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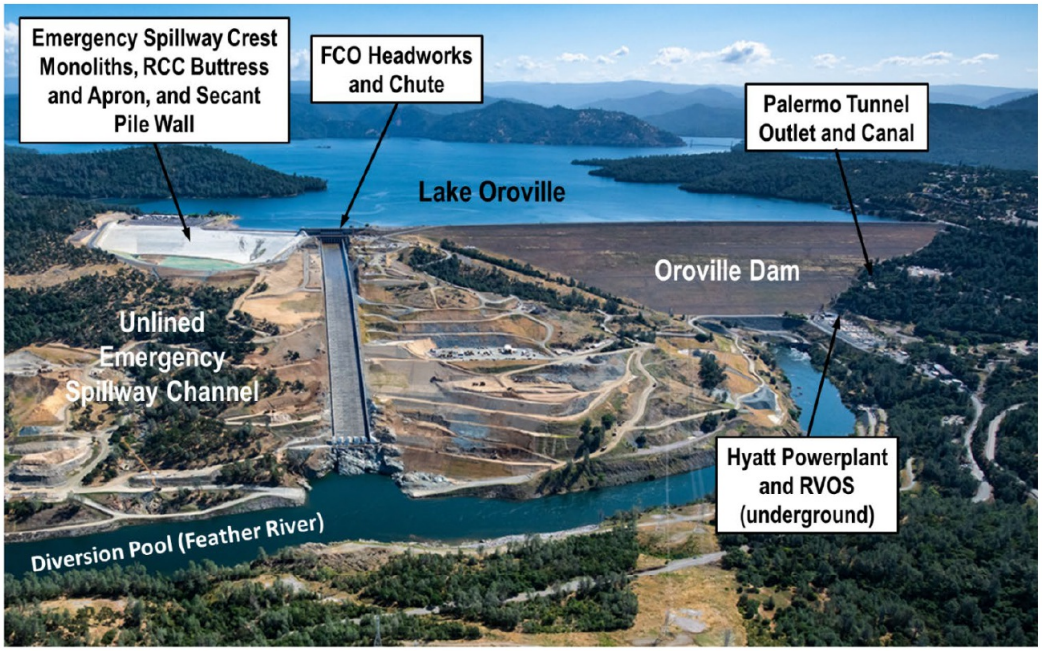
Oroville Dam Probable Maximum Floods and Spillway and Reservoir Design Floods — An update

August 14, 2023

Summary: The purpose of this memo is to describe what is known about Oroville Dam Probable Maximum Flood (PMF) estimates and related dam/spillway function matters. PMFs are deterministic model runoff estimates generated from a hypothetical near Noachian Deluge developed by the National Weather Service called the Probable Maximum Precipitation event (PMP). The PMF is used to ensure that dam spillways are sufficiently sized and capable to handle extremely rare but still possible dam outflows. Typically, FERC orders its licensees to make modifications to their dams or spillways to safely accommodate new assessments of PMFs. The Spillway Design Flood is the maximum inflow/outflow flood hydrograph that the spillways can accommodate within design freeboard, the latter the elevation differences (usually displayed in feet above sea level) between the "still water" surface of the reservoir and the crest of the dam(s) or top of spillway training wall(s). The Spillway Design Flood is presently the PMF at the time of the dam's design.

To telegraph the conclusion of this memo, the 2017 (and apparently current) Oroville Dam PMF is modeled to encroach on 40% (two feet) of the dam, saddle dams, and auxiliary spillway crests' nominal five-foot design freeboard during the Spillway Design Flood. In 2022, the Federal Energy Regulatory Commission (FERC) asked the owner of the Oroville Dam Complex, the California Department of Water Resources (DWR or Department), for an expeditious report and schedule for determining the safe capacity of the auxiliary spillway and spillway adequacy of DWR's Oroville Dam. The public version of DWR's reply concedes the obligation to safely pass the 2017 PMF but is silent on or averse to maintaining the five-foot operational design freeboard at the dam. Instead, DWR's reply proposes additional studies on the erodibility of the hillside below the auxiliary spillway, potentially serious erosion that could damage project lands and facilities and disrupt project operations for months to years during and after the PMF or Reservoir Design Flood.

Aerial View of Oroville Dam and Location of Appurtenant Facilities



DWR Oroville Dam Comprehensive Needs Assessment

Baseline Spillway and Reservoir Design Floods: The 1970 U.S. Army Corps of Engineers (Corps) Oroville Dam "Flood Control Manual" provides one of the better publications on the design baseline capabilities of the Oroville Dam spillways.[1] The spillways as originally designed consisted of a concrete main (service) spillway and a concrete hilltop auxiliary spillway, the latter with a natural hillside below. The service spillway partially failed and both spillways suffered from major unexpected hillside erosion in the 2017 Oroville Dam spillway incident.[2]

Spillway Design Flood: The Spillway Design Flood for Oroville Dam has a peak inflow of 720,000 cfs and a 72-hour runoff value of 2,510,000 acre-feet.[3] The 1968 "Spillway

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[1] Another publication describing the design features (and much more) is from DWR: California *State Water Project, Volume III, Storage Facilities, Bulletin Number 200* November 1974, State of California, The Resources Agency, Department of Water Resources. (DWR Bulletin 200.)

[2] *Independent Forensics Team Report, Oroville Spillways Incident,* January 5, 2018. (2018 IFT Report.) https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf. The post-incident auxiliary spillway crest had a downstream hilltop apron added.

[3] Oroville Dam and Reservoir, Feather River, California, *Report on Reservoir Regulation for Flood Control*, August 1970, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California, p. 13. (Oroville Flood Control Manual.) Access to reservoir regulation manuals Critical Energy Infrastructure Information (CEII) is not available to the public. Redacted versions may be available from the Corps under the Freedom of Information Act.

Design Flood Routing" curves show a peak inflow of 718,000 cfs and a peak outflow of 623,200 cfs.[4] The Probable Maximum Flood (PMF)[5] is described to be the basis of the Spillway Design Flood.[6] The maximum storage, including surcharge[7] "storage," attained in the PMF routing is 3,817,000 acre-feet,[8] corresponding to a reservoir elevation of 917.2 feet.[9] The nominal design elevation of the dam crest is 922 feet,[10] providing for a nominal design freeboard[11] (dam crest and spillway training wall

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[4] Id., Chart 33.

[5] "A deterministic approach should be used to determine the PMF. In the deterministic approach, a flood hydrograph is generated by modeling the physical atmospheric and drainage basin hydrologic and hydraulic processes. The approach attempts to represent the most severe combination of meteorologic and hydrologic conditions considered reasonably possible for a given drainage basin. The PMF represents an estimate of the upper limit of run-off that is capable of being produced on the watershed." *Engineering Guidelines for the Evaluation of Hydropower Projects*, FERC, p. 2-11. (FERC *Engineering Guidelines*) https://www.ferc.gov/sites/default/files/2020-04/chap2.pdf. The URL for the FERC *Engineering Guidelines* follows: https://www.ferc.gov/industries-data/hydropower/dam-safety-and-inspections/eng-guidelines.

[6] Id., p. 13.

[7] Surcharge "storage" here means the volume of water above a spillway crest. This water is flowing freely across and out of the reservoir, so the "storage" is ephemeral but can be determined by stage-to-storage charts from the licensee or reservoir regulation manuals.

[8] Oroville Flood Control Manual, Chart 33.

[9] Id., p. 12 of Chart 16. Rounding off, the Oroville Flood Control Manual alternatively reports that "Maximum storage during the spillway design flood is 3,814,000 acre-feet at 917.0 feet," Id., p. 18.

[10] Ibid. The dam's gross (normal) pool is 3,538,000 acre-feet. This is at elevation 900 feet. Ibid.

[11] DWR recently determined that the as-constructed spillway design flood has at least six feet of freeboard — at least for most of the dam. DWR told FERC that "[d]ue to the placement of a significant camber during original construction, the crest of the dam is generally at least 2 feet higher at elevation 924 feet or more for almost its entire length…However, the right end of the dam crest is below elevation 924 feet for only a relatively short distance: on the order of 300–400 feet. In this limited area, the crest appears to be on the order of elevation 923 feet or higher, not the elevation 922-foot nominally assumed." More precisely, "LiDAR surveys presented in Figure 2 show that the crest of the dam drops down to elevation 922 feet only on the non-overflow monoliths of the FCO [service spillway] Headworks Structure and at the *abutments of the embankment dam*. (emphasis added) (Letter from Gwen Knittweis, Chief, Hydropower License Planning and Compliance Office, Executive Division, Department of Water Resources, to Mr. Frank L. Blackett, P.E., Regional Engineer, Federal Energy Regulatory Commission, March 22, 2021, p. 3.) (DWR March 22, 2021, letter.) (FERC e-library no. 20210322-5282.) https://www.friendsoftheriver.org/wp-content/uploads/2022/07/20210322-5282_20210322_DWR-FERC_P2100_OERS_Response_PMF_Study.pdf. The letter does not provide information on the as-built elevation status of the auxiliary spillway training wall or auxiliary spillway crest. From previous statement, it would appear that as-built portions of the service spillway supporting structure are at elevation 922. This is consistent with DWR Bulletin 200: "The top of the 570-foot-long headworks is coincident with the top of the Dam (elevation 922 feet). The gated outlet passages are placed in an excavated channel depressed from the emergency spillway approach channel." (p. 93.)

elevation minus the stillwater PMF peak reservoir elevation)[12] of five feet. In addition to factors of safety (including malfunction of the service spillway), freeboard helps to contain chop and wind wave runup and allows for safer operation of the dam and related facilities.[13] In the modern context, sufficient freeboard could also serve to be a hedge against larger future PMF estimates.

