# The Oroville Dam 2017 Spillway Incident

## And Lessons from the Feather River Basin

September 2017

Friends of the River since 1973

California Sportfishing Protection Alliance · Since 1983 · CSPA

South Yuba River Citizens League SYRCL

American Whitewater AW

# Authors


Ron Stork, Friends of the River

Chris Shutes, California Sportfishing Protection Alliance

Gary Reedy, Contracted Project Manager

Katrina Schneider, River Science Consultant

Dave Steindorf, American Whitewater

Eric Wesselman, Friends of the River


**Oroville Dam Spillway, Feb. 27, 2017.** The Oroville dam main spillway after spill flow releases ceased for repair inspections. Oroville Dam is in the shadow on the upper right. *Source: Dale Kolke, CA Dept. of Water Resources (hereby DWR).*

# Acknowledgements


This project was funded through the California Hydropower Reform Coalition, and benefited from the volunteer editing by Jeanne Scarmon, and formatting by Kathy Dotson. We thank California Resources Agency staff for providing information on Oroville Dam. We appreciate the many citizens who have shown resilience to the Oroville incident of 2017 and who stepped up to contribute their concerns and knowledge to a positive aftermath.


**Cover photo image:** Aerial View of Oroville Reservoir and Spillways– emergency spillway on the right, and main spillway on the left – Feb. 27, 2017. Photo taken earlier in the day while flow released down main spillway. Note workers and new material placed in eroded emergency spillway zone. *Source: Dale Kolke, DWR.*

# Oroville Dam gained worldwide attention in February 2017

## Executive Summary

when crumbling spillways at the nation's tallest dam triggered one of the largest evacuations in California history. The near catastrophe remains a socioeconomic blow to downstream communities.

While some repair work is moving forward at Oroville, significant issues remain to be addressed. This incident is a wake-up call for action on several fronts at this facility and thousands of other high-hazard dams in the United States to ensure a safe and reliable water system that protects communities and the rivers that flow through them. A warming climate with changing precipitation patterns underscores the urgency.

*The Oroville Dam 2017 Spillway Incident: Lessons from the Feather River Basin* calls for action on 18 recommendations, and dozens of sub-recommendations, to address California's aging dam infrastructure, operate dams more safely and efficiently, advance multi-benefit flood management projects, and increase transparency and public engagement.

A chief recommendation is the need for a complete emergency spillway at Oroville Dam. At this time, there is no evidence that the Department of Water Resources plans to address this fundamental problem. The report also identifies several other dams in California that require investment in maintenance, repair, or reconstruction.

Improving dam operations is also critical to avoiding another incident like Oroville. This requires better flood modeling and scheduled updates of flood-control manuals with opportunities for robust public involvement. The Federal Energy Regulatory Commission (FERC) should also address dam safety issues as a part of relicensing hydropower projects. In the San Joaquin Basin, studies need to explore opportunities to increase maximum controlled flood flows from facilities like Don Pedro Dam on the Tuolumne River.

The report has several recommendations to reduce downstream risk in the event of flooding or infrastructure failure, through multi-benefit flood management projects. Funding the Central Valley Flood Protection Plan is critical to implementing several of these projects, such as the expansion of the Yolo Basin Bypass and the weirs that allow Feather River/Sutter Bypass and American River flood flows into the Yolo Bypass. Expanding the floodplain in the Oroville Wildlife Area and implementing the Lower Feather River Corridor Management Plan are also priorities in the Sacramento Basin. In the San Joaquin Basin, reservoir-based floodwater management is far less reliable than in the Sacramento Basin. This problem will only get worse as precipitation patterns shift with climate change. Key projects there include setback levees and a small San Joaquin River floodwater bypass in the lower Delta.

Finally, the report calls for a shift in the relationship between out-of-area water project developers and members of the local communities that house those projects. This relationship should be based on equality, fairness, respect, and transparency. In the case of Oroville, and similar projects, this requires public release of forensic investigations, new inundation maps, and Emergency Action Plans, combined with comprehensive assessments of impacts and mitigation actions for communities like Oroville.

The main lessons from the Oroville Incident and a summary of recommendations are provided in the following table.

| Lesson | Recommendations Summary |
| --- | --- |
| California's dam infrastructure is aging and needs to meet modern standards | • Complete planned reconstruction of the Oroville main spillway and relocation of powerline transmission towers and lines.<br>• Plan a real auxiliary/emergency spillway that does not risk large quantities of hillside soil and rock being eroded into the Feather River.<br>• Conduct a thorough review of the Oroville Dam complex's physical deficiencies and undertake appropriate upgrades.<br>• Systematically inspect dams across California and the U.S. to meet upgraded design and maintenance standards and procedures. |
| Dam operations need periodic reviews | • Update flood-control manuals for the Feather and Yuba River Basins.<br>• Re-evaluate the duration and character of floods modeled to exist in the future and make necessary modifications.<br>• Provide public involvement in the manual update process.<br>• Require the Army Corps to review and update flood manuals for all jurisdictional dams on a defined schedule.<br>• Require FERC to include dam safety in hydropower relicensing. |
| Floodplain capacity is limiting flood protection, environmental quality, and local economies | • Fund and implement the Central Valley Flood Protection Plan.<br>• Assemble diverse stakeholders to define and plan floodplain improvements.<br>• Evaluate and design multi-benefit floodplain projects (e.g., setback levees) that increase flood protection while creating more floodplain habitat.<br>• Develop and implement plans to create greater floodway capacity in the San Joaquin Basin. |
| People and communities matter | • Complete forensic investigations at Oroville and release to the public.<br>• Conduct comprehensive assessment of impacts to the Oroville and adjacent communities from 2017 spillway incidents.<br>• Establish new opportunities for mitigation and community development.<br>• Develop and make public new inundation maps and Emergency Action Plans.<br>• Reform the relationships between out-of-area water developers and local communities to create partnerships based on equality, fairness and respect. |

# Table of Contents

# Introduction

## Oroville Dam was headline news across the world for a few days in February.

Hundreds of millions of people saw images of two different spillway structures crumbling, and thousands of Californians evacuated under the threat of an uncontrolled reservoir release. Seven months later, the images from the Oroville Dam spillway incident are still fresh and relevant for the communities in the Feather River Basin, and people are striving to respond to the damages with understanding and action. The roar of the surging Feather River has subsided, but the questions still ring. How did this happen? What actions will ensure that this never happens again?

Everybody affected by the emergency should have the opportunity to be heard. Eleven public meetings hosted by the California Department of Water Resources (DWR), as well as many other town halls or community gatherings, were commendable strides in outreach and public engagement, and more are planned. Coalitions such as *Oroville Strong* have emerged to organize engagement of the community and focus ideas into action. But it is not enough that people are heard and the spillways get fixed. Much more needs to change.

The authors of this document have spent an average of nearly two decades working in regulatory processes concerning dams, flood management, hydropower, and river flows. Our objectives in this work focus mostly on improving the condition of rivers; however, we unquestionably support effective flood protection for communities behind the levees, and we have experience and insight to offer to this common and primary interest. We present this document to communities affected by the Oroville Emergency and to other communities at risk as an opportunity to learn together and to rebuild and reorganize for a safe and healthy future.

We begin with a review of Oroville Dam, its history, purpose, benefits, and impacts. Next, we look more closely at flood-control operations and the role of its regulators. We devote a section to describing the 2017 spillway emergencies, from forensics (technical investigation of the incident) to consequences. Finally, we present lessons-to-be-learned, both at and around Oroville and in other locations in California where lessons from the Oroville emergency and response can help prepare the way for better management.

**Oroville Main Spillway High Flows and Erosion, Feb. 11, 2017.**
Aerial view from a DWR drone shows a 55,000 cfs release down the main spillway. Despite existing damage to the main spillway, these high flows were released as the reservoir level exceeded 901 ft elevation, and water spilled at 5,000 to 10,000 cfs over the Oroville emergency spillway.
*Source: Zack Cunningham, DWR.*

# The Importance of Oroville Dam

## Historical and Physical Context

Rising 770 feet, Oroville Dam is the tallest dam in the United States. Oroville Dam is located on the Feather River in the Sierra Nevada foothills. The dam lies 70 river miles upstream of the Feather's confluence with the Sacramento River and is about four miles east of the center of the City of Oroville.

## Purpose of Dam

Oroville Dam was conceived in 1951 as the main storage reservoir of the State Water Project (SWP) and also as a multipurpose dam and reservoir with aqueducts and pumping plants. Part of original conception of the SWP included a peripheral canal around the Sacramento – San Joaquin Delta to transport water to central and southern California destinations. The SWP faced strong opposition by Northern California voters concerned that water that fell in northern California rightfully "belonged" to the north. Despite strong differences of opinion, the Burns-Porter Act to authorize the SWP was placed on the November 1960 ballot, and voters approved it by a very slim margin. Butte County, the eventual site of Oroville Dam, was the only northern California county in which a majority of votes favored the SWP.[1]

**Oroville Dam.** This aerial photograph was taken before 2017 and shows the dam on the right side, the concrete main spillway in the middle, and the emergency spillway on the left with a vegetated hillside below. *Source: DWR.*

## Oroville Dam and Reservoir At-A-Glance

| Parameter | Details | Perspective |
|---|---|---|
| Dam Height | 770 ft. | Tallest dam in the U.S. |
| Dam Crest Length | 6,920 ft. | Named as one of the seven wonders of engineering in CA in 1967 by CA Society of Professional Engineers. |
| Reservoir Capacity | 3.5+ maf | The largest reservoir in the SWP and second largest in CA. |
| Completed | 1968 | First conceived in 1951 |
| Dam Type | Earthen embankment | Maximum thickness of the dam: 3,570 ft. |
| Project Purposes | Water supply, Flood protection, Hydroelectricity, Recreation, Salinity control (Delta), Fish and Wildlife Enhancement | Facilities include: Oroville Dam and Reservoir; Hyatt Powerplant; Thermalito facilities (Diversion Dam, Powerplant, Power Canal, Forebay and Afterbay, and Pumping-Generating plants); Feather River Fish Hatchery; and a Visitors Center. |
| Hydroelectric capacity | 819 MW | Six power-generating turbines at Edward Hyatt Powerplant |
| Dam Cost | $3 billion ($2017) | Dam construction cost: $439 million ($1968) |

Construction of Oroville Dam began in 1961 and was completed in 1968. The reservoir, along with smaller reservoirs upstream, stores runoff from the Feather River Basin. The California Department of Water Resources (DWR) operates the SWP, including Oroville Dam, Oroville Reservoir, and adjacent infrastructure (known collectively as the "Oroville Facilities").[2] Designated project purposes for the Oroville Facilities include flood protection, water supply and storage, hydroelectric power generation, Delta salinity control, fish and wildlife enhancement, and recreation.

## How Water is Moved

Feather River water is released from Oroville Reservoir and flows downstream through an afterbay/forebay reservoir called the Thermalito Diversion Pool in the Feather River channel to the Thermalito Diversion Dam. From there, the project either diverts water into the Thermalito facilities or releases water into the "Low-Flow Channel" of the lower Feather River. Some of the water released to Thermalito rejoins water in the Low-Flow Channel at River Mile 59, and the combined flow in the "High-Flow Channel" moves down the Feather River toward the Sacramento River (Figure 1 inset). The lower Feather River downstream of Thermalito flows into the Sacramento-San Joaquin Delta.

Water (regardless of its source) that reaches the Delta is either diverted for local (largely agricultural) use, flows through Suisun, San Pablo, and San Francisco bays to the Pacific Ocean, or is diverted by the Central Valley Project or the State Water Project (SWP). SWP facilities in the Delta include the North Bay Aqueduct that diverts water to Solano County. The SWP's largest facility is the California Aqueduct. Most of the water in the California Aqueduct is delivered to the San Joaquin Valley and Southern California, but some is delivered to the southern Bay Area via the SWP's South Bay Aqueduct (Figure 1).

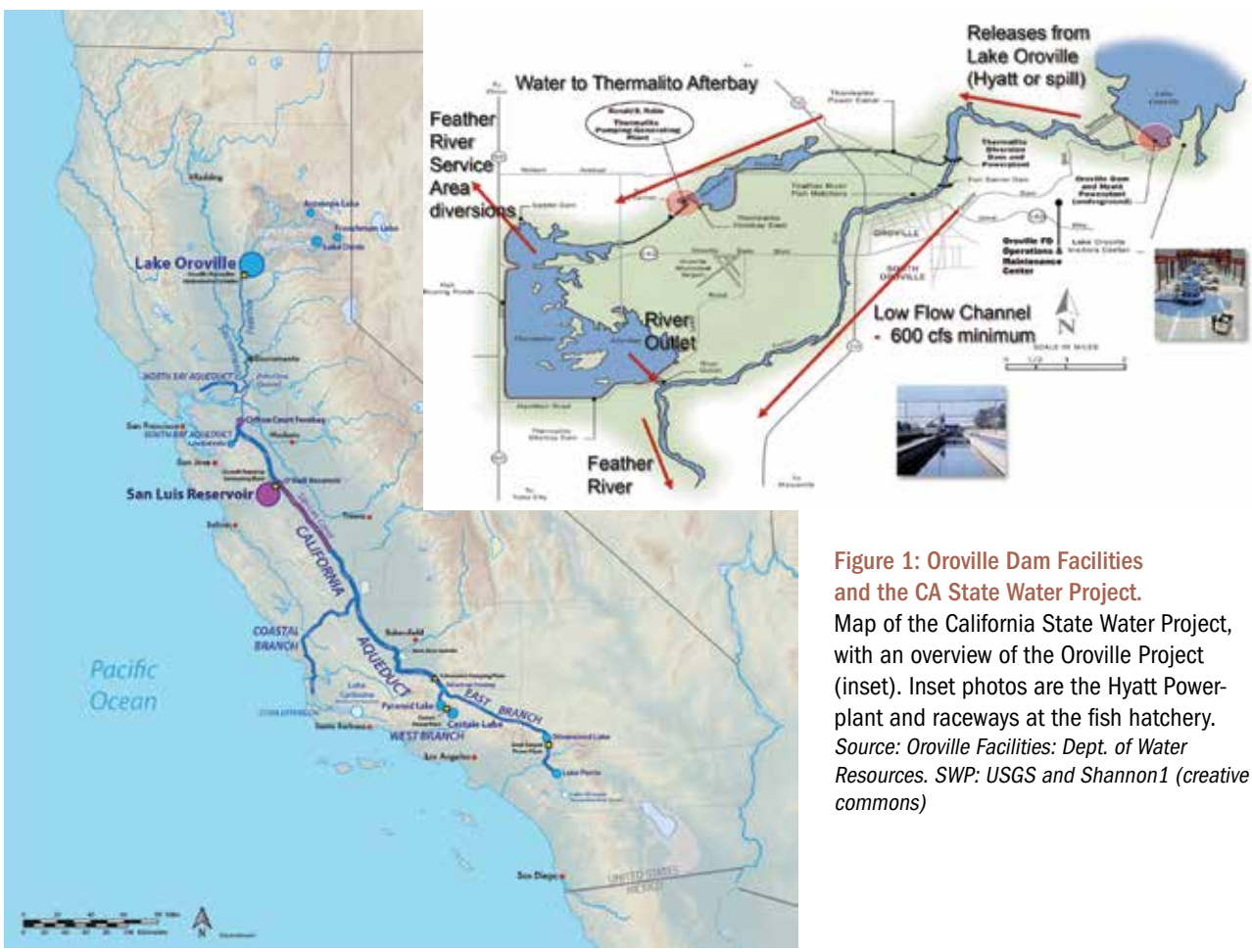



**Figure 1: Oroville Dam Facilities and the CA State Water Project.**
Map of the California State Water Project, with an overview of the Oroville Project (inset). Inset photos are the Hyatt Powerplant and raceways at the fish hatchery. *Source: Oroville Facilities: Dept. of Water Resources. SWP: USGS and Shannon1 (creative commons)*

# Project Benefits and Impacts

The Oroville Dam and Reservoir complex was built for three primary purposes: (1) water supply for the lower half of the state of California; (2) flood protection for the lower Feather River Basin; and (3) hydroelectricity. Additional project purposes include Delta salinity control, fish and wildlife enhancement, and recreation.

## Benefits

**Sunrise over Oroville Reservoir, Butte County.** Photo taken Feb. 23, 2017. *Source: Brian Baer, DWR.*

Water from Oroville Reservoir contributes to the State Water Project's delivery of water for the irrigation of 755,000 acres in the southern San Joaquin Valley and for a portion of the municipal supplies for approximately 25 million people.[3] DWR signed long-term contracts with public water agencies, or the "SWP Contractors," during the 1960s while the SWP was under construction. These contracts specify annual water contract amounts through 2035.[4] However, DWR bases actual allocations to contractors in any given year on water in storage and actual and predicted runoff; only in the wettest years do contractors receive substantial parts of their full allocation.[5]

At the time it signed contracts for water deliveries to the State Water Project contractors, DWR signed a separate series of contracts with senior water rights holders on the lower Feather River. These "Feather River Settlement Contracts" specify amounts of water that DWR delivers to these water users whose use pre-dated the construction of the State Water Project. The Settlement Contractors have priority over all other water users served by the SWP and are guaranteed full deliveries except during droughts, unlike the State Water Project contractors.[6] Deliveries from Oroville Dam and "excess" water in the Delta to SWP contractors and Feather River Basin Settlement Contractors have been averaging nine percent of statewide water use. The Settlement Contractors use about one quarter of the combined deliveries.[7]

Hydroelectricity from the Oroville-Thermalito facilities furnishes much of the power needed for SWP pumps on the California Aqueduct;[8] however, while the generation capacity and output of the Oroville Facilities are substantial, the State Water Project as a whole consumes more power pumping water than it produces with its turbines.

The total cost to build Oroville Dam is estimated at $3 billion dollars in today's dollars.[9] The State Water Project was financed by various sources, the majority from the sale of general obligation and revenue bonds to be repaid by the SWP contractors.[10]

## Impacts

Despite the significant state and nationwide benefits that the Oroville Facilities provide[11], the project has also caused significant negative impacts in the Feather River watershed. Most notably, Oroville Dam completely blocks access to 66.9 miles[12] of high quality habitat for native anadromous fish, primarily salmon and steelhead, upstream in the Feather River watershed.

