Introduction

As required by Water Code Section 165, the California Water Commission (Commission) conducts an annual review on the progress of the construction and operation of the State Water Project (SWP), and makes a report on its findings to the Department of Water Resources (DWR or Department) and the Legislature, with any recommendations it may have. The Water Commission’s role is to provide a forum to help the public stay informed of DWR’s efforts, and to provide recommendations to the Department based on the information received through these interactions. This report outlines key construction and operations activities conducted by the Department in 2017. It also recaps how the Commission and the public were kept informed throughout the year.

This report includes an Executive Summary, with Findings and Recommendations. The second section of the report includes more detailed information about the key issues, covering SWP operations, the Lake Oroville spillway incident, the findings of the Independent Forensic Team, and a summary of key construction projects of the SWP, with an update on the construction projects described in the 2016 Annual Review.

Consistent with the Commission’s statutory responsibilities under Water Code Section 161 (to confer with, advise, and make recommendations to the Director of DWR) and Section 165 (to conduct the annual review of the progress of the construction and operation of the State Water Project), the Commission recommends that DWR continue to provide regular briefings on the many important water infrastructure management issues addressed in this report.
EXECUTIVE SUMMARY

2017 was a year of extremes for water. The most severe drought in California's recorded history was interrupted by one of the wettest seasons on record. Snowpack was higher than average across the Sierra Nevada, and runoff filled most of the State's reservoirs to capacity.

While the events of 2017 posed extreme operational challenges for the State Water Project, they also provided a glimpse into the future and underscored the need to bolster dam safety, asset management and emergency response to prepare for the effects of climate change.

DWR is carrying out a suite of projects and initiatives to address these needs while maintaining and rebuilding key SWP infrastructure.

Lake Oroville Spillways Incident

January and February 2017 were the wettest two months in 110 years of the Feather River hydrologic record. In those two months, Lake Oroville received an entire year's average runoff of 4.4 million acre-feet. Amid this extreme weather, erosion discovered on the main, gated spillway at Oroville Dam triggered events that led to the use of the adjacent emergency spillway for the first time. Unexpected erosion of the hillside below the emergency spillway and concerns about its possible failure prompted the Butte County Sheriff to order a mandatory evacuation of nearly 200,000 people living downstream of Lake Oroville.

Following the emergency, repairing and reconstructing the main flood control spillway in time for the next flood control season was DWR's top priority. The Lake Oroville Spillways Emergency Recovery Project completed its first phase by the November 1, 2017, target date after a massive reconstruction effort that rebuilt and strengthened the 3,000-foot long main spillway so it can safely handle flows of 100,000 cubic-feet per second.

Construction in 2018 will focus on reconstructing the top 730 feet of the main spillway and adding structural concrete to the middle portion of the spillway to bring it to a final design capable of passing flows of 270,000 cubic-feet per second.

In addition, DWR and partner agencies will conduct a comprehensive needs assessment of the Oroville Dam complex that will determine whether additional improvements or facilities are needed. That assessment is targeted for completion by the end of 2019.

DWR briefed the Commission three times in 2017 on the Lake Oroville incident and its aftermath.

Dam Safety

In the wake of the events at Lake Oroville, the Federal Energy Regulatory Commission directed DWR to establish an Independent Forensic Team (IFT) to determine the root cause of the spillway incident, as well as other contributing causes including operations, structural, geologic, and management.

The IFT released an interim report in September and a final report in January 2018 that highlighted key findings on both the physical and organizational factors in the incident. DWR has said that it is incorporating the IFT’s findings
into its ongoing efforts to improve dam safety and assess its organizational structure.

In November 2017, DWR began a two-phased comprehensive evaluation of the SWP dam and spillway safety program. The evaluation includes program governance and administration, dam surveillance and inspection, operations and maintenance activities, emergency response and contingency planning.

Beyond SWP facilities, DWR directed the dam owners of 93 spillways with characteristics similar to Oroville’s main spillway to conduct comprehensive assessments of their spillways. DWR also publicly released the updated hazard potential, condition assessment, and restriction status of all jurisdictional dams in September 2017.

More spillways will be evaluated as the program progresses, and additional dam safety components and systems that pose the highest risk to the public will continue to be evaluated.

Asset Management/SWP Infrastructure

With much of the SWP’s infrastructure exceeding 50 years of age, the maintenance needs of the system have increased to require more frequent refurbishment, renewal, and replacement. DWR’s comprehensive asset management program recognizes the increased public safety issues resulting from population growth into areas around SWP reservoirs and other infrastructure, and takes account of the geology, environment, and regulatory obligations of the SWP.

Several key construction projects were underway in 2017 throughout DWR’s field divisions to maintain and update facilities such as power plants, pumping plants, and intakes and address seismic risks associated with dams and appurtenant structures.

In addition, DWR continues to make changes to SWP energy use and operations as part of its greenhouse gas emissions reduction plan. Actions include replacing carbon-intensive electrical generation throughout SWP operations with lower- and non-emitting generation such as natural gas, solar and hydropower. DWR is a member of The Climate Registry, which calls for annual submissions of emissions data and third-party verification of emissions inventories.

Subsidence of the California Aqueduct

In 2017, DWR found significant subsidence in three main areas of the California Aqueduct between Los Banos and Bakersfield. Between pools 17 and 20 in the San Luis Field Division, the recent drought resulted in average subsidence of four inches per year. The southern end of Pool 20 subsided at roughly seven inches per year. Over time, subsidence can reduce the maximum flow of water, although it has not yet limited DWR’s ability to deliver water to contractors in southern California.

DWR briefed the Commission on the subsidence issue in November 2017, and has identified immediate actions to mitigate the impacts of subsidence to be performed in 2018. The Department will conduct further studies to determine long-term solutions to restore capacity.
FINDINGS AND RECOMMENDATIONS

The Commission finds that:

• DWR responded effectively to manage the simultaneous threats associated with the Lake Oroville incident in February;
• DWR efficiently performed phase 1 repairs to the Lake Oroville spillway by Nov. 1, 2017 to handle flows of 100,000 cubic-feet per second in advance of the 2017-18 rain season;
• Throughout 2017, DWR provided timely and appropriate updates to the Commission and the public on its approach to addressing the critical maintenance and repair needs of SWP infrastructure;
• Implementation of DWR’s Asset Management Program will be key to incorporating the lessons learned from the events of 2017, and to adapting the aging infrastructure of the SWP to changing hydrologic conditions;
• DWR has reduced greenhouse gas emissions from SWP operations. The Department achieved its 2020 emissions reduction goal five years ahead of schedule, and has made significant progress toward its 2050 goal; and
• DWR demonstrates leadership in addressing climate change, as evidenced by its receipt of the Excellence in GHG Management and Organizational Leadership awards from the Center for Climate and Energy Solutions and The Climate Registry for the third time in four years.

The Commission recommends that:

• DWR brief the Commission on the status of emergency planning in all communities within the inundation area of Lake Oroville and other SWP dams.
• DWR provide regular updates on its progress with dam and spillway inspections, and subsequent plans for remediation work or improvements to SWP dams and spillways, as well as the potential costs. The updates would serve as public forums for discussing the management of the state water system, consistent with the Commission’s Strategic Plan and statutory obligations.
• DWR regularly brief the Commission on implementation of the Asset Management Program, and how the program improves risk management while maintaining SWP operations. The briefings should include information on how the program improves use of available budget for continued operation and capital improvement.
• DWR integrate climate change planning into its Asset Management program.
• DWR include activities that would improve ecosystem functions of the Feather River Watershed in its Asset Management Program (e.g. real-time data collection, coordinated land management activities).
• DWR update the Commission regularly on its plans and progress in adapting the operation of the SWP to changing hydrologic conditions.
• DWR and The Climate Registry brief the Commission on the status of California water suppliers participating in The Climate Registry, the development of the Water-Energy Nexus Registry, and how that may assist water agencies in reducing their GHG emissions.
• DWR brief the Commission in 2018 on the results of additional subsidence studies, and actions taken to address subsidence in the San Luis and San Joaquin Field Divisions.
SECTION 2

STATE WATER PROJECT OPERATIONS AND CONSTRUCTION

This section broadly describes the SWP operations and major construction projects in 2017. It includes a chronology of the Lake Oroville incident, and summarizes the findings of the Independent Forensic Team (IFT) as well as changes to DWR’s dam safety program. This section also contains brief reports on SWP efforts to comply with state and federal endangered species acts and the status of California WaterFix.

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2.1 Lake Oroville Spillway Incident

During the 2016-17 rainfall season, more than 50 atmospheric rivers\(^1\) dropped record-setting precipitation on California, ending the five-year drought. By February 2, DWR’s snow survey recorded the Sierra snowpack at 173 percent of normal levels.

At that time, Lake Oroville was at 849 feet (79 percent of capacity), with yet another atmospheric river in the forecast. To accommodate the expected runoff from the watershed, DWR released water down the Oroville flood control spillway, also known as the main spillway. From February 1, 2017 through the morning of February 3, 2017, main spillway releases were generally about 15,000 cfs. DWR then increased releases to about 25,000 cfs and maintained at that level until mid-day on February 6, 2017, at which time the releases were increased to between 42,000 and 45,000 cfs and held in that range until the morning of February 7. On February 7, while the spillway release was being ramped up to 52,500 cfs, an unusual pattern in the water flowing down the spillway caused DWR to stop the flow of water to investigate. DWR engineers found a large eroded area in the concrete spillway (approximate dimensions) in the vicinity of Sta. 33+50 in Lanes 3, 4, and 5.

Over the next several days, after consulting with the Division of Safety of Dams (DSOD) and the Federal Energy Regulatory Commission (FERC), DWR conducted test flows down the damaged spillway ranging from 20,000 cfs to 65,000 cfs. At these rates, investigators found that the eroded area continued to expand, both headward (uphill) and downslope toward the diversion pool. DWR, FERC, and DSOD were concerned that if the headward erosion got too close to the radial gate control structure, the spillway would have to be shut down, threatening DWR’s ability to manage lake levels.