The maximum Oroville Dam main service spillway (FCO) PMF release capacity is 296,000 cfs.[14] Additional flows from the service spillway are likely constrained by the gate support structures.[15] The auxiliary spillway and its surrounding lands are not similarly constrained. For PMF peak outflow, assuming no river valve outlet system (RVOS) or powerplant releases,[16] by subtraction from the design peak outflow, this would mean a 327,200 cfs release at the auxiliary[17] spillway during the Spillway Design

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[12] "Freeboard - Vertical distance between a specified stillwater reservoir surface elevation and the top of the dam, without camber." (FERC *Engineering Guidelines,* p. 2-1) "Minimum freeboard is defined as the difference in pool elevation between the top of the dam and the maximum reservoir water surface that would result from routing the IDF through the reservoir." (Id., p. 2-18.). The Inflow Design Flood (IDF), here, is the PMF. The IDF is a term used by FERC with, in part, the following purpose: "The IDF of a dam or other water impounding structure flood hydrograph is used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works, and for determining maximum height of a dam, freeboard, and temporary storage requirements. (Id., p. 2-2.)

[13] Id., pp. 2-18–2-20.

[14] Oroville Flood Control Manual, p. 19.

[15] "The headworks structure (Figure 77) has eight outlet bays controlled by *top-seal* radial gates, 17 feet - 7 inches wide by 33 feet high." (DWR Bulletin 200, p. 92.) (emphasis added)

[16] Reliable operation of the powerhouse and RVOS is not likely during a PMF-type event. During the 2017 spillway incident, among other reasons, high backwater stages at the powerhouse/RVOS from downstream hillside deposition partially damming the channel required a shutdown of both systems. Based on the 2017 experience, extensive use of the auxiliary spillway could also mobilize additional hillside deposition into the channel. Also, even in the absence of hillside deposition, high backwater stages at the powerhouse/RVOS outlet could also be expected to result from a PMF release into the downstream channel. Although substantially mitigated by post-spillway-incident construction, powerhouse releases could also be interrupted by the loss of transmission lines to electrical power load centers. According to FERC's *Engineering Guidelines,* "[o]nly those release facilities which can be expected to operate reliably under the assumed flood condition should be assumed to be operational for flood routing." (p. 2-14.) https://www.ferc.gov/sites/default/files/2020-04/chap2.pdf.

[17] DWR refers to the ungated spillway as the "emergency" spillway, a spillway category where more damage can be associated with their use under FERC's *Engineering Guidelines*, which were published after the Oroville Dam's design. In 2022, FERC told DWR to classify the spillway differently: "The emergency spillway should be reclassified as an auxiliary spillway since it is a secondary spillway in the project's current configuration and is being relied upon to pass more flow than the primary spillway (flood control outlet (FCO)) during a PMF event." (Letter to Mr. Ted Craddock, Oroville Emergency Recovery - Spillways, California Department of Water Resources, from Frank L. Blackett, P.E., Regional

Flood. If RVOS and powerhouse outlets were assumed to be used at their design capacities, by subtraction the design auxiliary spillway release would be closer to 300,000 cfs. Alternatively, in Chart 19, at elevation 917 feet, the combined rating curves of the two spillways achieve a maximum release of ~650,000 cfs.[18] Under this understanding, the arithmetic for the auxiliary spillway PMF flow at the design freeboard would then be approximately 354,000 cfs.

Reservoir Design Flood: The Reservoir Design Flood is a hypothetical flood hydrograph used to characterize the maximum floodwater management (flood-control) performance of a project (here the dam and downstream floodway). The Reservoir Design Flood typically is a smaller flood than the Spillway Design Flood, the latter which is used to determine the maximum dam-safety performance of a dam and its appurtenant features.

The Oroville Dam Reservoir Design Flood was the Standard Project Flood at the time of design.[19] A project/watershed Standard Project Flood (SPF) estimate is also a

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Engineer, San Francisco Office, Federal Energy Regulatory Commission, October 25, 2018, p. 3.) (FERC October 25, 2018, letter.) (FERC e-library no. 20181025-3103.) https://www.friendsoftheriver.org/wp-content/uploads/2018/10/20181025-310333211845-FERC-on-spillway-damage-and-auxiliary-spillway.pdf. There are FERC *Engineering Guidelines* consistency and potential regulatory consequences to such a determination. As described in the *Engineering Guidelines*, "Auxiliary spillways are usually designed for infrequent use, and it is acceptable to sustain limited damage during passage of the IDF" [inflow-design-flood, the PMF in this case]. Emergency spillways are different. "Emergency spillways may be used to obtain a high degree of hydrologic safety with minimal additional cost. Because of their infrequent use it is acceptable for them to sustain significant damage when used and they may be designed with lower structural standards than used for auxiliary spillways." (FERC *Engineering Guidelines*, p. 2-17.) Nevertheless, there are still constraints on even emergency spillway design: "Large conservation storage volumes should not be lost as a result of degradation of crest during operation" (Id., p. 2-18.) DWR objected to FERC's reclassification of the spillway arguing that "DWR believes there is no immediate reason to rename the spillway. DWR believes maintaining the original name that appears on all past and present official documents and reports would be prudent to avoid confusion, both for our respective organizations and the general public."(DWR March 22, 2021, letter, p. 4.) FERC's response was the following: "While we continue to hold to our previous comment regarding the classification of the emergency spillway, we have no objection to DWR continuing to use the current name for continuity, as proposed." (Letter from Frank Blackett, Regional Engineer, FERC Office of Energy Projects, Division of Dam Safety and Inspections, to Mr. Jeremiah McNeil, Acting Manager Hydropower License Planning and Compliance Office, California Department of Water Resources, July 14, 2022, p. 2.) (FERC July 14, 2022, letter.) (FERC e-library no. 20220714-3063.) https://www.friendsoftheriver.org/wp-content/uploads/2023/06/20220714-3063_P-2100-000-Oroville-PMF-Nos.-4-5-6-Responses-2021.pdf. We use FERC's preferred classification in this memo.

[18] Graphical interpretation of Chart 19, Oroville Flood Control Manual.

[19] Oroville Flood Control Manual, pp. 13 & 16.

deterministic estimate and is based on methodologies developed by the Corps to establish a reasonable "worst-case" flood-magnitude estimate for the purposes of sizing a floodwater-management project for an urbanized area.[20] The Oroville Dam SPF was "derived according to criteria published in the office report Standard Project Rain Flood Criteria, Sacramento-San Joaquin Valley, California, [ACE], April 1957."[21] The Oroville Dam SPF had a peak inflow of 440,000 cfs and a 72-hour volume of 1,520,000 acre-feet. It had SPF peak inflow to the then historic flood peak-inflow ratios of 1.76, 1.91, and 2.17 against the 1964, 1907, and 1955 floods. The corresponding ratios for the 72-hour inflow volumes were 1.72, 1.70, and 1.83.[22] The 1997 subsequent flood of record had a peak hourly inflow of 302,000 cfs, an SPF-to-historic-flood ratio of 1.46 to 1.[23] The SPF to PMF ratio at design was 0.61 to 1.0.[24] Since the prominence of SPFs for federal interest determinations has been subsequently overshadowed by the use of semi-probabilistic benefit-to-cost methodologies,[25] SPFs are now often scaled from PMFs.[26]

The Corps of Engineers intended to route the Oroville Dam SPF/Reservoir Design Flood in coordination with the still unbuilt Marysville Dam.[27] Until such time, an interim operations plan[28] involving reservoir surcharge is described in the still-in-force 1970

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[20] For details on the determination of standard project floods, see (*ACE Engineering Manual, 1110-2-141, SPF Determination, SPF Methodologies*, 1 March 1965.)

[21] Oroville Flood Control Manual, p. 13.

[22] Id., pp. 13–14.

[23] The 1997 peak daily inflow was 277,000 cfs. Both flow estimates can be found in the *Final Report, Governor's Flood Emergency Action Team*, May 10, 1997, The Resources Agency of California, Figure B-3, p. 185.

[24] Oroville Flood Control Manual, p. 14.

[25] https://www.iwr.usace.army.mil/portals/70/docs/iwrreports/iwrreport_09-r-3.pdf.

[26] However, according to DWR's John Leahigh, Water Operations Executive Manager, in answer to a question posed during a DWR Oroville Dam Comprehensive Needs Assessment (CNA) *Ad Hoc* meeting, the Oroville Dam design SPF was derived first, then the PMF was scaled from the SPF. For one description of the *Ad Hoc* see DWR's CNA web page: https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Dam-Safety-Comprehensive-Needs-Assessment. The CNA is discussed later in this memo.

[27] "A coordinated reservoir plan for the entire Feather-Yuba-Bear system is essential to proper regional flood control. The flood control operation of Oroville Reservoir will ultimately be directly related to that of other flood control reservoirs in the Feather-Yuba-Bear system. Of these, only Bullards Bar reservoir has been constructed, however, in order to insure future coordination, the channel capacities in Feather River below Yuba and Bear Rivers have been designed for controlled flows from these major tributaries." (Oroville Flood Control Manual, pp. 26–27.) See also Routing #3, Id., chart 32.

[28] Design Memorandum No. 3, March 1977, Marysville Lake, Yuba River California, General Design Memorandum Phase I Plan Formulation Preliminary Report, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California, p. 23. (Corps Marysville Dam Design

Corps Oroville Dam Flood Control manual.[29] In such interim SPF/Reservoir Design Flood operations, the surcharge[30] elevation would reach 910.8 feet (9.8 feet above the auxiliary spillway crest and 10.8 feet above normal pool),[31] to limit combined outflows to the Reservoir Design Flood objective release[32] of 150,000 cfs.[33] At the peak of such operations, ~150,000 cfs would be discharged[34] onto the hillside below the auxiliary spillway. This is ~ten times the 2017 Oroville Dam spillway-incident peak discharge.[35]

The Oroville Dam Flood Control Diagrams: Equally important, the 1970 Corps Oroville Flood Control Manual provides two operational diagrams: the Flood Control Diagram and the Emergency Spillway Release Diagram (ESRD).[36] Although the diagrams are more complex than this simplified description, the first diagram limits the operational release to 150,000 cfs[37] and generally applies to reservoir conditions below the auxiliary

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Memo)

[29] "Since the criteria for operating Oroville Reservoir are based on the Yuba River being controlled to 120,000 c.f.s. at its mouth, the entire Feather River from its junction with the Bear River will be provided complete standard project flood protection. During the interim period until storage is provided on the Yuba River, control is achieved by use of *maximum surcharge* at Oroville Dam." (Oroville Flood Control Manual, p. 25.) (emphasis added)

[30] The surcharge volume above elevation 901 (auxiliary spillway crest) would be ~158,000 acre-feet and above elevation 900 (normal pool) by 173,000 acre-feet. Id., pp. 18, charts 16 & 32.