Salmon, steelhead, and sturgeon are now restricted to the lower Feather River, where the operation of Oroville Reservoir for water supply purposes seriously alters natural flows and where rivers have to endure the hot Central Valley summers. In most years, winter-spring flows in the lower Feather River are low, when they would be naturally high. Summer flow releases from Oroville are high in the period when they would naturally be lower, in part to cool the summer water temperatures in the Feather River on the Valley floor. Except in very wet water years, spring conditions in the Lower Feather River are particularly bad for salmon rearing, sturgeon spawning, and steelhead spawning and rearing. The Lower Feather River is designated as critical habitat for Central Valley spring-run Chinook salmon and steelhead trout.[13] The operation of the Oroville Facilities affects other native species as well. Flow fluctuations and rapid stage reductions create poor conditions for trees along the lower river, negatively impacting riparian habitat for wildlife.

Salmon smolt stranded during rapid flow decreases in the Feather River, April 2017.
*Source: J. Stone, Nor-Cal Guides & Sportsmen Assoc.*

The construction of Oroville Dam has also had significant impacts on the local community. The City of Oroville sits below Oroville Dam. In the view of many area elected officials, the City once took pride in being home to the "tallest dam in America," but now the City is "not so sure."[14] Butte County Counsel Bruce Alpert reminded DWR on April 13, 2017 that documents dating from before the dam's construction promised to replace resources in areas inundated by Oroville Reservoir.[15] Lost resources included a power plant at Big Bend, roads, historic sites, the entire town of Las Plumas, and 41,000 acres of land that could have generated property taxes. Promised benefits included creation of jobs, economic development, low-cost energy, and road maintenance for Butte County, but these benefits never materialized.[16] The perception of exported resources is a serious concern for the City of Oroville, where the median income is $36,000 and almost 24% of the residents are below the poverty line.[17]

Impacts of the SWP are not limited to local areas. For example, some of the lands that the SWP serves in the southern San Joaquin Valley accumulate salt when irrigated. This results in land retirements and necessitates careful management of applied water to reduce adverse impacts to crops and groundwater-influenced surface water quality.[18]

# Oroville and Flood Management

One promised benefit of Oroville Dam and Reservoir was flood protection for the Lower Feather River Basin. The U.S. Army Corps of Engineers (Corps) is responsible for regulating flood operations. It has a flood-control manual for Oroville Dam that was created in 1970 and has not been updated.[19] Operators of Oroville Reservoir use the Oroville flood-control manual to determine how much space to leave in the reservoir at specified times to sufficiently capture mountain runoff to prevent levee-break flooding downstream. The manual dedicates as much as 750,000 acre-feet of the 3.5 million acre-foot Oroville Reservoir as flood space during the height of the winter flood season. Floodwater flow releases from Oroville Dam are limited to 150,000 cfs. This cap, when combined with releases from New Bullards Bar Dam on the Yuba River, restricts downstream flows to amounts that the Corps judges to be safe for conveyance between the levees along the Feather and Yuba Rivers.[20]

## Levee System Challenges

Since their construction, the Feather River Basin dams have mostly limited releases as expected. The levee systems have not performed as well. During a massive flood in 1986, peak inflow to Oroville Reservoir reached 275,000 cfs, and peak flow releases reached 150,000 cfs.[21] The outflow from Oroville Reservoir combined with flows in the Yuba River to trigger a levee break along the Yuba River, quickly inundating the towns of Linda and Olivehurst. This flooding occurred even though flows in the Yuba at the time were only 60% of the design capacity of the floodway formed by levees along the Yuba River. The 1986 floods damaged more than 3,000 homes and destroyed 895 homes [22] in the off-channel flood basin that the levees that broke were supposed to protect. Losses were estimated at $22 million, and flood concerns remained, despite U.S. Army Corps and State efforts to improve the area's levees.

**The Oroville Incident, Feb. 2017. The west levee of the Feather River does its job east of Highway 99 and near Live Oak in Sutter County.** Photo taken February 20, 1986. *Source: Norm Hughes / California Department of Water Resources*

The "New Year's flood" of January 1997, considered one of the largest floods in the Northern California record,[23] set flood records in the Feather River Basin.[24] Weather patterns from December 26, 1996 to January 3, 1997 brought warm tropical precipitation to high snow-covered elevations, with more than 40 inches of rain falling in 9 days in the Feather River Basin. In response to forecasts, DWR made early flood releases from Oroville Dam. As the event proceeded, outflows reached 150,000 cfs and then 160,000 cfs.[25] As reservoir inflows spiked (briefly up to a 302,000 cfs peak hourly flow), DWR operators believed that "pass through" operations were likely, and the City of Oroville was advised to prepare to evacuate.[26] In the end, there was no evacuation from Oroville and the reservoir peaked at 13.8 feet below full, with more than two hundred thousand acre-feet of unfilled flood-control space.[27] However, based on their own criteria, the cities of Marysville and Yuba City ordered evacuations as a precaution in case the high waters caused levee failures there.[28]

A little to the south, the precautions proved to be justified when the Feather River's left bank levee failed downstream of its confluence with the Yuba River, carrying an at-capacity flood flow. This was not surprising, since seven years earlier the Corps of Engineers had downgraded the expected performance of this levee protecting this off-stream flood basin.[29] The Feather River break was one of two serious levee breaks in the Sacramento Valley;[30] the other was along the Sutter Bypass west levee. Along the Feather, the 1997 flood caused flood depths up to 30 feet in some areas. Three people died. Flooding destroyed 322 homes and seriously damaged 407 more. Local damage from the 1997 floods was estimated to be more than $300 million.[31]

The Yuba-Feather Workgroup was formed following passage of the Costa-Machado Act of 2000 (Proposition 13) to evaluate environmentally sound methods of achieving greater California flood protection. The Yuba-Feather Workgroup's efforts led to the 2010 completion of the Feather River Setback Levee Project (see sidebox), which provides benefits for flood management, fish and wildlife habitat, water quality, groundwater recharge, open space, and recreation.

## The Yuba Feather Workgroup and the Feather River Setback Levee

Situated at the confluence of the Yuba and Feather Rivers, the Yuba City and Marysville area has a long history of catastrophic flooding. The 2000 state water bond allocated $70 million for non-dam flood protection on the Yuba and Feather Rivers, and provided an opportunity for diverse interests to come together to reduce the impacts from floods.

The Yuba-Feather Workgroup was formed to evaluate environmentally-sound methods of achieving greater flood protection and included the South Yuba River Citizen's League, CALFED agencies, Friends of the River, the Sierra Club, Yuba, Sutter, and Nevada Counties, the water agencies of Yuba and Sutter Counties, DWR, Fish and Wildlife, USFWS, and NMFS. The Three Rivers Levee Improvement Authority was established in 2004 to finance and construct levee improvements in south Yuba County.

The Feather River Setback Levee provided major flood protection improvements for the Yuba County communities of Arboga, Linda, Olivehurst, and Plumas Lake. This $165 million project was completed in 2010. It added three separate levee segments: Bear River to Star Bend, Star Bend to Shanghai Bend, and Shanghai Bend to the Yuba River. The Feather River Setback Levee improved local and regional flood protection by widening the floodway and also created nearly 1,500 acres of riparian floodplain habitat for fish and wildlife. The project received the American Society of Civil Engineers Sacramento Section Flood Control Project of the Year award in 2009.

## Oroville Project and FERC Relicensing

In accordance with the Federal Power Act, hydropower projects that are not owned by the federal government undergo relicensing of their facilities every 30 to 50 years. The Oroville Project, FERC Project No. 2100,[32] was originally licensed in February 1957 and began a Federal Energy Regulatory Commission (FERC) relicensing process[33] in December 2000, when DWR requested to use FERC's Alternative Licensing Process (ALP).[34]

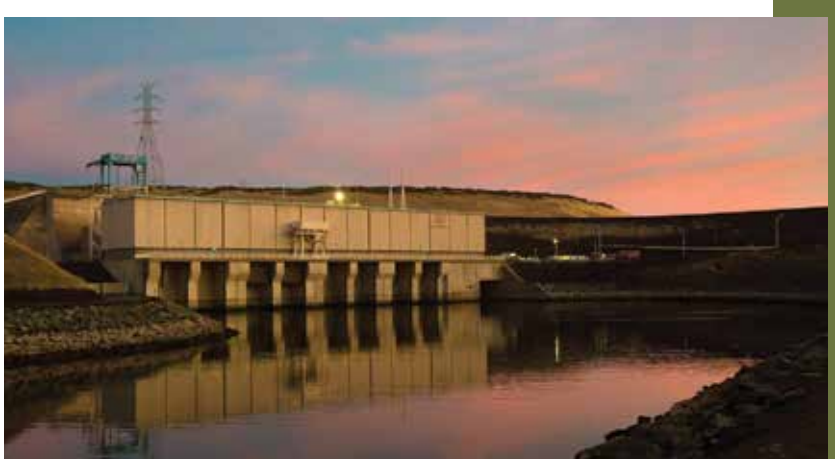
The hopes and expectations of a new license involve operational changes to benefit fish and wildlife, enhancements for recreation, improvements to project works, and support for local communities. In the Oroville relicensing, many of the ALP parties reached and signed a settlement agreement in 2006. FERC released a Final Environmental Impact Statement in 2007. The National Marine Fisheries Service published a Biological Opinion on December 5, 2016,[35] at which point there were no apparent remaining procedural preconditions to issuance of a new FERC license. Whether FERC will now delay license issuance is unknown.[36] Delay could be expected in light of the recent spillway incident and the significant reconfigurations of the project as compared to the project that the settlement agreement envisioned.

## Settlement Agreement Draws Support and Critics

This long and intensive Oroville relicensing and associated processes saw dozens of studies, hundreds of meetings, and hundreds of filings with FERC. The Oroville Settlement Agreement requires flow and water temperature improvements in the Feather River downstream of the dam, habitat enhancement to accommodate an estimated net increase in spawning habitat for 2,000 to 3,000 spring-run Chinook salmon with additional benefit for steelhead, and $60 million in recreation and other benefits to the Oroville region. DWR estimates recreation and other benefits to be $1 billion, including a $60 million Supplemental Benefits Fund to support projects outside of the license but within the Oroville region.

However, the Settlement did not meet with universal approval. The California Sportfishing Protection Alliance (CSPA) disputed the limitation of the geographic scope of the relicensing, which severed operation for hydropower from the operation of the State Water Project as a whole.[37] Plumas and Butte counties declined to sign and later initiated litigation against the Environmental Impact Report that DWR issued to support the Water Quality Certification, notably calling out DWR's failure to consider climate change in evaluating project hydrology. [38]

**Oroville Hydropower Facilities.** Located beneath Oroville Dam, the Edward Hyatt Powerplant contains six units, three to pump water and three to generate power for the operational needs of the DWR facility. *Source: DWR.* Ronald B. Robie Thermalito Pumping-Generating Plant, located at the Thermalito Afterbay, at sunrise 11/23/12. *Source: Florence Low, DWR.*



A number of parties to the relicensing sharply disputed the suitability of the emergency spillway [39] on Oroville Dam – the spillway that almost failed in 2017 and forced the evacuation of 188,000 people in the Feather River Basin. Friends of the River (FOR), the South Yuba River Citizens League (SYRCL), and the Sierra Club (collectively, FOR *et al.*) filed a Motion to Intervene in the Oroville relicensing on October 17, 2005.[40] The intervention arose after several years of discussion in the Yuba-Feather Workgroup of ways to improve flood-safety in the Feather River Basin. These discussions had been informed by a post-flood assessment with the Corps of Engineers in which it had become clear that the Corps' Oroville Dam flood-control manual effectively required DWR to have the emergency spillway available for operational as well as emergency use.[41]

In their intervention, FOR *et al.* argued that the unarmored and ungated emergency spillway did not have an actual concrete spillway and was thus in no condition to operate as envisioned in the flood-control manual. Indeed, in 1997 DWR seemed understandably reluctant to use this emergency/operational spillway, presumably because of the the danger of hillside erosion and the potential loss of the spillway's foundation that such use could cause. This reluctance, in turn, could cause DWR to over-ride the manual and release more water than downstream levees were designed to handle. Given its assigned mission and the damages that might be associated with its use, FOR *et al.* argued the emergency spillway did not meet FERC's engineering guidelines and other requirements. FOR *et al.* requested that FERC reclassify the emergency spillway as an auxiliary spillway and require DWR to armor this spillway with concrete.[42] In their respective interventions, CSPA and American Whitewater (AW) supported FOR *et al.'s* arguments relating to these needed flood facility modifications.[43]

The joint intervention of Sutter County, the City of Yuba, and Levee District 1 (Sutter County *et al.*) raised similar issues and concerns, when they argued that if Oroville Dam could not provide surcharge storage, then the flood-control manual should increase flood space from 750,000 to 900,000 acre-feet.[44]

Butte County raised public safety and other issues during the relicensing proceeding, contending that DWR had not adequately addressed significant public-safety risks associated with the Oroville Dam. Butte County expressed concerns about heavy rainfall events bringing Oroville Reservoir to possible overflow conditions.[45] The County criticized the Oroville Settlement Agreement for failing to address emergency operations, including the need to relocate the County's Emergency Operation Center out of the path of a flood in the event of dam failure or a large outflow from the reservoir.[46]

FOR *et al.*, Sutter County *et al.*, and Butte and Plumas Counties, among others, were unable to reach agreement with DWR and did not sign the Oroville Settlement Agreement. Over the course of the FERC proceeding, DWR took the position that it is neither necessary nor appropriate to address specific issues related to dam safety in relicensing.[47] Neither DWR nor other entities responsible for the dam indicated how the public could engage on dam-safety issues if not in relicensing. DWR argued that the geologic conditions at the emergency spillway had been recently reviewed, and that the review had determined that the spillway was a safe and stable structure founded on solid bedrock that would not erode.[48] The State Water Contractors and the Metropolitan Water District of Southern California (MWD) took the position that "Intervenors' Flood Control Arguments Are Misdirected and Unsupported," and that FERC's dam safety office in San Francisco and the Army Corps were the appropriate entities to address flood control.[49]

## The Government Responds

On May 18, 2006, FERC officials asked the San Francisco Regional Office (SFRO) of its Division of Dam Safety and Inspections to review the issues. SFRO issued a memo that stated there was nothing wrong with the emergency spillway and the emergency spillway could handle 350,000 cubic feet of water per second. The memo further maintained that the emergency spillway "would perform as designed," and that sediment resulting from erosion would be insignificant.[50] It is unclear whether SFRO contemplated the range of circumstances in which the physical deficiencies of the Oroville Facilities would be relevant, including the real-world effect of these deficiencies on operations and project lands and facilities. SFRO's memo assured FERC's Division of Hydropower Licensing that "during a rare event [with] the emergency spillway flowing at its design capacity, spillway operations would not affect reservoir control…." [51] However, the memo acknowledged that "during a rare flood event, it is acceptable for the emergency spillway to sustain significant damage...." FOR *et al.*, of course, had argued that the likely damages from use of the spillway were unacceptable.

FOR, SYRCL and Sierra Club argued that the likely damages from use of the emergency spillway were unacceptable. FERC licensing staff proposed to relicense the Oroville Facilities without spillway modifications.

FERC licensing staff accepted FOR *et al.*'s characterization of the Corps' operational requirements (750,000 acre-feet of ordinary flood-control reservation, plus another 150,000 acre-feet of surcharge[51] reservation); however, they punted the issue of the emergency spillway's inadequacy to FERC's Division of Safety of Dams and Inspections, which had already erroneously concluded that the spillway was adequate for its intended use. FERC licensing staff thus proposed to relicense the Oroville Facilities without spillway modifications.[52]

The State Water Resources Control Board issued a water quality certification for the Oroville project on December 15, 2010.[53] The Board did not take up the request of FOR *et al.* that it address the water-quality implications of the use of an erodible hillside to conduct surcharge operations.[54]

# The Oroville Spillway Incident Of 2017

## The Events of February: On the Edge of Disaster

### Flood Season 2017: A Wet Winter

The 2017 water year (October 1, 2016 through September 30, 2017) is the wettest year on record for many of the state's important watersheds, allowing rivers and reservoirs to recover from the four preceding years of drought. By mid-winter, DWR was making flood-control releases to maintain required space in the reservoir. Between February 6 and 10, 2017, almost 13 inches of rain fell in the Feather River Basin, increasing inflow into Oroville reservoir from 30,000 cfs to over 130,000 cfs on February 7.

### February 7: The Main Spillway Breaks

While releasing 54,000 cfs down the Oroville gated main spillway (hereinafter "the main spillway") on February 7, 2017, DWR identified an unusual flow pattern and stopped releases to discover a large crater spanning almost the entire width of the dam's concrete-lined main spillway.[55] The main spillway's concrete lining was completely destroyed in one section, and water was escaping the concrete chute to the side into a new and soon-to-be massive eroding gully.

**Oroville Dam's Main Spillway at 100,000 cfs.** An aerial view looking eastward toward Oroville Dam and Reservoir. The emergency spillway is on the left (note eroded red dirt area) and the damaged main spillway left of center. Oroville Dam is on the right. An outflow of 100,000 cfs travelled down the main spillway on Feb. 15, 2017. *Source: Dale Kolke, DWR.*

### February 8–10: Testing the Broken Main Spillway While the Reservoir Rises

In consultation with FERC and other dam safety agencies, DWR ran test flows down the damaged main spillway on February 8. On February 9, DWR increased releases down the main spillway, trying to strike a balance between the rapidly increasing erosion of a gully to the south side of the spillway and risk of loss of more concrete spillway versus rising reservoir levels and the prospect of using the dam's emergency spillway. The increasing erosion immediately created a new problem: extremely muddy water entered the Feather River Fish Hatchery just downstream of the dam and threatened to kill a year's production of over 8 million juvenile salmon and steelhead. The rapid mobilization and creative action of staff from the California Department of Fish and Wildlife (DFW) and other agencies were able to keep most of the young fish alive and transport them to a nearby alternative facility.[56]

Because DWR was not making releases that it would ordinarily implement, the reservoir flood reservation continued to be more and more encroached. The reservoir was filling up. While maintaining that it would not allow the reservoir to rise high enough to spill over the emergency spillway, but facing forecasts for heavy rain in the watershed, DWR began preparing for possible use of the emergency spillway.[57] Concurrent with increasing concerns over the condition of the main spillway, reservoir inflows peaked at more than 190,000 cfs from February 8 to 10.

## February 11: Water Pours Over the Emergency Spillway

The water level in Oroville Reservoir reached 901 feet late on Saturday February 11, causing the emergency spillway to spill water for the first time in history. Once water began flowing over the emergency spillway, hilltop erosion also began at a level much more severe than DWR expected. No more than 12,000 cfs flowed over the emergency spillway at any time during its use; however, in less than a day, back-stepping (headcutting) erosion of the hilltop immediately below the emergency spillway's concrete lip (see photo below) threatened to undermine and collapse the concrete lip that forms the emergency "spillway." According to estimates at the time, failure of this lip could have resulted in the sudden loss of the top thirty feet of water in the reservoir, with catastrophic flooding to communities downstream of the dam.[58] The true amount of reservoir loss, however, could have been greater; it was limited only by the depth of permeable and erodible rock and soil that formed the foundation of the emergency spillway.