Meanwhile, the wet weather continued and Lake Oroville rose to 890 feet early in the morning of February 9. At 901 feet, water would flow over the emergency spillway, which had never occurred since the dam’s completion in 1968. Because the headward erosion of the main spillway appeared to be stabilizing roughly 400 feet upslope of the initial damage, DWR and the other agencies calculated that they could increase the rate of flow down the spillway to 45,000 cfs to avoid using the emergency spillway. However, as a contingency plan in the event of the potential use of the emergency spillway, DWR began to clear the hillside below the emergency spillway.

The situation worsened later in the day on February 9, when the weather forecast called for 25 percent more rain than was previously forecast. To avoid using the emergency spillway, DWR increased the flows down the gated spillway to 45,000 cfs; however, inflow reached more than 190,000 cfs. Outflow from the Hyatt Powerplant ceased because debris below the damaged spillway caused water to back up into the diversion pool, raising water levels in the tailrace, near the generating turbines. This precluded DWR from safely operating the powerplant. In addition, headward erosion along the main spillway was within 100 feet of Tower No. 4 of PG&E’s 230 kv transmission line, which serves Hyatt Power plant. Loss of this tower would cause adjacent towers to fail as well, shutting down the powerplant and potentially impairing outflow at Hyatt for months.

Just after midnight on February 10, DWR increased releases down the damaged main spillway to 55,000 cfs, and then to 65,000 cfs. In doing so, DWR attempted

\(^1\) Atmospheric rivers, concentrated bands of water vapor transported by strong winds, can cause extreme amounts of precipitation under the right weather conditions.

https://water.ca.gov/LegacyFiles/waterconditions/docs/2017/Water%20Year%202017.pdf
to balance multiple risks: the potential for an uncontrolled release of water over the never-used emergency spillway; and the possibility that ongoing erosion from the gated spillway releases would severely damage the critical facilities (the main spillway gates, transmission lines and Hyatt Powerplant) used to control the water levels behind Oroville Dam.

As the lake levels continued to rise due to a larger and warmer storm than what was forecast, DWR continued flood-fighting inside the Hyatt Powerplant as the level of the tailrace waters reached historic highs. If the powerplant were to flood, it would be inoperable for up to a year or more. The powerplant is critical to DWR's ability to manage lake elevations as well as to meet all beneficial water use releases from Lake Oroville, including those to support Delta water quality, senior water rights, and endangered fish in the Feather River. In addition, DWR assisted the California Department of Fish and Wildlife with evacuating millions of juvenile salmon from the Feather River Fish Hatchery in Oroville due to turbidity and low water quality. By the end of the day on February 10, 2017, it was apparent the heavy rain would cause water to flow over the emergency spillway.

On February 11, the level of Lake Oroville exceeded 901 feet. At approximately 8 a.m., water flowed over the lip of the 1,700-foot-long concrete crest of the emergency spillway. Although DWR expected erosion on the hillside underneath the emergency spillway, the rate of erosion toward the crest concerned DWR, DSOD, and FERC. In consultation with the incident command team, made up of state and federal agencies, the Butte County Sheriff issued a mandatory evacuation order, affecting nearly 200,000 residents downstream of Lake Oroville. Governor Brown also issued an emergency order to bolster the State's response to Oroville Dam's emergency spillway and to support local evacuation efforts.

Yet the lake level continued to rise, peaking at 902.59 feet early in the morning of February 12. DWR increased the outflow on the flood control spillway to 100,000 cfs to hasten the end of the flow over the emergency spillway. By 8 p.m., the lake level dropped below 901 feet and flows over the emergency spillway ceased.

Over the next several days, DWR faced several simultaneous challenges. Because more rain was forecast, releases on the gated spillway continued at 100,000 cfs to lower lake levels to 850 feet. Erosion of the main spillway and adjacent hillside created an enormous mass of debris in the diversion pool, raising the tailrace elevation to 256 feet, four feet above the level at which the Hyatt Powerplant would flood. Inspectors and engineers monitored the erosion of the main spillway while DWR crews fortified the hillside under the emergency spillway and continued to fight flooding inside the Hyatt Powerplant. As DWR's actions reduced the risk of catastrophic erosion and flooding, the Sheriff modified the evacuation order to a warning on the February 14. By February 16, DWR reduced the outflow on the main spillway to 80,000 cfs, and eventually to 55,000 cfs on February 18 as the lake level reached 854 feet. By February 27, flows from the main spillway ceased, and crews could begin the work of removing the debris pile.

**Repair and Recovery**

Throughout the rest of 2017, DWR and its contractors worked around the clock to repair erosion and rebuild the spillways, as well as plan and perform dredging operations to remove the debris pile at the base of the spillway. The 730-foot section of the upper chute deemed structurally sound was repaired and will be removed and replaced in 2018. Demolition of the main spillway began on May 22, and completed on August 23. After excavating debris and cleaning rocks, crews placed reinforced, structural concrete on the lower chute and parts of the upper chute along with new drainage, while roller-
compacted concrete filled in the middle section of the spillway and scour holes. Phase One reconstruction of the main spillway ended on November 1.

Details of DWR's emergency response and recovery operations may be found in the Oroville spillway incident timeline on the DWR website, https://www.water.ca.gov/What-We-Do/Emergency-Response/Oroville-Spillways/Background. Key events are highlighted below.

March 27 Butte County Sheriff lifts evacuation warning.

April 6 Governor Edmund G. Brown Jr. issues Executive Order B-39-17 to further expedite the effort to repair the spillways at Oroville Dam before next winter.

April 17 DWR awards contract to Kiewit Infrastructure West Co. to repair spillways.

April 27 DWR holds the first of ten community meetings about the Oroville spillway recovery effort in Gridley.

May 5 Independent Forensic Team releases preliminary findings on potential physical factors contributing to Lake Oroville’s main spillway erosion on February 7.

May 19 Main spillway shut off.

May 22 Demolition begins with controlled blasting and clearing of spillway.

August 23 Main spillway’s lower chute demolition completed.

November 1 Crews complete Phase One reconstruction of the main spillway, able to handle flows of at least 100,000 cfs.

Oversight and Investigation

DWR engaged a five-member Board of Consultants, as required by Water Code Section 6056 and FERC, to review and comment on the recovery of the Lake Oroville spillways. Between March 10 and December 1, the BOC issued 14 memoranda on the spillways incident. They also reviewed and approved DWR’s spillway recovery reconstruction plans on June 3. The memoranda and more information about the BOC may be found at https://www.water.ca.gov/What-We-Do/Emergency-Response/Oroville-Spillways/Board-of-Consultants.

Shortly after the Lake Oroville spillways incident in February 2017, FERC asked for the formation of an independent team of dam experts and engineers to investigate the cause of the main spillway erosion, including factors such as operations and management. IFT members were chosen by the Association of State Dam Safety Officials (ASDSO) and the United States Society of Dams (USSD), two premier dam safety associations in the United States. The six member IFT included:

- John France, PE, D. GE, D.WRE, Team leader, expertise in geotechnical engineering
- Irfan A. Alvi, PE Hydraulic Structures Engineer and Human Factors Specialist
- Peter A. Dickson, PhD, PG Engineering Geologist
- Henry T. Falvey, Dr.-Ing, Hon.D.WRE Hydraulic Engineer
- Stephen Rigbey, Director of Dam Safety at BC Hydro, British Columbia, Canada and President, SJR Consulting Inc., Vancouver, Canada, expertise in operations
- John Trojanowski, PE, President, Trojanowski Dam Engineering, Limited, expertise in hydraulic structures
The IFT released three reports on factors potentially contributing to the Lake Oroville spillways incident. The three-page Preliminary and eight-page Interim Memoranda are attached to this report as Appendices. The Summary of the 584-page final report is included below. The January 5, 2018 Final Report is available here: https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf.

In its May 5, 2017, Memorandum the IFT outlined preliminary findings of candidate physical factors that might have contributed to the damage of the spillways. In this memo, the IFT stated its belief that the damages resulted from a combination of physical factors listed in the memorandum. They noted that although some factors may not have contributed to the damages, all the factors should be considered in new design and construction.

**Interim Memorandum Summary**

In its September 5 Interim Memorandum, the IFT noted that the summarized findings are supported by detailed evidence, which would be compiled and presented in the IFT’s final report.

**Physical Factors**

The IFT provided a refined update on the physical factors that led to the service spillway chute (main spillway) failure. The IFT concluded that the initial uplift and removal of the slab section downstream of Station 33+50 was most likely caused by water uplift pressure beneath a sufficiently large area of the slab. Once the upstream end of the slab section lifted into the flow, the pressure under the slab rapidly increased and produced the sudden failure of the slab. The IFT believes that some combination of the following physical factors played a role in the chute failure.

- New damage and/or deterioration of slab repairs that resulted in more potential flow disturbance locations and more flow into the foundation than during the prior spillway discharge events.
- Possible expansion of relatively shallow void(s) under the slab due to long-term erosion under the slab. The IFT found that the available evidence does not support the hypothesis that a deep void formed beneath the spillway chute due to foundation erosion, resulting in subsequent slab collapse, but shallow voids are conceivable.
- Corrosion of the rebar across the concrete cracks or joints, as evidenced by post-failure investigations and previous repair photographs.
- Reduction in anchor capacity due to erosion around anchors beneath the slab or anchor corrosion where anchors were not properly encapsulated in grout, also as evidenced post-failure.

The IFT believes that cavitation, groundwater, and seismic damage were either not involved or had only a small effect in contributing to the failure.

**Design and Construction Factors**

The IFT identified a number of design and construction fragilities which lead to vulnerability to uplift. These include:

- Underdrains that intruded into the chute slab section, reducing the thickness of concrete above the drains to 7 inches or less (compared to a design minimum thickness of 15 inches elsewhere), resulting in cracks above most of the...
herringbone drains; the cracks allow water to pass through the slab and also led to a propensity for concrete spalling.

• Absence of waterstops at contraction joints, and a less than optimal shear key configuration.

• The specified foundation preparation and treatment, which was followed for the headworks and emergency spillway crest structures, was relaxed during construction of the spillway chute slab. Up to 50 percent or more of the foundation in some areas was not properly treated by removal of weathered materials and cleaning of soil-like materials from the surface.

• Shallow rock anchorage of five-foot embedment length, and possibly less where the slab was thicker than the minimum of 15 inches, as well as inadequate development of the anchors in the slab. In addition, some anchors in the failed area were installed in highly weathered and fractured rock that was unlikely to develop the intended pull-out strength.

