarse to capture key features of California climate such as the orographic effects of the Sierra Nevada and microclimate over the San Francisco Bay Area. To make use of information from the climate projection simulations and generate atmospheric metrics that are useful at the Central Valley and sub-Central Valley resolutions, it is necessary to downscale GCM results to spatial and temporal scales useful for the planning process. In general, there are two basic approaches to downscaling: statistical and dynamical.

- **Statistical downscaling –** Statistical downscaling uses statistical relationships between coarse resolution and detailed resolution of climate variables. Statistical methods therefore are often much faster at generating downscaled data than dynamical methods. However, statistical downscaling methods assume stationarity, relying on relationships that are developed based on historical data. It is not certain if these relationships are always preserved with a changing climate. It should be noted that for the CAT reporting process of 2006

[2] See Khan and Schwarz (2010) for a more detailed description of these methods.

and 2009, as well as the BDCP process described above, statistical downscaling methods were used, as described by Wood et al. (2004).

Several statistical downscaling methods are available, each with different emphasis. One statistical downscaling method is the Constructed Analogues (CA) approach. The method constructs an analogue for a given coarse-scale daily weather pattern by combining the weather patterns for several days from a library of previously observed patterns (Hidalgo et al., 2008). Another technique is Bias Correction and Spatial Disaggregation (BCSD). BCSD adjusts GCM output so that it statistically matches observed data during common historical overlap periods (Wood et al., 2002). CA downscales daily large-scale data directly while BCSD downscales monthly data, with a random resampling technique to generate daily values (Maurer and Hidalgo, 2008). A third statistical downscaling approach, Bias Corrected Constructed Analogues (BCCA), combines the initial large-scale bias correction step of BCSD before applying the CA method (Maurer et al., 2010). Comparisons of various downscaling methods can be found in Murphy (1999), Hay and Clark (2003), Hanssen-Bauer et al. (2003), Wood et al., (2004), Maurer and Hidalgo (2008), and Maurer et al. (2010).

- **Dynamical downscaling –** Dynamical downscaling makes use of numerical models of the atmosphere and land system at a higher resolution and uses global climate simulations as initial and boundary conditions. Because they operate at more detailed spatial resolution, the areal extent of the model simulations must be smaller to maintain a reasonable computation time for the climate projection simulations. In addition to these simulations, some post-processing of results is often necessary to remove systematic bias from the regional climate model outputs. Dynamical models are able to put aside many of the assumptions of stationarity that are implicit in the statistical methods. However, dynamical models are currently constrained by a high computational burden, which limits their use to shorter downscaled periods. These short segments of dynamically downscaled climates and responses would have limited use for determining changes in frequencies and magnitudes of extreme events.

Downscaling will be an important element for providing inputs to atmospheric metrics. Further evaluation will be required to determine whether existing downscaled data sets offer sufficient information to provide atmospheric metric information, or if more research effort in this area is needed. However, based on the characteristics of these two general types of downscaling methodology, dynamically downscaling could be more suitable for the Threshold Analysis Approach in the long term because the pace of computer technology may alleviate the computational burden.

Sea level Rise Considerations

Sea level rise could affect flood management because of changes in downstream hydraulic conditions for riverine flooding conditions within tidal influence areas (e.g., the lower Sacrament River and lower San Joaquin River), increased range or magnitude of water-level fluctuation in estuary flooding conditions (e.g., Delta), or a combination of the above.

Although it is generally accepted that sea levels will continue to rise on a global scale, the exact rate of rise remains unknown. Projections have been developed by the OPC, and a study by the National Research Council (NRC) is in progress.

- **OPC Sea level Rise Guidelines –** Led by OPC, the Sea level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) developed sea level rise recommendations for California (OPC, 2010). The State has adopted the OPC recommendations as interim guidelines until the NRC study, described below, is completed. The guidelines, which use 2000 as a baseline, are outlined in Table 2-1.

Table 2-1. Ocean Protection Council Sea level Rise Guidelines

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

Source: OPC, 2010
Key:
cm = centimeter

- **National Research Council Sea level Rise Review –** The State of California, along with several federal agencies and the states of Oregon and Washington, has commissioned the NRC to conduct a scientific review of sea level rise for the West Coast. The NRC study will estimate values or ranges of values for sea level rise for planning purposes for 2030, 2050, and 2100. The CO-CAT Sea level Rise Task

Force, a working group comprising senior-level staff from California State agencies with ocean and coastal resource management responsibilities, will provide feedback to the NRC so that the guidelines NRC develops will reflect the range of planning needs in California. The sea level rise estimates are anticipated to be completed in 2012, and will be included in climate change analysis for the 2017 CVFPP and other water management planning studies.

Hydrologic and Operations Modeling Tools

A number of hydrologic and system operations modeling tools are available and under development by different agencies, entities, and institutes for planning, forecasting, and real-time flood management operation purposes. The merits of each model are not the subject of detailed discussions here; the emphasis is on their corresponding capacities to support intended decision making.

DWR has an existing methodology and a set of tools for assessing hydrologic conditions in a forecasting and project planning capacity. Current model capabilities include the National Weather Service River Forecasting System (NWS-RFS), the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center – Hydraulic Modeling System (HEC-HMS) and Corps Water Management System (CWMS), the U.S. Geological Survey (USGS) watershed model Precipitation-Runoff Modeling System (PRMS), and the Variable Infiltration Capacity (VIC) model. Before any one tool is selected for use in a Climate Change Threshold Analysis, it will be beneficial to compare the advantages and disadvantages of each model, and conduct a parameter sensitivity analysis for the hydrologic model based on inputs from GCMs. DWR is currently making significant investments to improve modeling tools by enhancing technical modeling integrity and data resolution and availability, to accommodate a greater range of decision support needs, including climate change impacts assessments.

2.3 Potential Applications

The Climate Change Threshold Analysis Approach is proposed for flood management in assessing climate change effects because of the inherent conflicts between traditional risk-based assessment and flood management needs; the occurrence probability of extreme events under climate change conditions is not supported by current scenario approaches, as discussed at length in Section 2.1.

The above conceptual design of the Climate Change Threshold Analysis Approach also suggests significant challenges and likely research required to better define causal relationships between atmospheric metrics, hydrologic metrics, and potential exceedence of the critical threshold of certain flood management system component(s), or community metrics. The inherent multiple-to-one relationships among these various layers of parameters are barriers to full implementation of the proposed bottom-up approach, although the approach could be foundational for identifying a systemwide investment strategy that would achieve broad public support.

The current 2012 CVFPP will be based on available information and modeling tools, with critical updates and enhancement. It is anticipated that the 2017 CVFPP update would benefit from the current investment of modeling tools, data development, and systemwide planning. Similarly, the 2017 CVFPP will benefit from the development of the Climate Change Threshold Analysis Approach. While available information and modeling tools do not support a complete application of the this approach for the 2012 CVFPP, to demonstrate the concept, a pilot study has been conducted and documented in the following chapter of this report.

The concepts of the Threshold Approach Analysis and the emphasis on the bottom-up vulnerability analysis are also applicable for other water management planning purposes. These concepts emphasize local and regional innovations and resources management to formulate the best approach and actions to resolve identified community vulnerabilities, particularly in long-term water management planning (Brekke et al., 2009).