## February 12: Evacuation

In view of the potential for imminent failure of the concrete portion of the emergency spillway and part of its foundation, the Butte County Sheriff issued a mandatory evacuation order on the afternoon of Sunday, February 12, that included the cities of Oroville and areas downstream. Downstream, officials extended the evacuation order or advisories to parts of Sutter and Yuba counties, including the cities of Yuba City and Marysville.[59] The evacuation orders covered 188,000 people.

In response to the erosion caused by use of the emergency spillway, on February 12 DWR further opened the gates to the main spillway to allow 100,000 cfs to pass, despite severe concerns about potential damage to the main spillway's foundations upstream of the break and the hillside erosion that using the main spillway would cause. The increased release from the main spillway pulled the reservoir down, reducing flows over the emergency spillway.

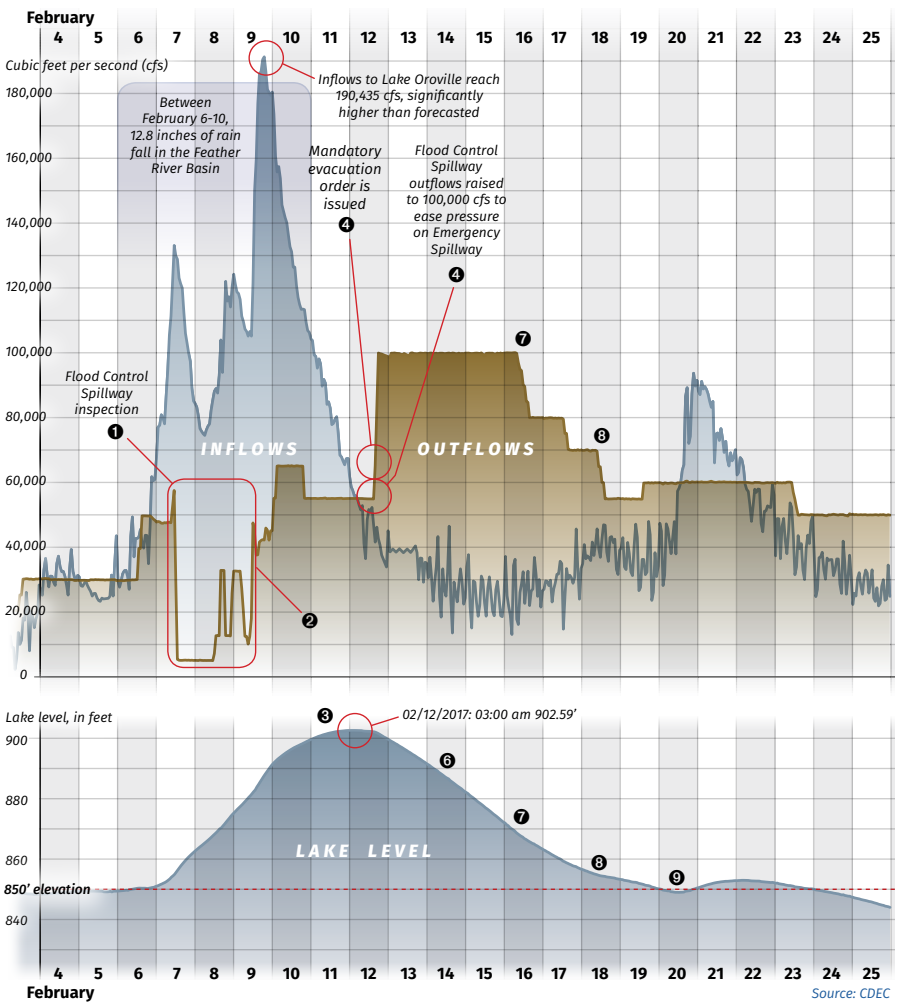
Emergency spillway flows stopped a few hours after the evacuation order. DWR maintained releases down the main spillway to relieve

**Emergency Spillway Flows and Erosion.** Water flows over the Emergency Spillway for the first time on Feb. 12, 2017, eroding gullies and destroying a roadway. *Source: Kelly M. Grow, DWR.*

pressure on the emergency spillway foundations and to recover the required reservoir flood reservation (required empty space in the reservoir to absorb flood inflows), into which high inflows had encroached during the previous days. DWR implemented "around the clock" rough repairs to erosion damage below the emergency spillway. The evacuation order remained in effect until Tuesday, February 14, when the Butte County Sheriff changed it to an evacuation warning.

All of the Oroville Dam complex's outlets were compromised. The emergency spillway was unsafe to use. The main spillway was broken and, although usable, was contributing massive amounts of sediment to the Feather River/Oroville Dam power afterbay (Thermalito Diversion Pool). The powerhouse at the base of Oroville Dam was unusable because of high water in its afterbay caused by debris in the afterbay and because PG&E had de-energized transmission lines to the powerhouse, whose towers were vulnerable to erosion from the use of either spillway. The river-valve outlets at the base of the dam were also not operational because of afterbay backwater conditions.[60]

## Oroville Spillway Timeline - February 2017




*Source: DWR.*
*http://www.water.ca.gov/oroville-spillway/pdf/2017/Lake%20Oroville%20events%20timeline.pdf*

**February 7:** Reservoir inflows exceed 130,000 cfs, and main spillway releases peak at 54,500 cfs. Unusual flow pattern observed. Releases are stopped, and a large crater/hole is observed. (1)

**February 8:** Tests are run on main spillway. DWR prepares for use of the emergency spillway. (2)

**February 11:** With inflows peaking at 190,435 cfs on Feb. 9, Oroville reservoir exceeds 901 feet and water flows uncontrolled down the emergency spillway for the first time. (3)

**February 12:** Emergency spillway erosion progresses much faster than expected. Butte County Sheriff issues a mandatory evacuation order at 4 p.m. for 188,000 people. Main spillway flows are increased to 100,000 cfs. (4)

**February 13:** DWR begins efforts to armor the emergency spillway. (5)

**February 14:** The mandatory evacuation order is modified to an evacuation warning. An 850 ft. elevation target for reservoir is set. (6)

**February 16:** Main spillway flows are reduced for debris clearing. Emergency spillway armoring efforts continue. (7)

**February 18:** Oroville level reaches 854 ft., and main spillway flows are reduced to 55,000 cfs. (8)

**February 20:** Oroville reaches 848.95 foot elevation. (9)

## Emergency Recovery Actions

DWR reduced flows in the main spillway on February 16 so that it could begin to clear debris (estimated at 1.7 million cubic yards)[61] from the main spillway. Hilltop efforts to stabilize the emergency spillway continued. When the reservoir level dropped to 854 feet on February 18, DWR reduced flows in the main spillway to 55,000 cfs, and barges began removing debris from the diversion pool at the base of the spillway. The reservoir elevation was down to 848.95 feet at 11a.m. on February 20.

Fortunately, the spring weather that followed was not as severe as the early February storm sequence. On an emergency basis, the erosion below the emergency spillway was filled in. Workers applied a rough concrete layer over some of the hilltop downhill from the lip of the emergency spillway. Pauses in the use of the main spillway allowed crews to shotcrete its foundations upstream of the break in order to reduce the likelihood of further back-stepping erosion up the hill. The channel was dredged enough to resume powerhouse releases as new transmission line connections were made. The river-valve outlets were made ready for fuller, though still limited, use.[62]

**Oroville Dam Main Spillway Repair.** Image date: August 9, 2017.
*Source: Florence Low, DWR.*

## 2017 Recovery and Reconstruction

By late spring, the reconstruction began in earnest, with the goal of reconstructing the lower main spillway and its foundations and making smaller repairs to the upper spillway during the 2017 construction season. The plan for the emergency spillway is to build a cutoff wall by November 1 that would be located downhill on the hilltop to prevent headcutting, if used. At a later time, the spillway lip would receive a roller-compacted-concrete buttress and a "splash pad" (or "apron").[63] Transmission towers and powerlines are being relocated out of harm's way.[64]

According to press accounts, DWR received formal permission to proceed with its 2017 construction plans from its Division of Safety of Dams and from FERC on July 15 and 17.[65] DWR had earlier received a similar recommendation from its Board of Consultants on June 3.[66] The announced follow-on construction activities do not include a spillway from the hilltop cutoff wall to the Thermalito Diversion Pool/Feather River downstream.

The reconstruction plans are dynamic, apparently responding to conditions encountered as construction proceeds. The 2018 schedule may include reconstruction of the upper main spillway and the work described above immediately below the emergency spillway.

## Lessons Learned?

There is no evidence that DWR has given any serious consideration to construction of a complete emergency spillway, although it maintains this is still an option.[67] DWR spokespersons reminded citizens during public meetings that FERC allows emergency spillways to sustain considerable damage when used.[68] Damage, in the case of significant use, would involve massive hillside erosion into the down¬stream channel with similar environmental and project operational impacts that occurred in 2017.

The Oroville Dam spillway incident demonstrated the legitimacy of concerns about the erodibility of the hillside that underlies the Oroville Dam complex spillways, the danger of using the emergency spillway, and the need for upgrades to the physical facilities of the dam complex so that they can be safely and confidently used. The incident also demonstrated the consequences of not attending to these issues: major damage and expensive repairs to the dam complex and the vulnerability of nearly 200,000 people in the Feather River Basin when things go wrong at Oroville Dam.

Though FERC and DWR deemed the emergency spillway able to handle 350,000 cfs and predicted that the emergency spillway "would perform as designed,"[69] the emergency spillway nearly failed during a short-term flow of only 10,000 cfs. Gross underestimation of erosion potential was not limited to the emergency spillway. Erosion depths in the new gully alongside the main spillway were an order of magnitude larger than DWR and SFRO had estimated were possible. No one was prepared for the extent of the damage to the hillside and what lay upon it, despite years of dam-safety inspections.

## Consequences

The 2017 Oroville Dam spillway incident has gained worldwide attention as one of the most noteworthy failures, or near failures, of a Commission-licensed dam in FERC's history. The near failure of the emergency spillway caused one of the largest evacuations in California history. 188,000 people were told to leave the Feather River Basin, completely disrupting the lives of people and communities in the evacuation area and those communities in the surrounding area that received the evacuees. Fortunately, the incident caused no known fatalities.

### Oroville Spillway Incident Impacts for the City of Oroville

Mayor Dahlmeier's letter to the Energy and Commerce Subcommittee Hearing (March 15, 2017) describes the following impacts:

**Road Repairs:** Degraded roads from thousands of truck trips bringing material to the dam site.

**Real Estate Losses:** Decline in real estate transactions and canceled escrows.

**Fishery:** Severe impacts to the Feather River fishery (one of the most important elements of the recreational economy) due to mud and silt and to abrupt shutoff of flow (from 50,000 cfs to 0 in just a few hours).

Consequences of the incident include direct impacts to evacuated people and communities, indirect effects to those communities, environmental impacts to the Feather River, and the direct costs for repair and recovery. Impacts to the residents and communities in the Feather River basin following the Oroville Dam spillway incident include: (1) emotional impacts (e.g. stress or trauma from evacuation order and prolonged fear or reduced sense of safety in the region); (2) financial impacts (e.g., lost productivity and wages and potential reductions in real estate values associated with lands downstream of the dam); (3) economic impacts from the loss of recreation at Lake Oroville Reservoir and the lower Feather River (e.g., boat ramp closure, trail closures, diversion pool closure); and (4) other regional economic impacts.

Removal of debris from Feather River diversion pool. *Source: DWR*

# Oroville Spillway Incident: Impacts to Recreation at the Lake Oroville State Recreation Area

## 1 Reservoir elevations have a significant impact on lake recreation.

While 2017 was the wettest year on record, DWR held the lake level of Lake Oroville down after the spillway incident to ensure that the spillways would not be used for the duration of spring runoff and to allow necessary repairs to get underway. On July 4, 2017, Lake Oroville was 90 feet below full pool. On the same date Lake Shasta was only 10 feet from the top. The reservoir is expected to be drawn down to 700 feet in elevation later this year, an elevation similar to the lowest levels during the recent drought.

## 2 Spillway Boat Ramp will be closed for the next several years,

and maybe indefinitely. This closure will reduce the number of boat ramp lanes available at low water by 50%. It will also eliminate 400 boat access parking spaces. This boat launch is particularly popular for the bass tournaments that occur at Lake Oroville Reservoir.

## 3 The Potters Ravine Trail near Oroville Dam and the Brad Freeman Trail that climbs the dam and also runs to either side of the lower Feather River many miles downstream are closed.

This is an 85% reduction in the trails available in the recreation area. These trails will remain inaccessible as long as access is closed across the top of Oroville Dam. They have become very popular with equestrians, mountain bikers and hikers.

## 4 The Diversion Pool, located immediately downstream of Oroville Dam, will be closed for the next several years.

The Diversion Pool offers some of the best flatwater, non-motorized paddling in Butte County. DWR just recently completed new boating access facilities that will be unavailable to the public.

## 5 Angling opportunities have been significantly reduced in the Feather River.

For many years, the River Reflections RV Park has catered to anglers who come to fish the Low-Flow Channel. This year, its angling bookings are down 94% because of the poor fishing conditions in the Feather River as a result of the spillway failures.

Butte County described some of the local impacts in a February 15, 2017, filing with FERC.[70] Noting many past warnings concerning dam safety at Oroville, Butte County requested that the Commission focus on public safety to ensure that 2017 "will be a one-time incident." The County noted the severe strain it had experienced providing "massive levels of emergency response required to adequately address the myriad of public-safety issues presented by the Oroville Project." Butte County additionally expressed concern about its costs in providing emergency services. Noting that it had been denied cost reimbursement following the 1997 floods,[71] the County proposed that FERC require DWR to immediately establish and fund its own Public Safety Program for the Oroville Project, including the necessary law enforcement and other personnel.[72] Butte County added that if DWR was unable to provide such services on its own, the County was willing to negotiate with DWR regarding reimbursement for the County's costs for providing emergency services for the Oroville Project.[73]

> DWR is well aware that Butte County is obligated by law and moral duty to protect the citizens of the County from harm. DWR also knows that providing such protection and emergency services comes at great cost to the County, and yet DWR, unlike other hydropower dam owners, refuses to reimburse the County for such costs.
>
> *Butte County, Filing to FERC, Feb. 2017*

Oroville Mayor Linda Dahlmeier sent a letter to the U.S. House Energy and Commerce Subcommittee Hearing on March 15, 2017. She described how virtually all of Oroville's residents were evacuated during the emergency, and gave a sense of what that meant on the ground. "People spent hours trying to flee just a few miles, not knowing if the spillway would fail, taking them and their loved ones away. Had the spillway failed … life as we know it in the state of California would forever be changed. This disaster is one of the worst nightmares any elected official could imagine for their community."[74] Along with the direct costs for repairs to the Oroville spillway, the Mayor cited incident costs that included degraded local roads, canceled escrows and declines in real estate transactions, and severe impacts to recreation, a core sector of the local economy that had "come to a standstill."[75]

The Mayor also described the serious impacts to the Feather River fishery, one of the important elements of the local recreation economy. These impacts included habitat buried under mud and silt and fish stranding following the rapid decrease in flow releases (from 50,000 cfs to 0 in a few hours). The rapid and extreme flow reductions also caused massive sloughing of river banks.

Mayor Dahlmeier requested a full analysis of the impacts of the spillway emergency event for Oroville and the surrounding areas that includes the following: (1) the direct and indirect impacts to services, infrastructure, and local economies and (2) the impacts to the Feather River and resulting recreational impacts (both current and future) for the region. Mayor Dahlmeier noted in her letter: "The fact is that the benefits from the Oroville project are immense. California does not exist in its current form without the water from this project."

**Oroville Dam Spillway Erosion, Feb. 11, 2017.** Water and debris from the emergency spillway failure flow into the diversion pool just downstream of the dam. *Source: Dale Kolke, DWR.*

# Oroville Spillway "Autopsies"

## FERC/DWR

On February 13, 2017, FERC's headquarters office of the Division of Safety of Dams and Inspections sent a letter to DWR in response to the spillway incident. The letter required DWR to "initiate immediate redesign of emergency repair." It also ordered DWR to appoint an independent board of consultants to advise DWR on measures to weather the ongoing incident, design the reconstruction, and conduct a forensic investigation on the incident's causes.[77] In this letter and following communications, FERC's Division of Safety of Dams and Inspections has assumed the role of regulator in charge of DWR's recovery efforts.[78]

Some or perhaps much of the day-to-day communications between DWR and the Board of Consultants is unavailable to the public, classified under FERC's regulation that allows project operators to withhold "Critical Energy Infrastructure Information" (CEII) from the public; however, some written communications have been released to the public, although often in a redacted state or in only summary form.[79] The Board of Consultants' first memo was inadvertently released by FERC in full and gave some early insights that main spillway foundation conditions were one of the failure mechanisms under consideration.[80]

## Corps of Engineers

The U.S. Army Corps of Engineers also briefed its senior management on the likely failure mechanisms, going into more depth than other early reports. It also offered some speculation whether the problems would have been discovered by Corps of Engineers inspection programs. The Corps also expressed concern that its current dam-safety programs might not have caught and corrected some of the design and maintenance problems that were likely causes of the spillway incident. The briefing was not intended for public release, but a copy was found and published by the Sacramento Bee.[81]

## Dam Safety Organizations

The Association of State Dam Safety Officials and the U.S. Society on Dams has also formed an Independent Review Panel to work with DWR.[82] It has produced a list of twenty-four candidate physical failure mechanisms for the main spillway and four candidate mechanisms for the near failure of the emergency spillway.[83] Presumably, this Panel will have access to CEII information, which it will have to remove from any public reports it may issue.

An aerial view of the diversion pool on the Feather River as outflow from the damaged Oroville Dam spillway was being reduced from 50,000 cubic feet per second (cfs) to zero on February 27, 2017. *Source: Dale Kolke / California Department of Water Resources*

# Preliminary Root Causes Analysis of Failures of the Oroville Dam Gated Spillway

Summary of Findings from R.G. Bea, April 17, 2017

## Design Defects and Flaws

The gated spillway failures are rooted in pervasive design defects and flaws developed by DWR and include:

- Insufficient thickness of spillway base slabs for the design hydraulic conditions (4 to 6 inches at min. points).
- Spillway base slabs are not joined with 'continuous' steel reinforcement to prevent lateral and vertical separations.
- Lack of effective water stop barriers embedding in base slabs to prevent water intrusion under the base slabs.
- Spillway base slabs not designed with two layers of continuous steel reinforcement to provide sufficient flexural strength required for operating conditions.
- Ineffective 'ground' anchors for spillway base slabs to prevent significant lateral and vertical movements.