• A drainage system with many deficiencies, such as no filtering, possibly broken or disconnected pipes caused by the method of placement, and likely inadequate collector drain capacity for the flow that occurred through the slab.

• Single top layer of nominal reinforcement bars.

• A relatively large concrete aggregate size, resulting in a propensity for cracking and spalling at keys and over drains, and damage to drain pipes.

Emergency Spillway Factors

The IFT identified the following four physical factors that contributed toward the damage at the emergency spillway:

• Significant depth of erodible rock and soil in orientations that allowed rapid headcutting toward the crest control structure; these materials also appear to be associated with geologic features such as shear zones.

• Hillside topography that concentrated flows and increased erosive forces, facilitating headcut formation.

• Insufficient energy dissipation at base of the spillway crest.

• Absence of erosion protection downstream of the crest structure.

Human and Organizational Factors

The IFT outlined the human and organizational factors under investigation, including:

• Pre-design investigations;

• Design aspects, considered in the context of standards of practice of the era;

• Construction aspects;

• Operations and maintenance; and

• Organizational aspects, including their evolution from pre-design until the spillway incident.

Lessons Learned

The IFT shared three higher-level lessons learned regarding DWR and industry dam safety practices that had been identified thus far. These are:
1. Physical inspections, while necessary, are not sufficient to identify risks and manage safety.

2. Comprehensive periodic reviews of original design and construction, taking into account comparison with the current state of the practice, are needed for all components of dam projects.

3. Compliance with regulatory requirements is not sufficient to manage dam owners’ and public risk.

Lake Oroville spillway on November 22, 2017. Source: Department of Water Resources

**IFT Final Report Summary**

On January 5, 2018, the IFT issued its Report on the Oroville Dam Spillway Incident. In this final report, the IFT identified what caused the damage to the spillway and how similar incidents can be avoided in the future, both at the Oroville facility and elsewhere. Below we include the Summary from the IFT Final Report.
SUMMARY

The Oroville Dam spillway incident was caused by a long-term systemic failure of the California Department of Water Resources (DWR), regulatory, and general industry practices to recognize and address inherent spillway design and construction weaknesses, poor bedrock quality, and deteriorated service spillway chute conditions. The incident cannot reasonably be "blamed" mainly on any one individual, group, or organization.

During service spillway operation on February 7, 2017, water injection through both cracks and joints in the chute slab resulted in uplift forces beneath the slab that exceeded the uplift capacity and structural strength of the slab, at a location along the steep section of the chute. The uplifted slab section exposed the underlying poor quality foundation rock at that location to unexpected severe erosion, resulting in removal of additional slab sections and more erosion.

Responding to the damage to the service spillway chute necessitated difficult risk tradeoffs while the lake continued to rise. The resulting decisions, made without a full understanding of relative uncertainties and consequences, allowed the reservoir level to rise above the emergency spillway weir for the first time in the project’s history, leading to severe and rapid erosion downstream of the weir and, ultimately, the evacuation order.

There was no single root cause of the Oroville Dam spillway incident, nor was there a simple chain of events that led to the failure of the service spillway chute slab, the subsequent overtopping of the emergency spillway crest structure, and the necessity of the evacuation order. Rather, the incident was caused by a complex interaction of relatively common physical, human, organizational, and industry factors, starting with the design of the project and continuing until the incident. The physical factors can be placed into two general categories:

- Inherent vulnerabilities in the spillway designs and as-constructed conditions, and subsequent chute slab deterioration
- Poor spillway foundation conditions in some locations

A simplified overview of how human, organizational, and industry factors interacted with these two general categories of physical factors is given in Figure S-1, and is broadly outlined below.

The inherent vulnerability of the service spillway design and as-constructed conditions reflect lack of proper modification of the design to fit the site conditions. Almost immediately after construction, the concrete chute slab cracked above and along underdrain pipes, and high underdrain flows were observed. The slab cracking and underdrain flows, although originally thought of as unusual, were quickly deemed to be “normal,” and as simply requiring on-going repairs. However, repeated repairs were ineffective and possibly detrimental.

The seriousness of the weak as-constructed conditions and lack of repair durability was not recognized during numerous inspections and review processes over the almost 50-year history of the project. Over time, chute flows and temperature variations led to progressive deterioration of the concrete and corrosion of steel reinforcing bars and anchors, with likely loss of slab strength and anchor capacity. There was likely also some shallow underslab erosion and some loss of underdrain system effectiveness, which contributed to increased slab uplift forces. The particularly
poor foundation conditions at the initial service spillway chute failure location contributed to likely low anchor capacity and shallow underslab erosion.

Due to the unrecognized inherent vulnerability of the design and as-constructed conditions and the chute slab deterioration, the spillway chute slab failure, although inevitable, was unexpected.

Once the initial section of the chute slab was uplifted, the underlying poor quality foundation materials were directly exposed to high velocity flows and were quickly eroded. Undermining and uplift of other portions of the chute slab resulted in further removal of slab sections and more foundation erosion.

Although the poor foundation conditions at both spillways were well documented in geology reports, these conditions were not properly addressed in the original design and construction, and all subsequent reviews mischaracterized the foundation as good quality rock. As a result, the significant erosion of the service spillway foundation was also not anticipated.

Following the unexpected chute slab failure and erosion, and subsequent closure of the service spillway gates to examine the damage, delicate and difficult risk tradeoffs, involving myriad considerations, were necessary over the next few days in order to manage the incident. Either the gates would need to be re-opened, with the potential for further service spillway damage and/or damage to a transmission tower, or the lake levels would rise and the emergency spillway weir would be overtopped, with the potential for erosion at the emergency spillway. In addition, erosion had transported a tremendous amount of debris into the river channel, and the resulting high tailwater was threatening to flood the powerhouse. The decision-makers attempted to find a “sweet spot,” such that the service spillway would continue to be used, but with discharges no greater than necessary to just prevent the lake from rising above the emergency spillway weir.

There were decision points during the incident when discharge through the service spillway was specifically limited, even though risks to the powerhouse from further discharge were clearly diminishing. These decisions ultimately resulted in the lake rising high enough to initiate flow over the emergency spillway weir. The decisions were made with the best of intentions, but against the advice of civil engineering and geological personnel, who had by then recognized the poor bedrock conditions and the potential for unsatisfactory performance of the previously untested emergency spillway. In limiting service spillway discharge to reduce the likelihood of powerhouse flooding, the additional dam safety risk associated with use of the emergency spillway was not appropriately considered. Once the emergency spillway was allowed to overtop, this additional risk was soon realized, and the evacuation order became a necessary precaution.

There were many opportunities to intervene and prevent the incident, but the overall system of interconnected factors operated in a way that these opportunities were missed. Numerous human, organizational, and industry factors led to the physical factors not being recognized and properly addressed, and to the decision-making during the incident. The following are some of the key factors which are specific to DWR:

- The dam safety culture and program within DWR, although maturing rapidly and on the right path, was still relatively immature at the time of the incident and has been too reliant on regulators and the regulatory process.
Like many other large dam owners, DWR has been somewhat overconfident and complacent regarding the integrity of its civil infrastructure and has tended to emphasize shorter-term operational considerations. Combined with cost pressures, this resulted in strained internal relationships and inadequate priority for dam safety.

DWR has been a somewhat insular organization, which inhibited accessing industry knowledge and developing needed technical expertise.

DWR’s ability to build the appropriate size, composition, and expertise of its technical staff involved in dam engineering and safety has been limited by bureaucratic constraints.

In addition to lessons which are specific to DWR, as described in this report, the following are some of the general lessons to be learned by the broader dam safety community:

- In order to ensure the safe management of water retention and conveyance structures, dam owners must develop and maintain mature dam safety management programs which are based on a strong “top-down” dam safety culture. There should be one executive specifically charged with overall responsibility for dam safety, and this executive should be fully aware of dam safety concerns and prioritizations through direct and regular reporting from a designated dam safety professional, to ensure that “the balance is right” in terms of the organization’s priorities.

- More frequent physical inspections are not always sufficient to identify risks and manage safety.

- Periodic comprehensive reviews of original design and construction and subsequent performance are imperative. These reviews should be based on complete records and need to be more in-depth than periodic general reviews, such as the current FERC-mandated five-year reviews.

- Appurtenant structures associated with dams, such as spillways, outlet works, power plants, etc., must be given attention by qualified individuals. This attention should be commensurate with the risks that the facilities pose to the public, the environment, and dam owners, including risks associated with events which may not result in uncontrolled release of reservoirs, but are still highly consequential.

- Shortcomings of the current Potential Failure Mode Analysis (PFMA) processes in dealing with complex systems must be recognized and addressed. A critical review of these processes in dam safety practice is warranted, comparing their strengths and weaknesses with risk assessment processes used in other industries worldwide and by other federal agencies. Evolution of “best practice” must continue by supplementing current practice with new approaches, as appropriate.

- Compliance with regulatory requirements is not sufficient to manage risk and meet dam owners’ legal and ethical responsibilities.

Some of these general lessons are self-evident, and have been noted by others previous to the IFT’s investigation of this incident. The question is whether dam owners, regulators, and other dam safety professionals will recognize that many of these lessons are actually still to be learned. Although the practice of dam safety has certainly improved since the 1970s, the fact that this incident happened to the owner of the tallest dam in the United States, under regulation of a federal
agency, with repeated evaluation by reputable outside consultants, in a state with a leading dam safety regulatory program, is a wake-up call for everyone involved in dam safety. Challenging current assumptions on what constitutes “best practice” in our industry is overdue.

Figure S-1: Overview of interacting factors leading to the Oroville Dam spillway incident
2.2 Dam Safety

The February 2017 spillway failure at Oroville demonstrated that California needed a more extensive evaluation of the adequacy, stability and structural integrity of the appurtenant structures.

Currently, about 1,250 dams are subject to the state’s jurisdiction with respect to safety and regulated by DWR’s Division of Safety of Dams (DSOD). These dams are inspected annually and before July 1, 2017, these dams were classified in three categories consistent with federal definitions; 678 high hazard, 281 significant hazard, and 289 low hazard.

DWR’s Dam Safety Program comprises four basic safety activities, including annual maintenance inspections, construction oversight, application reviews, and re-evaluation of existing dams. Over the last ten years, the re-evaluation component of the program focused on the highest risk to California dams, including a seismic re-evaluation of dams in areas that have a high probability of a major earthquake. The seismic re-evaluations led to over $1 billion in repairs to dams.