3.0 Pilot Study

The pilot study provides a proof of concept that demonstrates the merits of the Climate Change Threshold Analysis Approach for the CVFPP decision-making process. Results of this study will give direction to scientists on key areas requiring further research and, more importantly, provide critical references for policy makers in formulating a State flood system investment strategy. However, because it is a demonstration, the pilot study is not likely to be sufficient for providing recommendations on future investment because the models, data, and techniques are preliminary results from many ongoing studies.

3.1 Pilot Study Scope

The pilot study focuses on critical reservoir operational thresholds at Oroville Dam on the Feather River. Oroville Dam and Lake Oroville lie in the foothills on the western slope of the Sierra Nevada, 1 mile downstream from the junction of the Feather River's major tributaries. DWR owns and operates the dam to store winter and spring runoff, which is released into the Feather River to meet downstream environmental needs and SWP water supply. Lake Oroville also provides pumped-storage capacity, 750,000 acre-feet of flood management storage, recreational opportunities, and freshwater releases to control salinity intrusion in the Delta and to protect fish and wildlife.

Oroville Dam is the only major flood control reservoir in the Central Valley that is included in the SPFC (DWR, 2010). It has a significant flood management function and its operation coordinates with the operation of New Bullards Bar Reservoir on the North Yuba River. Therefore, if Oroville Dam loses its capacity to regulate flows (i.e., is required to release water from its emergency spillway), there would be considerable potential for widespread effects throughout the State-federal flood management system. The initial intent of the pilot study was to investigate the possibility of Oroville Dam being forced to use its emergency spillway if the system were overwhelmed by increased inflow under climate change. However, it is important to recognize that the spillway of Oroville Dam has never been used since Oroville Dam was constructed in 1967. The analysis therefore also investigated exceedence of objective releases from Oroville Dam, New Bullards Bar Dam, and two control points downstream.

3.2 Pilot Study Methodology

The pilot study has two parts: (1) a vulnerability assessment at Oroville Dam using hydrology from the *Sacramento and San Joaquin River Basins Comprehensive Study* (Comprehensive Study) (USACE, 2002) and HEC-ResSIM reservoir operations model, and (2) an assessment of climate change impacts on precipitation and runoff processes associated with temperature increases.

3.2.1 Vulnerability Assessment

Hydrology from the Comprehensive Study (USACE, 2002) and a HEC-ResSIM reservoir operations model were used to assess the vulnerability of Oroville Dam to changes in the volume of inflow. As previously mentioned, the volume of a flood hydrograph is a hydrologic metric that can be used for the Climate Change Threshold Analysis Approach. Because current flood management protocols cause Oroville Dam and Yuba County Water Agency's New Bullards Bar Dam to operate for a common compliance point (USACE, 1970), the vulnerability assessment was completed for the Oroville-New Bullards Bar complex as a whole.

HEC-ResSIM 3.0 Reservoir Operations Model

A HEC-ResSIM 3.0 reservoir operations model was developed by USACE as part of the DWR Forecast Coordinated Operations Program for the Feather and Yuba rivers (YCWA, 2005). DWR is developing a new set of Central Valley flood hydrology in collaboration with USACE, with results anticipated in 2012. As part of this effort, additional updates were made to the HEC-ResSIM model. USACE provided a working version of this model for use in the pilot study (USACE, 2011).

The model uses inflows as an upstream boundary condition for reservoir operations and downstream routing. HEC-ResSIM routes flow through reservoirs based on specified operational criteria. Operational criteria in the HEC-ResSIM baseline models strictly observe guidelines established within the reservoir's water control manual (USACE, 1970) and focus on flood damage reduction operations and winter operations for water supply and hydropower. Under normal conditions, when reservoir storage encroaches into the flood pool (i.e., storage exceeds the top of conservation pool), reservoir outflow increases up to the objective release to evacuate water from the flood pool. The objective release is based on downstream channel capacity and reservoir outlet capacity. If inflow into the reservoir is greater than outflow, the volume of water in the reservoir continues to increase and emergency spillway releases (which are greater than objective releases) begin when storage reaches the gross pool.

Objective flows and storage volumes for Oroville Dam and Lake Oroville and New Bullards Bar Dam and Reservoir are presented in Table 3-1 (USACE, 2002).

Table 3-1. Objective Flows and Storage Volumes for Feather and Yuba River Reservoirs

Reservoir	River	Objective Flow	Gross Pool Storage (TAF)	Maximum Flood Space (TAF)
Oroville Dam and Lake Oroville	Feather River	Below dam – 150,000 cfs Gridley – 150,000 cfs Yuba City – 180,000 cfs Feather – Yuba River Junction – 300,000 cfs Nicolaus – 320,000 cfs	3,538	750
New Bullards Bar Dam and Reservoir	Yuba River	Below dam – 50,000 cfs Marysville at Yuba River – 180,000 cfs	970	170

Source: USACE, 2002
Key:
cfs = cubic feet per second
TAF = thousand acre-feet

Inflow Hydrology

As previously mentioned, DWR is developing a new set of Central Valley flood hydrology, in collaboration with USACE. The results are anticipated in 2012 and were not available for the pilot study.

For demonstration purposes and consistency with 2012 CVFPP development, the pilot study uses hydrology from the Comprehensive Study (Appendix A) as inflows for the HEC-ResSIM model. The Comprehensive Study hydrology was formulated in the context of the "Composite Floodplain" concept that a frequency-based floodplain is not created by a single flood event, but by a combination of several events, each of which shapes a floodplain at different locations. To construct a Composite Floodplain, a series of storm centerings, which is a set of storms with different return periods assigned to a set of tributaries, was developed to characterize flooding in different parts of the basin (Hickey et. al., 2003).

Synthetic hydrology was developed so that the Composite Floodplain would represent the maximum extent of inundation possible at all locations for any of seven simulated synthetic return period storm events (USACE, 2002). Synthetic storm runoff centerings were generated based on the analysis of 19 historical storms. The center of a storm is the location in the system with the highest intensity and is defined as a set of tributaries. Two basic types of storm runoff centerings were developed: mainstem (basin-wide storms that stress the system on a regional basis) and tributary (storms that generate extremely large floods on individual tributaries). Tributary centerings were prepared for 18 individual rivers (USACE, 2002).

The pilot study used the 1 percent annual exceedence probability (AEP) centering for the Feather River at Oroville. The 1 percent AEP event was chosen because downstream channel capacity is generally not exceeded for baseline conditions in the Feather River Basin for storms with a higher AEP. If channel flows are within channel capacity, it is assumed that the system can safely convey the water without flooding adjacent areas. Because flow is within channel capacity, operational changes would not affect the volume of flooding.

In the Comprehensive Study, the basic pattern of all synthetic flood hydrographs was a 30-day hourly time series consisting of six waves, each 5 days in duration. Volumes were ranked and distributed into the basic pattern. The highest wave volume was always distributed into the fourth wave, or the main wave. The second and third highest volumes preceded and followed the main wave, respectively. The fourth highest volume was distributed into the second wave and the fifth highest was distributed into the final of the six waves. The sixth and smallest wave volume was distributed into the first wave of the series. The shape of each wave is identical, and the magnitude is determined by the total volume that the wave must convey. The pilot study used a 7-day period centered on the largest volume (fourth) flood wave. The 7-day period was chosen over the complete 30-day synthetic hydrology to focus the analysis on a high-intensity storm, such as would be associated with an atmospheric river.