Main Spillway, Feb. 27, 2017. As DWR decreases flows on the damaged main spillway to assess damages.
*Source: Bill Husa, Chico Enterprise-Record.*

## Construction Defects and Flaws

The design defects and flaws were propagated by DWR during construction of the spillway, and include:

- Failure to excavate the native soils and incompetent rock overlying the competent rock foundation.
- Failure to prevent spreading gravel used as part of the under-slab drainage systems and 'native' soils to form extensive 'blankets' of permeable materials in which water could collect and erode.

## Maintenance Defects and Flaws

The design and construction defects and flaws were propagated by DWR during maintenance of the spillway and include:

- Repeated ineffective repairs made to cracks and joint displacements to prevent water stagnation and cavitation pressure intrusion under the base slabs with subsequent erosion of the spillway subgrade.
- Allowing large trees to grow adjacent to the spillway walls whose roots could intrude below the base slabs and into the subgrade drainage pipes resulting in reduced flow and plugging of the drainage pipes.

*Source: R.G. Bea, Center for Catastrophic Risk Management. April 17 2017. Preliminary Root Causes Analysis of Failures of the Oroville Dam Gated Spillway. www.documentcloud.org/documents/3676605-Robert-Bea-Oroville-Spillway-Failure-Root-Cause.html*

## U.C. Berkeley

A team from UC Berkeley is also conducting an independent review based on publically available information and less official sources knowledgeable about conditions at the dam complex before the spillway incident. Members of this team have already provided insight into why the country's tallest dam's spillway failed so spectacularly in the winter of 2017. The team includes one of the country's foremost experts on catastrophic engineering failures, Professor Emeritus Robert Bea. Bea is a founder of UC Berkeley's Center for Catastrophic Risk Management and a reviewer of other high-profile disasters, such as Hurricane Katrina and the BP oil spill; he produced an independent analysis of the dam spillway failure that reveals design and construction flaws dating back to the 1960s. The first major report from the UC Berkeley group was the 78-page report titled *Preliminary Root Causes Analysis of Failures of the Oroville Dam Gated Spillway*; it consists mostly of photographs and diagrams illustrating his forensic assessments.[84] The report's findings highlight pervasive design defects in the gated spillway, flaws propagated by construction defects and inadequacies in maintenance.

The Berkeley group has created two additional reports that have focused on the physical causes of the main spillway failure and also highlighted possible additional and so-far-unaddressed physical problems at the Oroville Facilities.[85] The reports have also discussed institutional and cultural issues that have contributed to the apparent failures.

Bea says that with every disaster he reviews, he sees a pattern of design, construction, and maintenance shortcomings. He notes that by the time of the February 2017 spillway releases, the gated spillway had likely become heavily undermined and its subgrade eroded by previous flood releases. Bea asks a key question in his analysis: "Why did DWR and the responsible State and Federal regulatory agencies (DWR Division of Safety of Dams and FERC) allow these root causes to develop and persist during the almost 50-year lifespan of the gated spillway?"[86] Using his experience analyzing past failures in infrastructure, Bea concludes that it is likely that the "wrong standards and guidelines are being used to requalify many critical infrastructure systems for continued service."[87]


**Oroville Forensics.** Bea points out the many cracks on the surface of the spillway, as well as trees growing too close to the edge of the structure in this 2010 satellite image (left). Bea believes a hidden drain pipe proved the critical weakness along the spillway (right). *Image source: Bea, Root Causes Analysis, using GoogleEarthPro and DWR images.*

## Other Known Incidents at the Oroville Facilities that Might Merit More Review

The forensics groups that formed because of the Oroville spillways incident put a series of highly visible spillway design and inspection problems into the national headlines, but there have been previous incidents at the Oroville Facilities. In 2009, there was a serious incident in the river-valve outlet chamber.[88] An energy dispersion ring, designed by the U.S. Bureau of Reclamation and installed when the powerhouse was constructed, had been damaged in 1968 and ultimately removed in the spring of 2009. The importance of its presence for safe operations of the valve had been confirmed by U.C. Davis engineers in a DWR-commissioned study that began in the early 1990s.[89] In spite of this, later in 2009 workers were ordered to test the system by fully opening the valves, resulting in vacuum pressures that detached a break-away wall, seriously injuring one worker and endangering others in the chamber.[90] The valve system and control functions have been refurbished, but operating restrictions preventing its full design use indicate that a new energy dispersion ring has not yet been installed. Downstream in November 2012, the Ronald B. Robie (Thermalito) pumping/generating plant at the Oroville Facilities was destroyed by fire.[91] It has not yet been fully reconstructed.

**The Oroville Incident, Feb. 2017.** As the Oroville Reservoir main spillwaycrumbles, mud, rocks and concrete flow in to the Feather River on February 8,2017. *Source: Bill Husa, Chico Enterprise-Record.*

# Lessons to be Learned and Recommendations

## Currently constructed flood and water management systems

are built on lessons learned and relearned from the past. For example, the first failed dams in the early 1900s on the Colorado River created the incentive for engineering advances that led to the construction of 726-foot-tall Hoover Dam in 1935. More recently, a levee breach on the Cosumnes River created the "Accidental Forest" and, following research and education, revealed a wealth of benefits from reconnected floodplains.

Analysis of the Oroville spillway incident will contribute its own expansion of knowledge and experience. Insights from Oroville will be valuable, not only for understanding the causes of the spillway failures and means to reduce such risks in the future, but for a variety of applications in water resources management and community interaction with flood-control and hydropower projects.

The following four "take-away" lessons provide a framework for ongoing learning from the Oroville Dam spillway incident of 2017.

**Damaged Main Spillway, Feb. 27, 2017.** An aerial view of the damaged main spillway and resulting debris field. Flows were reduced from 50,000 cfs to zero on Feb. 27 to allow reduction of the water elevation in the diversion pool, removal of debris, and re-initiation of power generation at the Edward Hyatt powerhouse. *Source: Dale Kolke, DWR.*

| Lesson | Recommendations Summary |
| --- | --- |
| California's dam infrastructure is aging and needs to meet modern standards | • Complete planned reconstruction of the main Oroville spillway and relocation of powerline transmission towers and lines.<br>• Plan a real auxiliary/emergency spillway that does not risk large quantities of hillside soil and rock being eroded into the Feather River.<br>• Conduct a thorough review of the Oroville Dam complex's physical deficiencies and undertake appropriate upgrades.<br>• Systematically inspect dams across California and the U.S. to meet upgraded design and maintenance standards and procedures. |
| Dam operations need periodic reviews | • Update flood-control manuals for the Feather and Yuba River Basins.<br>• Re-evaluate the duration and character of floods modeled to exist in the future and make necessary modifications.<br>• Provide public involvement in the manual update process.<br>• Require the Army Corps to review and update flood manuals for all jurisdictional dams on a defined schedule.<br>• Require FERC to include dam safety in hydropower relicensing. |
| Floodplain capacity is limiting flood protection, environmental quality, and local economies | • Fund and implement the Central Valley Flood Protection Plan.<br>• Assemble diverse stakeholders to define and plan floodplain improvements.<br>• Evaluate and design multi-benefit floodplain projects (e.g., setback levees) that increase flood protection while creating more floodplain habitat.<br>• Develop and implement plans to create greater floodway and floodplain capacity in the San Joaquin Basin. |
| People and communities matter | • Complete forensic investigations and release to the public.<br>• Conduct comprehensive assessment of impacts to the Oroville and adjacent communities from 2017 spillway incidents.<br>• Establish new opportunities for mitigation and community development.<br>• Develop and make public new inundation maps and Emergency Action Plans.<br>• Reform the relationships between out-of-area water developers and local communities to create partnerships based on equality, fairness, and respect. |

# California's Dam Infrastructure is Aging and Needs to Meet Modern Standards

## The Oroville spillway incident revealed serious shortfalls

in the Oroville Dam Complex's ability to accomplish its missions safely. The shortfalls go back to design, increasing age, insufficient maintenance, and failure to re-examine the dam complex with a fresh and modern engineering eye.

Although the forensic investigations have only reached preliminary conclusions, most of the candidate failure mechanisms (e.g. drainage problems, thin concrete, and insufficient anchoring) go back to initial design and construction choices. And yet many of these problems tend to get worse with time. Maintenance issues, such as incomplete repair of concrete cracks, can increase vulnerabilities of the concrete to cavitation and can allow spillway flows to reach erodible foundations below the spillway.

**Main Spillway Erosion:** A view of the erosion cavity at the Oroville main spillway – an infrastructural failure combining design, construction and maintenance issues. May 1, 2017. *Source: Mike Burns, DWR.*

The main spillway break and the extent of the hillside erosion near and below it demonstrated errors in previous geotechnical assessments. In the case of the emergency spillway, erroneous assessments may have nearly led to the catastrophic loss of the upper part of the reservoir. Yet post-assessment commentary by geologists (and plant ecologists looking at the generously vegetated hillside) expresses a degree of bewilderment regarding why this broken, battered, and weathered geologic unit should have ever been expected to resist high energy flows passing over it.[92]

## Reconstruction on a Tight Timeline

DWR has announced that it intends to rebuild the main spillway with an eye to addressing all the identified candidate failure mechanisms. This approach is necessary because the results of the forensic reviews won't be complete until after most of the 2017 construction season. The reconstruction of the main spillway and its foundations and work expected on the emergency spillway hilltop require a fast pace so that the main spillway can be operational and a cutoff wall below the emergency spillway in place before the next flood season. Tight construction deadlines are likely to lead to compromises in the extent of foundation work, quality of roller-compacted concrete, and the various concretes that are intended to be placed at the Oroville Facilities. Thus, shortcomings in design, inspections, and construction quality may be inevitable.

As noted earlier, DWR's plans for improving the emergency spillway do not include a concrete spillway to prevent mobilization of erodible hillside soil and rock.

# Recommendations for Oroville Spillway Reconstruction

1. DWR should proceed with reconstruction of the main spillway to address all potential failure mechanisms.

2. DWR should proceed with relocation of Oroville Dam complex powerline transmission towers and any PG&E lines to avoid hillside erosion from use of a broken main spillway or a native hillside spillway.

3. DWR should construct a functional auxiliary/emergency spillway since the Corps of Engineers requires that the emergency spillway be used to conduct ordinary flood-control operations in circumstances where the reservoir fills. Mobilizing large quantities of hillside soil and rock into the Feather River afterbay/forebay channel downstream creates considerable havoc for project operations and environmental resources and also creates some risk of uncontrolled erosion that could threaten a sudden release of part of the reservoir.

4. If DWR and its regulators are unwilling to order a complete concrete auxiliary/emergency spillway, then the Corps or FERC (or DWR on its own initiative) should establish a larger reservoir flood-control reservation and require any necessary augmenting to, or deepening or enlarging of, the main spillway headworks so that DWR can properly utilize the flood-control space.

5. DWR and its regulators should conduct a thorough review of the dam complex's physical deficiencies and undertake appropriate upgrades. A non-exhaustive list of issues for this review includes the following: multiple redundant power supplies to the dam complex's operational features; warning systems; a fully operational river valve outlet system; features to keep the powerhouse capable of making releases; remediation of cracking concrete and differential settlement on the main spillway's headworks and bridge; and investigation of potential water seepage through the dam.

6. DWR and its regulators should strive to maintain high standards of design investigations, design, construction, and inspections for this reconstruction. Material samples and good documentation should be preserved for all of these elements. Future engineers must have enough information on any issues that may develop at the reconstructed Oroville Facilities that require attention or even reconstruction when there is more time to make informed decisions, deploy better materials, and sequence construction.

# A Wider View

The Oroville incident highlights the need to act now to maintain and upgrade California's and the nation's dam infrastructure. The average age of the country's 90,580 dams is 56 years, with 15,500 dams deemed "high-hazard potential dams."[93] The American Society of Civil Engineers (ASCE) gave the country's dams an average grade of "D" and estimated a funding need of at least $45 billion to repair critical aging high-hazard dams.

**Isabella Dam on the Kern River gets a major seismic upgrade** by the Army Corps of Engineers to reduce the risk of dam failure.
*Source: www.wikiwand.com/en/Isabella_Dam*

Faced with the serious consequences of neglect, California's dam operators need to reinvest in maintenance, repair, reconstruction, and management of *existing* water and flood dam infrastructure. In addition to making this infrastructure safer and more resilient, there are numerous opportunities for improvements to existing infrastructure, such as the addition of low-level spillways and other flood release works. Improvements can address a number of opportunities, such as the following: enhance effective flood storage capacity, reduce peak flood levels, mitigate environmental impacts, or provide a back-up insurance policy when existing project works malfunction or fail.

## Beyond Oroville

Oroville Dam is far from having the only aging dam infrastructure that has problems or is in need of improvements. The U.S. Bureau of Reclamation's Folsom Dam is currently undergoing a $1.3 billion upgrade. The authorized work at Folsom will: improve its seismic safety and flood-control performance; increase its spillway capacity to handle modern assessments of hypothetical extreme floods ("PMFs") that are used in the U.S. and other countries to size spillways; address inadequacies related to static loading (reservoir weight/pressure against the concrete dam structure); increase the effective size of the flood pool; and install more effective powerhouse inlets that provide better water temperatures to downstream fisheries.

The Corps of Engineers recently (2004) rebuilt the spillway infrastructure at Terminus Dam on the Kaweah River so that the hypothetical flows in a newly assessed PMF there would not endanger the dam.[94] The Corps is also giving Isabella Dam on the Kern River a major seismic upgrade after imposing reservoir-level controls to reduce the risk of dam failure.[95]

The Corps of Engineers has a webpage graphic devoted to its assessments of seismic, over-topping, and seepage failure risks. Regrettably, the page does not appear to be regularly updated, but as of December 2013, ten of its dams (including Isabella Dam) in or affecting the Central Valley were conditionally, potentially, or confirmed unsafe. Reconstruction of these dams is identified as high priority, urgent, or urgent and compelling. [96]

Engineering judgments about seismic safety can vary with time, even prompting internal and public controversy. The Corps' Success Dam on the Tule River is built on sediments that the Corps warned could liquefy and cause dam failure, according to their own seismic analysis initiated in 1992. In 2006, the Corps imposed locally unpopular operating restrictions on the dam to prevent it from filling. In 2014, on the basis of another analysis, the operating restrictions were eliminated, and in 2017, the Corps even approved the placement of sandbags on the spillway to allow the reservoir to overfill.[97]

It is important to note that there are also dams not owned by the Corps of Engineers that have known or suspected serious potential problems (mostly seismic), but for which final engineering assessments have not been completed. Thus, they have neither undergone refit nor had operating restrictions imposed to reduce the risk of dam failure. These include the U.S. Bureau of Reclamation's giant San Luis Dam and DWR's Clifton Court Forebay. Reclamation's giant Trinity Dam has outlet works that could be compromised by landslides from seismic events. It also lacks an emergency spillway. [98] DWR, as a result of an order from Governor Jerry Brown, is conducting a spillway review of State Water Project facilities, beginning with Pyramid Dam's gated spillway. The Governor has also proposed legislation to increase the level of inspections for the some 1,200 dams under the jurisdiction of DWR's Division of Safety of Dams (DSOD).[99]

Spillway reviews seem to be the current focus. For example, although the detailed orders and any findings are unavailable to the public because they are classified as CEII, FERC's Division of Dam Safety and Inspections has been ordering a large number of dam and spillway inspections throughout California as a direct result of the Oroville Dam spillway incident.[100] DWR's Division of Safety of Dams has ordered spillway inspections of 93 dams after a preliminary review.[101]

## Flood Protection Improvements at New Bullards Bar Dam

Yuba County Water Agency (YCWA) plans to construct two new features at its New Bullards Bar Project that will improve capacity to reduce peak flood levels in the Yuba River and lower Feather River. YCWA's application for a new FERC license describes:

- A Flood Control Outlet at New Bullards Bar Dam (estimated cost of $126M), which would release up to 66,000 cfs during the lead-up to the largest inflows. In combination with the existing spillway, the new infrastructure will double total spill capacity and make the 17% of the reservoir devoted to flood-control space more effective.
- A Tailwater Depression System at New Colgate Powerhouse (estimated cost of $12M), which will allow the facility's hydroelectric turbines to continuously discharge up to 3,500 cfs throughout high flow events and thus further contribute to flood storage space.

YCWA will pay for its new infrastructure with hydropower revenues. The new works will contribute additional capacity for flood management under the Forecast-Coordinated Operations for the Feather and Yuba Rivers.

*For more, see http://www.ycwa.com/the-ycwa/flood-management/forecast-coordinated-operations/*

## Dam-safety Institutions Matter

But a wider focus is also important. Dam-safety regulators need to confront and correct their failures at Oroville Dam, and presumably at other dams across the country too. The Sacramento Bee reported a noteworthy set of remarks at a conference of the American Society of Civil Engineers in Sacramento after the spillway incident. According to the Bee, Regional Engineer Frank Blackett of FERC's Division of Safety of Dams and Inspections:

> listed the array of state and federal inspectors who visited Oroville Dam over the years. All of them, he said, missed signs that could have foreshadowed the gaping crater forming in the dam's concrete spillway in early February, eventually leading to the frantic evacuation of 188,000 people.…

The Bee also noted that '[i]n 2014, an inspection "actually dismissed the plausibility" of failures arising from erosion at the emergency spillway "or a failure of the concrete chute" in the main spillway, said Mark Andersen, a DWR acting deputy director. "So clearly ... we need to look institutionally at how we are doing these inspections and what we're learning from them," Andersen said.'[102]

## Paying for It

And there is always the question of money. Owners of dams clearly have a responsibility to have the financial wherewithal to undertake routine maintenance and inspections and to implement any necessary changes, repairs, or even major reconstructions that are identified by the owners or dam-safety officials. Dams are expensive to own and operate and, in some cases, very costly to remove responsibly. The beneficiaries of dams need to recognize that with the benefits there are costs that they must assume. Unsafe dams are unacceptable; so is a financial strategy of hoping that general taxpayers will assume the financial burdens of dam maintenance, rehabilitation, reconstruction, and liabilities.

Finally, California's dam owners should also view the Oroville Dam spillway incident as a wake-up call regarding the need to identify and implement a suite of necessary infrastructure improvements for their dams. Dam owners can make some of these improvements as part of facility relicensing processes, as Yuba County Water Agency has elected to do at New Bullards Bar Reservoir (see sidebox, previous page).