[31] Oroville Flood Control Manual, charts 16 and 32.

[32] The "objective release" for a dam is the maximum floodwater management release from a dam. This release is reached when reservoir levels, inflows, and perhaps projected inflows justify such a large release, usually as dictated by a "flood control diagram" in a governing Army Corps of Engineers water (flood) control manual. This release is sustained, if necessary, to maximize use of downstream floodways and reservoir flood regulation space in managing high inflows. The objective release is not intended to exceed dam release or floodway design capacities. If reservoir levels, inflows, and perhaps projected inflows reach severe enough levels to justify moving to releases governed (in water control manuals) by "emergency spillway release diagrams." These releases shift the emphasis from floodwater management to the safety of the dam. Such releases are not intended to maintain the integrity of the downstream floodwater management system. Instead, emergency spillway release diagram releases are aimed to prevent dam failure or uncontrolled releases from loss or partial loss of reservoir crest control.

[33] Id., p. 15. More accurately, the SPF Routing #1 (no Marysville Dam and a Feather River SPF storm centering) outflow exceeds the 150,000 cfs objective release and makes a 170,000 cfs maximum release from Oroville Dam. Id., chart 32, routing #1.

[34] Graphical interpretation, Chart 19, Oroville Flood Control Manual. At elevation 910.8, ~170,000 c.f.s. would be discharged over the auxiliary spillway hillside. Ibid.

[35] 2018 IFT Report, p. 26.

[36] Flood Control Manual, Charts A-1 and A-2.

[37] "The 1970 WCM flood control diagram (FCD) specifies the allocation of storage for conservation purposes and flood management, adjusting these based on the time of year and a watershed

spillway crest.[38] The second diagram generally applies to hydrologic events larger than the Reservoir Design Flood, events that could be expected to result in reservoir conditions above the auxiliary spillway. The second diagram no longer limits outflows to expected safe releases downstream and instead prescribes larger outflows for dam safety purposes.[39]

The diagrams themselves were never modified to reflect the "interim operations plan" referred to in the Corps Marysville Dam Design Memo.[40] As the September 1971 diagrams exist in the Oroville Flood Control Manual, the simplified transitions between the two diagrams occur with 21 feet of reservoir elevation (including 5 feet of freeboard) before overtopping of portions of the embankment dams, spillway crest training walls, and service spillway headworks. As modified by the SPF/Reservoir Design Flood operations specified in the Oroville Flood Control Manual, chart 32, routing #1, this transition would be expected in events more severe than those causing nearly 10 feet of surcharge operations. This could leave only 6 feet for ESRD operations before hitting the design freeboard, leaving a smaller margin for error in inflow projections that may have a bearing on operational decisions and outcomes. This longstanding reduction in ESRD operating space increases the importance of taking actions to increase the elevation of the dam and relevant appurtenant facilities to mitigate for the loss of ESRD operational space, especially with the modeled loss of freeboard in 2017 PMF. It also argues for updates in the two diagrams.

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wetness index that accounts for the runoff response characteristics of the watershed."(Lake Oroville 2018/2019 Flood Operations Plan, p. 4.) (DWR 2018 Interim Ops Plan) The 2018 Interim Ops Plan is available from DWR: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Oroville/Misc/Lake_Oroville_2018-2019_FloodOps_Plan_011819_ay_19.pdf. WCM is an abbreviation of "Water Control Manual," a more precise description of the more colloquial "Oroville Flood Control Manual" used in this memo.

[38] "When water is stored in the flood pool of Lake Oroville (depicted in Figure 3-1), rules in the 1970 WCM specify rates of release and manner of use of the outlets to make those releases. The rules consider observed or forecasted inflow, downstream flow, maximum non-damaging release rates at communities downstream, and safe rate of release changes." Ibid.

[39] "(Note that 1970 WCM operation was originally developed based on the objective of passing the SPF without use of the Emergency Spillway and the assumption that Marysville Dam was constructed.)" (Id, p. 1.) "An Emergency Spillway release diagram (ESRD) specifies minimum release from the dam for dam safety, considering current pool elevation and rate of rise of the pool. The objective of the ESRD is to prescribe operation that will ensure the integrity of the dam." "Use of the ESRD may result in releases greater than 150,000 cfs." Id., p. 4.

[40] "Oroville Dam release rules were developed considering joint operation of Oroville Dam and Marysville Dam and Reservoir. The latter never was constructed, but the 1970 WCM has not been formally modified to reflect the absence." Ibid.

Varying PMF estimates: Varying PMF estimates have been made over the years. Some were compiled in the December 15, 2014, "Oroville Dam Part 12D Report " prepared as part of the Federal Energy Commission's (FERC) Office of Energy Projects, Division of Dam Safety and Inspections'[41] periodic reviews. They were presented in tabular form as adapted here, in which I have also added data from recent FERC/DWR correspondence:

Study Identifier	Author/date	PMP Basis	Initial reservoir elevation	Inflow/outflow in cfs	Peak reservoir elevation
PMF-58	USACE 1958	HMR 36	900 ft.	718,000/ 624,000	917 ft.
The preceding document includes an analysis of the Standard Project Flood and includes estimates of the PMF and freeboard requirements for Oroville Reservoir. The precipitation depth used to develop the hydrology for the PMF was developed by the Hydrometeorological Section of the U.S. Weather Bureau using HMR 36.					
FR-58	USACE 1958	HMR 36	900 ft.	718,000/ 624,000	917 ft.
The preceding flood routing (FR) report utilizes PMF-58 to develop the flood control operation requirements that were used to assist in the project design. Operation criteria included rules both for the use of regular flood control space and for the operation of spillway gates during extreme flood emergencies. Reservoir release limitations, flood control storage, and emergency spillway release diagrams were also included in this report.					
FR-70	USACE 1970	HMR 36	900 ft.	960,000 (likely inflow, the table is not clear.)	NA
The preceding "Feather River Basin, California, Probable Maximum Flood For Lake Oroville", October 1980 is an update and addendum to PMF-58. This update included the development of a HEC-1 model and model calibration to the December 1964 flood. Inputs were generally carried over from PMF-58, except that the PMP was revised to 28.9 inches from 21.1 inches, an additional 4.5 inches to the PMP from snowmelt was calculated, and overtopping flows from Butt Valley Dam (assumed failed) and Bucks Lake Dam were included.					
FR-81	Leps 1981	HMR 36	—	—	—
The preceding flood routing (FR-81) memorandum was developed to address the reasonableness of the use of substantially lower initial Oroville Lake elevation before routing the PMF-80 flood. It was determined that El 855.0 was an acceptable and logical initial reservoir elevation before the occurrence of a PMF, assuming that the flood control discharge rules that are outlined in the FR-70 study are followed. The FR-81 study also provides a table that includes results from a hydrologic analysis for several storm events. The table provides the initial reservoir elevation, peak inflow, maximum reservoir elevation, and resulting peak outflow for each scenario.					
FR-83	DWR 1983	HMR 36	855 ft.	1,167,000/ 798,000	921.41 ft.
The preceding report provides an analysis of a hypothetical dam break at Butt Valley Dam to evaluate the effects of the resulting flood wave upstream and through Oroville Reservoir during a PMF event. The computer program DAMBRK was used to calculate the flood wave discharge, depth, and velocity. The FR-83 report also provides a wind-wave analysis to evaluate overtopping potential due to wave run-up.					

[41] FERC is the Oroville Dam Complex's federal regulator. The state dam safety regulator is the California Department of Water Resources Division of Safety of Dams (DSOD).

PMF-03	DWR 2003	HMR 59	900 ft.	725,000/ 675,000	917.5
The preceding study (PMF-03) is considered an update and addendum to the PMF-80 report. This report uses HMR 59 to estimate the PMP and the resulting PMF at Lake Oroville. This report also includes the conversion of the basin model from the original HEC-1 model to the newer HEC-HMS model. The change to HMR 59 from HMR 36 resulted in a 17 percent decrease in peak flow through the reservoir. This study also eliminated overtopping failure of the Butt Valley Dam from the PMF inflow and it is unclear whether snowmelt impacts were considered in the results.					
FR-06	DWR 2006	HMR 59	901 ft.	725,000/ 675,00	917.5
The preceding memorandum (FR-06) includes routing of the PMF-03 that was developed in the 2003 study through the spillway at Oroville Reservoir under various conditions. A review of Oroville Dam in 1999 by the Director's Safety Review Board (Sixth Part 12D Board) advised that for the development of an updated PMF, routing should consider full operation of the spillway gates and the effect of non-operation of one and two spillway gates. As a result, this study utilized PMF-03 for each modeling scenario, and only the initial reservoir elevation and spillway discharge curves were adjusted to evaluate the peak discharge and resulting reservoir water surface elevation.					
	DWR 2017	HMR-59 NOAH Atlas 14		743,800/ 716,000	919.2 ft.
The preceding information was gathered from FERC/DWR correspondence from 2018 to 2022 because, apparently, estimates of hypothetical “Noachian” deluges (PMFs) are regarded as Critical Energy Infrastructure Information and are not currently available to the public.					