Inflow Changes

To simulate larger storm events resulting from climate change, changes were made to reservoir inflows in HEC-ResSIM. For illustrative purposes, the pilot study uses only the Comprehensive Study hydrology from the Oroville storm centering, and focuses on the main wave portion of the 30-day hydrology. The resulting 7-day hydrograph from the 1 percent AEP Feather River at Oroville centering was scaled upward from zero to 50 percent in increments of 10 percent. Scaling was performed such that a 10 percent increase in volume resulted in a 10 percent increase in peak volume. Fifty percent was chosen as a reasonable upper bound for potential inflow increases; fifty percent is well above the upper end of the range of expected increase in the intensity of atmospheric rivers (Dettinger, 2011).

Threshold Exceedence

The occurrence and magnitude of threshold exceedence was identified for each scaling factor. Threshold exceedence was identified at Oroville Dam, New Bullard's Bar Dam, at the confluence of the Feather and Yuba rivers in Marysville, and on the Feather River at Nicolaus.

Sensitivity Analysis on Initial Reservoir Storage

Threshold exceedence depends on not only the volume of inflows from a storm event, but also the initial storage level of a reservoir. Therefore, sensitivity of these results to various initial reservoir storage conditions was also required for better understanding the associated vulnerability. For the pilot study, initial reservoir storage was initially assumed to be at the top of the conservation pool, and was increased in increments of 10 percent, to simulate encroachment into the flood pool before the advent of the modeled storm.

Possible Other Factors Not Considered

Threshold exceedence considered in this pilot study would likely be influenced by additional atmospheric and hydrologic factors such as seasonality, time to peak flows, and initial watershed conditions, among others. However, for the demonstration purpose of the pilot study, only changes in volume and initial storage were considered.

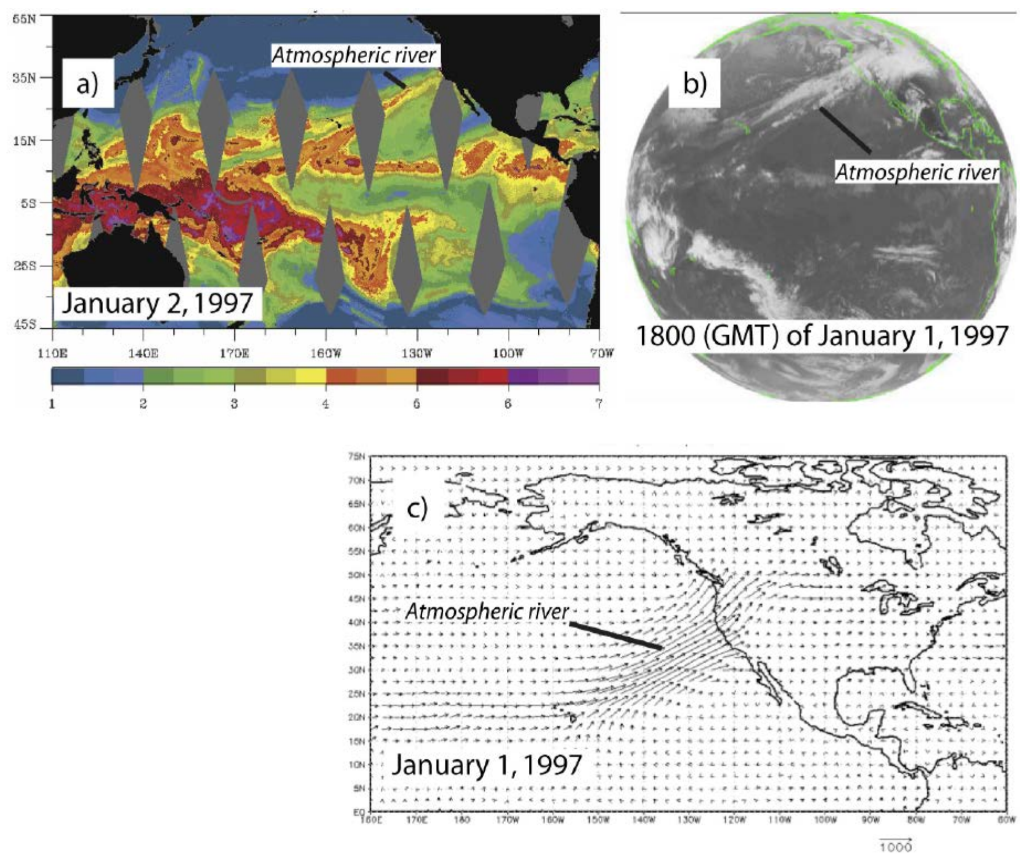
3.2.2 Assessment of Climate Change Impact on Hydrologic Processes

Future extreme precipitation events are difficult to project because climate projections from GCMs have difficulty providing regional and local scale precipitation patterns, and because of the substantial influence of both human settlement patterns and water-management choices on overall flood risk (DWR, 2005). As previously mentioned, the Atmospheric River Index could be an atmospheric metric used in the Threshold Analysis Approach; however, research on this topic is preliminary. For demonstrative purposes, a recently developed tool for identifying atmospheric river events in GCMs was used in the pilot study to estimate potential changes in extreme precipitation events.

Atmospheric River Analysis

Atmospheric rivers are narrow, intense bands of moist air associated with enhanced vapor transport (Dettinger et al., 2009). Atmospheric rivers are typically several thousand kilometers long and only a few hundred kilometers wide, and a single atmospheric river can carry a greater flux of water than the Earth's largest river, the Amazon River (Zhu et al., 1998). Atmospheric rivers can be referred to as tropical plumes, Hawaiian fire hoses, or Pineapple Expresses (Kerr, 2006).

Atmospheric rivers have been identified as the primary (and, in some settings, essentially only) cause of flooding of California rivers (Dettinger et al., 2011). One example is the widespread, devastating 1997 flood in the Central Valley. Figure 3-1 shows several visualizations of the atmospheric river event impacting California on January 2, 1997 (Dettinger et al., 2009).



Source: Dettinger et al., 2009

Figure 2-6. Visualizations of 1997 Atmospheric River Conditions

Integrated Water Vapor Flux Tool

The change in intensity of atmospheric rivers is used in the pilot study as a proxy for changes in extreme atmospheric conditions under climate change, and relates to resulting reservoir inflow changes. This analysis qualitatively assesses how future changes to atmospheric river characteristics could affect reservoir vulnerability. The pilot study demonstrates this approach using a recently formulated integrated water vapor flux tool to detect atmospheric river events.

This atmospheric river detection approach involves calculating daily vertically integrated water vapor (IWV) in the atmosphere and daily wind speeds and directions at the 925 millibar pressure level for a GCM grid cell just offshore from the Central California coast. An atmospheric river event is determined to be occurring when IWV is greater than 2.5 cm at the same time that the upslope component of wind is greater than 10 meters per second (i.e., IWV flux is 25 meters per second - centimeters or greater). The National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Testbed Program has identified this threshold in IWV flux as a threshold for extreme precipitation events that can lead to flooding (Neiman et al., 2009).