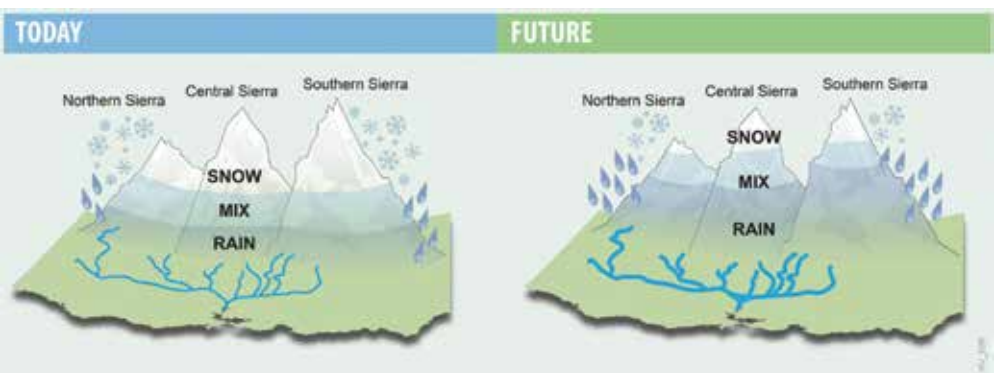
**Contractors remove sediment and debris from the Feather River below the damaged main spillway.** Photo taken on March 9, 2017. Approximately 715,000 cubic yards of material were removed from the debris pile by this date. *Source: Dale Kolke/ California Department of Water Resources.*

## California's climate is the most naturally variable climate

in North America, with alternating periods of dry and wet years and extreme cases of both.[103] California's climate fluctuations are anticipated to become even greater as global temperatures rise from climate change. Higher temperatures cause precipitation to arrive as rain instead of snow and cause snowpacks to melt quickly.

# Dam Operations Need Periodic Reviews

Fortunately, planners designed Sacramento Valley dams and reservoirs with flood-control responsibilities to handle very large runoff events. Many Sacramento Valley dams, including Oroville, can successfully prevent damaging flood releases for runoff events greater than those that have occurred in the historic record. And yet the trend of higher temperatures, which can mean wetter storms, make a case for updating and optimizing flood-control operations.[104]




**A Changing California Climate.** Projections include intensified extreme precipitation events, with more rain and less snow, and more rapid snowmelt. *Source: CVFPP 2017 Update*

## Flood Manuals Matter

Minimum flood-control operations are usually governed by U.S. Army Corps of Engineers flood-control manuals.[105] These manuals prescribe the seasons of flood operations, how much and when reservoir empty space in reservoirs is required, how much to release, and when to transition from managed flood-control releases to dam-safety releases designed to prevent dam failure rather than to prevent levee-break flooding downstream.

The use of the Oroville Dam emergency spillway and its near failure was not a failure of the Corps flood-control manual. Rather, it resulted from the filling of the reservoir when DWR made an emergency departure from the flood-control manual and limited releases while officials inspected the broken spillway.

Nevertheless, the Yuba and Feather River Basin manuals (one for New Bullards Dam, the other for Oroville Dam) are in need of major updates. These manuals were created in 1972 and 1970 respectively and assumed the construction of a major additional dam on the Yuba River. Operations for floods that could be regulated and would have to use the emergency spillway get but one paragraph and one chart in the Oroville Dam manual. Also, these manuals expect coordination with each other's dam operators but provide little direction on how to do this.

Updates to the flood-control manuals for the Feather and Yuba rivers have been contemplated for decades, but no obvious progress has been made. The following recommendations should guide the long-overdue updates of these manuals.

# Recommendations for the Yuba-Feather Basin Flood-control Manuals

1. The Oroville Dam manual should not assume that a Marysville Dam exists. The existing manual in large part does, making the emergency spillway release diagram out of date.[106]

2. The new Oroville Dam manual's design flood should assume surcharge operations for the purpose of controlling the Reservoir Design-Flood (the largest inflow the dam is expected to successfully regulate for flood-control purposes) as it does now. [107]

3. If surcharge operations remain unsafe because of lack of a full emergency spillway, the new manual for Oroville should require interim operational mitigation measures such as a larger below-spillway flood reservation.

4. The Oroville Dam Emergency Spillway Release Diagram and rules should carefully address transitioning from reservoir design floods to dam-safety spillway design floods, especially if surcharge operations remain an operational feature of the manual.[108]

5. The Oroville and New Bullards Bar manuals should address circumstances such as those that occurred in 1997 when levees in the system were known to be unable to reliably accommodate their design flows.

6. The manuals should re-evaluate the duration and character of floods modeled to exist in the future and make necessary modifications within the authority of the Corps and the dams' owners.[109]

7. Forecast-influenced operations for both reservoirs should implement early releases, such as those DWR made in 1997, to more easily manage very high inflows.[110]

8. The two manuals should expect and provide guidance for coordinated operations between Oroville and New Bullards Dams.

9. The manuals should emphasize the importance of competent physical works needed to accomplish operational requirements.

10. The manuals should emphasize the importance of preserving flood-control space in the reservoirs.

11. Periodic (perhaps decadal) reviews should be required, and the Corps should revise or reissue manuals when new infrastructure alleviates spillway constraints (e.g. YCWA's proposed new spillways at New Bullards Bar).

12. Environmental impacts of floodwater management operations should be reviewed and feasible mitigation implemented.

13. A major Sacramento River Basin flood-control manual, the manual for Folsom Dam, is in the last stages of completion. The manuals for Oroville and New Bullards Bar dams should draw on the new Folsom Dam manual substantively and thematically as appropriate.

# A Wider View

The operations of the reservoirs in the Yuba and Feather watersheds are not alone in needing review. Forecast-influenced operations offer some promise of mitigating some of the impacts of a warming earth and sky. If coordinated well with available capacity in downstream floodways, early releases can improve current floodwater-management performance. Conditional storage in flood reservations can improve water-supply performance and not impair floodwater-management performance if dam operators have the capability and obligation to safely and reliably release excess water when meteorological conditions dictate.

San Joaquin Basin reservoirs, unlike Sacramento Basin reservoirs, manage two different kinds of floods: rainfloods (from rain) and spring/early summer snowmelt floods. But it's rainfloods that have the planners' focus.

It is likely that in the future, very heavy rainfall will reach higher elevations than it has historically, increasing the magnitude of immediate runoff.[111] Unfortunately, unlike in the Sacramento River Basin, flood releases from major reservoirs above the San Joaquin Valley are highly constrained by floodways that have capacities much smaller than potential reservoir inflows.[112] This is reflected in the physical infrastructure of the large dams in the basin: their low-level outlet capabilities are limited, and their spillways can only make large releases when reservoir levels are high. This means that many San Joaquin Basin dams cannot make an early release much in excess of their constrained floodways before their flood pools are encroached, limiting their capacity to take full advantage of forecast-influenced operations and increasing their chances of filling and spilling large inflows.

## The Tale of Two Floods

Governor Wilson's 1997 Flood Emergency Action Team recommended studies to increase maximum controlled flood flows in the lower Tuolumne River from 9,000 cfs to 20,000 cfs to better control reservoir levels at Don Pedro Reservoir and reduce the frequency and volume of spills from both rainfloods and snowmelt floods.[113] If all of its low-level outlets are functioning, a 20,000 cfs outflow is close to their capacity and easily within the capacity of the spillway gates if the reservoir has risen to within thirty feet of the normal maximum level. [114] The recommendation has not been implemented—until this year, although just as a trial.

Flows leaving the damaged Oroville Main Spillway enter the diversion pool of the Feather River, April 14, 2017. *Source: Kelly M. Grow, DWR.*

The lessons of these two flood years are best described as the tale of two floods. In 1997, following the existing manual,[115] operators were unable to prevent Don Pedro Reservoir from slowly encroaching into its required flood-control space while they kept flows below the 9,000 cfs target in Modesto. But that meant that when heavy rains continued the reservoir filled and then spilled a damaging 50,000 cfs.[116] In 2017, when reservoir operators were faced with a nearly full reservoir they expected to fill and spill, they requested and received special permission from the Corps of Engineers to exceed the 9,000 cfs downstream flow target. Operators released 18,000 cfs, declining to 16,000 and 14,500 cfs for six days. Reservoir operators calculated that without those special releases, the reservoir would have spilled over the unlined emergency spillway hillside at 31,000 cfs.[117] The trial worked. The 2017 flood release was less damaging than the one in 1997.

## Risking it

There are also some cautionary lessons from the Oroville spillway incident and this year's operational experience. Based on historical runoff events, the operators at the major dam to the south of Don Pedro, the New Exchequer Dam, have proposed to reduce their flood-control space and to wall off much of their emergency spillway since they calculate that neither is needed. They have not proposed to expand their downstream floodway, something that could mitigate for their proposed loss of reservoir flood-control space. They propose to route any flood flows that might have required the use of their emergency spillway through their gated spillway based on the assumption that the gates will always operate properly.

These conceptual ideas have garnered much local popular support. However, they have not been presented to flood-management and dam-safety officials, who are unlikely to find them prudent in confronting a warmer world where infrastructure redundancy is an increasingly important requirement for dam safety.[118]

## Tough Choices

Given the challenges of floodwater management in the San Joaquin River Basin, it is fortunate that many cities, such as most of Modesto, are on comparatively high ground and are not menaced by full reservoirs with high inflows. For lands and the few smaller communities in the basin not on higher ground, changes in reservoir management can only offer limited protection since operators of reservoirs with small downstream floodways will still encounter weather conditions when they are unable to prevent these reservoirs from being significantly encroached—and often for long periods—during the flood season.

In the end, climate reality will require floodplain management … to accommodate inevitable flooding in the appropriate unpopulated places.

Changes in reservoir management can be difficult. For example, larger flood reservations are not popular with the owners of San Joaquin River Basin dams, who can and often do place a higher priority on water deliveries than better floodwater management. And dam owners usually avoid working for larger floodways and dedicated floodplains, which involve costs and the necessity to work with governments with land-use powers and many individual landowners.

Still, to mitigate the effects of climate change, DWR is modeling combinations of larger objective releases, forecast-influenced operations, forecast-coordinated operations, and groundwater-recharge operations accompanied by larger flood reservations.[119] For in the end, climate reality will require floodplain management and land management actions in the San Joaquin Valley to accommodate inevitable flooding in the appropriate unpopulated places.[120]

# Reforms that Require Federal Action

1. FERC needs to modernize the relicensing process so that it evaluates project effects in the context of present and future climate variation. FERC relicensing proceedings do not currently require study and mitigation of hydrological conditions under changed climate conditions. The events at Oroville should motivate FERC to change this policy.

2. At present, FERC relicensing presents one of the few opportunities for the public and resource agencies to advocate for improvements to dam operations. FERC needs to expand its existing relicensing process to include consideration of dam safety and flood-control operations. Within this expansion, FERC needs to sort through how it will meaningfully allow discussion and evaluation of dam safety and flood control in relicensing in the context of CEII constraints.

3. The Army Corps should establish scheduled, recurring reviews of flood-control operations at all its dams, with opportunities for public input and participation similar to those that FERC relicensing provides. One option is for any new flood-control manual to explicitly define within it the required substance, timeline, and process of periodic reviews of the manual.

4. The Corps, DWR, and dam operators need to find a way to increase flood-space requirements or practices in watersheds with limited flood reservations and as recommended in the Central Valley Flood Protection Plan or its Basin-Wide Feasibility Studies.

5. The federal government needs to advance weather forecast technology with applied research and tools as a matter of public safety. The federal government should increase funding to improve forecasting technology and should expand programs that incorporate and develop climate research programs such as those at the National Oceanic and Atmospheric Administration and the National Weather Service.

# Dam Management Recommendations for the San Joaquin Basin

1. San Joaquin flood managers should explore more formal adoption of forecast-influenced operations, recognizing that floodway and downstream floodplain capacity constraints, as well as the distance to the ocean, make revisions to manuals less beneficial than for Sacramento Valley reservoirs.

2. Coordinated operations among reservoirs are important in this basin since the San Joaquin River has, in a formal sense, less floodway capacity than its tributaries. Manuals should provide guidance on such coordinated operations, including recommendations on how to prioritize and make tough decisions.

3. As with manuals in the Sacramento watershed, the new San Joaquin manuals should provide some direction on how dam operators should respond to impairments to downstream infrastructure.

4. The manuals should re-evaluate the character of expected rain and snowmelt floods.

5. Provisions should be explicit for updating manuals as conditions change. Updates should not be opportunities to reduce floodwater management performance of dams.

6. New manuals should consider provisions for making releases greater than current objective releases to avoid reservoir-filling events that may result in still larger releases. The varying degrees of vulnerable infrastructure downstream should help to provide a framework for this kind of adjustments to manuals. Dam operators and owners must be sure that people downstream understand the potential consequences of larger but necessary releases in the future.

7. New manuals should emphasize the importance of the full range of dam outlet infrastructure (river outlets, powerhouses, gated and ungated spillways). Dam infrastructure that historically has seen only rare or occasional use will likely see more use in a warmer world.

## Alongside the Sacramento River and Feather River

are low-lying lands that are a relict from the low sea levels of the ice ages. These basins are the backbone of the Sacramento Valley's flood-control system, including what flood-control engineers call bypasses, and they are accommodating far more flood flows than the Sacramento River itself.

# Floodplain Capacity is Limiting Flood Protection, Environmental Quality, and Local Economies

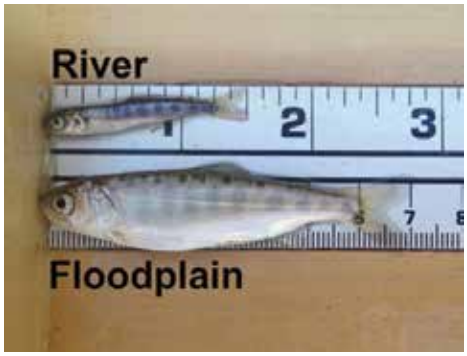
But some of these flood basins are also places located behind the Valley's extensive levee system, where farms and cities are situated. Although some of these basins can be protected, the geographic reality is that they will always be vulnerable to some risk of catastrophic flooding. Planning for recovery from flooding (both financial and how best to rebuild or relocate) should be part of the way of life for these areas.

There has been an additional cost to the "reclamation" of the Valley. Functional floodplains provide an example of how nature functions as a series of inter-related systems. Floodplains do much more than provide storage areas for high flows. While holding high floodwaters, floodplains recharge groundwater, provide exceptional fish habitat, generate healthy riparian forests, and filter water for measurable water quality benefits.

Today, levees disconnect many of our rivers from their floodplains. Reduction of natural seasonal floodplain inundation has resulted in serious impacts to ecological communities. Disconnecting floodplains has contributed to the extinction risk for native fishes and has vastly reduced the regeneration of the sycamore and valley oak trees that historically grew in expansive groves.

The Corps of Engineers and the Central Valley Flood Protection Board (formerly the Reclamation Board), along with local reclamation and levee districts, other local governments, and ultimately, the taxpayers, are responsible for the design, maintenance, rehabilitation, and improvements of the Sacramento and San Joaquin River Basin flood-control systems.

Increasingly, the state's Central Valley Flood Protection Board and DWR have become responsible for planning in this system, rather than the Army Corps of Engineers. Major improvements are planned in the Sacramento Valley, with the centerpiece being an expansion of the Yolo Bypass and the weirs that allow Feather River/Sutter Bypass and American River flood flows into the Yolo Basin Bypass. This is expected to lower flood flow stages (water levels) significantly in the Feather River Basin, in addition to augmenting the capacity of the Sacramento River flood-protection system. Habitat improvements within the footprint of the Valley flood-control systems are also contemplated.




**Floodplain Benefits.** Two images showing some of the many floodplain benefits, including food sources for: (1) Snow geese over Sacramento valley wetlands. *Source: Brocken Inaglory, Wikimedia Commons.* (2) "Floodplain fatties" – juvenile Chinook salmon from the Feather River (top) and Knaggs Ranch floodplain habitat (bottom) Feb. 23, 2014. *Source: CalTrout.*

# Feather River Basin - A Leader

Levees surround both the Feather and Yuba rivers; but unlike the levees along the rivers in the San Joaquin River Basin and along much of the Sacramento River, the levees along the Feather and Yuba are set back from the river channels. Setting back levees protects them somewhat from erosive flows and allows the Feather and Yuba rivers to convey volumes of floodwater that could otherwise overtop Oroville and New Bullards Bar dams.

That said, river flows found their way through or under the levees in the great floods of the last half of the twentieth century. In response, local, state, and federal agencies have worked together, often in collaboration with environmental groups, to modify the system. Indeed, this is the only basin where significant relocations of "project" levees have occurred.[121] Two river bends, Star and Shanghai, have been widened (straightened). The lower Bear River levees near the confluence with the Feather River, along with levees along a reach of the Feather River, have been set back.

> We will never be able to restore endangered salmon populations if we don't first restore the floodplains which feed them.
>
> *Jacob Katz, Central Valley Senior Scientist, Ph.D., CalTrout*

In addition, many miles of levees have been stabilized with slurry walls, drainage systems, and supporting embankments. This work has increased system reliability. These levee and other flood-control improvements didn't come about without major engagement among flood-control officials, interested environmental groups, and the commitment of public and sometimes other funds.

A good example of collaboration followed the 1997 flood and involved engagement by flood-control agencies, DWR, CALFED agencies, and environmental groups to examine how to improve flood control along with the river environment. Known as the Yuba-Feather River Workgroup, it

The Bear River Setback Levee provides 625 acres if restored floodplain area. *Source Eric Ginney / Zeke Lunder.*

cast the net wide: it evaluated dam improvements, levee setbacks, and shoring up existing levees. All the improvements that have been constructed and most of those still on the drawing boards were identified, probed, and discussed at the workgroup. The physical deficiencies at Oroville Dam were not left out of the discussions either.

The Workgroup faded away as projects shifted to more intense planning, design, and construction, and when some participants were unsuccessful in persuading others to recognize and fix the problems at Oroville Dam. But the working relationships among these and other parties have continued through the years, particularly as the Central Valley Flood Protection Board fashioned its 2012 Central Valley Flood Protection Plan and its 2017 update. These plans feature multi-benefit projects (flood protection, recreation, groundwater recharge, and environmental) to improve the backbone of the mainstem river levee and bypass system.

Inundated orchard in the Feather River floodplain and new sediment deposits, March 2017. *Source: J. Stone, Nor-Cal Guides & Sportsmen Assoc.*

In considering recommendations for flood control, floodplain improvements, and land-use planning, the difficulty is as much in defining the actors that need to make these improvements as what the improvements must be. DWR is the entity that needs to repair and improve the spillways at Oroville Dam. However, in the floodways downstream, there are overlapping jurisdictions, diverse landowners, and wide-ranging interests. While some individual entities have defined roles and responsibilities in the floodways, there would be substantial benefit and efficiency if multiple entities acted together in coordination to define and implement improvements.