The Most Recent PMFs: Reviewing the preceding table and setting aside the perturbations induced by modeled PMF upstream dam failures,[42] two upward PMF revisions from the design PMF can be seen. The first was the 2003 PMF revision, which was associated with a 0.5 foot increase in the design PMF peak reservoir elevation. The second was the 2017 PMF revision associated with a 2.0 foot increase in PMF elevation.

There have not been any modifications to the dams or spillway crest training walls in response to these two revisions and the dam-failure scenarios — at least so far. Nevertheless, the upward trend of PMFs should be troubling, and regulator or operator

[42] David Sarkisian, Manager of Dam Safety Services, Division of Operations and Maintenance, California Department of Water Resources, reported to the Oroville Citizens Advisory Committee that PG&E had modeled a dam failure at the upstream Canyon Dam that impounds Lake Almanor with Oroville Reservoir at gross (normal/full) pool. Mr. Sarkisian reported that Oroville Reservoir would reach elevation 916 feet, 15 feet above the crest of the auxiliary spillway. A graphical interpretation of the Oroville Flood Control Manual auxiliary rating curve shows a release of 310,000 cfs over this spillway at this elevation, with no doubt erosive consequences to the hillside. Mr. Sarkisian did not report under what background inflow conditions the modeled elevation was reached. This information is not included in the preceding table entries with upstream dam failures, 1:36, https://www.youtube.com/watch?v=Wpj2_-6APw8. (David Sarkisian presentation to the July 7, 2023, Oroville Citizens Advisory Committee meeting)

responses warranted. However, in the last few years, there have been two responses to the 2017 PMF: (1) DWR's Comprehensive Needs Assessment and (2) an inchoate response by FERC.

The California Department of Water Resources (DWR or Department) public version of the 2020 Oroville Dam *Comprehensive Needs Assessment*[43] (CNA) did not provide any quantitative information on Oroville Dam PMFs or acknowledge any recent revisions to the PMF or contain any discussions on the implications to the adequacy and capacity of the dam's auxiliary spillway,[44] although the apparent deficiencies in the developing public draft and scope of the CNA were repeatedly raised by this member of the Department of Water Resources' CNA *Ad Hoc*.[45] The *Ad Hoc* was not provided any estimates of the PMF, the recent PMF changes, or their implications for spillway capacity and other improvements at the auxiliary spillway.

What is known about these questions is what can be gleaned from the publically available correspondence between FERC's Office of Energy Projects, Division of Dam Safety and Inspections, and the Department.

First, although the 2018 modifications and additions increased the likely resistence of the auxiliary spillway to backstepping erosion resulting in an uncontrolled release from the reservoir,[46] the geometric-based capacity of this spillway — determined by the

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[43] The public version of the CNA can be found here: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Oroville-CNA/Files/20201030_Oroville_CNA_Project_Report_Summary_Final_Accessibility-Check-FINAL.pdf.

[44] The CNA public draft did recommend a three-foot dam raise of the Parish Camp Saddle Dam as an Interim Implementation Project, to be completed in the near term. "While DWR is considering long-term risk-reduction measures for the entire SWP as part of its overall asset management approach, including potential risk-reduction plans at the Oroville Dam Complex, the CNA recommends several interim risk-reduction actions for the Oroville Dam Complex be completed in the near term (considered to be within approximately five years)." (CNA, p. 11.) The CNA noted that the PMF would not *overtop* the saddle dam (or other dams) (p. 7), but the Parish Camp Saddle Dam work was justified for potential events more rare than the PMF because of the relatively low cost of the raise. (CNA, p. 78.) The CNA did not discuss PMF *freeboard* encroachments or regulatory reluctance to allow freeboard encroachments. Nevertheless, the three-foot raise would exceed by six feet the 2017 PMF, one foot more than the design freeboard. The only other CNA mention of the PMF was in the definition section. (CNA, p. 94.)

[45] As noted earlier, for descriptions of the *Ad Hoc* see CNA p. 4 and DWR's CNA web page: https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Dam-Safety-Comprehensive-Needs-Assessment.

[46] During the post-spillway-incident construction, the hilltop downstream of the auxiliary spillway was armored with a 730-foot-long concrete apron terminated by a vertical secant cutoff wall. https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Spillways.

height difference between the lip of the spillway crest (at 901 feet) and the elevation of the dam and spillway crest training wall(s) (at 922 feet) minus freeboard and multiplied by the width of the spillway[47] — remained unaltered.[48] The same cannot be said about the PMF. The 2017 PMF inflow determination[49] resulted in a new hydrograph[50] with a

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https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Spillways/Reconstruction-Plans. However, the extensive hillside below remains susceptible to erosional mobilization and deposition of large volumes of earth and rock into the downstream channel if significant water is discharged over the auxiliary spillway.

[47] The width of the Oroville Dam auxiliary spillway is 1,730 feet. (Oroville Flood Control Manual, p. 19 and DWR Bulletin 200, p. 92.)

[48] "At the conclusion of the current spillway modifications, the original design capacity of the flood control outlet (FCO) will be restored;" (FERC October 25, 2018, letter, p. 2.)

[49] DWR has compared the 2017 PMF versus ARkStorm 2.0's ARkHist and ARkFuture precipitation figures. The 30-day ARkStorm 2.0 precipitation in the Oroville Dam watershed is said to be unremarkable, even from a floodwater management perspective. This is true but less so for the expected to be more challenging 72-hour totals. The 2017 PMF is based on a 72-hour basin precipitation of 22.8 inches, the ARkHist 8.6 inches and the ARkFuture 10.5 inches. DWR has developed some ARkStorm 2.0 to 2017 PMF 72-hour volume percentages: 37.8% (ARkHist) and 46.1% (ARkFuture). (David Sarkisian presentation to the July 7, 2023, Oroville Citizens Advisory Committee meeting, 1:33, https://www.youtube.com/watch?v=Wpj2_-6APw8.) The ARkStorm 2.0 scenarios are thus much smaller than the Spillway Design Flood. More relevant are peak volume percentages for ARkStorm 2.0 in comparison to the Oroville Dam Reservoir Design Flood. The design SPF inflow (Reservoir Design Flood) to design PMF inflow percentage at Oroville Dam was 61%. (Oroville Flood Control Manual, p. 14.) Rechecking these calculations, the design SPF to design PMF peak 72-hour flows were 61% and the corresponding volume percentage could be calculated to be 60%. The design SPF to 2017 PMF peak 72-hour flows are 59%, and the 72-hour volume percentage is 49%. The 72-hour ARkFuture volume is 46.1%, approaching but not exceeding the 72-hour Reservoir Design Flood volume (1,169,000 acre-feet ARkHist and 1,425,000 acre-feet ARkFuture to 1,520,000 acre-feet for the Reservoir Design Flood. Interestingly, the Sacramento Area Flood Control Agency has conducted a similar analysis with similar unremarkable runoff events for the 30-day ARkStorm 2.0 scenarios and the more challenging runoff estimates for the 72-hour ARkFuture events in the Folsom Dam watershed that still do not exceed the Reservoir Design Flood of Folsom Dam. (Personal communication with SAFCA.) The typical SPF to PMF percentages at the time of the creation of the area water control manuals were around 60%, sometimes because of direct scaling. Peak inflows versus volumes did not differ much. The 2017 PMF peak inflow and volumes to the corresponding design SPF ratios do, likely because of the lengthy duration of the ARkStorm 2.0 events. It should be noted that 72-hour peak runoff hydrographs are generally the most meaningful test of the competence of the dams with Corps flood control manuals that ring the Sacramento Valley. In contrast, the small designated floodways below the Sierran dams above the San Joaquin Valley make these dams unable to meaningfully evacuate water encroached into their flood control reservations. This makes them especially vulnerable to exceedances of objective releases from the longer multi-wave events that characterize the ARkStorm 2.0 model — in addition to significant vulnerabilities to from 72-hour inflows.

[50] This is not the only relevant performance standard that may (should) change with time. Regardless, when PMFs are updated, the SPFs should also be updated, although SPF revisions have not found well-exercised regulatory settings — in contrast to PMFs. Perhaps consequently, The CNA did not

peak inflow of 743,800 cfs and a 72-hour volume of 3,092,000 acre-feet[51] (compared with the original design peak inflow of 718,000 cfs and a 72-hour runoff volume of 2,510,000 acre-feet[52]). That is a 3.6% increase in the 72-hour peak inflows and a 19% increase in 72-hour peak inflow volume in comparison to the design PMF. Perhaps more meaningfully, the 2017 PMF outflow from the auxiliary spillway is now referred to as 420,000 cfs, roughly 70,000 to 100,000[53] (or more) cfs more than the design spillway capacity at the design freeboard.[54] The 2017 PMF peak reservoir elevation is 919.2 ft, increasing 1.7 feet from the 2003/2006 PMF estimate and 2-feet from the design PMF.[55]

discuss any potential upward revising of the SPF or Reservoir Design Flood.

[51] FERC October 25, 2018, letter, p. 1.

[52] Oroville Flood Control Manual, p. 13.

[53] Confusingly, apparently conflating spillway capacity and engineering resilience, FERC had also written to DWR the following: "[h]owever, the design capacity of the emergency spillway is on the order of 100,000 cfs to 300,000 cfs lower than the maximum PMF discharge through the emergency spillway." (FERC October 25, 2018, letter, p. 2.) This writer is unaware of any recent PMF estimates that would result in an *excess* PMF discharge of more than 120,000 cfs over the design outflow of the auxiliary spillway, but since PMF studies and estimates apparently are no longer public information, this writer cannot confirm this. Subsequent correspondence from DWR may have clarified this: "DWR identified an interim maximum combined spillway design flow of approximately 400,000 cubic feet per second (cfs) at the conclusion of construction in 2018 pending further evaluations of the integrity of the Emergency Spillway (ES). One hundred thousand cfs flow was the portion that would pass over the ES. The 100,000 cfs is the flow of unlimited duration that could be safely passed over the end of the roller compacted concrete (RCC) apron without inducing significant damage to either the secant pile wall or the RCC apron." (DWR March 22, 2021, letter p. 1.) This is not necessarily reassuring, and note the absence of attention to hillside erosion and downstream channel deposition.