Orographic precipitation processes are not well represented in current GCMs; the primary avenue for inferring possible future changes in this mechanism for flood generation is analysis of atmospheric river conditions just offshore and just before their flood-generating encounters with mountain ranges after many thousands of kilometers of passage over uninterrupted ocean surfaces. This limitation of current GCMs is the motivation for the focus of the present analysis on atmospheric rivers just offshore (Dettinger, 2011).

In the pilot study, IWV flux was determined, based on information from GCMs, for each day in four 20-year epochs: 1961 through 1980, 1981 through, 2046 through 2065, and 2081 through 2100. These simulation periods were chosen because daily water vapor, winds, and temperatures were available from only a few IPCC GCMs. More GCMs will provide this detailed data in the next round of IPCC simulations.

Consistent with the demonstration purpose of the pilot study, the A2 scenario (IPCC, 2007) was used because it provides the strongest greenhouse forcing on climate, and the clearest indications of directions of change in natural variability, among the scenarios for which climate projections were commonly available. A more detailed description of the IWV flux methodology for the atmospheric river analysis can be found in Neiman et al. (2009) and Dettinger (2011).

3.3 Pilot Study Results

This section presents the results of the two major components of the pilot study: the vulnerability assessment and likelihood assessment.

3.3.1 Vulnerability Assessment

Scenarios of 1 percent AEP reservoir inflows, increased in 10 percent increments up to 50 percent, were modeled for the Feather-Yuba flood management system.

Key assumptions in this demonstration analysis include the following:

- The initial storage in Lake Oroville is at the top of the conservation pool for January (2.788 million acre-feet)
- The initial storage in New Bullards Bar Reservoir is at the top of the conservation pool for January (790,000 acre-feet)
- The assumed storm is of 1 percent AEP
- Existing flood operation rules for both reservoirs

Figure 3-1 presents the results of each of these six scenarios for Lake Oroville, New Bullards Bar Reservoir, and three downstream control points: the Yuba River at Marysville, the confluence of the Feather and Yuba rivers, and the Feather River at Nicolaus. The threshold is identified for each location based on the objective flow.

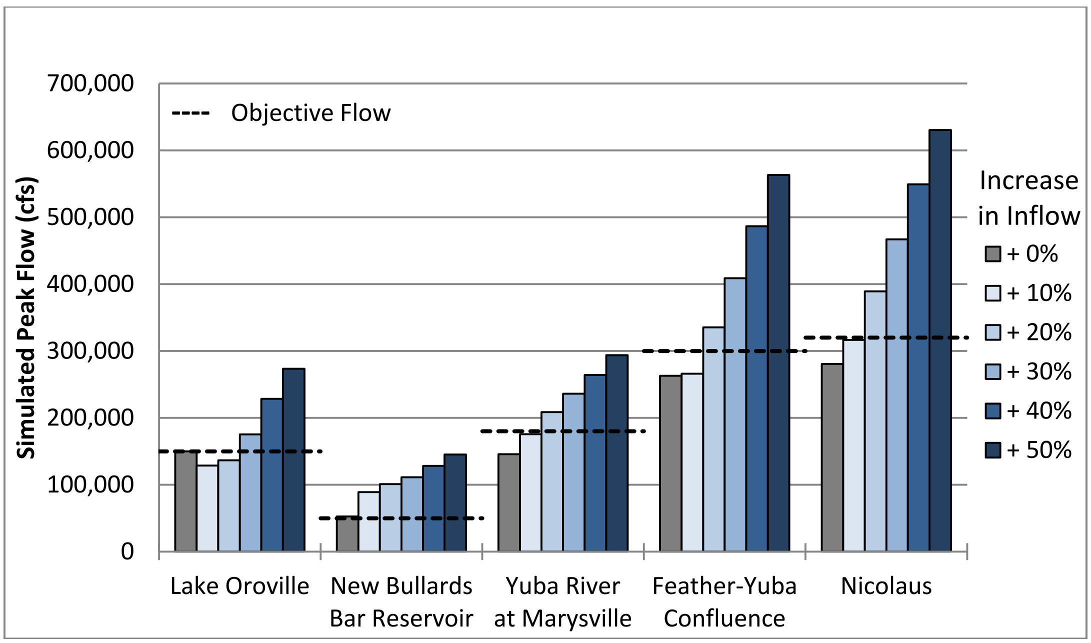


Figure 3-2. Simulated Peak Flow by Inflow Scenario

With initial storage assumed to be at the top of the January conservation pool in Lake Oroville and New Bullards Bar Reservoir before the 1 percent AEP storm, increasing the peak inflow volume by 30 percent or greater led to exceedence of the objective release during peak outflows. Interestingly, inflow increases of 10 and 20 percent resulted in reduced outflows relative to the baseline. This outflow reduction is a result of Lake Oroville's joint operation with New Bullards Bar Reservoir. New Bullards Bar Reservoir exceeded its objective release at any increase in inflows. As New Bullards

Bar Reservoir was forced to release greater flows, Lake Oroville released less to meet objective flows at the downstream control points. However, when inflows were increased by 30 percent, the objective release at Lake Oroville was exceeded. Objective releases were exceeded at all three downstream control points when inflows were increased 20 percent or greater.

These results are translated into identification of threshold exceedence and summarized in Table 3-2. Detailed figures showing simulated hydrographs, reservoir storage, and thresholds are presented in Appendix A.

Table 3-2. Potential Threshold Exceedence by Increase in Inflow

Control Point	Potential Threshold Exceedence by Increase in Inflow					
	0%	10%	20%	30%	40%	50%
Lake Oroville	No	No	No	Yes	Yes	Yes
New Bullards Bar Reservoir	No	Yes	Yes	Yes	Yes	Yes
Yuba River at Marysville	No	No	Yes	Yes	Yes	Yes
Feather-Yuba Confluence	No	No	Yes	Yes	Yes	Yes
Nicolaus	No	No	Yes	Yes	Yes	Yes

Key:
Green = threshold not exceeded
Red = threshold exceeded

This assessment identifies New Bullards Bar Reservoir as a critical point of vulnerability within this portion of the flood management system. Lake Oroville is likely of less concern under lower levels of inflow increases.

3.3.2 Likelihood Assessment

The vulnerability assessment identified components of the flood system that would be vulnerable to hydrologic changes. However, for this analysis to be useful for planning future flood management system investments, an assessment of the likelihood of these changes occurring is required. As mentioned, this likelihood assessment was conducted for the pilot study using potential changes to atmospheric rivers as an indicator of changing atmospheric conditions.

Figure 3-3 shows results of the atmospheric river analysis, using IWV flux as a proxy for atmospheric river intensity. For the 1 percent AEP event, relative to a baseline from 1961 through 2000, simulation results from the seven GCMs indicate a range of average atmospheric river intensities from 94 percent to 125 percent from 2046 through 2065, and from approximately 91 through 132 percent from 2081 through 2100. The simulated change in atmospheric river intensity was similar for each of the simulated events.