Flood-protection and environmental problems require long and persistent personal engagement. When regulatory roles and responsibilities are not clearly defined, it is often individuals with longstanding personal relationships that conceive, design and implement projects. Whether a new forum or venue for coordination defines itself as a successor to the Yuba-Feather Workgroup, there are many opportunities for productive collaboration in the watershed. Recent pilot experiments in rearing juvenile salmon in the upper Yolo Bypass should be of particular interest to environmental and fisheries advocates working on the Feather and Yuba rivers.[122]

# Floodplains Provide Multiple Benefits

Restoring "natural flood protection infrastructure" by reconnecting rivers and floodplains also restores myriad other key benefits like recharged groundwater, wetlands for native species, recreational space, and clean filtered water. Examples of such multi-benefit flood-management solutions include:

## The Yolo Bypass

Yolo Bypass, Feb. 23, 2017. *Source: Steve Matarano, USFWS.*

The recent events at Oroville dam highlight the vital role of the Yolo Bypass for the Sacramento area. Managed as a designated flood basin since 1926 when the Sacramento Weir was completed, the Yolo Bypass is a 59,000-acre floodway that includes 70,000 acres of farmland and wildlife areas. Releasing Sacramento River water into the bypass, which can take up to 80% of flood flows, diverts floodwaters around the city of Sacramento. Instead, floodwaters flow towards undeveloped farmlands. Flooding of these lands results in vast wetlands whose massive plankton and insect blooms feed diverse waterfowl and native fish species.. The 16,600-acre Yolo Bypass Wildlife Area is a haven for waterfowl, shorebirds, wading birds, neo-tropical migratory birds, raptors, invertebrates, snakes, turtles, toads, and bats. During winter floods, juvenile salmon and splittail thrive in the productive habitats of the Yolo Bypass.

## Feather River Setback Levees

The Feather River Setback Levee. *Source: Eric Ginney / Zeke Lunder.*

The Feather River Setback Levee helped further local Yuba County flood-management goals and larger regional flood protection by widening the Feather River floodway and creating nearly 1,500 acres of riparian floodplain habitat for fish and wildlife. Completed in 2010, the levee improvement projects consist of three different segments, with the bulk of the project's $192 million cost paid by DWR ($138.5 million), and Yuba County. Yuba County Water Agency, Reclamation District 784, and one local landowner partnered to provide $53.3 million in local funding.

# Recommendations for the Yuba-Feather Basin

1. The state and federal governments and other responsible entities need to fund and implement the Central Valley Flood Protection Plan. The Flood Plan represents a commonly held vision of improvements of the flood-control system.

2. Land-use planners need to understand the Flood Plan, including many elements that focus on how to keep unwise development from impairing the flood-control system or future improvements.

3. Diverse entities need to recognize and address the flood-safety issues in the Feather-Yuba Basin that are not yet addressed in the Flood Plan and its first update. Not yet included in the Plan are improvements to physical facilities of dams, improvements to levees on tributaries of the Sacramento, and real specifics on updates to flood manuals.

4. Public and private funders need to provide financial support for planning processes that will improve the flood-control, groundwater recharge, and fish and wildlife functions of floodplains in the Feather-Yuba watershed.

5. Diverse entities need to embrace and collaborate on floodplain projects that have multiple benefits. They need to plan work in the basin that involves a mix of strengthen-in-place levee improvements, levee relocations, and even new levees from time to time. We also need to design and implement projects (e.g., setback levees) that increase flood protection while creating more floodplain habitat. A good beginning would be expansion of the floodplain in the Oroville Wildlife Area and implementation of actions identified in the Lower Feather River Corridor Management Plan.[123]

6. All stakeholders in the Basin need to have realistic conversations that honestly recognize how low-lying flood basins will always be subject to some risk of flooding. Floodplain management is not just what happens within floodway corridors: it is what happens behind the levees, whether the land is in the official federal and state floodplains or not. This implicates how, what, and where one builds; public awareness and emergency management; financial arrangements for recovery; and the nature of that recovery.

# The Wider View - The San Joaquin Basin

Floodway corridors in the San Joaquin Basin are small fractions of their natural corridors. This is because of the relative rarity of very large rainfloods in the San Joaquin River Basin, the desire to reclaim for agriculture the greatest amount of ground possible, and the relative absence of large cities exposed to riverine flooding from the larger rivers. In major rain years with large inflows to reservoirs, flood-control reservoirs in the San Joaquin Basin have difficulty maintaining their flood-control reservations because downstream flood releases are so constrained (once full, they take a long time to empty). This inability to maintain flood reservations means that reservoir-based floodwater management in the San Joaquin Basin is far less reliable than in the Sacramento Basin.[124]

Consequently, the San Joaquin system is generally designed with smaller flood corridors and accommodates large floods in low-lying floodplains. These floodplains recharge groundwaters while they slowly move downriver, past the Delta cities to the state and federal pumps or into Suisun Bay.

The environmental benefits of these flood-prone lands have been recognized by state and federal wildlife agencies, which have created wildlife refuges or hold development easements on these lands. Non-governmental organizations, from environmental groups to private hunting clubs, also hold interests in these lands. Clearly there are multiple benefits to land uses that keep people and damageable property out of harm's way.

## Recommendations for the San Joaquin River Basin

1. The state and federal governments and other responsible entities need to fund and implement the Central Valley Flood Protection Plan's recommendations for flood management improvements.
2. Flood planners and land-use planners must make the necessary arrangements to make floodway floodplain expansions feasible. This means that land-use activities must be compatible with occasional and increasingly more frequent flooding as the atmosphere warms during the coming decades
3. Diverse entities should work with the Central Valley Flood Protection Board in future plans to identify promising or necessary floodwater and floodplain management actions.

Potential improvements in the San Joaquin Basin vary just as the river reaches vary. The Central Valley Flood Protection Plan recommends a levee setback and new ring levee to protect the City of Firebaugh. It also recommends a small San Joaquin River floodwater bypass in the lower Delta to improve conveyance in the mainstem. These recommendations are more important in light of the lessons from Oroville.

Oroville and the Feather River Basin demonstrate the importance of generously-sized floodways. In comparison to the San Joaquin River Basin, Oroville Dam's operators had a lot of flexibility to shut off flood releases and then make huge flood releases with relatively little concern that high releases could not be accommodated downstream. As a result, the reservoir recovered from encroachment in several days, something that in the San Joaquin Basin could take weeks to months.

From the perspective of improved floodwater management, enlarging the small floodways in the San Joaquin would be a desirable focus in many watersheds here.[125] Although the Central Valley Flood Protection Plan does not focus on expansion of tributary flow capabilities to the mainstem San Joaquin River for cost reasons, its Basin-Wide Feasibility Study does demonstrate the floodwater-management value in the ability to make more competent flood releases.[126]

Other relevant lessons from Oroville applicable here include the realization that dam infrastructure can fail even if it passes periodic inspections. Also, having emergency spillways that work safely is an important backup, even if used rarely.

# People and Communities Matter

In the first two months following the Oroville spillway incident, local public representatives expressed frustration over the amount and quality of information provided to explain the causes of the incident and the plans for repair and remediation. At some meetings, citizens responded to the public-relations efforts of project officials with anger and distrust. Beginning in late April, DWR hosted a series of eight town hall meetings throughout the affected region, during which a large panel of staff and experts presented extensive information and spent up to three hours responding to people's questions and concerns.

This effort of public engagement opened the possibility for a resolution among community members and the agencies responsible for the incident. However, any such resolution will require continued and sincere public engagement by project officials. It will not be enough to provide the public with updates. As with other projects of great impact to communities, a successful outcome will require transparency of information, accountability for all impacts, meaningful actions to mitigate for those impacts, and the actual hard reality that reconstruction decisions ensure that the Oroville Facilities can and will meet the full range of their operational, environmental, and public-safety responsibilities.

For a successful technology, reality must take precedence over public relations, for nature cannot be fooled.

*Richard Feynman, Nobel Laureate, Challenger Disaster Investigation member*

**Feather River Basin Community.** Hundreds of local residents attend the Gridley community meeting on April 27, 2017.
*Source: Kelly M. Grow, DWR.*

The tallest dam in the United States should have first-class engineering behind it, something that a healthy, proud, and secure local community deserves. As the spillways are reconstructed, the desired social and economic condition can be created or restored. This need is best represented by the coalition of community groups, local governments, and businesses organizing to interact with authorities in the aftermath of the spillway incident.[127] To succeed, DWR and its regulators must practice transparency of information and sincerely pursue mechanisms for community development.

*"Oroville spillway conditions negatively affect our communities downstream, communities that are composed of low-income, minority and economically depressed constituencies. In the City of Oroville for example, 24% of the population lives in poverty. Just downstream in Marysville, the poverty rate is nearly 29%. The benefits of the Oroville Dam project are significant throughout the state, providing water to 24 million people in California. But the extreme danger and burden of flood water is shouldered by our disadvantaged communities alone. We view this as a social, economic and environmental justice issue that must be addressed."*

*Letter to Governor Brown and Secretary Laird signed by Assemblyman Gallagher, Senator Nielsen and 40 community and business leaders.* ***www.orovillestrong.org***

## Transparency

Transparency of information is often thwarted by institutional barriers. Since 2003, FERC licensees have been encouraged to classify documents that describe project works as "Critical Energy Infrastructure Information" (CEII) that is then exempt from the Freedom of Information Act. While such provisions may at times be necessary to reduce risk of potential terrorist threats, there is no clear line between legitimately sensitive information and information that is inconvenient to make public or simply embarrassing. In depriving the public of access to information and access to operations personnel, FERC license holders often make their facilities and the public less safe. The authors of this report have seen dozens of cases where local residents are the first to provide a heads-up to hydropower project operators that some part of project facilities is not working properly. In its communications with the Commission last year on proposed CEII regulations, the Hydropower Reform Coalition (HRC) wrote: "(T)he HRC believes that informed public participation and citizen oversight of power producers have an important role to play in the protection of energy infrastructure as it relates to maintenance and normal operations for both power and non-power purposes." [128]

**Damaged Oroville Main Spillway.**
Mud and debris tumble down the newly eroded channel alongside the Oroville main spillway on Feb. 8, 2017.
*Source: Bill Husa, Chico Enterprise-Record.*

In 2005, when FOR *et al.* intervened in the licensing proceeding and made the case for a real emergency spillway for the tallest dam in the U.S., FERC's licensing officials referred the matter to FERC's dam safety officials. The conclusion of those officials was wrong—and nearly disastrous. It was also made behind the scenes. As FERC's Final Environmental Impact Statement for the Oroville relicensing noted, such dam-safety deliberations are CEII, effectively off-limits to even official parties to the licensing proceeding. This created a condition of complete non-accountability to those seeking to understand the basis for FERC's conclusion that the safety infrastructure the intervenors proposed was unwarranted.

# Recommendations for Improving Community Involvement and Confidence in Dam Safety

1. DWR and the other forensic teams need to complete their investigations on what led to the largest evacuation in California history. This is as much an investigation into decision-making culture as an inquiry into the engineering and geotechnical reasons for the failure. The results of these investigations need to be made public.

2. The forensic examiners must look at other relevant infrastructure and operational safety issues with the dam that were not involved with the spillway incident but need to be addressed.

3. DWR, forensic teams, and dam regulators need to provide periodic updates to the public on their assessments, recommendations, and decisions. Such updates should provide the opportunity for meaningful dialog.

4. DWR, or other authorities if necessary, should conduct a comprehensive assessment of the spillway incident's impacts to the local community, including evacuations, environmental impacts, property values, and other economic impacts.

5. DWR should team with local officials and other appropriate stakeholders to evaluate and mitigate the impacts of the spillway incident and to facilitate community recovery and development. Solutions must be effective, and DWR must support their implementation with appropriate mechanisms and adequate resources. The local community should emerge stronger than before.

6. DWR and other responsible agencies should develop and publicly share Emergency Action Plans and floodplain inundation maps.

7. FERC needs to clarify the procedure for Oroville Dam relicensing and dam-safety proceedings given that these multiple proceedings may affect area communities. At Oroville, more than anywhere else, there must be a clear roadmap for meaningful public involvement.

8. FERC should more greatly circumscribe the use of the CEII classification. The public must have confidence that CEII classification does not conceal potential physical and operational deficiencies and constraints. FERC's Division of Dam Safety and Inspections must find a way to allow for and define more public processes.

9. The state needs to assess whether the Division of Safety of Dams should remain a division of DWR.

Even today, after such a spectacular demonstration of the erodibility of the spillway hillside during high flows, DWR does not appear to have plans to construct an emergency spillway, the use of which would keep the hillside from tumbling into the water below. The reason for this apparent decision might be revealed some day, but perhaps a day too late to object.

The implication of the CEII policy is that the even involved members of the public have no real business in shaping the project that can affect their very lives. The public is compelled to trust the people who are behind the CEII wall, in many cases the same people who assured licensing parties that the spillway complex was on solid ground and safe. It was not.

There must be a dam-safety decision-making culture that does not fail so spectacularly. There must be a decision-making culture that is not afraid of sharing information with the affected public in ways that are meaningful. Decision-makers must provide confidence that reconstruction decisions are well-founded and that Oroville Dam in the future has the infrastructure to operate well and safely.

## The Wider View

There needs to be an overall culture shift in how water and power projects and the people who work for them interact with the communities that house them. Dam owners have an affirmative responsibility to the public that goes beyond meeting "regulatory constraints" or "obligations." Water managers must develop partnerships with the people whose communities and resources water developers tap. These partnerships must be founded on equality, fairness, and respect.

One can rightfully see many water developments across rural California as, in significant measure, battlefield monuments to historical conquests by outside forces. In competing for water, rural areas and their residents have often been out-maneuvered, out-lawyered, and outspent. Past attitudes of out-of-area developers generally ranged from indifferent to awful. Only recently, and far too sporadically, have water agencies and utilities whose beneficiaries and decision-makers are far away begun to treat the areas of origin more equitably and with more respect.

The Oroville Dam spillway incident of 2017 is a textbook case of how a legal victory at FERC to keep the emergency spillway out of relicensing was in fact no victory at all.

Neither the priority system of water rights in California nor the acumen of engineers in siting water infrastructure has been kind to rural communities. In most California watersheds, water is already over-allocated. Most rivers are thoroughly dammed. While it is sometimes unfortunately true that local entities would like to compete with out-of-area developers to repeat water-development attitudes and mistakes of the past, new reservoirs today are rarely a feasible option.

Water and power regulators have not often encouraged improvements in the way project operators treat local communities. FERC, in particular, has an established policy that license holders are not obligated to local authorities to provide public services. The hydropower dockets at FERC are littered with denied requests for help from economically limited towns, cities, and counties.

The hydropower relicensing industry that has developed over recent decades does not limit its efforts on behalf of licensees to deny assistance with public services. The consultants and attorneys that represent

licensees have done a very good job of limiting the obligations of their clients. Their approach is not simply to argue that it is a bad thing to pay for police, or consider how a reservoir relates to when and where it delivers water, or whether a dam needs an emergency spillway. The approach, rather, is to say that it is not their problem or FERC's problem, at least not at this particular time. The Oroville Dam spillway incident of 2017 is a textbook case of how a legal victory at FERC to keep the emergency spillway out of relicensing was in fact no victory at all. FERC needs to re-evaluate how it narrows the scope of oversight and mitigation in relicensing proceedings.

Water managers need to recognize that how they do business is as important as the business they do.

In recent years, a few forward-thinking water agencies have begun to change their relationships with other water agencies and with organizations that represent environmental and recreational interests. Sometimes, when the old bully and litigate model fails, water agencies choose instead to see discussion and consultation with public advocacy groups as opportunities to do outreach and improve outcomes on the front end. Surely the people who manage water agencies and power projects can start to do the same for the communities whose resources they share.

Better regulation is only part of the answer. No one foresaw the failure of Oroville's main spillway any more than anyone foresaw the partial collapse of the upper deck of the San Francisco Bay Bridge in the Loma Prieta earthquake of 1989. After 1989, hundreds of volunteer architects and structural engineers intensely reviewed building codes and recommended whole classes of buildings for retrofitting. Dam owners across California and the country similarly need to both re-evaluate construction and maintenance standards and reassess the safety and reliability of their water infrastructure.

Feather River Fishing. Steelhead fishing below Oroville Dam. *Source: Lance Gray, Fly Fishing Guide*

Water managers need to understand community needs and see them as their own. More decision makers for water and power companies need to live in the communities that house their facilities. Those decision makers need to involve local communities in decision making and have a regular and positive presence with local decision-making bodies.

Water managers need to recognize that how they do business is as important as the business they do.

# Endnotes

[1] http://www.water.ca.gov/swp/history.cfm

[2] See "Oroville Facilities Overview" at http://water.ca.gov/swp/facilities/Oroville/index.cfm

[3] http://www.water.ca.gov/swp/

[4] http://www.water.ca.gov/swp/contractor_intro.cfm. As the State Water Project (SWP) was constructed during the 1960s, long-term contracts were signed with public water agencies, known as the SWP contractors. They receive annual allocations, specified annual amounts of water, as agreed to in their contracts, which will expire in 2035. In return, the contractors repay principal and interest on both the general obligation bonds that initially funded the Project's construction and the revenue bonds that paid for additional facilities. The contractors also pay all costs, including labor and power, to maintain and operate the Project's facilities.

[5] DWR shows its annual allocations on this web page: http://www.water.ca.gov/swpao/deliveries.cfm
Before the 1994 Monterey Agreements, municipal water contractors had priority access to SWP supplies. Since that time, access priority has been more equal, and market mechanisms and Kern County ground-water storage (now mostly owned by local agencies, some of whose groundwater storage was formerly owned and controlled by DWR) have been used to buffer supply shortages to urban customers.
https://californiawaterimpactnetwork.files.wordpress.com/2016/06/monterey-amendments-a-history-carolee-2-28-10.pdf

[6] See http://www.water.ca.gov/swpao/wc_b.cfm. Even in severe drought conditions in 2014, Feather River Settlement Contractors received full deliveries (869,403 acre-feet). See Bulletin 132-15, p. 178 at
http://www.water.ca.gov/swpao/docs/bulletins/bulletin132/Bulletin132-15.pdf

[7] 2013 California Water Plan Update. Depending on the period, export SWP deliveries average 2.5, 2.6, or 2.8 million acre-feet. DWR Bulletin 132 lists deliveries to Feather River non-SWP agencies, typically around 900,000 acre-feet. The U.S.G.S. estimated California water use in 2010 at 42,600,000 acre feet. Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, *Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405*, p. 9.
http://dx.doi.org/10.3133/cir1405

[8] http://www.water.ca.gov/swp/benefits.cfm

[9] This estimate was derived by UCLA Professors Alex Hall and Associate Vice Chancellor Mark Gold using the contract builders' cited total price tag for dam construction at $439 million (1968 dollars) and applying an inflation calculator to translate this value in to today's dollars (personal communication, Prof. Alex Hall, April 7, 2017).