[54] In a subtle twist of definition, DWR refers to the resulting auxiliary spillway elevation and discharge of the 2017 PMF as the "capacity" of the spillway — apparently neglecting this new definition's departure from the design freeboard previously used to define the capacity of the auxiliary spillway. "The hydraulic capacity of the ES [emergency spillway] is approximately 420,000 cfs at the peak stage of the PMF at elevation 919.2 feet." (DWR March 22, 2021, letter, p. 2.) "As it stands, the hydraulic capacity of the emergency spillway is 420,000 cubic feet per second (cfs) during the probable maximum flood." (DWR Director Karla Nemeth email to Ronald Stork, July 28, 2022.) (Director Nemeth email, July 28, 2022)

[55] DWR March 22, 2021, letter, p. 2.

Thus, the peak stillwater[56] reservoir elevation stage for the 2017 encroaches on 40% of the nominal five feet of design freeboard.[57]

Setting aside wave runup, the new PMF analysis does demonstrate that the 2017 PMF stillwater reservoir surface can be routed over the spillways without spilling over the dam — something that DWR provides assurances to the public.[58] However, DWR has not so far discussed that it does so by encroaching on 40% of the design freeboard of the auxiliary spillway, which it apparently regards as an acceptable condition.[59]

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[56] Reservoirs during stormy and windy conditions can have wave runup. This is one of the reasons for design freeboard. In correspondence with DWR, FERC noted that "the wind wave setup and runup study showed that 3.8 feet of overtopping of the Main Dam is possible at the peak of the new PMF determination." (FERC October 25, 2018, letter, p. 2) The Department responded with a "Critical Energy Information Infrastructure" (CEII) analysis that wave runup would be no further than 0.8 feet below the design elevation of the dam and that the majority of the dam reached an elevation higher than 922 ft. (DWR March 22, 2021, letter, p. 3) In 2023, FERC accepted the DWR analysis (see later discussion). CEII materials are not available for public review.

[57] As noted earlier, the as-built freeboard in most, *but not all*, reaches of Oroville Dam exceeds the PMF design freeboard by more than one foot — although no public information exists for the auxiliary spillway training wall(s).

[58] "This flow through the emergency spillway coupled with additional flow that would occur through the flood control outlet [FCO, the main service spillway] is adequate to pass the probable maximum flood without overtopping Oroville Dam." (Director Nemeth email, July 28, 2022.) "[A]ll three embankment dams can safely retain flood waters associated with a probable maximum flood (PMF), the largest flood loading generally required by dam safety regulatory agencies to be safely retained by a dam." (CNA, p. 7.)

[59] The slide deck of DWR's July 29, 2022, presentation to its Oroville Citizen's Advisory Committee meeting (https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Oroville/20220729-oro-slidedeck.pdf) displays the Department's relatively low priority assigned by DWR in addressing spillway capacity deficiencies:

> Between 2018–2020, DWR conducted two parallel risk assessments, the Comprehensive Needs Assessment, and the Level 2 Risk Analysis, the latter of which followed FERC's risk processes.
> Both studies found that risks associated with the Emergency Spillway were less than the risks associated with other areas we have been working and reporting on.
> DWR responded to FERC comments on the Probable Maximum Flood study on March 22, 2021. DWR indicated further studies evaluating the erodibility/performance of the Emergency Spillway would be implemented after studies for higher risks identified by the CNA and 10th Part 12D Independent Consultants.

DWR's 2020 Comprehensive Needs Assessment approaches Oroville Dam facility modifications on what it describes as Risk Analysis Methodology.[60] This methodology does not approach PMF issues in the context of a deterministic standard by regulators that licensees are required to meet, although the CNA concedes that FERC generally requires that its licensed dams meet that standard.[61] Rather, it asserts that the PMF is so rare that under risk-informed decision-making no spillway or dam elevation immediate measures are required.[62] The CNA does not discuss a design freeboard for the Spillway Design Flood.[63]

The CNA does not discuss the FERC October 25, 2018, letter to DWR that the auxiliary spillway itself may sustain moderate to severe damage during the spillway design flood or the new PMF,[64] even apart from the mobilization of portions of the downslope

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[60] "The risk-informed methodologies and standards used by the CNA project team were informed by risk-informed decision-making (RIDM) guidelines published by FERC, and by other federal agencies such as the United States Army Corps of Engineers, and the United States Bureau of Reclamation." (CNA, p. 16.)

[61] "[P]robable maximum flood (PMF), the largest flood loading generally required by dam safety regulatory agencies to be safely retained by a dam." (CNA, p. 7)

[62] CNA, p. 74, although this low-probability theme is carried through much of the CNA. This theme goes back to the original frugal design philosophy of the auxiliary spillway. "Except for a narrow strip immediately downstream of the weir, the terrain below the weir was not cleared of trees and other natural growth because emergency spillway use will be infrequent." (DWR Bulletin 200, p. 200.) The susceptibility of this slope to erosion was not appreciated by DWR decision makers, something documented in the 2018 IFT Report, see especially pp. 38–41, 53–56 and portions of Appendix C.

[63] DWR's extensive publication on the history of the design and construction of Oroville Dam states that auxiliary spillway was sized to operate with freeboard during a PMF: "The emergency spillway, in conjunction with the flood control outlet, has the capacity to pass the maximum probable flood release of 624,000cfs for the drainage area (peak inflow 720,000 cfs) while maintaining a freeboard of 5 feet on the embankment." (DWR Bulletin 200, p. 92–93.) However, DWR now may be arguing that such freeboard should not continue to be required. A senior DWR staff member communicated with this writer that there is no "design freeboard" at Oroville Dam, that such a concept does not exist at FERC (at least in the FERC's Risk-informed decision-making world). (Personal communication with John Yarbrough, PE, DWR Assistant Deputy Director, State Water Project.)

[64] "At the conclusion of the current spillway modifications, the original design capacity of the flood control outlet (FCO) will be restored; however, the design capacity of the emergency spillway is on the order of 100,000 cfs to 300,000 cfs lower than the maximum PMF discharge through the emergency spillway. The emergency spillway and natural discharge channel would likely sustain substantial headcutting erosion downstream of the secant pile wall when passing the expected full peak flow of approximately 420,000 cfs. In addition, it is likely the roller compacted concrete (RCC) apron section would experience moderate to severe damage from flows of this magnitude as well. A more robust and resilient design of the emergency spillway may be required to prevent the possibility of moderate to severe damage to the emergency spillway structure for the expected full peak flow of approximately 420,000 cfs. Further hydraulic and erodibility analyses of the emergency spillway structure should be

hillside being swept into the downstream channel. In 2021, after the completion of the CNA, DWR responded to FERC's 2018 letter. DWR said that it had evaluated the damage that might occur to the auxiliary spillway and any associated breeching of the spillway during extreme events.[65] It also noted that such an event was rare[66] and that "emergency" spillways can be expected to sustain damage during extreme events.[67] However, DWR also noted that Oroville Dam auxiliary spillway potential failure modes (PFMs) do not or very rarely are expected to involve loss of life.[68]

In the same reply letter, DWR also responded to FERC's 2018 direction that "[t]he emergency spillway should be reclassified as an auxiliary spillway."[69] Here, DWR argued that the "emergency" spillway classification be retained to ensure consistency with documents using the previous appellation.[70] DWR also began, but did not complete, a concession that the expected engineering performance in FERC's *Engineering Guidelines* of an emergency spillway in comparison to an auxiliary spillway may differ.[71] DWR did not repeat its CNA's concession that use of the auxiliary spillway could cause serious damage to other Oroville Dam Complex project works and lands and cause multi-year operational disruptions to energy production and deliveries to the State Water Project[72] — a description probably not consistent with either spillway

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performed to determine if it can safely pass PMF outflows." (FERC October 25, 2018, letter p. 2.)

[65] DWR March 22, 2021, letter p. 2.

[66] Ibid.

[67] Ibid.

[68] Ibid.

[69] As noted earlier, "DWR believes there is no immediate reason to rename the spillway. DWR believes maintaining the original name that appears on all past and present official documents and reports would be prudent to avoid confusion, both for our respective organizations and the general public." (DWR March 22, 2021, letter, p. 4.)

[70] Id., p. 6.

[71] Id., p. 4. For the FERC *Engineering Guidelines* on damage acceptability differences, see p. 2-18. Importantly, DWR also offered an explanation for the original classification of the spillway: "The Oroville Dam 'Emergency Spillway' [ES] was named by DWR during original design in the 1960s, prior to FERC Engineering Guideline's definitions. The name was likely selected to be consistent with its function of only passing flows for flood events greater than the Standard Project Flood. Over the past 50 years the ES has only operated once (in 2017 when the Flood Control Outlet spillway experienced damage or 'malfunctioned')." (DWR March 22, 2021 letter, p. 4.) The DWR letter does not discuss the Army Corps of Engineers Oroville Flood Control Manual that requires a major *regulated* spill over the auxiliary spillway to successfully route the SPF/Reservoir Design Flood. (emphasis added). The Corps obligation is not for dam safety operations, but for successful floodwater management operations required of the dam.

[72] "[T]wo PFMs [potential failure mode] were identified that straddled the tolerable risk reference line within the lower red zone of the CNA risk matrix and were on the border of being unacceptable….

classification or FERC's interest in its licensees having project facilities that are adequate to fulfill their stated functions.