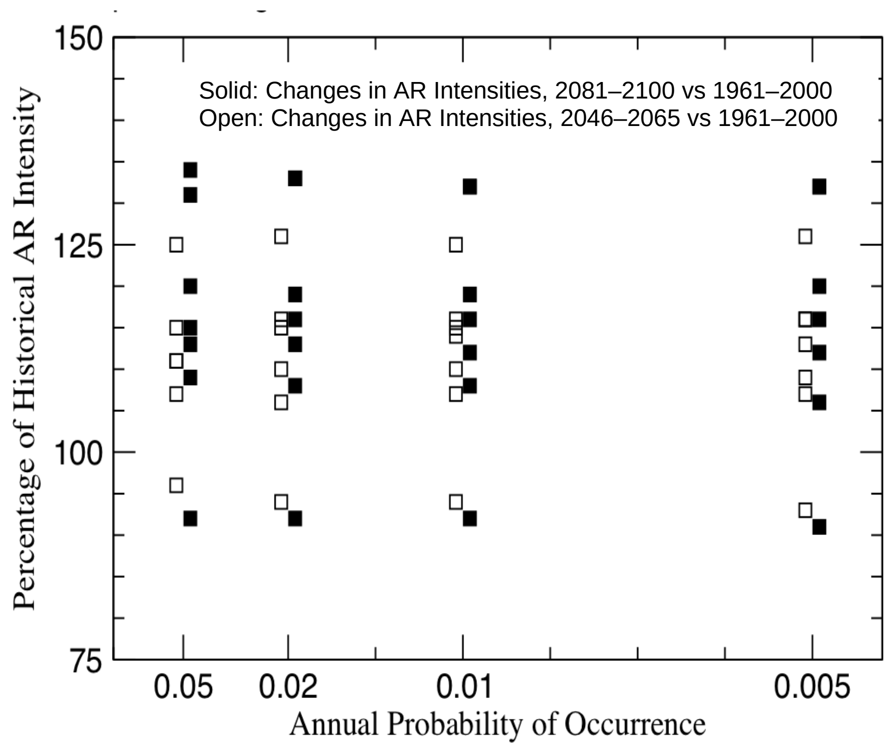


Figure 3-3. Changes in Estimates of Atmospheric River Intensities Based Climate Change Simulations by Seven Global Climate Models Using the A2 Emissions Scenario

These results, while subject to the substantial uncertainties identified in the methodology section, confirm that inflow changes modeled in the reservoir threshold analyses are within a reasonable range. The higher inflows are likely to be conservative.

3.4 Findings

The Climate Change Threshold Analysis Approach was designed to result in three possible outcomes: (1) threshold exceedence is a potential concern, (2) it is not a concern, or (3) further research is required.

The results of the pilot study indicate that at Lake Oroville, threshold exceedence would occur with an approximate 20 to 30 percent increase in inflows from the 1 percent AEP event. The results of the likelihood analysis, using atmospheric river changes to represent climate change, confirm that this increase is within a reasonable range, although it is on the upper end of the range. Therefore, threshold exceedence at Lake Oroville could indeed be a concern under reasonable simulations of future conditions.

However, the analysis also shows that New Bullards Bar Reservoir would be much more sensitive to inflow changes than Lake Oroville; critical thresholds would be crossed at much lower inflow increases, primarily because of physical constraints on releases from New Bullards Bar Dam. This implies that when pursuing long-term changes to improve flood management for the Yuba-Feather river system, it would be more reasonable to explore investing in flood management actions at New Bullards Bar Dam than at Oroville Dam.

The pilot study analysis also identified critical data gaps and areas of future research. In particular, the analysis was limited by the lack of a relationship between atmospheric river intensity and precipitation rates, which would make the critical connection that would be necessary for any quantitative threshold analysis. Atmospheric river events were used in the pilot study as a reasonable proxy, but do not fully represent the potential range of changes to extreme precipitation processes under climate change. The pilot study did not use an atmospheric-watershed model to connect atmospheric river changes to the reservoir operations model because these tools are still in development. It was assumed for the purposes of the pilot study that simulated changes in atmospheric river events and temperature translated to changes in inflow at Lake Oroville. Additional uncertainties that are not accounted for in this analysis include uncertainties in watershed controls on precipitation processes, the effect of changing freezing elevations, and rain-on-snow events. As a result of these substantial uncertainties in the analysis, this pilot study was conducted at a qualitative level. The results of this study are helping guide development of improved modeling tools (discussed in Section 2.2.4), which should enable a more quantitative analysis for the 2017 CVFPP.

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5.0 Acronyms and Abbreviations

°C .... degrees Celsius
°F .... Degrees Fahrenheit
AEP .... annual exceedence probability
AR .... Atmospheric River
BCCA .... Bias Corrected Constructed Analogue
BCSD .... Bias Correction and Spatial Disaggregation
Board .... Central Valley Flood Protection Board
CA .... Constructed Analogue
CAT .... Climate Action Team
CCSDWG .... Climate Change Scope Definition Work Group
CCTAWG .... Climate Change Threshold Analysis Workgroup
CEC .... California Energy Commission
cfs .... cubic feet per second
cm .... centimeter
CO-CAT .... Coastal and Ocean Climate Action Team
Comprehensive Study Sacramento and San Joaquin River Basins Comprehensive Study
CVFPP .... Central Valley Flood Protection Plan
CVP .... Central Valley Project
CWMS .... Corps Water Management System
Delta .... Sacramento-San Joaquin River Delta
DWR .... California Department of Water Resources
GCM .... Global Climate Model
HEC-HMS .... Hydrologic Engineering Center – Hydraulic Modeling System
IPCC .... International Panel of Climate Change
IWV .... integrated water vapor
M&I .... municipal and industrial
mm/yr .... millimeter per year
NOAA .... National Oceanic and Atmospheric Administration
NRC .... National Research Council

NWS-RFS..................National Weather Service River Forecasting System
O&M ....operations and maintenance
OPC...........................Ocean Protection Council
PRMS ....Precipitation-Runoff Modeling System
SPFC ....State Plan of Flood Control
State ....State of California
SWP ....State Water Project
USACE ......................U.S. Army Corps of Engineers
USGS ........................U.S. Geological Survey
VIC............................Variable Infiltration Capacity

CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE
CALIFORNIA

Public Draft

2012 Central Valley Flood Protection Plan

Attachment 8K: Climate Change Analysis – Appendix A. Pilot Study Figures

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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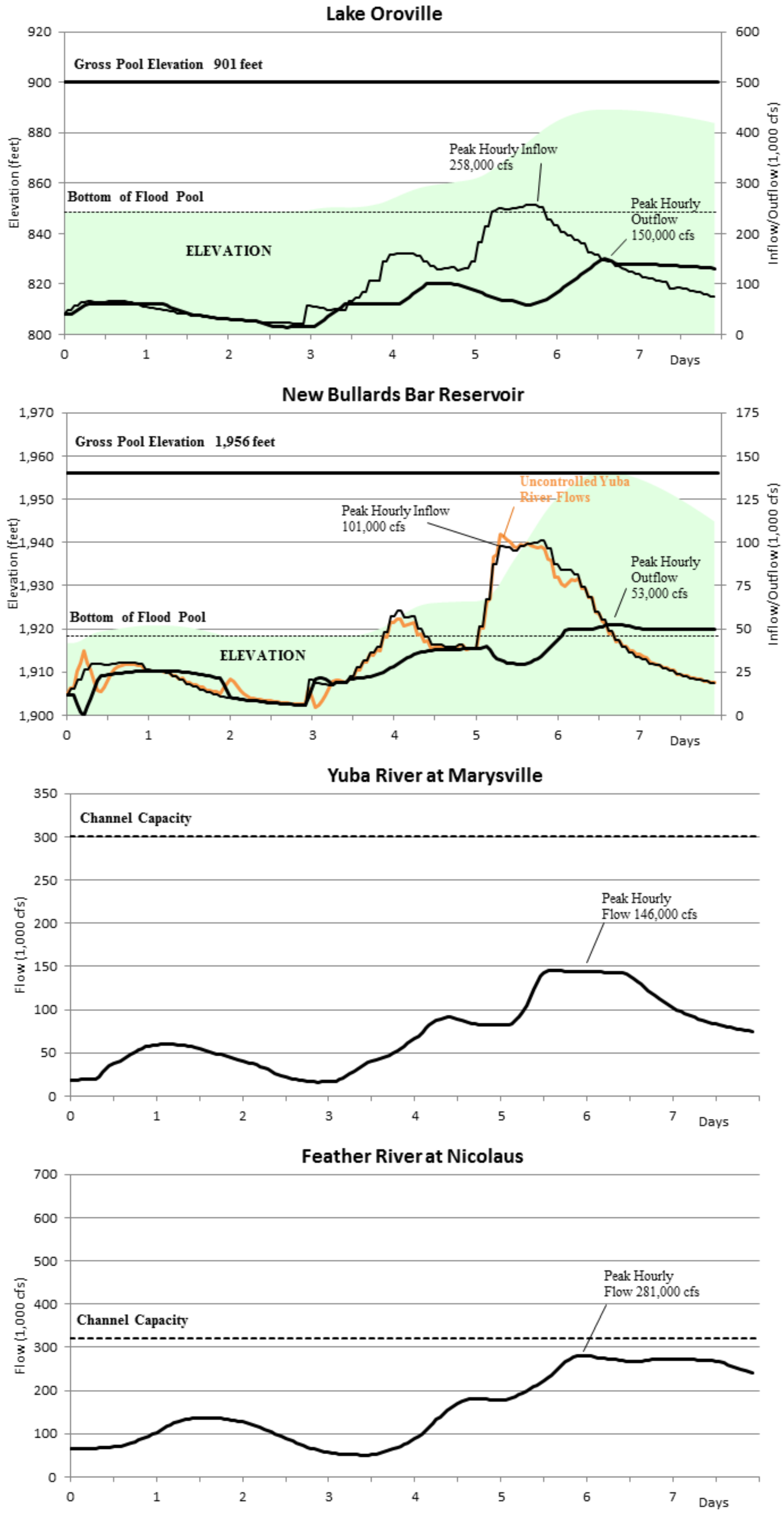