[10] http://www.water.ca.gov/swp/swptoday.cfm

[11] The State Water Contractors (an organization of the State Water Project contractors) estimate that the SWP provides $400 billion in annual benefits to California's $2.5 trillion economy.
https://web.archive.org/web/20131016051029/http://www.swc.org/issues/state-water-project/history-of-the-state-water-project

[12] SWRCB Water Quality Certification, ORDER WQ 2010-0016, FERC Project 2100. p. 1.
http://www.water.ca.gov/orovillerelicensing/docs/401cert/401certification.pdf (SWRCB 2010 Water Quality Certification).

[13] *Id.*, p. 2. Document notes:

> In 1999 the Central Valley Spring-run Chinook Evolutionary Significant Unit (ESU) was listed as threatened under the federal ESA and under the California ESA. National Oceanic and Atmospheric Administration (NOAA) Fisheries concluded that the hatchery produces spring-run Chinook salmon that are genetically more similar to fall-run. In March of 1998, naturally spawned Central Valley steelhead was listed as threatened under the Federal Endangered Species List (ESA).

[14] Letter from Mayor Linda Dahlmeier to Congressman Upton, Chair of the Energy and Commerce Committee (Energy Subcommittee), March 15, 2017 Hearing on "Modernizing Energy Infrastructure."
https://www.americanwhitewater.org/content/Document/view/documentid/1623/

[15] Chico News and Review, "Broken Promises," April 13, 2017. https://www.newsreview.com/chico/broken-promises/content?oid=24094307

[16] *Id.* According to original plans, the DWR was also supposed to develop a lodge and other recreation facilities, including a tram to Kelly Ridge, to help draw an estimated 1 million visitors each month. Alpert said FERC ordered the DWR to make millions of dollars' worth of improvements in a 1994 revised recreation plan that also haven't been done.

[17] See note 14.

[18] *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley, Final Report of the San Joaquin Valley Drainage Program*, September 1990, U.S. Department of the Interior, California Resources Agency.

[19] *Oroville Dam and Reservoir, Feather River, California, Report on Reservoir Regulation for Flood Control,* August 1970, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California (*Oroville Reservoir Regulation Manual*).

[20] Snowmelt floods are a trivial challenge for Oroville Dam and its downstream flood corridor. The manual, therefore, is designed to manage rainfloods. Maximum reservoir flood space ranges between 350,000 to 750,000 acre-feet depending on the preceding rainfall conditions. In most flood seasons, the full reservation is required. The Oroville Dam flood-control rule curve is available at: http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Oroville-rule-curve-use.pdf.

[21] http://www.cnrfc.noaa.gov/storm_summaries/feb1986storms.php. For perspective on the 1986 flooding, this NOAA site reports that the precipitation gage at Bucks Lake (5,750 feet elevation in the No. Sierra Nevada) received 55.72 inches of precipitation, mostly in the form of rain, during the 10-day period of the 1986 flood event (Feb. 11–20, 1986).

[22] http://www.bepreparedyuba.org/pages/prepare/history.aspx

[23] http://cepsym.org/Sympro1997/Roos.pdf. Flood records begin in 1906.

[24] http://www.cnrfc.noaa.gov/storm_summaries/jan1997storms.php. Details on the NOAA site show that when the Dec. 1996 and Jan. 1997 precipitation is combined and averaged over 8 precipitation gages, the 47.84 inches observed sets the record for the wettest back-to-back precipitation months.

[25] Lake Oroville Operations, Feather River, *Final Report, Governor's Flood Emergency Action Team*, May 10, 1997. (FEAT Report) This page represents hourly operations. http://www.water.ca.gov/floodsafe/docs/Governor%27s-Flood-Emergency-Action-Team-FEAT-May10-1997-OCR.pdf

[26] "In 1997, it [was] believed that Oroville storage was almost to a point where 300,000 cfs of inflow was going to pass through the reservoir. DWR was making plans to evacuate the power plant. The 300,000 cfs would have topped the levees and put 10 feet of water into the town of Oroville." *DWR Oroville Facilities Relicensing, Engineering and Operations Work Group — Issue Sheet Development*, revised May 21, 2001. (EE56).

[27] Maximum 1997 pool elevation from *Technical Memorandum on Controlled Surcharge of Lake Oroville for Additional Flood Control*, Yuba County Water Agency, August 2012, p. II-8. From this data, the "Area Capacity Table," Chart 16, from the *Oroville Reservoir Regulation Manual,* shows 215,000 acre-feet of unused flood reservation in 1997 floods. http://www.friendsoftheriver.org/wp-content/uploads/2016/01/YCWA-Oroville-Surcharge-Memo-excerpts-ocr-highlighted-Aug-2002.pdf

[28] http://www.sfgate.com/bayarea/article/PAGE-ONE-FLOODWATERS-RISE-THOUSANDS-FLEE-2861037.php.

[29] http://cepsym.org/Sympro1997/Roos.pdf. Roos notes in his 1997 summary that at one point forecasters thought the inflow to the reservoir would fill and spill to about 250,000 cfs, but rains eased up sooner than expected, and Oroville was able to contain the runoff.

The Feather River Arboga levee break occurred in an area identified in 1990 with levee foundation problems, meaning that this portion of the Feather River floodway could only reliably accommodate 268,000 cfs, rather than the 300,000 cfs design flow. (ACE, *Sacramento River Flood Control System Evaluation, Phase II – Marysville/Yuba City Area, EA/Initial Study*, April 1993, p. 6). This new floodway-competence assessment was not reflected in ACE or licensee Oroville Dam operation.

[30] http://cepsym.org/Sympro1997/Roos.pdf. "Inflows to Oroville reservoir reached more than 331,000 cfs, yet flood releases from the dam were maintained at 170,000 cfs — within the 210,000 cfs channel design capacity of the channel from the Thermalito Complex to the Yuba River confluence but exceeded the Oroville Dam objective release of 150,000 cfs for perhaps half a day."

[31] http://www.bepreparedyuba.org/pages/prepare/history.aspx

[32] For relicensing, DWR changed the project name to "Oroville Facilities."

[33] https://www.ferc.gov/resources/processes/hydro-proj.asp. The Federal Energy Regulatory Commission (FERC) is an independent regulatory agency that regulates the transmission and sale of electricity and natural gas, among other responsibilities. One of FERC's major hydropower activities is relicensing existing projects whose licenses are due to expire. Staff prepares either an Environmental Assessment or an Environmental Impact Statement and bases recommended license conditions on these reviews.

[34] http://www.hydroworld.com/articles/hr/print/volume-27/issue-3/feature-articles/ferc-licensing/a-retrospective-on-the-oroville-facilities-relicensing-making-collaboration-work.html. According to the source, the alternative licensing process (ALP) was chosen over the traditional licensing process (TLP) for two primary reasons: (1) the ALP encourages greater public involvement, enabling the licensee and stakeholders to collaboratively design the consultation process and jointly propose license terms and conditions; and (2) the ALP permits the licensee to complete the applicant-prepared environmental assessment, allowing DWR to utilize its own internal expertise.

[35] http://www.water.ca.gov/orovillerelicensing/

[36] Representative Doug LaMalfa, for example, has asked FERC to delay issuance of the Oroville Facilities new license until various matters related to the spillway incident have been sorted out.
http://eastvalleytimes.com/lamalfa-requests-delay-oroville-dam-relicensing/.
https://lamalfa.house.gov/media-center/press-releases/lamalfa-requests-delay-in-oroville-dam-relicensing.
A group of local governments and organizations led by the Oroville Chamber of Commerce has also requested a delay in licensing for similar reasons. See "After 10 years of delays on dam relicensing, these groups want more time" at Oroville Mercury Register:
http://www.orovillemr.com/general-news/20170720/after-10-years-of-delays-on-dam-relicensing-these-groups-want-more-time. https://elibrary.ferc.gov/idmws/file_list.asp?accession_num=20170808-5104

[37] CSPA, Motion to Intervene and Comments on Draft EIS of CSPA, December 19, 2006, FERC eLibrary no. 20061219-5016, pp. 2–3.

[38] The Superior Court ruled against the complaint of Plumas and Butte, and the case is now before the State Court of Appeals.

[39] The ungated spillway at Oroville Dam has been characterized in many ways. Older documents refer to it as the emergency spillway. DWR officials during the Spillways incident refer to it as either the emergency or auxiliary spillway. Friends of the River *et al.* in their FERC filings argue that because of uses assigned to it by the U.S. Army Corps of Engineers, it should be characterized by FERC as an auxiliary spillway. A precise characterization would be that it has an operational use in conducting surcharge flood-control operations and an emergency use when dam-safety is the priority. In 2017, it provided an emergency use when DWR was reluctant to use the broken main service spillway. It is probably most simply described as a dual-purpose auxiliary/emergency spillway. However, for editorial simplicity in this report, we will usually use the simpler term, emergency spillway.

[40] Motion to Intervene of Friends of the River, Sierra Club, South Yuba River Citizen's League, Project No. 2100-052 (filed Oct. 17, 2005), FERC eLibrary no. 20051017- 5033 (FOR *et al.* Intervention). The general link for the FERC eLibrary is https://elibrary.ferc.gov/idmws/search/fercgensearch.asp

[41] http://www.friendsoftheriver.org/wp-content/uploads/2016/01/MBK-Oroville-ops-manual-ltr-to-DWR-April-17-2001.pdf

[42] FOR *et. al.* Intervention, p. 9. The groups specifically requested FERC to require DWR to "armor or otherwise reconstruct the ungated spillway and to make any other needed modifications so that the licensee (DWR) can safely and confidently conduct required surcharge operations consistent with the Corps of Engineers Oroville Dam Reservoir Regulation Manual."

[43] CSPA Motion to Intervene, *op cit,* p. 2. Motion to Intervene of American Rivers, American Whitewater and Chico Paddle heads, March 31, 2005, eLibrary no. 20060331-5090, p. 5.

[44] Amended Motion to Intervene of the County of Sutter, the City of Yuba City, and Levee District No. 1 of Sutter County, March 24, 2006, FERC eLibrary no. 20060324-5069, p. 8. Sutter County, the City of Yuba, and Levee District 1 (Sutter County *et al.*) asked, in part, the Commission for the following:

> A relicensing order should be issued, consistent with the Commission's duty under section 10(a) of the Federal Power Act, which directs the licensee to investigate the adequacy and structural integrity of Oroville Dam's ungated auxiliary spillway that may currently pose a risk to the Project facilities and downstream levees in Sutter County in the event extreme flood releases are required, as recently experienced in flood release events of 1986 and 1997, and to take all necessary actions to correct any identified deficiencies, in this regard.

[45] Submittal of Butte County, *Report: Operational Impacts of the Oroville Project Facilities on Butte County*, February 15, 2006, FERC eLibrary no. 20060217-0010, pp. 15, 50. Butte County noted on p. 15: "When heavy rains bring the Lake Oroville level to possible overflow conditions, it triggers major flood management operations at Oroville Dam.… Scenarios generated by DWR in its flood plain analysis indicate a large geographic area below the Dam would be inundated if the Dam failed."

[46] Butte County, California, Comments in Opposition to and Contest of the California Department of Water Resources' Settlement Agreement for Licensing of the Oroville Facilities and Request for Evidentiary Hearing, April 26, 2006, FERC eLibrary no. 20060426-5060, pp. 4, 47, 48. Butte County states on p. 48:

> DWR must be directed to work with the County to address these potential risks, including the provision of additional security at the Oroville Dam.… It is beyond dispute that warnings alone are insufficient to address the great risk posed to the County and its over 210,000 residents, particularly where the Project has rendered the County's [downstream] emergency coordination facilities functionally ineffective to respond to flood emergencies.

In a June 29, 2007 filing entitled Comments of Butte County California on Legal and Factual Errors in in the Final Environmental Impact Statement for the Oroville Facilities Project, the County highlighted the situation during the 1997 floods. During these floods, DWR warned Butte County to evacuate its Emergency Operations Center due to an imminent flooding threat. Butte County responded that the Emergency Operations Center could not assist with the evacuation of the City of Oroville if the Center was evacuated or preparing to evacuate at the same time (Butte County, FERC eLibrary no. 20070629-5083, pp. 18–19).

[47] Response of the CA Dept. of Water Resources to Recommendations, Terms and Conditions, Prescriptions, and Settlement Comments, pp. 96–97, May 26, 2006, FERC eLibrary no. 20060526-5039. (*DWR Response*). Arguments include:

- [I]t is neither necessary nor appropriate to address specific issues related to dam safety in the relicensing context.
- DWR is in full compliance with FERC's dam safety regulations and the State of California's dam safety program, and nothing in the record supports Friends of the Rivers' speculation regarding the potential for flood impacts in the event of dam failure.
- [T]he Oroville Dam, including its appurtenant facilities, has repeatedly been found safe and adequate for its intended purposes, which include emergency spillway operations.
- The last five years of the [the Department's] Division of Safety of Dams' inspection reports all state: "From the known information and the visual inspection, the dam, reservoir, and the appurtenances are judged satisfactory for continued use."
- DWR recently reviewed the geologic conditions at the emergency spillway and concluded that the spillway is a safe and stable structure founded on solid bedrock that will not erode.
- The [Department's] Project Geology Section determined that there are only one to four feet of erodible top soil in the downstream area, and that erosion would not compromise the stability of the emergency spillway.

[48] Letter from DWR Acting Deputy Director, Raphael Torres to FERC regarding Project No. 2100-CA, Review of Seventh Independent Consultant's Safety Inspection Report for Thermalito Diversion Dam at "DWR Oroville Em Spillway Soil depth ltr 1-3-2006 highlighted (ocr)." http://www.friendsoftheriver.org/our-work/rivers-under-threat/feather-threat/.

[49] Response of the State Water Contractors and Metropolitan Water District of Southern California to Interventions, Recommendations, Terms and Conditions, Prescriptions, Settlement Comments, pp. 56–60, May 26, 2006, FERC eLibrary no. 20060526-5069.

[50] Memo from John Onderdonk, Senior Civil Engineer, San Francisco Regional Office, Division of Dam Safety and Inspections Emergency Spillway Safety Questions related to Intervention Motion, Proj. No. 2100, Letter to John Mudre, FERC Division of Hydropower Licensing, July 27, 2006, FERC eLibrary no. 20060801-0158. (Onderdonk Memo).

[51] In circumstances of a full reservoir and very high inflows, the Corps' flood control manual for Oroville requires DWR to *surcharge* the reservoir rather than make releases that would overwhelm downstream levees. Surcharging is accomplished by allowing water to reach a height as high as ten feet above the lip of the emergency spillway while backing off the releases from the main spillway so that the combined release from both spillways is no more than 150,000 cfs. Surcharge storage, measured as the height of flow over the emergency spillway and across the reservoir, could add 144,000 acre-feet of reservoir storage and allow control of larger storms.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/MBK-Oroville-ops-manual-ltr-to-DWR-April-17-2001.pdf

[52] *Federal Energy Regulatory Commission Final Environmental Impact Statement for the Oroville Facilities Project Docket No. P-2100-052*, May 18, 2007, FERC eLibrary no. 20070518-4001. ("FERC Oroville Facilities FEIS or FEIS").

[53] *SWRCB 2010 Water Quality Certification, op cit.*

[54] Joint comments of Friends of the River, Sierra Club, and South Yuba River Citizens League on Oroville Facilities Relicensing, FERC Project 2100, draft EIR, August 20, 2007. http://www.friendsoftheriver.org/wp-content/uploads/2016/01/FOR-Sierra-Club-SYRCL-comments-Oroville-relicenisng-EIR-text-recoghighlighted.pdf

[55] http://www.water.ca.gov/oroville-spillway/pdf/2017/Lake%20Oroville%20events%20timeline.pdf
According to this DWR timeline, reservoir levels peaked at 902.59-foot elevation on 02/12/2017: 03:00 a.m. One of the more complete discussions by DWR on Oroville Dam spillway incident operations can be found at "Responses to April 19, 2017 Oroville Spillway Questions from Assemblymembers E. Garcia and Gallagher, DWR," pp. 7–9, May 9, 2017.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/DWR-Response-ASM-WPW-Oroville-Questions-Responses.pdf

[56] Los Angeles Times, "Downstream from the stricken Oroville Dam, the Feather River Fish Hatchery manages to save millions of fish", February 17, 2017, http://www.latimes.com/local/lanow/la-me-ln-oroville-fish-hatchery-20170217-story.html; Fish Sniffer, "CDFW rescues 8 million young salmon, 1 million steelhead on Feather River", February 10, 2017, http://fishsniffer.com/index.php/2017/02/10/cdfw-rescues-8-million-young-salmon-1-million-steelhead-on-feather-river/.

[57] DWR was obviously cutting it pretty close. Indeed, on the same day, the Sacramento Bee ran two different stories in its electronic versions, one claiming the reservoir would not fill and spill, the other that it would.
http://www.sacbee.com/news/state/california/water-and-drought/article131941279.html
http://www.sacbee.com/news/state/california/water-and-drought/article132123804.html

[58] Based on the elevation/reservoir-volume tables in the Reservoir Regulation Manual, 453,000 acre-feet of the reservoir would be lost if 30 feet of reservoir containment was lost. If this volume were lost in twelve hours, the average outflow would be roughly 450,000 cubic-feet per second (cfs), although the outflow would be unlikely to be even, meaning instantaneous flows part of the time would be larger, perhaps much larger. If the loss of reservoir volume was over a briefer period, outflows in cfs would be larger. These flows could be expected to cause catastrophic downstream flooding.