In general, DWR's focus in the CNA and in its correspondence with the FERC Office of Energy Projects, Division of Dam Safety and Inspections was on traditional dam safety issues, although broader in dam safety scope than previous analyses[73] but approaching them from the Department's Risk Analysis Methodology.[74] In neither case did DWR focus on the broader relicensing applicant's duty under FERC's 18 C.F.R. 4.51(g)(3) to furnish information "to demonstrate that existing and proposed structures are safe and *adequate to fulfill their stated functions*," the latter a somewhat broader responsibility.[75] The CNA does concede that the use of the auxiliary spillway during "moderate to large flood events" could cause damage to, and create major operational difficulties for, the project.[76]

The CNA did not discuss the Oroville Dam standard project flood. It did not discuss and thus consider that the standard project flood estimate might also be expected to

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"The other higher-risk PFM was associated with the potential for major erosion on the unlined channel below the secant pile wall on the emergency spillway during future moderate to large flood events. The risk for this latter PFM was not dominated by potential life-loss, but rather associated with financial impacts resulting from the flooding of the Hyatt Powerplant induced by partial blockage and elevation of the diversion pool. These financial impacts include direct impacts associated with the repair of the Hyatt facilities and indirect financial impacts downstream of the dam associated with the disruption of water deliveries. Flooding of the powerplant would be expected to result in an extended outage of at least five years for this powerplant, which serves as the primary water delivery system of reservoir water to the SWP. An extended outage of the powerplant would result in significant impacts to SWP water deliveries." (emphasis added) (CNA, p. 74.)

[73] According to DWR, "The CNA project was performed to identify potential dam safety and operational needs, and what enhancements, if any, are needed for dam safety or facility reliability. The CNA was the most comprehensive risk analysis that DWR has undertaken for any of its facilities and is possibly the most comprehensive such risk analysis for any non-federal dam in California. It is also one of the first such risk analyses to consider failure states other than uncontrolled release of reservoir water, and one of the first to fully consider multiple consequences other than life-loss or financial impacts." (CNA, p. 73.)

[74] CNA, p. 4.

[75] The DWR Oroville facilities are still undergoing FERC relicensing. This "adequacy" issue was a feature to the intervention of Friends of the River, South Yuba River Citizens League, and Sierra Club. (Motion to Intervene of Friends of the River, Sierra Club, South Yuba River Citizen's League, Project No. 2100-052, filed Oct. 17, 2005.) (FOR *et al.* Intervention.) (FERC e-library no. 20051017- 5033.) DWR's and FERC's response are discussed in the 2018 IFT Report, pp. C-28–C-32. https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf.

[76] CNA, p. 74. In general, "moderate to large" are not terms usually applied to PMFs — and perhaps not even to SPFs. "Extreme" is the more typically applied adjective.

increase similarly with the PMF. It did not discuss the Reservoir Design Flood and its relationship to the standard project flood estimates at design or in the future. It did not discuss required without-Marysville Dam surcharge operations for very large events up to and including the Reservoir Design Flood.

In contrast, the CNA *Ad Hoc* was briefed on the post-spillway-incident interim operations plan (DWR 2018 interim ops plan) for Oroville Dam.[77] In this plan, the maximum seasonal flood reservation is moved from 750,000 acre-feet (not accounting for surcharge) to 920,000 acre-feet to avoid use of the auxiliary spillway during the SPF/Reservoir Design Flood.[78] The interim operations plan is adopted annually[79] and does not specify the circumstances when the interim operations end.[80] The DWR 2018 interim ops plan focuses on standard flood operations up to the original design

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[77] Beginning in the 2017/2018 and 2018/2019 flood seasons, DWR's interim flood season operations plans increased the 750,000 acre-feet maximum flood reservation by 170,000 acre-feet to avoid use of the auxiliary spillway during the Reservoir Design Flood. This amount is similar to the without-Marysville Dam SPF maximum surcharge storage volume above the normal pool in the Oroville Flood Control Manual. (Oroville Flood Control Manual, chart 32, routing #1.) The interim operations are discretionary operations plans by DWR, although developed with concurrence from the Army Corps of Engineers and FERC, and may change in the future. "The Plan does not deviate from our Manual or existing agreements. Therefore, relative to our regulatory role and associated policies, it does not require our approval or concurrence." (Letter to Mr. Joel Ledesma, State Water Project Deputy Director, from Colonel David G. Ray, Commander, Sacramento District, U.S. Army Corps of Engineers, January 3, 2018.) https://www.friendsoftheriver.org/wp-content/uploads/2023/06/Sacramento-District-Oroville-interim-ops-approval-2018-ocr.pdf.

[78] DWR 2018 Interim Ops Plan, pp. 1, 2, 6–8, 12, 16, 18, 20, 21, and 23.

[79] DWR developed its first interim plan for the 2017–2018 operating season. (FERC e-library no. 20171017-5033.) https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/FOTR/for_13.pdf. https://water.ca.gov/News/News-Releases/2017/Oct-17/DWR-Releases-2017-18-Lake-Oroville-Flood-Season-Operations-Plan. DWR has subsequently been submitting yearly notifications to the Corps of Engineers (and filed with FERC e-library nos. 20191001-5257, 20201013-5335, 2021124-5180, & 20221209-5004) confirming their intention to follow their published 2018/2019 "final" interim Oroville Flood Operations Plan for the upcoming annual flood season.

[80] DWR's expected end to its 2018 Interim Ops Plan is better described as ambiguous. It could be a continuous operation until the Corps Oroville Flood Control Manual is updated. It could also be 2019. "Once the construction of the FCO Spillway is completed and is deemed available for use, flood control operations will align with 1970 WCM as modified with the enhanced flood pool described in this Plan. It is anticipated that the FCO will be available for operation by December 2018. The 1970 WCM as augmented with the interim enhanced flood pool is intended to meet flood protection during the remainder Emergency Spillway recovery reconstruction effort, which is scheduled to be complete in spring of 2019." (DWR 2018 Interim Ops Plan, p. 2.) However, as noted previously, the Department has notified FERC annually since 2019 that it intends to follow the 2018 Interim Ops Plan.

Reservoir Design Flood. As with the CNA, the interim ops plan does not focus on management of the Spillway Design Flood or current Inflow Design Flood. Consistent with that, the 2018 Interim Ops plan does not purport to modify the emergency spillway response diagram.

The modest aspirations and contemplated actions of the CNA can be summarized in its own words:

> The CNA's results showed that there are no dam safety issues that exhibit a need for immediate risk-reduction actions.
>
> Though no unacceptable risks were found, and therefore no immediate actions need to be taken, DWR concluded that there were potential vulnerabilities identified that require further consideration and examination to better estimate their actual risk. In addition, the CNA developed potential risk reduction measures for consideration to potentially reduce risks to even lower levels, and recommended implementation of these measures if they are found to be reasonably practicable. To be reasonably practicable, a risk reduction measure must be capable of being implemented and to be cost effective – that is, the cost of implementation must not be disproportionately large compared to the benefits obtained.
>
> The CNA project team recommended the implementation of several of these potential risk-reduction measures, or improvements, to be completed over three phases (early, interim, and long-term). The first phase (early) is already underway and the second phase (interim) would be completed within approximately the next five years. Risk management and implementation of any additional major risk-reduction measures or plans at Oroville over the long-term will depend upon the risks that exist at Oroville relative to those at other SWP dams and facilities. Since there are no unacceptable risks at Oroville, there is not a need for any immediate risk reduction actions. DWR will need to make balanced risk-informed decisions regarding where the highest risks are with the SWP, and to then set priorities to reduce those risks across the entire SWP.[81]

In that context, the CNA identified only three projects recommended for "Interim Risk Reduction Actions." At least one might be considered a project of value in extreme runnoff events: the recommended 3-foot raise of the Parish Camp Saddle Dam.[82] However, consistent with the CNA's Risk Reduction Methodology theme, the raise is

[81] CNA, p. x.

[82] Id., pp. 78–80.

not proposed to meet a traditional regulatory PMF framework. However, in a perhaps unremarkable "coincidence," the raise would restore the existing PMF five-feet design freeboard for the 2017 PMF.

The CNA also adopted six "Additional Recommended Interim Measures," three of which may have value for PMF and floodwater management operations. Two are notable: (1) complete a *study* to examine the feasibility and risk reduction for adding small and limited crest parapet walls on the Oroville Dam at the left and right abutments and (2) *implement* flood-influenced-reservoir-operations (FIRO) and coordinated operations with New Bullards Bar Dam.[83] Again, neither is characterized as a measure to meet any of the following (1) a potential regulatory standard such as the design PMF freeboard (for the parapet wall study) or (2) an original project design objective such as managing outflows for the existing or potentially revised Reservoir Design Flood.

The CNA also devised four actions on a "Recommended Long-Term Path Forward for Future Consideration of Alternative Risk-Reduction Plans."[84] The first advocated essentially a fleet management approach (rather than a response to regulator requirements) to prioritize addressing risks within a portfolio of all the critical facilities of the State Water Project (SWP). The Oroville Dam Complex would be just one of many potential projects within the SWP, potentially deprioritizing addressing deficiencies in the safety and the adequacy of the FERC-licensed Oroville facilities to fulfil their stated functions.[85]

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[83] Id., p. 84. The inter-government Yuba-Feather FIRO Steering Committee has been examining the viability of forecast-informed reservoir operations (FIRO) at New Bullards Bar and Oroville Dams. In December 2022, it produced a Preliminary Viability Assessment with a section title considering the benefits of Yuba County Water Agency's proposed ARC auxiliary spillway entitled "Adapting Infrastructure at NBB to Maximize FIRO Benefits." https://cw3e.ucsd.edu/FIRO_docs/Yuba-Feather_PVA.pdf. On June 23, 2023, Yuba County Water Agency posted in the FERC e-library a notice of availability of Draft Non-Capacity License Amendment for an Atmospheric River Control (ARC) Spillway for New Bullards Bar Dam. (FERC e-library No. 20230623-5180) https://www.yubawater.org/252/ARC-Spillway-at-New-Bullards-Bar-Dam.

[84] Id., p. 85.