The inspection process focused heavily on the dam itself, and included a visual inspection of the appurtenant structures, such as spillways. At the time of the Oroville spillway incident, Emergency Action Plans were not required for all jurisdictional dams; however, about 70 percent of the high-hazard dams had them, including Oroville.

Prior to July 1, 2017, inundation maps, the cornerstone of emergency plans, were created or updated only at the time the dam was built or enlarged. A dam inundation map delineates the area that would be flooded by a hypothetical dam breach or failure. It includes downstream effects and shows the probable path of water released due to the failure of a dam or from abnormal flood flows released through a dam’s spillway and/or other appurtenant works.

SB 92, the Budget Trailer bill for 2017, requires DSOD to re-classify jurisdictional dams as extremely high, high, significant or low risk, and to require inundation maps and Emergency Action Plans for all jurisdictional dams, allowing a waiver for low hazard dams. During regular inspections, the Department will track any dams where the hazard classification has changed and reassess the waiver as necessary. The DSOD will identify which scenarios, other than a complete dam failure, require a separate inundation map. The dam owner will create the inundation map and submit to DSOD, for review and approval of the map. The approved maps will then be posted publicly on the Department’s website.

Cal OES will coordinate emergency response drills with dam owners and local emergency management agencies. The dam owner will be required to update the Emergency Action Plans regularly in accordance with federal guidelines and update the inundation maps every ten years or sooner if there is a change in dam status or change in downstream risk.

2.3 Climate Change and Emissions Reduction

Climate change is affecting the planning and operation of the SWP. California is likely to experience more frequent extremes of drought and heavy precipitation, as in the winter of 2016-2017. More rain and less snowpack will affect how DWR balances the need to maintain space in reservoirs for flood waters with the competing management objective of storing water for deliveries.
In 2016, the Governor signed AB 2480 into law (Water Code section 108.5), declaring that it is state policy that source watersheds are recognized and defined as integral components of California’s water infrastructure. AB 2480 noted the importance of source watersheds to maintaining the reliability, quantity, timing, and quality of California’s water supply as climate change advances. In particular, the bill made certain ecosystem restoration and conservation activities eligible for the same forms of financing as other water collection and treatment infrastructure.

The Global Warming Solutions Act of 2006, or Assembly Bill (AB) 32, along with Executive Order S-3-05 established greenhouse gas emission (GHG) reduction targets for the State. In 2012, DWR adopted a GHG emissions reduction plan, which covers DWR operations, including operations of the SWP and state flood control infrastructure. The plan includes a near-term goal to reduce GHG emissions to 50 percent below 1990 levels by 2020, and a long-term goal to reduce emissions to 80 percent of 1990 levels by 2050. DWR’s GHG emissions reduction goals are more aggressive than statewide goals set forth in both law and policy. DWR outlined 11 GHG emissions reduction strategies in the plan, including eliminating use of coal-fired power, energy efficiency improvements, and procuring renewable energy. The strategies aim to reduce emissions from all sources.

In November 2017, DWR briefed the Commission on progress toward greenhouse gas (GHG) emissions reduction goals and renewable energy procurement.

Approximately 63 percent of power for the SWP currently comes from emissions-free sources. That amount is expected to increase to 73 percent by 2030 and 96 percent by 2050. Those emissions-free sources include both large and small hydroelectric plants and solar power resources. Approximately 31 percent of the SWP’s power currently comes from market purchases. As DWR increases contracted renewable energy resources, market purchases are expected to decrease and DWR anticipates making no market purchases for the SWP by 2050. DWR currently has one contract for natural gas, three contracts for hydroelectric power, and three contracts for solar power.

DWR’s Greenhouse Gas Emissions Reduction Plan calls for annual monitoring reports. The most recent report (from 2015) found that DWR’s 5-year average of GHG emissions spanning years 2011-2015 was 1,307,060 metric tons of carbon dioxide equivalents (mtCO2e). This number is 52 percent below 1990 levels and 49 percent below 2010 levels. This level of emissions is the lowest ever recorded by DWR and represents substantial and consistent reductions in emissions over the last decade. DWR is already well ahead of schedule for achieving its 2020 and 2050 GHG Emissions Reduction Goals. The GHG Emissions Reduction Plan projected that 2015 emissions should be around 2.1 million metric tons CO2e to be on track to achieve the reduction goals by 2020. In fact, DWR achieved its target emissions reductions for 2020 in 2015, five years ahead of schedule.

DWR’s emissions vary greatly from year to year because SWP operations are hydrologically dependent and increasing water deliveries increases emissions. Even with these variations, DWR is currently on track to meet its 2020 and 2050 emissions reduction targets. DWR is also actively monitoring the increase in emissions due to the Oroville spillways recovery effort and does not expect that activity to change the overall trajectory of emissions reduction.
**Boulder Canyon Project (Hoover)**

In October 2017, DWR began receiving carbon free energy from a new 50-year contract with the United States Department of Energy Western Area Power Administration, Desert Southwest Regional Office, and the United States Department of the Interior, Bureau of Reclamation. Western Area Power Administration Desert Southwest and Bureau of Reclamation will provide DWR up to 6.55 GWh annually.

### 2.4 California Aqueduct Subsidence

In 2017, DWR completed the California Aqueduct Subsidence Study, which assessed the impacts of subsidence, reviewed the California Aqueduct operational limits, and explored actions to mitigate the impacts of subsidence.

In November 2017, DWR staff briefed the Commission on the study’s findings, remedial work, and next steps. This section summarizes the findings of the subsidence study and DWR’s presentation to the Commission.

Subsidence in the San Joaquin Valley has been recorded, analyzed, and studied since the 1920s. Before the construction of the Aqueduct in the mid to late 1960s, portions of the Valley had subsided by 20 to 30 feet. Consequently, subsidence was factored into the planning and the design of the Aqueduct. Different alignments were considered to avoid areas that were thought to have a high potential for subsidence. Consolidation ponds were constructed to induce hydrocompaction (shallow subsidence) before Aqueduct construction. The Aqueduct embankments and concrete-lined freeboard were built higher than normally required to accommodate for future subsidence. During the planning of the Aqueduct, it was thought that most of the future subsidence would occur during Aqueduct construction, and that once the Aqueduct began delivering water the overdraft of groundwater would stop and subsidence would cease.

Subsidence continued during the construction of the Aqueduct (as planned) at an average rate of 6.4 inches per year in Pool 17 through Pool 20 of the San Luis Field Division, with the highest rate of 18.2 inches per year in Pool 19. In most areas, the higher embankments and freeboard were adequate to accommodate the active subsidence. But, in 1969 and 1970, the embankment and liner were raised 4 feet near Check 17 to restore the required amount of freeboard.

After water deliveries from the Aqueduct began, subsidence rates decreased to an average of less than 0.1 inch per year during the normal to wet hydrologic years. But, during dry to critical hydrologic years, subsidence increased to an average of 1.1 inches per year in Pool 17 through Pool 20. The slow, but ongoing, subsidence decreased the Aqueduct’s concrete freeboard to a point that canal embankment and liner raises were required in 1982 in the San Luis Field Division, and in 1989 and 1996 in the San Joaquin Field Division.

In 2006, the San Luis Field Division of the DWR’s Division of Operations and Maintenance (O&M) began to see a reduction in flow capacity through the California Aqueduct Pools 20 and 21. Subsidence had lowered portions of the Aqueduct and reduced the concrete liner freeboard (the vertical distance between the water surface and the top of the concrete liner) from its normal of 3 feet, to less than 1 foot. Subsidence had also decreased the ability to store water in those pools, which is normally done to add operational flexibility and to manage pumping at the Aqueduct’s pumping plants. While subsidence has reduced the amount of freeboard and flow capacity at specific
locations, contracted deliveries have not been curtailed through 2016.

DWR’s subsidence study found that the recent drought produced subsidence rates similar to those seen before the Aqueduct began delivering water. Between 2013 and March 2015, the average subsidence in Pool 17 through Pool 20 was 4.0 inches per year, with as much as 7.5 inches per year near the southern end of Pool 20. From March 2015 through August 2015, Pool 20 experienced an average of 6.9 inches of subsidence.

DWR assessed where subsidence is affecting the Aqueduct, how it is impacting water deliveries, and near-term and long-term solutions. The study found three main areas of subsidence roughly between Los Banos and Bakersfield. Over time, the maximum flow rate through many sections of the Aqueduct has decreased, with the greatest reductions in the most subsided areas. The Aqueduct was built with extra capacity to accommodate subsidence, so recent subsidence has not limited DWR’s ability to deliver water to contractors in Southern California. However, decreases in capacity can impact operational flexibility.

The magnitude and rates of subsidence found in the study demonstrate that subsidence continues during dry, normal, and even wet years. As subsidence continues, the flow capacity, storage volume, and freeboard of the Aqueduct will continue to decrease. DWR has identified the following subsidence work to be done in 2018:

- Complete the Phase 1 Supplemental Report, which will include:
  - Aqueduct hydraulic model update;
  - Predictions of future subsidence;
  - Evaluation/summary of impacted structures; and
  - Updated survey information.
- Complete short-term actions in San Luis Field Division, including:
  - Adding concrete liner along select portions of the Aqueduct;
  - Modifying select drain inlets;
  - Modifying selected turnouts; and
  - Adding additional instrumentation.
- Begin actions in San Joaquin Field Division, including:
  - Adding concrete liner along select portions of the Aqueduct;
  - Modifying overchutes in select locations; and
  - Adding additional instrumentation.
- Begin Phase 2 of the California Aqueduct Subsidence Study to develop, evaluate, and select alternative(s) for addressing impacts from subsidence.

In the planned Phase 2 study, DWR will quantify how hydraulic limitations have impacted operations and will estimate future impacts to deliveries, based on forecasted subsidence rates. DWR also plans to evaluate and implement long-term solutions to restore capacity. In addition, DWR is providing stakeholder input in the development of Groundwater Sustainability Plans to protect SWP interests.
2.5 Water Deliveries and Power Generation

During 2017, exceptionally high precipitation and snowfall ended California’s five-year drought. The amount of water the SWP delivered during this time reflects these conditions. In April 2017, DWR increased the final 2017 allocation from 60 percent to 85 percent of the SWP Contractors’ requested Table A amounts, which is approximately 4.2 million acre-feet. Table 1 shows deliveries in recent years.