[59] Butte County Sheriff Evacuation Order.
https://www.facebook.com/bcsonews/posts/781255845358029.
"Evacuation Orders Intact As Water Officials Analyze Oroville Dam Emergency Spillway," CBS News Sacramento.
http://www.newslocker.com/en-us/region/sacramento/evacuation-orders-intact-as-water-officials-analyze-oroville-dam-emergency-spillway/view/
"No Word on When Evacuation Order will be Lifted," Sacramento Bee, February 12, 2017.
http://www.sacbee.com/news/state/california/water-and-drought/article132332499.html

[60] "The River Valve Outlet System (RVOS) was available for use prior to February 7. It was flooded during the spillway incident with resulting damage to some of the operating and control components and had to be taken offline in February 2017. It was repaired in May 2017 and is currently available at a tested safe capacity of 4,000 cfs." June 7, 2017, Letter from DWR Chief Deputy Director, Cindy Messer.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Final-Signed-DWR-Response-to-Coalition-Letter_linked.pdf

[61] https://ww2.kqed.org/news/2017/03/23/engineers-assess-spillway-problem-at-oroville-dam/

[62] "The outlets are now judged to be able to run for limited times at as much as the 4,000 cfs of their rated 5,000 cfs of their rated capacity. This is an increase from 2,000 cfs." DWR response to FERC, June 5, 2017. FERC eLibrary no. 20170605-5228. See also DWR presentation on drought emergency operations, February 17, 2015 at
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/River-Valve-Outlet-System-RVOS-DWR-2015.pdf

[63] Oroville Spillway Recovery: Plans Under Design, DWR, April 6, (revised May 24) 2017.
http://www.water.ca.gov/oroville-spillway/pdf/2017/a3186%20Oroville%20Spwy%20Recovery_v6.pdf
http://www.water.ca.gov/oroville-spillway/recoveryplans.cfm
"While DWR does not intend to operate the emergency spillway, the emergency spillway will be able to pass 30,000 cfs by November 1 by placing a concrete cutoff downstream of the emergency spillway. Work will continue on the emergency spillway after November 1 which will continue to increase the capacity until it meets the previous design capacity of over 400,000 cfs." Responses to April 19, 2017 Oroville Spillway Questions from Assemblymembers E. Garcia and Gallagher, DWR, p. 13.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/DWR-Response-ASM-WPW-Oroville-Questions-Responses.pdf

[64] High Voltage Transmission Line Relocation, DWR letter to FERC, May 17, 2017. FERC eLibrary no. 20170517-5093.
"PG&E to fly poles as it re-routes power lines near Oroville Dam Spillway," Gridley Herald, May 26, 2017,
http://www.gridleyherald.com/article/20170426/NEWS/170429740

[65] https://mavensnotebook.com/2017/07/27/oroville-update-final-2017-construction-plans-for-lake-oroville-spillways-project-approved-with-video/

[66] http://www.water.ca.gov/oroville-spillway/pdf/2017/June%203%202017%20Oroville%20BOC%20Letter%20-%20Final.pdf

[67] http://www.capradio.org/100137
http://www.capradio.org/articles/2017/08/07/cutoff-wall-but-no-chute-this-year-for-oroville-dam-emergency-spillway/

[68] For example, testimony of Dave Gutierrez, former Chief of DWR's Division of Safety of Dams, before CA legislative over sight committee hearing, May 10, 2017.

[69] *Onderdonk Memo, op cit.*

[70] Butte County, California, Emergency Petition of Butte County, California to Require Licensee to Correct Safety Deficiencies and Establish a Public Safety Program, February 15, 2017, FERC eLibrary no. 20170215-5102 (*Butte Emergency Petition*).

[71] County of Butte, CA v. Calif. Dept. of Water Resources, 128 FERC ¶ 61,068 (2009).

[72] *Butte Emergency Petition*, pp. 7–8. Butte County requested that the Commission:
(O)rder DWR immediately to establish its own Public Safety Program, including providing for the necessary law enforcement and other personnel in lieu of the Butte County law enforcement and other personnel that have been, and continue to be, devoted to ensuring public safety in the face of threats attributable to the Oroville Project (including not just flood hazards but also fire, crime, and other emergency services), as delineated in numerous filings with the Commission over the years, as well as providing a myriad of other necessary public works services related to the Oroville Project.

[73] *Id.*, p. 8.

[74] *Mayor Dahlmeier, March 2017*, op cit, p. 2. See note 14.

[75] *Ibid.*

[76] *Id.*, p. 3.

[77] FERC Division of Dam Safety and Inspection, Letter to California Department of Water Resources regarding the emergency repair and Board of Consultants for the Oroville Dam Spillway under P-2100, FERC eLibrary no 20170213-3006.

[78] DWR FAQ: Who approves construction design? http://www.water.ca.gov/oroville-spillway/faqs.cfm

[79] http://www.water.ca.gov/oroville-spillway/bocreports.cfm

[80] http://www.sacbee.com/news/state/california/water-and-drought/article140390898.html
http://www.sacbee.com/news/state/california/water-and-drought/article143990719.html

[81] "What went wrong at Oroville Dam? Analysis points to drainage, problematic soils," Dale Kasler, Sacramento Bee, April 25, 2017. http://www.sacbee.com/news/state/california/water-and-drought/article146789099.html
"Preliminary Lessons Learned from Oroville Incident," Memo to Eric Halpin, Deputy, U.S. Army Corps of Engineers, Institute for Water Resources, Risk Management Center.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Army-Corps-Briefing-on-Oroville-Dam-April-7-2017.pdf

[82] http://damsafety.org/article/media/oroville-investigation-team.

[83] http://damsafety.org/sites/default/files/Memorandum_050517.pdf

[84] R.G. Bea, Center for Catastrophic Risk Management. April 17 2017. Preliminary Root Causes Analysis of Failures of the Oroville Dam Gated Spillway, p 1. (*Bea, Root Causes Analysis*). https://www.documentcloud.org/documents/3676605-Robert-Bea-Oroville-Spillway-Failure-Root-Cause.html.

[85] Legislative Testimony Report, Oroville Dam, R.G. Bea, Center for Catastrophic Risk Management, U.C. Berkley, April, May 11, 2017. https://drive.google.com/open?id=0Bz1I1mIutSEnWHozRUsyNFl1Y2c.
Root Cause Analysis of Oroville Dam Spillway Failure and other Developments, R.G. Bea, Tony. Johnson, Center for Catastrophic Risk Management, U.C. Berkley, July 20, 2017.
https://drive.google.com/open?id=0Bz1I1mIutSEnbFJuVUJZWWNNVlU

[86] *Bea, Root Causes Analysis,* p. 2.

[87] *Bea, Root Causes Analysis,* p. 3.

[88] "Investigators seek cause of accident deep with Oroville Dam," Sacramento Bee, July 23, 2009.
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Investigators-seek-cause-of-accident-deep-in-Oroville-Dam.pdf

[89] "River Valve Outlet System (RVOS) DWR, 2015."
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/River-Valve-Outlet-System-RVOS-DWR-2015.pdf

[90] "Oroville RVOS accident report OSHA2-10" (January 21, 2010).
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Oroville-RVOS-accident-report-OSHA2-10.pdf

[91] http://www.hydroworld.com/articles/hr/print/volume-34/issue-3/articles/investigation-re-creation-indicates-likely-ignition-point-of-thermalito-fire.html
https://conferences.wsu.edu/forms/hrs/HRS14/2014HRS/Lectures/Thermalito.pdf

[92] https://ww2.kqed.org/science/2017/04/07/how-incompetent-rock-led-to-the-oroville-dam-crisis/

[93] American Society of Civil Engineers (ASCE) 2017 Infrastructure Report Card.
https://www.infrastructurereportcard.org/cat-item/dams/

[94] http://www.waterpowermagazine.com/features/featurethey-might-be-giants-terminus-dam-s-new-fusegates/

[95] "Isabella Lake Dam Safety Modification Project," USACE.
http://www.spk.usace.army.mil/Missions/Civil-Works/Isabella-Dam/

[96] Dam Safety, Reducing Flood Risk in California's Central Valley, Modernizing Our Aging Dams, USACE. http://www.spk.usace.army.mil/Portals/12/documents/civil_works/dam_safety/Dam_Safety_Infograph_12DEC13.pdf

[97] "Success Dam Modification Study," USACE. http://www.spk.usace.army.mil/Missions/Civil-Works/Success-Dam/

[98] For San Luis and Trinity Dams, see, https://www.eenews.net/stories/1060054182. For another news piece on Trinity Dam, see, http://www.redding.com/story/news/local/2017/06/07/officials-worried-trinity-dam-safety/373015001/. Clifton Court Forebay (the facility used to send SWP water into the California Aqueduct) has underseepage issues (Suzanne Womack, before the State Water Resources Control Board in the WaterFix Change Petition Hearing) and does not appear have been designed to withstand accelerations used by the DWR Division of Safety of Dams in need of an in-depth seismic analysis. (DWR Bulletin 200 says it was design for 0.15g.) Table 5 of the seismology technical memo for the Delta Risk Management Strategy estimated peak ground accelerations of 0.40g at the Clifton Court Forebay for a 1-in-500-year event (10% in 50 years).

[99] Responses to April 19, 2017 Oroville Spillway Questions from Assemblymembers E. Garcia and Gallagher, DWR, p. 14, May 9, 2017. DWR Response ASM WPW Oroville Questions - Responses May 9, 2017. http://www.friendsoftheriver.org/wp-content/uploads/2016/01/DWR-Response-ASM-WPW-Oroville-Questions-Responses.pdf

[100] See, for example, the Letter to Merced Irrigation District re the new focused spillway assessments for the McSwain Dam under P-2179. FERC, May 1, 2017, FERC eLibrary no. 20170615-0215.
According to a May 21, 2017 Sacramento Bee report, FERC Division of Dam Safety and Inspections Regional Engineer, Frank Blackett, told an American Society of Civil Engineers gathering in Sacramento that FERC has sent letters to the nation's dam operators ordering them to conduct thorough on-site inspections of their spillways, re-evaluate their construction and design plans, and try to envision scenarios to determine "how that structure could fail."…"We want all of our licensees to focus on these features and determine if they have a potential Oroville waiting to happen." The article continues:

> Earlier this month, FERC asked Pacific Gas and Electric Co. to perform inspections on 33 spillways the power company oversees and compile a report on the state of their spillways by the end of the year, said PG&E spokesman Paul Moreno. The largest of the PG&E dams is on Lake Almanor, a reservoir whose releases drain into the same Feather River watershed as Oroville. Almanor is about one-third the size of Oroville.
>
> On the Yuba River, which drains into the Feather below Oroville Dam, FERC inspectors are meeting this week with the operators of New Bullards Bar Dam for an annual inspection, said Curt Aikens, the general manager of the Yuba County Water Agency. New Bullards Bar is slightly smaller than Folsom Lake.

http://www.sacbee.com/news/state/california/water-and-drought/article151889912.html

[101] "California orders closer look at these 93 dams after Oroville crisis" Sacramento Bee, July 17, 2017. http://www.sacbee.com/news/state/california/water-and-drought/article164021327.html http://www.modbee.com/news/article164067777.html

[102] The San Jose Mercury News was able to obtain records of the 2014 Probable Failure Mode Analysis under a Public Records Act request. The resulting article reported that failure of the main and emergency/auxiliary spillways were considered for analysis but dismissed as too unlikely to be considered. The article also noted that water underflow problems were known to DWR and that the main spillway had undergone "top to bottom" repairs in 1977, 1997, and 2009. https://ww2.kqed.org/news/2017/08/09/oroville-dam-spillway-ferc-safety-review-2014-ruled-out-spillway-failure/

[103] "Historical and Future Relations Between Large Storms and Droughts in California," Mike Dettinger, Ph.D., Research Hydrologist, National Research Program, U.S. Geological Survey, Carson City, NV, California Extreme Precipitation Conference, July 11, 2017. http://cepsym.org/proceedings_2017.php

[104] Climate Change and Flood Operations in the Sacramento Basin, California (2011) Ann D. Willis, Jay R. Lund, Edwin S. Townsley, and Beth A. Faber. San Francisco Estuary and Watershed Science. July 2011. https://watershed.ucdavis.edu/shed/lund/papers/Willisetalpaper2011.pdf

[105] Army Corps of Engineers flood-control manuals are more formally known as reservoir regulation manuals. In California, with its Mediterranean climate, the more formal title is misleading because the manuals only regulate flood season operations.

[106] The Friends of the River *et al.* FERC filings describe the nature of the coverage and lack of coverage of the Oroville Dam flood-control manual as it applies to operations with inflows that might require the use of the emergency spillway. The Emergency Spillway Release Diagram in the manual is for use with a Marysville Dam in place. There is no Emergency Spillway Release Diagram in the manual for the present circumstances of no Marysville Dam. See "MBK Oroville ops ltr to DWR April 17 2001" at http://www.friendsoftheriver.org/wp-content/uploads/2016/01/MBK-Oroville-ops-manual-ltr-to-DWR-April-17-2001.pdf

[107] As used here, "reservoir design flood" refers to the size (usually an inflow hydrograph, a graph that displays inflows on the y-axis and time on the x-axis) that a reservoir can accommodate without exceeding design flood-control outflows (150,000 cfs in the case of Oroville Dam). In contrast, a "spillway design flood" refers to an inflow hydrograph that can be contained within the reservoir while making full use of the dam's spillways (nearly 600,000 cfs). The latter is a dam-safety operation rather than one for flood control.

[108] "Technical Memorandum on Controlled Surcharge of Lake Oroville For Additional Flood Control," (YCWA Technical Memo) Yuba County Water Agency, August 2002, p II-8. http://www.friendsoftheriver.org/wp-content/uploads/2016/01/YCWA-Oroville-Surcharge-Memo-excerpts-ocr-highlighted-Aug-2002.pdf

[109] Bills have been introduced in the Congress (H.R. 5247 Costa, Garamendi & H.R. 813 Huffman, 114th Congress) directing the Corps to undertake revisions to improve water-supply operations of reservoirs with Corps flood-control manuals. Revisions to these manuals should also be directed to increase the flood-control operations to these reservoirs given the likely increase in flood magnitudes in the future.

[110] DWR began making releases of 50,000 cfs before the flood-control manual required making any flood-control releases on the basis of the 1997 New Year's Day Flood weather forecasts. See Final Report, *Governor's Flood Emergency Action Team*, May 10, 1997 *(FEAT* Report).
http://www.water.ca.gov/floodsafe/docs/Governor%27s-Flood-Emergency-Action-Team-FEAT-May10-1997-OCR.pdf

[111] *Draft Basin-Wide Feasibility Study, San Joaquin Basin*, DWR, October 2016, p. 2.31.

[112] "The San Joaquin Valley is also rimmed with dams, but floodway capacities in this system are small and designed for managing snow-melt flooding. Unregulated rain-flood flows from many dams are quite foreseeable (and occurred in 1997), in part because major reservoir-flood-space encroachments can occur from storms that may have happened days, weeks, or even months earlier." A California Challenge — Flooding in the Central Valley, DWR Independent Review Panel on Central Valley Flooding, October 15, 2007, pp. 11–12.
http://www.water.ca.gov/news/newsreleases/2008/101507challenge.pdf

[113] *FEAT* Report, op cit., p. 119. The report makes ...", op. cit. Its most substantive and specific recommendation was the targeted study on increasing the size of the Tuolumne River floodway.

[114] "Don Pedro Lake, Tuolumne River, California, Pertinent Data," Don Pedro Lake, Tuolumne River, California, *Reservoir Regulation for Flood Control*, August 1972, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California.

[115] *Id.* at "Flood Control Diagram," "Emergency Spillway Release Diagram," and *FEAT Report.*

[116] "Don Pedro swallowed hard, stemmed flow to the end," The Modesto Bee, Special Report Flood Watch 1997, Sunday, January 12, 1997.

[117] "Real-Time Modeling During Flood Control Operations," Wes Monier, Manager, Strategic Issues and Planning Dept., Turlock Irrigation District, Turlock, CA, Norman H. Crawford, Ph.D., President and Founder, Hydrocomp, Inc., Menlo Park, CA, California Extreme Precipitation Conference, July 11, 2017.
http://cepsym.org/proceedings_2017.php

[118] The Merced Irrigation District has floated a series of ideas to wall off much of its 1,070-foot-wide emergency spillway and to reduce the size of New Exchequer Dam's flood reservation. See,
http://www.friendsoftheriver.org/wp-content/uploads/2016/01/Merced-R-ws-threat-fact-sheet-4-5-26-3016.pdf

[119] *Basin-Wide Feasibility Study,* San Joaquin Basin, DWR, March 2017, section 4.2.
http://www.water.ca.gov/cvfmp/docs/2017/BWFS-SJR-Rpt-March2017.pdf

[120] "Risk management approaches in the San Joaquin basin are largely the official recognition of flood-plain flooding and some relatively minor levee improvements and setbacks." A California Challenge — Flooding in the Central Valley, DWR Independent Review Panel on Central Valley Flooding, October 15, 2007, pp. 11–12.
http://www.water.ca.gov/news/newsreleases/2008/101507challenge.pdf

[121] "Project levees" is a term for levees that have been federalized one way or another in the sense that modifications to these levees require permission from the U.S. Army Corps of Engineers.

[122] http://caltrout.org/tag/knaggs-ranch/; http://www.multibenefitproject.org/floodplain-scientific-and-management-research-projects/knaggs-ranch/

[123] The Lower Feather River Corridor Management Plan (produced by AECOM for DWR in 2014; http://www.water.ca.gov/floodmgmt/fmo/msb/lfrcmp) evaluates are variety of potential actions and proposes implementing actions that maintain flood-control facilities, enhance habitat and ecosystem functions, and support agricultural and recreational activities.

[124] "In contrast to the Sacramento Valley, in the San Joaquin Valley, the effectiveness of dam operation for modification of rain-generated floods is substantially limited by the Valley's minimal floodway capacity. The first flood fills the reservoir, and evacuation of the water is limited by the downstream channel capacities. This makes the likelihood of spilling large flood flows from the reservoir much greater during subsequent flood events." *A California Challenge — Flooding in the Central Valley*, DWR Independent Review Panel on Central Valley Flooding, October 15, 2007, pp. 11–12. http://www.water.ca.gov/news/newsreleases/2008/101507challenge.pdf

[125] "Expansion of floodways in tributary streams would be very helpful for dam operations during floods if the water could be either safely routed through the Sacramento/San Joaquin River Delta or into valley-bottom floodplains." *Ibid.*

[126] *Draft Basin-Wide Feasibility Study, San Joaquin Basin*, DWR, October 2016, section 4.

[127] Coalition efforts include a letter to Governor Brown and Secretary Laird signed by Assemblyman Gallagher, Senator Nielsen and others.https://www.orovillestrong.org/wp-content/uploads/2017/05/OroDamLetterSigned.pdf

[128] Hydropower Reform Coalition, "Comments on Proposed Rulemaking- Regulations Implementing FAST Act Section Docket No. 61003 – Critical Electric Infrastructure Security and Amending Critical Energy Infrastructure Information (FERC Docket No. RM16-15-000)," p. 2. FERC eLibrary no. 20160818-5218.

Back cover photo image: Crews continue the placement of rebar panels for the new side walls on the lower chute of the Lake Oroville flood control spillway in Butte County, California. Photo taken September 5, 2017.
*Source: Ken James / California Department of Water Resources,*