Figure A-1. Zero Percent Increase in Inflows

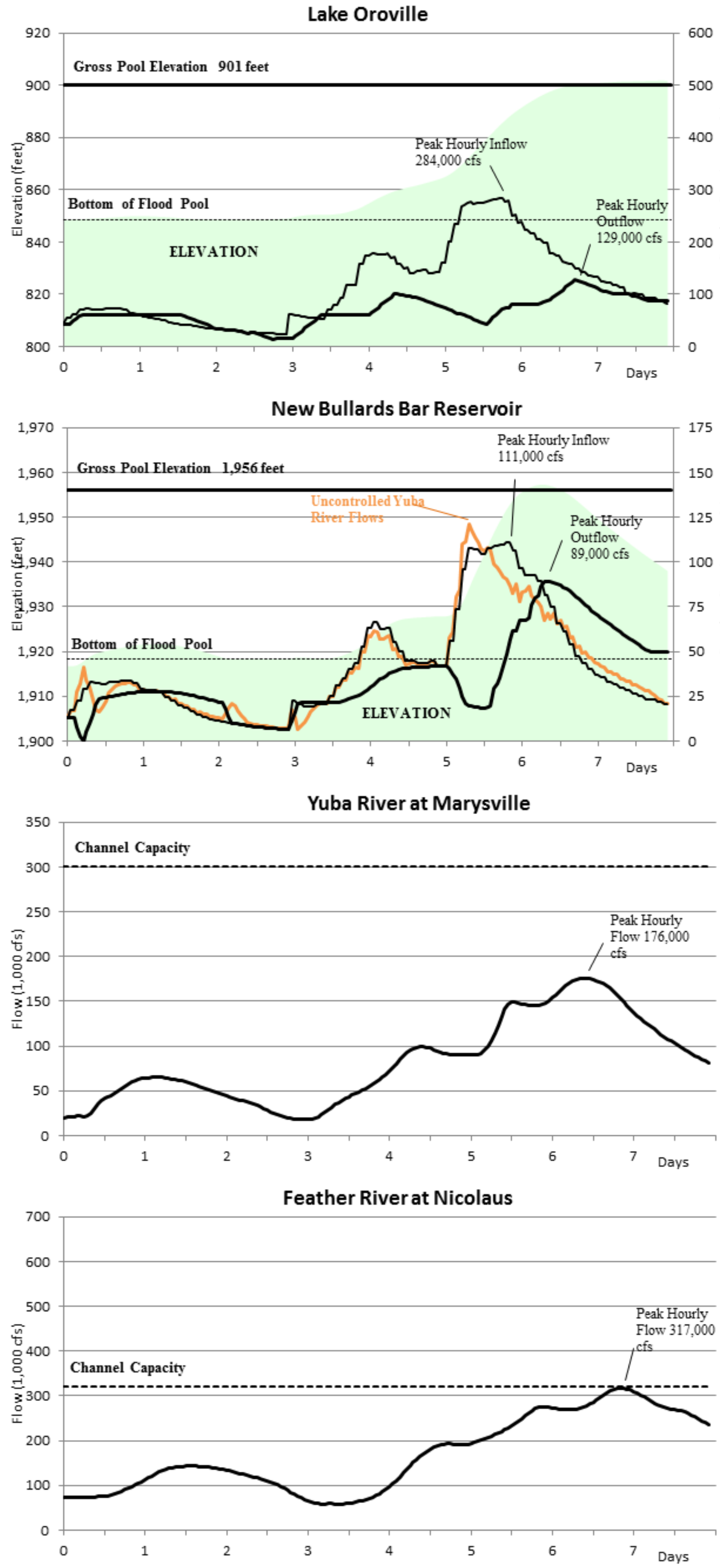

Figure A-2. Ten Percent Increase in Inflows

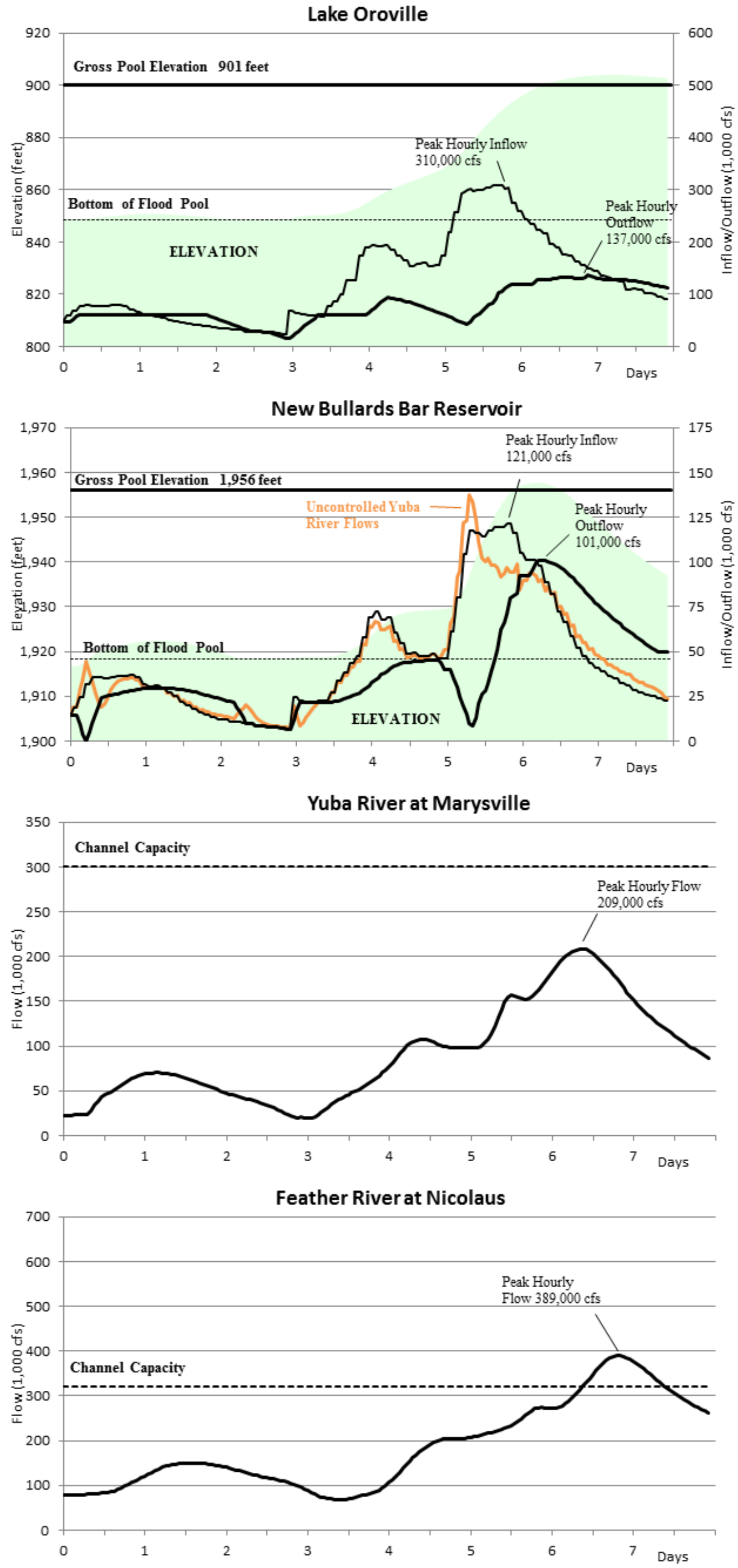

Figure A-3. Twenty Percent Increase in Inflows

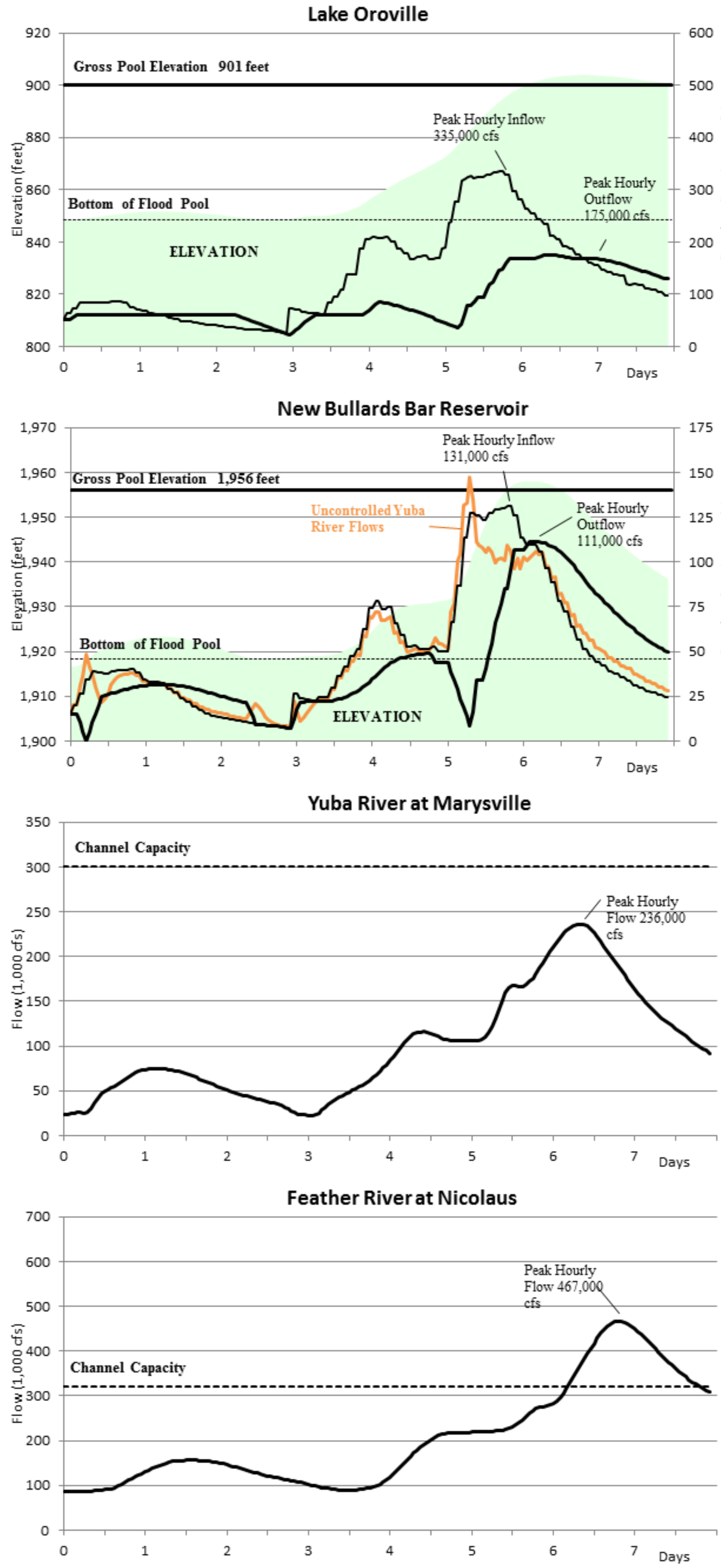