[85] "The actual implementation of any potential risk-reduction plan at Oroville would depend upon the risks that exist at Oroville relative to those at other SWP dams and facilities. Since there are no unacceptable risks at Oroville, DWR will need to make balanced risk-informed decisions regarding where the highest risks are within the SWP, and to then set the priorities to reduce those risks across the entire SWP." (CNA, p. 9.)

The second recommended long-term action was, *after* completion of the SWP portfolio risk assessment, to *consider* one of the ten CNA "Alternative Plans Recommended for Future Consideration" for implementation. Some included obvious PMF measures,[86] although cloaked in the language of Risk Reduction Methodology language of the CNA.[87] Eight alternative plans recommended for further consideration include measures for supplementary spillway capacity that may provide for better floodwater management, especially with a FIRO operation (CNA pp. 67 & 69.)

In effect, DWR's CNA argues that addressing many issues of traditional regulatory concern be postponed to the indefinite future. These include: (1) physical competence to conduct expected or required operations, (2) PMF competence and capacity, and (3) potential damage to project lands and facilities at the Oroville Dam and appurtenant facilities from contemplated operations.

Regulator reaction? Last summer, one year ago, FERC seemed to have rejected that approach.[88] On July 14, 2022, the Department received a letter from the FERC's Office of Energy Projects, Division of Dam Safety and Inspections' Regional Engineer.[89] He states:

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[86] CNA chapter five describes alternative plan development (Ten developed). CNA pp. 63–64 & 76 describes some of the potential risk-reduction measures within some plans. At least one measure looked like but was not described as a PMF mitigation measure: "Modifications to the upper portion of the Oroville Dam, particularly at the right abutment, and limited raises (e.g., 3 feet) at all three embankments to reduce the risks of internal erosion or flood overtopping breaches at the dams." Three of the alternative plans raise the dam 3 feet (accomplishing 6 feet of freeboard). (p. 69.) Another should be easily characterized by FERC as a project facility adequacy measure: "[a]rmoring measures for the unlined portion of the emergency spillway channel to reduce the potential for scour erosion into the Diversion Pool (Feather River) and the threat of flooding of the Hyatt Powerplant." One alternative plan includes this measure (although an additional five plans with reinforced concrete spillways were accompanied by illegal facilities, see conclusion of this note). (pp. 67 & 69.) Nine of the ten alternative plans include outlet bulkhead gates for the Hyatt Powerhouse to prevent high stages from backing up water into the powerhouse/RVOS. (pp. 67 & 69.) The measures also include "[m]ajor new facilities such as a new gated concrete spillway to replace the emergency spillway." The CNA does not note that the latter measure may not be possible to license because of a conflict with provisions of 16 U.S.C. 1278, protecting the Middle Fork Feather River from reservoir construction. Five of the alternative plans included this legally doubtful measure. (p. 67.)

[87] CNA, p. 84.

[88] This writer is unaware of any similar state regulator correspondence from the California Department of Water Resources' Division of Safety of Dams.

[89] FERC July 14, 2022, letter. (FERC e-library no. 20220714-3063.) https://www.friendsoftheriver.org/wp-content/uploads/2023/06/20220714-3063_P-2100-000-Oroville-PMF-Nos.-4-5-6-Responses-2021.pdf.

> Regarding the capacity of the emergency spillway, the previously-accepted plan and schedule for resolving this comment was tied to the Comprehensive Needs Assessment (CNA), which was submitted to FERC by letter dated August 28, 2020. We note that the CNA did not definitively resolve this topic nor did it provide a firm schedule going forward. Although the response in the subject letter provided some insight into this comment, the letter provided insufficient documentation of the emergency spillway's ability to safely convey the PMF…. The letter notes that no emergency spillway-focused studies were identified by the 10th Part 12D Independent Consultants. This is because, at DWR's request, the consultants were not required to assess that structure as it was under construction at the time of the Part 12D inspection.
>
> DWR's proposal for risk reduction measures to 'be considered for future implementation', or studied 'after completion of the studies and investigations identified by the CNA' is not acceptable. It is imperative that DWR develop and submit a detailed plan and schedule for determining the safe capacity of the emergency spillway and the spillway adequacy of Oroville Dam.
>
> …Within 60 days from the date of this letter, submit a plan and schedule for addressing the comments.[90]

By this letter FERC was taking regulatory action to require that DWR *determine* the "*safe capacity*" of the auxiliary spillway and "spillway *adequacy*" of Oroville Dam. Perhaps, if only by implication, FERC might relatively expeditiously require modifications be made to the Oroville Dam Complex in response to such detailed plans and schedules. FERC certainly routinely does this for other licensees.

On September 9, 2022, DWR added a CEII response and a public response to FERC's letter to the FERC Oroville Dam docket.[91] It is unknowable what is in the CEII response. However, the public response is brief. The two-page cover letter and four-page table documents a number of studies, findings, actions, and commitments.[92] Importantly, this

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[90] FERC July 14, 2022 letter, pp. 1–2.

[91] (DWR September 2022 letter.) FERC e-library no. 20220912-5065. https://www.friendsoftheriver.org/wp-content/uploads/2023/07/20220912-5065-DWR-Response-to-FERC-July-14-2022-ltr.pdf.

[92] By December 1, 2023, "DWR will update the Computational Fluid Dynamic model with the 2017 PMF and as built conditions to verify ability of ES to pass 425,000 cfs, and verify the RCC berms provide containment. This study would also update flow velocities for verification of lack of RCC apron scour/erosion." (Table p. 2.) "DWR plans further study of potential head-cutting erosion and channelization of flows considering flows up to and including the PMF event (919.1 ft, estimated 425,000 cfs), as-built conditions of secant pile wall, and any further geologic exploration to reduce uncertainty in

letter accepts the responsibility for managing the 2017 PMF: "DWR will utilize the findings of that study [the 2017 PMF] as the Inflow Design Flood of record for Oroville Dam."[93]

However, DWR's September 2022 public docket reply is silent on what freeboard DWR wishes to be required to safely pass the IDF/2017 PMF.[94] By implication, though, DWR is proposing a revised project freeboard to FERC: "Please find enclosed a table that summarizes key studies, their submittal dates, findings, and areas of additional study that DWR believes will further demonstrate the *safe capacity* of the spillways at Oroville Dam."[95] (emphasis added)

Beyond any implication, DWR's reply adopts a 2017 IDF/PMF maximum reservoir routing as elevation 919.1 feet.[96] Thus its reply can be read, consistent with DWR's CNA conclusions that no modification to the dam, saddle dams, and spillway is required, that three feet, rather than five feet, of freeboard should meet its FERC PMF obligations.[97]

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rock quality." DWR plans to submit a workplan to examine some of these issues by September 30, 2023. (Table p. 3) (DWR September 2022 letter.)

[93] Id., p. 2.

[94] As noted earlier, FERC's *Engineering Guidelines* describe the purpose of the IDF: "The IDF of a dam or other water impounding structure flood hydrograph is used in the design of a dam and its appurtenant works particularly for *sizing the spillway* and outlet works, and for *determining maximum height of a dam*, freeboard, and temporary storage requirements" (FERC *Engineering Guidelines*, pp. 2-1, 2-2.) (emphasis added)

[95] DWR September 2022 letter, p. 1.

[96] Id., p. 2. The stillwater PMF reservoir elevation of 919.1 feet in DWR's reply differs slightly from DWR's elevation 919.2 feet assessment in its DWR March 22, 2021, letter, pp. 2 & 3. The difference is unexplained.

[97] More precisely, in addition to wishing to depart from the 1958 design freeboard, DWR may be arguing that their wave run-up modeling should satisfy the Corps of Engineers and FERC PMF requirements. DWR reported in their March 22, 2021, letter to FERC, that their 2017 PMF wave run-up analysis was 0.8 feet below the minimum dam height of elevation 922 feet — just 2.1 feet above the still-water 2017 PMF surface. (p. 3.) FERC's earlier letter had told DWR that "[t]he wind wave setup and runup study showed that 3.8 feet of overtopping of the Main Dam is possible at the peak of the new PMF determination." (FERC October 25, 2018, letter, p. 2.) FERC's July 14, 2022 letter replied that DWR's response was "acceptable." (FERC July 14, 2022 letter, p. 2.) DWR replied that it would use the its 2017 PMF analysis going forward, presumably including its 0.8 foot containment modeling. (DWR September 2022 letter, p. 2.) By inference, DWR may be supporting its current freeboard justification by this additional wave run-up containment modeling.

Reviewing the four-page table reply, DWR does not contemplate the need for taking any further PMF-stage-related freeboard actions at Oroville Dam.[98] The table also states that any physical changes to the RCC apron below the auxiliary spillway to prevent structural damage during use are unnecessary.[99]

Perhaps meaningfully, DWR's public docket reply letter does not assert that the previous and current studies that claim to address the *safe capacity* of the spillways also address the *adequacy* of the spillways at Oroville Dam. These are different but related matters. This is a matter of evident concern to FERC's Office of Energy Projects, Division of Safety of Dams and Inspections in the FERC July 14, 2022, letter.

DWR's public docket reply to FERC does not assert that the U.S. Army Corps of Engineers believes in the *adequacy* of the Oroville Dam and spillways to undertake the operations prescribed in the Corps's 1970 Oroville Flood Control Manual. The Corps' view may be relevant to FERC.[100]

Two matters may be of obvious concern to the Corps: (1) The maximum storage during the Spillway Design Flood (the 1958 PMF) was, rounding off, at elevation 917.0 feet, five feet below the nominal and apparently minimum height of the dam and key appurtenant structures.[101] Loss of 40% of Oroville Dam's existing design freeboard may not be consistent with the Corps' view of safe PMF operations. (2) The planned discharge of the Reservoir Design Flood over the unprotected hillside below the auxiliary spillway apron should also be of concern to the Corps — especially since operators may choose to conduct emergency spillway release levee-breaking operations

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[98] DWR does report that it elevated the left training wall of the post-2017-incident roller-compacted concrete (RCC) hilltop apron below the auxiliary spillway crest in response to modeling showing a six-inch overtopping of the left training wall. (DWR September 2022 letter, p. 3.) The modeled design freeboard of the training walls of the RCC apron auxiliary spillway may be unnecessarily cloaked in CEII communications and thus not currently available to the public.

