FRIENDS OF THE RIVER

KELLY PARK CENTER, 3336 BRADSHAW ROAD, SUITE 335,
SACRAMENTO, CA 95827

PHONE: 916/442-3155

WWW.FRIENDSOFTHERIVER.ORG

Oroville Probable Maximum Floods and Spillway Design Floods

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Summary: The purpose of this memo is to describe what is known about Oroville Dam Probable Maximum Flood (PMF) estimates. These are runoff estimates derived from a hypothetical "Noachian deluge" called the Probable Maximum Precipitation event (PMP) used to ensure that dam spillways are sufficiently sized and capable to handle any potential dam outflows. The Spillway Design Flood is the maximum flood hydrograph that the spillways can accommodate within design freeboard, the latter the elevation (usually measured in feet above sea level) difference between the surface of the reservoir and the top of the top of the dam or spillway training walls. To telegraph the conclusion of this short memo, the 2017 (and apparently current) Oroville Dam Probable Maximum Flood is modeled to encroach on 40% (two feet) of the dam and auxiliary spillway's five-foot design freeboard during the Spillway Design Flood. The Federal Energy Regulatory Commission is now asking for an expeditious report and schedule from the California Department of Water Resources on determining the safe capacity and adequacy of the auxiliary spillway of Oroville Dam.

Baseline PMFs and Spillway Design Floods: The 1970 Army Corps of Engineers Oroville Dam "Flood Control Manual" provides the design baseline capabilities of the Oroville Dam spillways.

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.[1] The 1968 "Spillway Design Flood Routing"

[1] 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)

curves show a peak inflow of 718,000 cfs and a peak outflow of 623,200 cfs.[2] The Probable Maximum Flood (PMF) is described to be the basis of the Spillway Design Flood.[3] The maximum storage attained in the PMF routing is 3,817,000 acre-feet,[4] corresponding to a reservoir elevation of 917.2 feet.[5] The design elevation of the dam crest is 922 feet,[6] providing for a design-freeboard (dam elevation minus the still-water PMF peak reservoir elevation) of five feet. In addition to factors of safety, freeboard helps to contain wind and wave runup and allows for safer operation of the dam and related facilities.

The maximum Oroville Dam main service spillway (FCO) PMF release capacity is 296,000 cfs.[7] For PMF peak outflow, assuming no river valve outlet system (RVOS) or powerplant releases, by subtraction from the design peak outflow, this would mean a 327,200 cfs release at the auxiliary[8] spillway during the Spillway Design Flood. If RVOS and powerhouse outlets were assumed to be used at their design capacities, 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

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[2] Id, Chart 33.

[3] Id, p. 13.

[4] Id, Chart 33.

[5] Id, Page 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, p. 18.

[6] Id, p. 18.

[7] Id, p. 19.

[8] 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. FERC now wishes 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 Engineer, San Francisco Office, Federal Energy Regulatory Commission, October 25, 2018, p. 3.) (FERC October 25, 2018, letter). https://www.friendsoftheriver.org/wp-content/uploads/2018/10/20181025-310333211845-FERC-on-spillway-damage-and-auxiliary-spillway.pdf. DWR objected. 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 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). https://www.friendsoftheriver.org/wp-content/uploads/2022/07/20210322-5282_20210322_DWR-FERC_P2100_OERS_Response_PMF_Study.pdf. We use FERC's preferred classification in this memo.

release of 650,000 cfs.[9] Under this understanding, the arithmetic for the auxiliary spillway PMF flow at the design freeboard would then be approximately 354,000 cfs.

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) Division of Safety of Dams and Inspections' 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
"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.

[9] Id. Graphical interpretation of Chart 19.

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.					
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 New PMF: The California Department of Water Resources (DWR or Department) public draft of the 2020 Oroville Dam *Comprehensive Needs Assessment* (CNA) did not provide any quantitative information on Oroville Dam PMFs or acknowledge any recent additions to revisions to the PMF or any implications to the adequacy and capacity of the dam's auxiliary spillway,[10] although the apparent

[10] 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) (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 and the low cost of the raise (p. 78). The CNA did not discuss freeboard encroachments or regulatory reluctance to allow encroachments. The only other CNA mention of the PMF was in the definition section (p. 94).
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.

deficiency in the public draft of the CNA was repeatedly raised by this member of the Department of Water Resources' *Ad Hoc*[11] semi-advisory body to the CNA. The *Ad Hoc* was not provided any estimates of the PMF, the PMF changes, or their implications to the need for spillway capacity improvements of 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. There isn't much, but what there is appears to be meaningful.