Table 1. SWP Water Deliveries

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Delivered (acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>3,584,668</td>
</tr>
<tr>
<td>2001</td>
<td>2,042,130</td>
</tr>
<tr>
<td>2002</td>
<td>2,850,219</td>
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<tr>
<td>2003</td>
<td>3,167,607</td>
</tr>
<tr>
<td>2004</td>
<td>3,119,583</td>
</tr>
<tr>
<td>2005</td>
<td>3,627,007</td>
</tr>
<tr>
<td>2006</td>
<td>3,691,573</td>
</tr>
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<td>2007</td>
<td>2,996,638</td>
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<tr>
<td>2008</td>
<td>1,950,972</td>
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<tr>
<td>2009</td>
<td>1,933,739</td>
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<td>2010</td>
<td>2,660,964</td>
</tr>
<tr>
<td>2011</td>
<td>3,596,754</td>
</tr>
<tr>
<td>2012</td>
<td>2,848,085</td>
</tr>
<tr>
<td>2013</td>
<td>2,107,574</td>
</tr>
<tr>
<td>2014</td>
<td>1,079,385</td>
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<tr>
<td>2015</td>
<td>1,375,538</td>
</tr>
<tr>
<td>2016</td>
<td>2,299,679</td>
</tr>
<tr>
<td>2017</td>
<td>3,724,834</td>
</tr>
</tbody>
</table>

1Source: Department of Water Resources’ State Water Project Analysis Office. (In addition to Table A, reported deliveries include Carryover, Article 21, other SWP deliveries such as Settlement, Permit and Flexible Storage, and other non-SWP deliveries such as Dry Purchase, Temporary Transfer and Water Bank Recoveries.)

2As of January 2018.

During 2017, the SWP generated 5,027 gigawatt hours (GWh) of energy. During the same period, the SWP used 9,655 GWh of energy. Nearly 70 percent of this power is used by the Valley String Pumping Plants which are pumping plants in the San Joaquin Valley ranging from Dos Amigos to Edmonston Pumping Plants. The Valley String Pumping Plants work to lift the water more than 3,000 feet from the floor of the southern San Joaquin Valley, over the Tehachapi Mountains, and into Southern
California. Table 2 reflects recent years’ energy generation and usage. As expected, SWP power usage increases with SWP water deliveries. Moreover, DWR’s divestiture of Reid Gardner Unit 4 coal–fired power plant in 2013 resulted in a reduction in SWP power generation of about 1,500 GWh annually, most of which has been replaced by power purchase agreements.

Table 2. SWP Power Generation and Usage¹

<table>
<thead>
<tr>
<th>Year</th>
<th>Power Generated (GWh/year)</th>
<th>Power Used (GWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>7,515</td>
<td>9,109</td>
</tr>
<tr>
<td>2007</td>
<td>6,410</td>
<td>9,276</td>
</tr>
<tr>
<td>2008</td>
<td>4,100</td>
<td>5,701</td>
</tr>
<tr>
<td>2009</td>
<td>4,255</td>
<td>5,438</td>
</tr>
<tr>
<td>2010</td>
<td>4,368</td>
<td>7,184</td>
</tr>
<tr>
<td>2011</td>
<td>5,258</td>
<td>8,583</td>
</tr>
<tr>
<td>2012</td>
<td>4,810</td>
<td>7,404</td>
</tr>
<tr>
<td>2013</td>
<td>3,679</td>
<td>5,733</td>
</tr>
<tr>
<td>2014</td>
<td>1,438</td>
<td>2,787</td>
</tr>
<tr>
<td>2015</td>
<td>1,699</td>
<td>3,483</td>
</tr>
<tr>
<td>2016</td>
<td>3,535</td>
<td>6,598</td>
</tr>
<tr>
<td>2017²</td>
<td>5,027</td>
<td>9,655</td>
</tr>
</tbody>
</table>

¹Source: Department of Water Resources’ State Water Project Analysis Office.
²As of January 2018.
2.6 Status of SWP Construction Projects

This section highlights key projects and projects of interest to the Commission—it is not a comprehensive list of SWP construction projects. The Department of Water Resources provided the following information to the Commission.

State Water Project - Oroville Field Division

Hyatt Powerplant Fire Detection System

The Hyatt Fire Protection Modernization project will increase personnel safety and protect equipment by modernizing the fire protection systems and improving emergency egress at Hyatt Powerplant, Oroville Field Division Operations and Maintenance Center, Thermalito Diversion Dam Powerplant, Hyatt Intake, Oroville Spillway Control Structure, Feather River Outlet Control Structure, and the Area Control Center.

The project was significantly impacted by the 2017 Oroville Spillway Incident, resulting in a five-month delay. In addition, fire suppression to control structures at Oroville Spillway, Thermalito Diversion Dam, and Feather River Outlet were added to the scope. The project is nearly 75 percent complete and is scheduled to complete by the end of 2018.

Hyatt Unit 1 Turbine Upgrade and Turbine Shutoff Valve Refurbishment

The Hyatt Unit 1, 3, and 5 turbine generators have been in service for over 40 years and have exhibited numerous thrust bearing failures over the years. As a result, DWR issued an order to design and furnish new robust thrust bearings and a new turbine runner for Unit 1, which have been received at the Hyatt Powerplant. In addition, the turbine shaft and many other components required to maintain efficiency have also been refurbished.

The Hyatt turbine shut-off valves (TSV) seats are worn and in need of replacement to ensure the future reliability of the valves. The refurbishment work includes retrofitting the TSV with mechanical locks, replacing portions of the TSV, designing new valve seats, and pressure testing the refurbished TSV.

Work on the Hyatt Unit 1 turbine replacement and TSV refurbishment experienced several months of delays in 2017 due to the Oroville Spillway incident. Commissioning and testing of the turbine and TSV is scheduled for completion by Fall 2018.

Thermalito Pumping-Generating Restoration and Modernization

On November 22, 2012, the Ronald B. Robie Thermalito Pumping–Generating Plant (THPP), part of the Oroville complex, suffered a catastrophic fire rendering the plant inoperable. A fire clean-up project removed damaged plant components and hazardous materials resulting from suppressing the fire and was completed in April 2014.

The THPP Restoration Project commenced in April 2015 to restore the plant’s electrical, protection, controls, and communications systems. The plant is being modernized to maximize fire protection and life safety, enhance reliability, reduce maintenance, and minimize unplanned outages. Full operation of the plant will provide as much as 300,000 MWh annually and potentially restore SWP pump-back operational flexibility.

Completion of the Restoration Project which includes all four units fully operational is scheduled for January 1, 2019. The project is currently on-schedule and on-budget.
State Water Project - Delta Field Division

Clifton Court Forebay Intake Structure Apron Repair

In March 2017, Delta Field Division visually identified damage to the wing-wall, on the downstream side of the Clifton Court Forebay Intake Structure. Subsequent sonar and dive inspections determined damage to the apron as well as undercutting foundation scour would require repair. A project was immediately initiated and repairs to the wing-wall section and concrete apron along with voids under the slab were completed. Riprap was placed and grouted downstream of slab to provide additional protection. Work was completed on May 7, 2017.

South Bay Aqueduct Compression Vault Project

Three pipelines, two owned by Santa Clara Valley Water District (SCVWD) and one owned by DWR, were enclosed within the Penetencia Valve Vault located along the South Bay Aqueduct. The vault was located at the toe of a massive, active (i.e. moving) landslide. Within the vault, each pipeline had an expansion joint to help account for this anticipated ongoing movement. The joints had reached their design life and had to be replaced. In addition, seismic analysis suggested up to 7 feet of movement may occur due to earthquake where the existing joints could not accommodate this magnitude of movement.

To replace the expansion joints, new pipe sections were installed to accommodate ongoing and anticipated future movement. Because of limited access and limited work area, all three pipes had to be worked on at one time. DWR partnered with the SCVWD, who took the lead in planning, design, and construction to address the identified deficiencies.

North Bay Aqueduct Alternate Intake

The environmental review process is currently underway for the North Bay Aqueduct Alternate Intake Project (NBA AIP), a new facility that will improve water quality and provide reliable delivery of SWP water to the Solano County Water Agency (SCWA) and the Napa County Flood Control and Water Conservation District (Napa County FCWCD). The SCWA and Napa County FCWCD initially requested that DWR study the feasibility of changing the location of the North Bay Aqueduct intake in 2007. The NBA AIP will include the construction and operation of an alternate intake that will draw up to 240 cubic feet per second (cfs) of water from the Sacramento River, and connect to the existing North Bay Aqueduct (NBA) system. The proposed alternate intake may be operated in conjunction with the existing NBA intake at Barker Slough thereby increasing operational flexibility.

The draft Administrative EIR is being updated in response to comments received in July 2016. The final EIR completion is on hold until further notification. The Administrative record will be updated and a memo is being prepared that will indicate what steps are needed to update the draft EIR when it is determined to move forward with this project.

State Water Project - San Luis Field Division

Gianelli Pumping and Power Plant Unit 7 - Butterfly Valve, Motor, and Turbine Refurbishment

The San Luis Joint-Use Complex serves the California State Water Project and federal Central Valley Project. DWR operates and maintains the complex. The Gianelli
Pumping Plant, located between San Luis Reservoir and O’Neill Forebay, and pumps water into San Luis Reservoir for storage and release as needed. This project involves the disassembly, refurbishment, and reassembly of Gianelli Unit 7 Butterfly Valve, motor generator, and turbine. This project is expected to be completed by August 2019.

**State Water Project - San Joaquin Field Division**

**Edmonston Pumping Plant Unit 7 Pump Refurbishment**

Edmonston Pumping Plant, the highest-lift pumping plant in the State Water Project, moves water across the Tehachapi Mountains into southern California. This project involves partially disassembling the pump, cleaning, inspecting, and documenting component conditions, manufacturing a new pump shaft, and conducting electrical and mechanical tests on the pump before returning the unit to service. The project is expected to be completed by December 2018.