[99] Id. p. 2.

[100] FERC is responsible for ensuring that the licensed facilities of the Oroville Dam Complex are adequate to fulfil DWR's self-assigned purposes and the purposes and direction from the Corps' Flood Control Manual. DWR notes that "Lake Oroville is a keystone facility of the State Water Project (SWP) and is owned and operated by DWR. With a capacity of approximately 3.5 million acre-feet, it is the largest reservoir of the SWP." "Lake Oroville's primary purposes are for water supply and flood control. It also provides power generation, recreation, and fish and wildlife enhancement. The reservoir is operated in a coordinated manner with other reservoirs to regulate flood flow within the Yuba-Feather basin and to provide water supply for the State Water Project." DWR 2018 Interim Ops Plan, p. 3.

[101] "Maximum storage during the spillway design flood is 3,814,000 acre-feet at 917.0 feet." (Oroville Flood Control Manual, p. 18.)

rather than conduct SPF/Reservoir Design Flood surcharge operations featured in the 1970 Corps Oroville Flood Control Manual. It is unwise to put operators in the dilemma of choosing between Manual operations that could result in years of State Water Project delivery interruptions versus prematurely and perhaps unnecessarily flooding lands and cities in the Feather River Basin protected by the project.[102]

DWR continues to approach these issues outside of the traditional deterministic spillway standards for dams such as PMFs and SPFs. It prefers a probabilistic risk assessment approach. It recently reported to FERC that it is developing a "stochastic hydrology workplan." "The work plan will indicate: (1) how the stochastic hydrologic analysis results could be used in future risk assessments, (2) how the stochastic results might better inform future risk assessments when compared with the existing deterministic hydrologic hazard information."[103]

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[102] The 1997 flood of record operational dilemmas are discussed in the 2005 FOR *et al.* intervention. https://www.friendsoftheriver.org/wp-content/uploads/2016/01/Oroville-Dam-joint-intervention-1.pdf. In summary, the dilemmas began before 1997. In 1990, the ACE made a determination that levee foundation problems along Feather River floodway between the Bear and Yuba River confluences meant the levees could only reliably accommodate 268,000 cfs, rather than the 300,000 cfs design flow. ("U.S. Army Corps of Engineers Sacramento River Flood Control System Evaluation, Phase II – Marysville/Yuba City Area," EA/Initial Study, April 1993, p. 6.) No provisions were made to modify upstream reservoir operations to account for the 1990 Corps levee assessment. Indeed, the Department did not seem to be aware of the Flood Control Manual surcharge operations. Instead, it appeared that the operators were preparing for ESRD levee-breaking operations from the service spillway to avoid up to 150,000 cfs of regulated surcharge releases down the hillside. "In 1997, it [was] believed that Oroville storage was almost to a point where 300,000 cfs of inflow was going to pass through the reservoir. DWR was making plans to evacuate the power plant. The 300,000 cfs would have topped the levees and put 10 feet of water into the town of Oroville." (DWR Oroville Facilities Relicensing, Engineering and Operations Work Group — Issue Sheet Development, revised May 21, 2001.) In the end, the inflow projections estimate proved to be inaccurate: reservoir storage peaked 200,000 acre-feet and 13.8 ft below the auxiliary spillway crest. DWR chose to release 160,000 cfs from Oroville Dam, 10,000 cfs above the objective release. The left Feather River levee downstream of the Yuba River confluence failed at the design stage for 300,000 cfs (the design flow there), doing a little better than the Corps' 1993 determination. The levee break resulted in loss of life and significant property damage.

[103] "DWR August 1, 2023, response to FERC comments, p. 1. (FERC e-library 20230801-5070) "This letter provides our plan to further evaluate the risk associated with overtopping potential failure modes for the Oroville Dam, Bidwell Bar Canyon Saddle Dam, and Parish Camp Saddle Dam." "DWR plans to use the findings and results of the IES [issue evaluation study] to support future dam safety decisions regarding whether risk reduction actions are justified or not. Eventually, if DWR decides actions are justified, DWR may proceed with a corrective action alternatives study that may consider risk reduction alternatives such as raising Parish Camp Saddle Dam and/or constructing parapets on Oroville Dam and Bidwell Bar Canyon Saddle Dam." DWR August 1, 2023, response to FERC comments, p. 1. https://www.friendsoftheriver.org/wp-content/uploads/2023/08/20230801-5070_20230801_DWR-FERC_P2100_PS_10t

Reflections

The current circumstances at Oroville Dam do not meet a conservative standard for a large reservoir behind the tallest dam in the United States — and at an embankment dam, a type of dam not designed to be overtopped. And not to be forgotten, the discussions between the Department and FERC seldom discuss the consequences of failure to fully construct an auxiliary spillway that does not represent a danger of major erosion of the hillside below the RCC apron.

Stepping back, FERC's Office of Energy Projects, Division of Dam Safety and Inspections primary focus has historically addressed vulnerabilities that may result in a loss of crest control at a FERC-licensed dam and its spillways. In potential contrast, FERC's Office of Energy Projects, Division of Hydropower Licensing, appears to have the responsibility to license projects that are safe and adequate to fulfil their stated functions. These responsibilities clearly overlap. Moreover, these divisions operate differently. Most of the Division of Dam Safety and Inspections' work is continuous (punctuated by scheduled assessments every five or ten years) and does not involve public participation. The Division of Hydropower Licensing attends to these matters (or does not attend to these matters in deference to the Division of Dam Safety and Inspections) during licensing/relicensing and license amendments, something that can occur as rarely as once in a half century. Its proceedings are largely public. Marrying the work of these two divisions in the FERC Office of Energy Projects has no doubt proven difficult.[104] However, the Oroville Dam is still in relicensing, and the Division of Dam Safety and Inspections is corresponding with the Department about all or a portion of the matters discussed in this memo.

The determination of whether the Oroville facilities are "adequate to fulfil their stated functions" is properly before the FERC, likely under the purview of both Divisions. However, it seems as if the Division of Dam Safety of Dams and Inspections is in the lead at present.

Decisions still needed from DWR and its Regulators:

- Should the original five-feet PMF/IDF design freeboard be considered merely to be the freeboard at the design of the project and thus subject to change?

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h_Part_12D_SIR_Recommend_ORDM_BCDM_PCDM.pdf.

[104] Some of the NGO parties in the relicensing requested clarification and a series of workshops to sort these inter-Divisional matters out. (FERC e-library no. 2017419-5231) There was no response.

- If a new freeboard is considered, what degree of deference should be given to the original design freeboard?
- Under the 2017 PMF/IDF, what freeboard should be adopted and what criteria should be used to determine it?
- Should a decision to adopt any new or reaffirmed design freeboard be influenced by climate change PMF trends?
- Should structural or operational changes be ordered by regulators to meet the 2017 PMF/IDF, including a hillside concrete spillway below the auxiliary spillway apron?
- How long should any structural or operational changes take to be implemented?
- Should facility adequacy determinations be influenced Corps of Engineers operational requirements for the project? DWR operational requirements?
- Should potential major State Water Project energy and supply disruptions from required or contingent auxiliary spillway operations influence FERC facility adequacy determinations?
- Should adequacy determinations consider resolving operator dilemmas involving the threat of major consequences to project facilities and operational disruptions versus prematurely abandoning flood-control operations and beginning dam-safety operations?
- Will the standard project flood be updated?
- Should the Reservoir Design Flood be updated?
- Hydrographs and estimates of peaks in cfs and acre-feet per unit-time fit more comfortably with the capacity of engineering works and floodways than probabilistic characterizations of flows. Will Spillway and Reservoir Design Flood hydrographs be updated, including peak and volume estimates to allow comparison with previous assessments?
- Should the Reservoir Design Flood use the auxiliary spillway? If not, should a long-term operations plan be put in place to avoid its use during the Reservoir Design Flood?
- Can PMF adequacy deficiency mitigations address Reservoir Design Flood dilemmas?
- Should low-level outlet improvements complementary to FIRO operations soon (a few years) to be required by the Corps be considered in adequacy for Oroville Dam project works determinations.
- Did the DWR 2018 Interim Ops Plan expire in 2019 or is it in place until a new Corps Flood Control Manual is in place?
- Will the updated Corps Oroville Flood Control Manual use the DWR 2018 Interim Ops Plan objective of passing the SPF without using the auxiliary spillway?

- Will the updated Corps Oroville Flood Control Manual provide hydrographs and peak and volume estimates to allow comparison with previous deterministic operational plans?

Conclusion: This memo is admittedly a dense read. It is relatively comprehensive information vehicle for technically inclined others about the story of DWR's efforts to avoid any additional capacity and adequacy improvements subsequent to the 2017–2019 post-spillway-incident reconstruction efforts. In effect, it represents a follow-up to the FOR/CSPA/SYRCL/AW publication "The Oroville Dam 2017 Spillway Incident, Lessons From the Feather River Basin."[105] Although this publication benefitted from a larger team of writers, an investment in readability and formatting with images and figures, and a print run, it has been nearly five years since its publication. Time has moved on, and the intense press interest has faded. Nevertheless, some key deficiencies at Oroville Dam are quietly unaddressed — and remain so more than a year after FERC informed DWR that the lack of action in the Department's Comprehensive Needs Assessment was unacceptable.

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[105] A relatively low-resolution and thus low-byte version can be found. https://www.friendsoftheriver.org/wp-content/uploads/2016/01/The-Oroville-Dam-2017-Spillway-Incident-Lessons-from-the-Feather-River-Basin-Final.pdf