Figure A-4. Thirty Percent Increase in Inflows

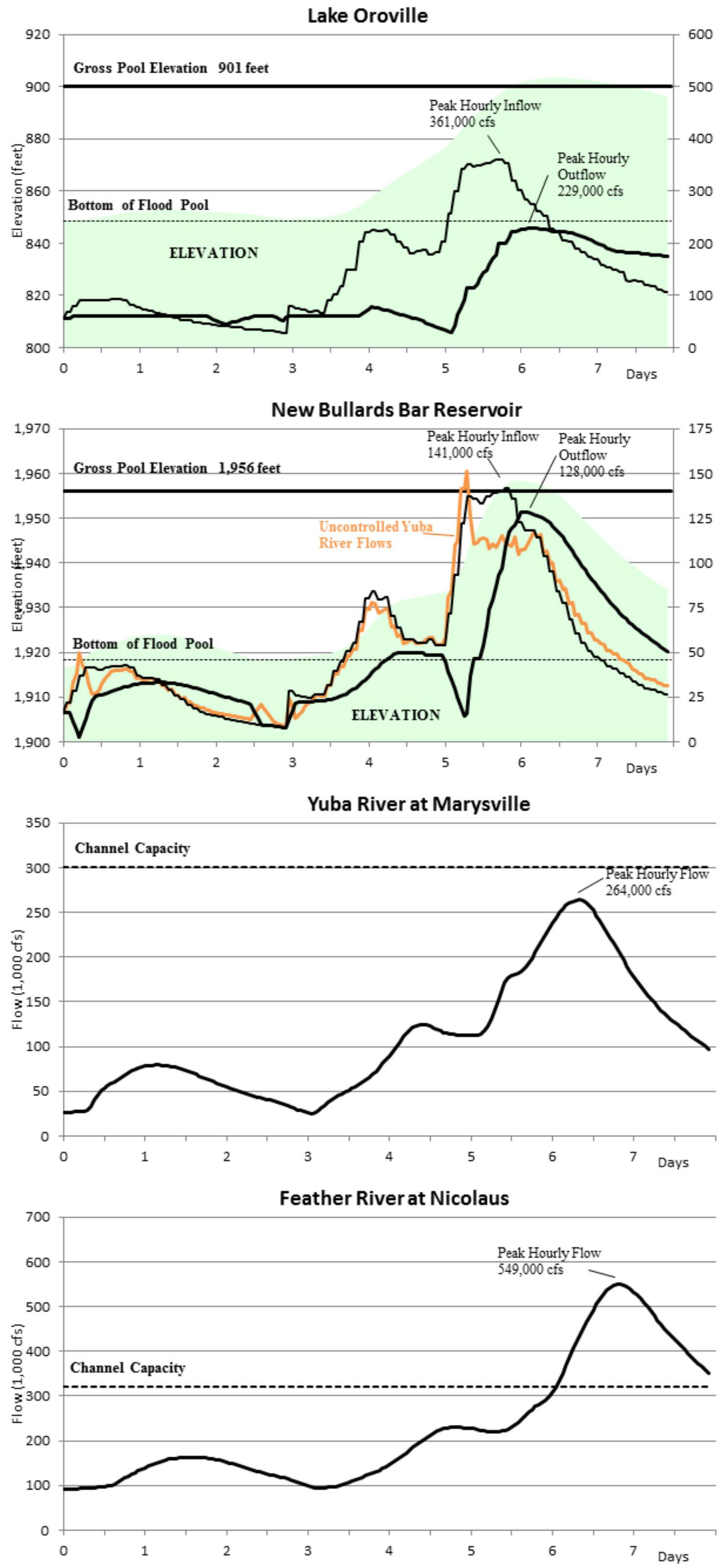

Figure A-5. Forty Percent Increase in Inflows

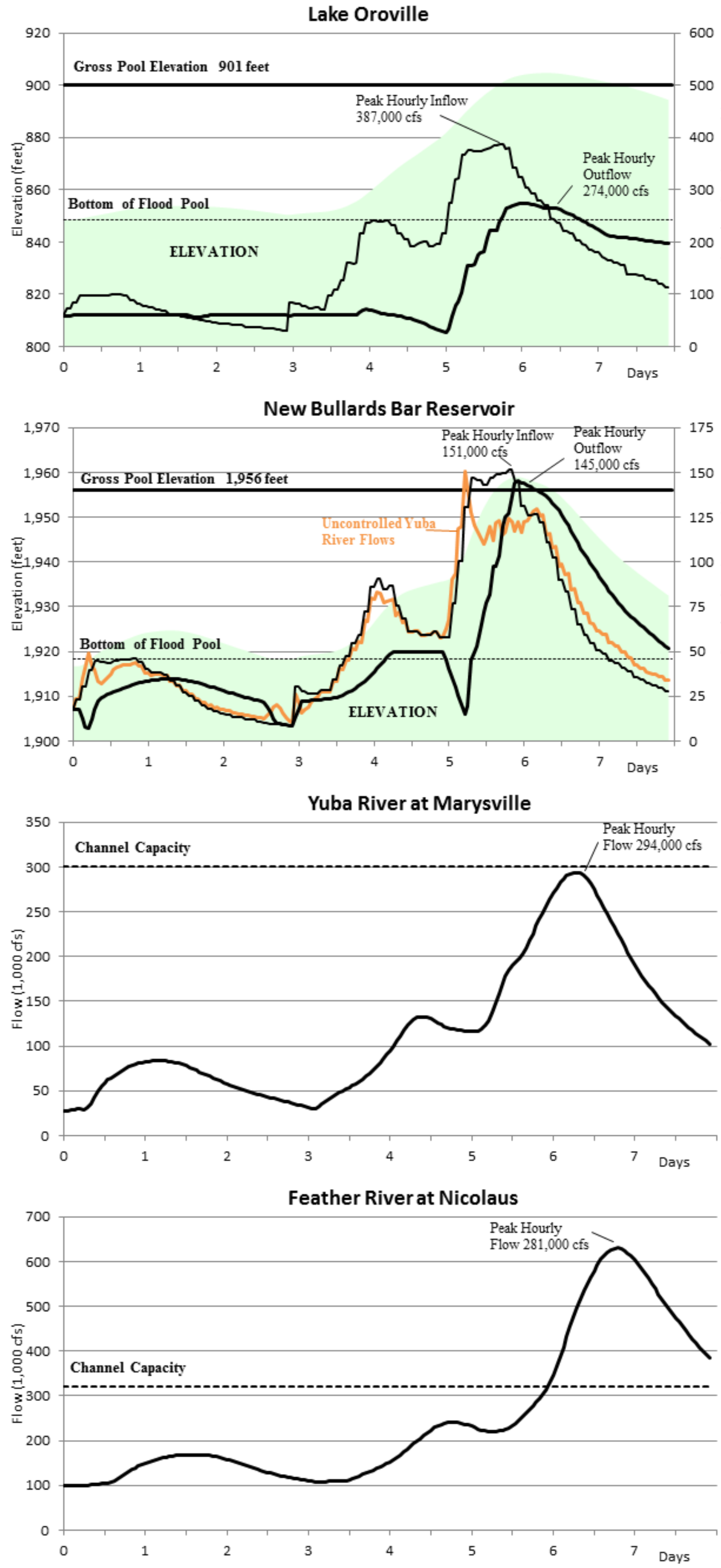

Figure A-6. Fifty Percent Increase in Inflows

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