**State Water Project - Southern Field Division**

**Perris Dam Remediation Program (PDRP) - Dam Remediation**

Lake Perris, located in northern Riverside County, is the southernmost SWP facility and the southern terminus of the East Branch of the California Aqueduct. In 2005, DWR identified potential seismic safety risks in the foundation of Perris Dam. While there was no imminent threat to life or property, in the interest of ensuring the maximum public safety, DWR lowered the water level of Lake Perris until repairs are made.

The remediation of Perris Dam facilities is a major capital improvement program and comprises four projects: foundation remediation, outlet tower improvements, an emergency release facility, and seepage recovery. These are described in more detail below. The EIR for the PDRP was certified in November 2011 and the foundation remediation and outlet tower improvements were approved to move forward with design. DWR advertised the construction contract for the PDRP in April 2014 and awarded to Pulice Construction Inc. in July 2014. The contractor completed the stabilizing berm and deep soil cement mixing system to strengthen a portion of the dam's foundation in November 2017. The contract is expected to be completed in early 2018.

The design for the Emergency Release Facility project will begin in 2018. The Draft EIR was recirculated between September 29, 2017 and November 13, 2017.

Analyses of the Perris Outlet Tower have indicated the tower can survive the Maximum Credible Earthquake. This project is now focusing on a seismic retrofit to the tower's bridge, retrofits and replacement of critical operating equipment, and the modification to the outlet structure to refurbish the existing slide gate and provide a second redundant slide gate. The second slide gate will replace a bulkhead that poses an impractical feature to remove in the midst of an emergency drawdown.

The Emergency Release Facility project’s EIR is anticipated be certified in the first half of 2018. Final Design efforts will occur in 2018 as well, with construction anticipated to initiate in late 2020. Major features include the construction of bridges as Lake Perris Drive and Evans Road to allow for conveyance of emergency releases to the Perris Valley Channel.
Perris Seepage Recovery

This project involves qualifying and quantifying subsurface reservoir seepage downstream of Perris Dam, installation of observation/monitoring wells and thermal probes, test wells; design and construction of a seepage collection system including: production water wells, collector pipeline(s) and appurtenances, permanent power supply and distribution, and controls and communications. It will also entail an operation and maintenance agreement between DWR and the Metropolitan Water District (MWD). This effort will also require the development or use of a groundwater model to analyze the project's impacts to the groundwater basin. This project is currently scheduled to complete by the end of 2020.

East Branch Extension - Phase I Improvements

The East Branch Extension (EBX) is a cooperative effort among DWR, San Bernardino Valley Municipal Water District (SBVMWD), and San Gorgonio Pass Water Agency (SGPWA) to deliver SWP water to the east side of SBVMWD’s and SGPWA’s service areas in Riverside and San Bernardino counties. The project conveys water from the Devil Canyon Powerplant Afterbay to Cherry Valley through a series of existing and new facilities. Construction for Phase I was completed in 2003, however, subsequent construction of Phase I Improvements followed with the construction of the Yucaipa Connector Pipeline and Crafton Hills Reservoir Enlargement, which provide additional storage for operational reliability and reduce energy demands during peak demand periods. Yucaipa Pipeline created a bypass around the Crafton Hills Reservoir during the enlargement and maintained water deliveries while the Crafton Hills Reservoir is off-line and under construction. Spare pump units were added at Greenspot Pump Station, Crafton Hills Pump Station, and Cherry Valley Pump Station. EBX Phase I Improvements were completed in 2017, and, tree-planting as part of environmental mitigation is scheduled for completion in 2018.
**East Branch Extension - Phase II**

The East Branch Extension Phase II Project increased the conveyance capacity of the East Branch Extension and provided additional pumping capacity to convey the full contracted amount of SWP water (17,300 acre-feet) to the SGPWA. In addition, the project allowed the SBVMWD to increase its distribution system capacity to the Redlands and Yucaipa Valley service areas. Construction of Phase II was completed in 2017. Principal features of this project included approximately six miles of a new large diameter pipeline, a new reservoir (Citrus Reservoir) with a capacity of 400 acre-feet, a new 160 cfs pump station (Citrus Pump Station), expansion of the existing Crafton Hills Pump Station from 60 cfs to 135 cfs, and installation of an additional pump at the existing Cherry Valley Pump Station to increase the capacity from 32 cfs to 52 cfs. Remaining activities include the Santa Ana River weed removal and monitoring as part of environmental mitigation which is scheduled for completion in 2019.

**Alamo Powerplant Unit 2**

Installing a second generating unit at Alamo Powerplant would capture the hydroelectric power generating potential of flows that are currently diverted through the spillway during outages on Alamo Unit 1 and during high flow conditions. The estimated design and construction cost of Alamo Unit 2 is $57 million. The estimated generation value of Alamo Unit 2 is $40 million over 30 years.

DWR seeks “Cap and Trade” funds for a portion of the design and construction to bridge the gap between the cost to the SWP and the benefits the SWP will receive. DWR submitted a funding package to the California Air Resources Board (CARB) in April 2016. In October 2016, the CARB deferred DWR’s funding request and requested that DWR resubmit in the spring of 2017. In April 2017, DWR submitted a Cap and Trade funding package for $1.4M in FY 18-19 and $10.6M for FY 19-20. However, the request was denied without prejudice. The proposal was also denied because the framework of the Administration’s expenditure plan already accounted for the funds in the Greenhouse Gas Reduction Fund, and this proposal was not part of that framework.

**2.7 Biological Opinions on the Coordinated Long-Term Operation of the Central Valley Project and State Water Project**

In 2009, the National Marine Fisheries Service (NMFS) issued its Biological Opinion and Conference Opinion on the Long-term Operation of the Central Valley Project (CVP) and State Water Project (SWP) (NMFS Operation BO). The NMFS Operation BO concluded that, if left unchanged, CVP and SWP operations were likely to jeopardize the continued existence of four federally-listed anadromous fish species: Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, California Central Valley steelhead, and Southern Distinct Population Segment (DPS) North American green sturgeon. The NMFS Operation BO sets forth Reasonable and Prudent Alternative (RPA) actions that would allow continuing SWP and CVP operations to remain in compliance with the federal Endangered Species Act (ESA). Construction for two projects to address regulatory compliance are as follows:

**Wallace Weir Fish Rescue Facility Project**

In 2017, the Wallace Weir Fish Rescue Facility Project entered its second construction season. The focus this season was to incorporate safety features, including stop logs
both upstream and downstream of the structure. Other construction during 2017 included: anchoring the picket weirs, hoist, and clutch assembly; installing a debris boom; fabricating the fish crowder and brail design for the fish collection component; building and additional crane pad for maintenance activities; and integrating operations with the Supervisory Control and Data Acquisition software for remote monitoring and operations.

**Fremont Weir Adult Fish Passage Modification Project**

Construction activities for this project consisted of exclusively of clearing trees within the project footprint. This should enable the construction to begin in the spring of 2018. A Spring 2018 construction start date should result in the entire project to be completed in 2018, addressing the critical fish passage improvement objectives in time for listed anadromous fish migration timing in Fall 2018.

**Tule Red Restoration Project**

Tule Red is the first tidal restoration project counting toward the 8,000-acre requirement to break ground. When completed, the project will receive approximately 600 acres of credit toward the 2008 United State Fish and Wildlife Biological Opinion of the CVP and SWP.

The State and Federal Contractors Water Agency broke ground on the Tule Red Restoration Project in September 2016 and were able to get two weeks of earth work completed before the construction window closed. In 2017, dewatering of the project site began with natural drainage. The contractor was to supplement dewatering the site by, in part, removing some vegetation. The contractor was unprepared for the wet conditions and requested construction change orders. As a result, construction was halted for the remaining year. Construction will commence in 2018.
2.8 California WaterFix

The Department of Water Resources and the United States Bureau of Reclamation submitted the Final Bay Delta Conservation Plan/California WaterFix Final EIR/EIS (Final EIR/S) on December 22, 2016. DWR certified the Final EIR/S in July 2017. DWR then adopted Findings and a Statement of Overriding Considerations, submitted the Mitigation Monitoring and Reporting Program, approved the California WaterFix (alternative 4a), and filed the Notice of Determination (NOD) with the Governor’s Office of Planning and Research.

The National Marine Fisheries Service (NMFS), United States Fish and Wildlife Service (USFWS), and the California Department of Fish and Wildlife requested an independent scientific peer review of the aquatic science used in the environmental review and analyses of the California WaterFix Final EIR. Representatives from the Delta Science Program convened in December 2016 and January 2017 for a two-phased independent scientific peer review. This peer review resulted in a final report which was titled the Aquatic Science Peer Review and released on March 10, 2017. The Biological Assessment was updated in June 2017 and NMFS issued their Biological Opinion on June 16, 2017 while the USFWS issued their Biological Opinion on June 23, 2017. The California Department of Fish and Wildlife issued the 2081(b) incidental take permit on July 28, 2017.

The State Water Resources Control Board (SWRCB) change petition hearings continued during 2017. Rebuttal hearings for the Change in Point of Diversion, Part 1, Effects of the Petition on Municipal, Industrial and Agricultural Uses of Water, Including Associated Legal Users of Water, began in April 2017 and concluded in July 2017. Hearings for Part 2, Effects of the Petition on Fish and Wildlife and Recreational Uses, including What Appropriate Delta Flow Criteria Should Be Included in any Project Approval; Public Interest Considerations; and Consideration of the Final CEQA Document, are set for early 2018.

The California WaterFix planning and permitting efforts to date have been funded through agreements between and amongst certain CVP and SWP water contracting public agencies.
APPENDIX A: INDEPENDENT FORENSIC TEAM
PRELIMINARY MEMORANDUM
Memorandum

To: Mr. Paul Dunlap, California Department of Water Resources

From: Oroville Dam Spillway Incident Forensic Investigation Team

Date: May 5, 2017

Re: Preliminary Findings Concerning Candidate Physical Factors Potentially Contributing to Damage of the Service and Emergency Spillways at Oroville Dam

According to the Work Plan, the Forensic Investigation Team’s (Team’s) assignment is to complete a thorough review of available factual information to develop opinions on the chain of conditions and actions that caused the damages to the service spillway ¹ and emergency spillway at Oroville Dam, and why opportunities for intervention in the chain of conditions or actions may not have been realized. Evaluations of actions and decisions for the various stages of the project (pre-design, design, construction, and operations and maintenance) will consider the states of practice applicable to those various time periods.

At this time, the Team is still in the information gathering and review stage of its work, and it has not yet reached conclusions. However, the Team recognizes that the California Department of Water Resources (DWR) is in the process of designing and constructing interim and permanent repairs to the service and emergency spillways at Oroville Dam. As requested by DWR, to provide input to the repair efforts, the Team provides the following preliminary lists of candidate physical factors that are being considered as potentially contributing to the damages that occurred at the spillways in February 2017. At this time, the Team does not believe that it is likely that there are singular physical causes of the spillway damages, but rather that the damages were the results of some combination of physical factors from the lists below. However, based on what is known at this time, it would be prudent that the design of repairs consider all of the physical factors listed below.

Separate lists of physical factors are provided for the service spillway and the emergency spillway. The reader is cautioned that additional factors may be identified as the investigation proceeds.

Candidate physical factors potentially contributing to service spillway damage:

1. Thinning of the chute slab above herringbone drains; these locations can promote cracking.
2. Large variations in slab thickness.
3. Limited slab reinforcement consisting of one layer of light reinforcement in the top of the slab.
4. Lack of continuous tension reinforcement across slab joints.
5. Corrosion and failure of reinforcing bars across cracks.

¹ The service spillway has historically been referred to as the flood control outlet (FCO) or flood control outlet spillway.
6. Slab joints with insufficient keys or lack of keys.
7. Slab placement sizes which were too large to control cracking.
8. Lack of waterstops in slab joints.
9. Hydraulic pressures and flows transmitted beneath the slab sections through open cracks and joints.
10. Increase in spillway discharge shortly before slab failure.
11. Plugging or collapse of drains or collector pipes, including potential plugging by tree roots.
12. Flow into the foundation that exceeded the capacity of the drain pipes, including possible flows from areas adjacent to the chute.
13. Lack of redundancy in collector drains.
14. Unfiltered drains; the gravel envelope may not serve as a filter.
15. Herringbone drains crossing joints in the slab.
16. Weathered rock and completely weathered rock that is soil-like material as slab foundation, without appropriate modification of the chute slab design, resulting in potentially erodible material beneath the slab and lack of foundation bond with concrete; the weathered rock and completely weathered rock appears to be associated with geologic features such as shear zones, and the degree of weathering changes relatively rapidly between some areas of the chute slab.
17. Less rigorous foundation preparation, resulting in lack of foundation bond with concrete.
18. Extended drought impacts on foundation materials.
19. Insufficient anchorage, due to limited anchor development in the concrete, short anchor length, inadequate grouting or grout strength, and/or installation in weak foundation material.
20. Relatively high spillway flow velocities in the lower chute for higher spillway discharges.
22. Spalling and/or delamination of concrete at slab joints.
23. Groundwater pressures; although current evidence suggests this may not have been a significant factor.
24. Cavitation; although preliminary analysis suggests this may not be a significant factor.

Candidate physical factors potentially contributing to emergency spillway damage:

1. Significant depth of erodible rock and soil in orientations that allowed rapid headcutting toward the crest control structure; these materials also appear to be associated with geologic features such as shear zones.
2. Hillside topography that concentrated flows and increased erosive forces, facilitating headcut formation.
3. Insufficient energy dissipation at base of the spillway crest.
4. Absence of erosion protection downstream of the crest structure.
It is important to understand that not all of the factors listed above may eventually be judged to have significantly contributed to the actual damages to the spillways, after all facts and as-constructed conditions are collected and fully evaluated. However, these factors should be considered and addressed in the ongoing new design and construction.
APPENDIX B: INDEPENDENT FORENSIC TEAM INTERIM MEMORANDUM
DWR Statement Regarding Independent Forensic Team Memo

SACRAMENTO – Today the Department of Water Resources (DWR) released the following statement regarding the interim memo released by the Independent Forensic Team investigating the Lake Oroville spillways incident:

“Today, the Independent Forensic Team (IFT) published an interim memorandum summarizing their findings of the Oroville spillways failure and briefed DWR leadership.

Protecting public safety is the state’s top priority, and we are committed to applying lessons learned from Oroville.

DWR agrees with the IFT that dam owners need to reassess current procedures as visual inspections would not have caught the February failure. The additional spillway evaluations already underway are the start of that process.

The reconstruction efforts at Oroville will bring the spillway design and construction up to today’s standards to ensure we address the physical causes that led to the February failure.

The IFT’s findings and recommendations are relevant not just for Oroville or DWR but for all dam owners. The IFT’s research will push the entire dam safety community forward to make lasting changes and improvements internationally.

The IFT shared this information ahead of their final report to inform ongoing spillway evaluations at other projects and educate the dam safety community. DWR is grateful for the team’s work and thanks the Association of State Dam Safety Officials and the United States Society of Dams for choosing this independent team of world-renowned experts with specialties in dams and spillways.”

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For more information, follow us on Twitter or Facebook, read our news releases or visit our Oroville Spillway Incident webpage.
Memorandum

To: Mr. Paul Dunlap, California Department of Water Resources
From: Oroville Dam Spillway Incident Independent Forensic Team
Date: September 5, 2017
Re: Interim Status Memorandum

Introduction – The Independent Forensic Team (IFT)1 is conducting a thorough review of available information to develop findings and opinions on the chain of conditions, actions, and inactions that in February 2017 caused the damage to the service spillway2 and emergency spillway at Oroville Dam, and why opportunities for intervention in the chain of conditions, actions, and inactions were not realized.

On May 5, 2017, the IFT published a memorandum presenting its preliminary findings concerning candidate physical factors potentially contributing to damage of the service and emergency spillways. At that time, the IFT was still in the information gathering and early review stages of its work, and had not developed any conclusions. The preliminary lists of candidate physical factors that were being considered by the IFT were presented in May to provide input to the ongoing repair efforts, so that those physical factors could be considered in the repairs.

The IFT has subsequently progressed its investigation of both physical factors and human and organizational factors. The IFT has noted that efforts have been initiated in California and elsewhere to evaluate spillways at other dams. Although the IFT’s work will not be completed and its final report will not be issued until fall 2017, the IFT wanted to share some of its findings to date, so that they may inform the ongoing spillway evaluations at other projects.

In this interim status memorandum, the IFT’s findings to date are presented in only summary form. All of the findings are supported by detailed evidence, which will be compiled and presented in the IFT’s final report.

Work Completed and In Progress – The IFT has carefully reviewed extensive documentation related to the geology and subsurface conditions of the spillway foundations; design and construction of the spillways; inspection, evaluation, maintenance, and repair of the spillways; the California Department of Water Resources (DWR) dam safety program management; and the regulatory framework for the project.

In addition, the IFT has studied photos and videos of the spillways, and post-incident forensic field investigation reports related to the failure and post-failure conditions. The post-incident studies include geologic investigations, ground penetrating radar (GPR) studies, video inspections of the remaining drainage system of the service spillway, evaluations of local trees and tree root growth, field inspections of the damaged areas of the service spillway chute, and forensic excavation and removal of portions of service spillway chute slabs in the sections of the chute remaining after the chute failure.

1 Resumes for members of the IFT can be found at the following link: https://damsafety.org/sites/default/files/Oroville%20Investigation%20Team%20Resumes%20FINAL.pdf
2 The service spillway has historically been referred to as the flood control outlet (FCO) or flood control outlet spillway or gated spillway.
The California Department of Water Resources (DWR) has made available a very large volume of information for the IFT to review, and the IFT has interviewed personnel on site at the time of the service spillway chute failure, personnel involved in emergency management efforts and recovery efforts, and personnel involved in dam and spillway engineering and safety at DWR, the DWR Division of Safety of Dams (DSOD), the Federal Energy Regulatory Commission (FERC), and several consulting firms.

The IFT is continuing review of documents, photos, and videos, and conducting additional interviews. In addition to reviewing information provided by others, the IFT has completed independent analyses, provided direction for certain aspects of the post-incident field investigations, completed reviews of historical spillway design and construction practices, issued a public call for pertinent information, and established an email box for receipt of comments. As information has been collected and reviewed, the IFT has held eight meetings, some multi-day, to discuss and evaluate the collected information.

The IFT is nearing completion on its deliberations regarding the physical factors involved with the spillway incident and has substantially progressed its investigation of human and organizational factors. The IFT is now focusing most of its efforts on completion of the investigation of human and organizational factors and compilation of its findings in a final report.

**Update on Initiating Event of Service Spillway Chute Failure** – The IFT believes that the service spillway chute failure most likely initiated by the uplift and removal of a section of the slab in the chute downstream of Station 33+50 at shortly after 10:00 am on February 7. Once the initial section of the chute slab was removed, the underlying moderately to highly weathered rock and soil-like material beneath the slab in this location was directly exposed to high-velocity spillway flow. The high-velocity flow rapidly eroded the foundation materials at this location, removed additional chute slab sections in both upstream and downstream directions, and quickly created the erosion hole that was observed by 12:30 pm on February 7, as flows diminished following spillway gate closure – see photo below. These findings are based on eyewitness accounts, and photo and video records.
Update on Physical Factors Evaluation for Service Spillway Chute Failure – While there are numerous physical factors that contributed to the failure, which the IFT has studied in detail, the IFT has focused on the critical factors that it believes likely played the most significant roles in the failure of the service spillway chute. As noted above, the IFT had previously prepared a list of potential physical factors under consideration, and now has a more refined view of these factors.

The IFT has concluded that the initial uplift and removal of the slab section downstream of Station 33+50 was most likely caused by water uplift pressure beneath a sufficiently large area of the slab, producing an uplift force that exceeded the uplift capacity of that particular section of slab. The resistance to uplift is provided by a combination of the weight of the slab, the weight of the water above the slab, the structure of the slab, and the uplift resistance provided by the foundation anchor system. Once the upstream end of the slab section lifted into the flow, the pressure under the slab rapidly increased and produced the sudden failure of the slab.

The excessive uplift pressure was mainly due to high-velocity spillway flow injecting water into slab surface features, such as open joints, unsealed cracks over the herringbone drains, spalled concrete at either a joint or drain location in either a new or previously repaired area, or some combination of these features. Localized slab deterioration and repairs pre-existed in this area prior to February 7, and these deteriorated and repaired locations may have been vulnerable to damage during high-velocity spillway flow.

During spillway releases, the slab chute surface features allowed water to flow into the foundation. The resulting flow was observed at the collector drain outfalls. Once the inflow exceeded the local drainage capacity, the flow backed up around the drains. Water that collected around the herringbone drains would have increased the pressure under the slab.

Since all physical evidence at the point where the failure initiated was destroyed, it will never be possible to confirm exactly where the initiating event occurred. Others have suggested that the uplift initiated at Station 33+00 (see photo above). However, the IFT has concluded that, although there may have been water injection along the Station 33+00 joint, that was almost certainly not the location of the initial failure. Had the failure initiated along that joint, the concrete keys at the joint would have been damaged, and this was not observed when the spillway gates were closed, and the eroded hole was inspected on February 8 by a climb team engaged by DWR. The slab section downstream of the joint at that location could not have lifted without shearing the concrete key in the upstream slab section, and this condition was not observed in the photos and videos taken by the climb team, which were carefully reviewed by the IFT.

Flows into the foundation would generally increase as flow velocities near the chute surface increased. The failure occurred immediately after the gates were opened further to increase flow down the spillway chute, which likely led to higher surface flow velocities, injection flows, and uplift pressures. There are a number of possibilities as to why this flow resulted in chute slab failure on February 7 when, historically, the chute had survived much larger flows, the last time being about eleven years before the chute failure. The IFT believes that some combination of the following factors most likely was involved:

- New damage and/or deterioration of slab repairs that resulted in more potential flow disturbance locations and more flow into the foundation than during the prior spillway discharge events.
- Possible expansion of relatively shallow void(s) under the slab due to long-term erosion under the slab. The IFT found that the available evidence does not support the hypothesis that a deep void formed beneath the spillway chute due to foundation erosion, resulting in subsequent slab collapse, but shallow voids are conceivable.
- Corrosion of the rebar across the concrete cracks or joints, as evidenced by post-failure investigations and previous repair photographs.
• Reduction in anchor capacity due to erosion around anchors beneath the slab or anchor corrosion where anchors were not properly encapsulated in grout, also as evidenced post-failure.

The IFT continues to study the spillway chute underdrain system. However, it can be confidently concluded at this time that flows observed exiting from the spillway chute drain outfalls are almost entirely from leakage through joints and cracks when water flows through the chute, and that the volumes of drain flow during spillway operation are much larger than intended in the design. Significant flows through the drains have been observed whenever there is flow in the chute, beginning with the first spillway discharge in 1969. Quantitative data concerning chute drain flows are limited, however, records and photos of drain flows from 1969 to present show that flows from individual outfalls vary over time, the most extreme example being drains that flow at some times but not at others. The IFT is continuing to evaluate possible reasons for variations in drain flows, including potential tree root intrusion, with results of a study on tree root characteristics expected soon from experts engaged by DWR, in part at the request of the IFT.

The IFT believes that moderately to strongly weathered rock and soil-like foundation conditions beneath the failed chute reduced effectiveness of slab anchorage, allowed for at least some under-slab erosion, and certainly dictated the extent of the ensuing damage. Areas immediately downstream from the initial damage area have much less weathered foundation rock conditions, where both bonding of the concrete slab and bonding of the anchor bars to the foundation rock offered significantly greater resistance to uplift, and some sections of these slabs remained in place when the gates were closed after the initial chute failure.

The IFT believes that the following factors were either not involved or had only a small effect in contributing to the failure:

• Cavitation: The conclusion that cavitation was not a significant factor is based on computations for historic flows and visual observations of the remaining downstream chute, where telltale indicators of incipient cavitation were not found.

• Groundwater: The geological features and visual evidence of groundwater flow indicate that the amount of groundwater flow was minor, and could have easily been accommodated by the slab underdrain system.

• Seismic damage: A review of seismic activity in the project region, since the last larger flow in 2006, indicates no ground motions large enough to have significantly affected the stability or condition of the spillway chute.

**Update on Design and Construction Factors Evaluation for Service Spillway Chute Failure** – The IFT has identified a number of design and construction fragilities which lead to vulnerability to uplift. These include:

• Underdrains that intruded into the chute slab section, reducing the thickness of concrete above the drains to 7 inches or less (compared to a design minimum thickness of 15 inches elsewhere), resulting in cracks above most of the herringbone drains; the cracks allow water to pass through the slab and also led to a propensity for concrete spalling.

• Absence of waterstops at contraction joints, and a less than optimal shear key configuration.

• The specified foundation preparation and treatment, which was followed for the headworks and emergency spillway crest structures, was relaxed during construction of the spillway chute slab. Up to 50 percent or more of the foundation in some areas was not properly treated by removal of weathered materials and cleaning of soil-like materials from the surface.

• Shallow rock anchorage of 5-foot embedment length, and possibly less where the slab was thicker than the minimum of 15 inches, as well as inadequate development of the anchors in the slab. In addition,
some anchors in the failed area were installed in highly weathered and fractured rock that was unlikely to develop the intended pull-out strength.

- A drainage system with many deficiencies, such as no filtering, possibly broken or disconnected pipes caused by the method of placement, and likely inadequate collector drain capacity for the flow that occurred through the slab.
- Single top layer of nominal reinforcement bars.
- A relatively large concrete aggregate size, resulting in a propensity for cracking and spalling at keys and over drains, and damage to drain pipes.

**Update on Physical Factors Evaluation for Emergency Spillway Damage** – In the May 5, 2017 memorandum, the IFT identified the following four candidate physical factors for the damage at the emergency spillway:

- Significant depth of erodible rock and soil in orientations that allowed rapid headcutting toward the crest control structure; these materials also appear to be associated with geologic features such as shear zones.
- Hillside topography that concentrated flows and increased erosive forces, facilitating headcut formation.
- Insufficient energy dissipation at base of the spillway crest.
- Absence of erosion protection downstream of the crest structure.

Based on further evaluation completed to date, the IFT believes that all four of these factors contributed to the observed damage at the emergency spillway.

**Update on Human and Organizational Factors** – Human and organizational factors which potentially contributed to the chain of conditions, decisions, actions, and inactions resulting in the spillway damages are being investigated by various methods, including extensive review of technical and historical documents, numerous interviews within and beyond DWR, online surveys, and solicitation of public input.

The IFT is considering a broad scope of human and organizational factors spanning various categories. A list of these human and organizational factors is provided below.

- Pre-design investigations
  - Scope and methods of pre-design investigations for spillway location selection and evaluation of foundation conditions
  - Characterization and communication of findings of the pre-design investigations
- Design aspects, considered in the context of standards of practice of the era
  - Composition and processes of design teams
  - Design methodologies and reference resources
  - Design budgets and schedules
  - Characteristics of the spillway designs
- Construction aspects
  - Construction budgets and schedules
Differences between observed spillway foundation conditions and the foundation conditions assumed in the spillway design, and how those differences were addressed, including relaxation of specification requirements for foundation weathered rock removal and cleanup

- Other deviations from design plans and intent during construction
- Relationships and communications between designers, geologists, construction contractors, construction inspectors, consultants, and other parties during construction
- Potential inadequacies of slab anchor testing
- Documentation of the construction process and as-built conditions

- Operations and maintenance
  - Programs for spillway chute inspections, maintenance, and repairs, including their intentions, efficacy, budgets, and schedules
  - Technical background, expertise, training, and continuing education of individuals involved in dam and spillway engineering and safety decision-making
  - Systems and processes for managing and sharing the large volume of information related to the Oroville facilities
  - Regulatory reviews and processes, including DSOD and FERC inspections and Potential Failure Mode Analysis (PFMA) evaluations

- Organizational aspects, including their evolution from pre-design until the spillway incident
  - Organizational structure, culture, policies, communications, and coordination
  - Priority placed on dam and spillway safety versus other organizational goals
  - Organization and functioning of DWR’s dam safety management program, in the context of DWR’s overall organizational structure and its interactions with regulators

The IFT’s findings with respect to these human and organizational factors will be presented in its final report.

Lessons to be Learned – There will be numerous lessons to be learned in terms of current DWR and industry dam safety practices, and these lessons will be developed and presented in the IFT’s final report. At this time, the IFT shares three higher-level lessons that have been identified so far:

1. Physical inspections, while necessary, are not sufficient to identify risks and manage safety. At Oroville Dam, more frequent physical inspections would not likely have uncovered the issues which led to the spillway incident.

2. Comprehensive periodic reviews of original design and construction, taking into account comparison with the current state of the practice, are needed for all components of dam projects. These reviews should be:
   - Thorough, taking advantage of all available information
   - Critical and independent, rather than relying largely on the findings of past reviews
   - Completed by people with appropriate technical expertise, experience, and qualifications to cover all aspects of design, construction, maintenance, and failure modes of the assets under consideration

The IFT has not seen any indication that such a review for the service spillway chute at Oroville Dam has ever been conducted since original construction. Such a review would likely have “connected the
dots” and informed the PFMA process, by identifying the physical factors that led to failure of the service spillway chute, including:

- Design shortcomings relative to current state of the practice
- Construction procedures, decisions, and changes to the designs that exacerbated the shortcomings of the design
- Drain flows well beyond what were intended in design and beyond observed drain flows at other spillways
- Subsurface geologic conditions that left portions of the spillway susceptible to uplift and subsequent foundation erosion
- Chute slab repairs that were generally limited in extent, rather than designed to reliably and durably withstand high-velocity flows, thermal effects, and other loading conditions

3. Compliance with regulatory requirements is not sufficient to manage dam owners’ and public risk.

- Current regulatory requirements are generally focused on preventing failures involving uncontrolled releases of stored water. Serious incidents can occur that do not necessarily lead to uncontrolled release, but still have significant impacts to the owner and public, such as a) limitations on an owner’s ability to control the reservoir, b) costs of emergency management and repairs, c) damage to or loss of resources and project benefits, d) environmental damage, e) impacts on society, f) damage to reputation, and g) potential legal liability.
- Current PFMA and risk analysis processes are also focused on uncontrolled release of reservoir water and generally do not include development of scenarios for non-release incidents that can result in the same impacts noted in the previous bullet point.
- Regulators have an essential role in management of dam safety, but do not have the resources nor the primary responsibility for managing dam safety. That responsibility, both ethically and legally, rests with dam owners, and dam owners must, therefore, develop and maintain mature dam safety management programs which are based on a strong “top-down” dam safety culture.