First, although the 2017–2018 reconstruction and additions increased the reliability of the auxiliary spillway,[12] the capacity of the spillway — determined by the height difference between the lip of the spillway (at 901 feet) and the elevation of the dam and spillway training walls (at 922 feet) — remained unaltered.[13]

The same cannot be said about the PMF. The 2017 PMF inflow determination resulted in a new hydrograph with a peak inflow of 743,800 cfs and a 72-hour volume of 3,092,000 acre-feet[14] (compared with the original peak inflow of 718,000 cfs and a 72-hour runoff volume of 2,510,000 acre-feet[15]). Perhaps more meaningfully, the PMF outflow for the auxiliary spillway is now referred to as 420,000 cfs, roughly 70,000 to 100,000[16] cfs or

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[11] https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Dam-Safety-Comprehensive-Needs-Assessment

[12] The hilltop downstream of the auxiliary spillway was armored with concrete and a terminal cutoff wall. However, the 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 this spillway. This should be planned for. In order to regulate the Reservoir Design Flood (a hypothetical flood used to understand the flood-control performance of the project — a smaller flood than the Spillway Design Flood used to evaluate dam-safety performance), using the design flood space reservation, up to 130,000 cfs would be discharged onto the hillside. This is ten times the 2017 peak discharge. Current interim operations increase the flood-season flood reservation (and decrease top-of-conservation) to avoid use of the auxiliary spillway during the Reservoir Design Flood, but these discretionary operations by DWR, although developed with concurrence from FERC and the Army Corps of Engineers, may change in the future.

[13] "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.

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

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

[16] Confusingly, FERC had also written to DWR the following: "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." (FERC October 25, 2018, letter, p. 2.) We are unaware of any

more than the design spillway capacity at the design freeboard.[17] The 2017 PMF peak reservoir elevation is 919.2 ft.[18] Thus, the peak still-water[19] reservoir elevation stage for the 2017 encroaches on 40% of the five feet of design freeboard.[20]

Setting aside the question of wave runup, the new PMF analysis does demonstrate that the PMF can be routed over the spillways without spilling over the dam — something that DWR provides assurances to the public.[21] It has not so far discussed that it does so

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recent PMF estimates that would result in an excess discharge of more than 100,000 cfs over the auxiliary spillway, but since PMF studies and estimates apparently are no longer public information, we cannot confirm this. Subsequent correspondence, 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." Letter from Gwen Knittweis, Chief, Hydropower License Planning and Compliance Office, Executive Division, Department of Water and Power, to Mr. Frank L. Blackett, P.E., Regional Engineer, Federal Energy Regulatory Commission, March 22, 2021, p. 1. https://www.friendsoftheriver.org/wp-content/uploads/2022/07/20210322-5282_20210322_DWR-FERC_P2100_OERS_Response_PMF_Study.pdf. (DWR March 22, 2021, letter) This is not necessarily reassuring.

[17] "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)

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

[19] Reservoirs during windy conditions can have wave runup. 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) The Department responded with a "Critical Energy Information Infrastructure" (CEII) analysis that wave runup would be no more 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) CEII materials are not available for public review.

[20] There is more freeboard in many, but not all, reaches of the dam, although no public information exists for the auxiliary spillway training walls. DWR has subsequently discovered the following: "It should also be noted that this minimum dam crest elevation of 922 feet only exists near the abutments of Oroville Dam. Due 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." (DWR March 22, 2021, letter, p. 3) Unfortunately, low points of embankment structures can cause failure of the entire structure when overtopped as demonstrated during the failure of the Auburn dam coffer dam.

[21] "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)

by encroaching on 40% of the design freeboard of the auxiliary spillway, which it apparently regards as an acceptable condition.[22]

Action possible? Some action, may be forthcoming, however. On July 14, 2022, the Department received a letter from the FERC Regional Engineer. He states:

> 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.
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> …Within 60 days from the date of this letter, submit a plan and schedule for addressing the comments.[23]

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[22] 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.

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

It is possible that FERC is preparing to take regulatory action to require that DWR not only determine the safe capacity of the auxiliary spillway (such as recovering its design freeboard) but require modifications be made to the Oroville Dam complex in response. FERC certainly routinely requires other FERC licensees to have adequate freeboard on spillways regulated by FERC. DWR may be hoping for less:

> Last week FERC responded to an approach that DWR proposed in March 2021 and informed DWR that their view is that a more detailed plan and schedule is needed with additional focused analysis to better inform decisions around whether additional investments should be made. DWR will be responding to FERC with this plan and schedule within the next 60 days.[24]

It would seem that there is some chance that spillway or outlet improvements are being contemplated for near-term implementation by FERC's Division of Dam Safety and Inspections. For intervenors in FERC Oroville Dam relicensing proceedings who raised spillway issues, those who followed the discussions in the CNA *Ad hoc,* or observers of DWR's and FERC's dam-safety programs, it will be meaningful if FERC is setting up a decision framework that may lead to action instead of indefinite delay.[25] In addition, since some of the possible spillway modification actions may also benefit the floodwater management functions of the dam, these matters should be followed closely.[26]

This should be a time where active engagement with DWR and FERC could well prove important — in meeting both ordinary dam-safety requirements and the expectations for floodwater management performance at the dam.

Ronald Stork
Friends of the River
rstork@friendsoftheriver.org

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[24] Id.

[25] The CNA advocated a "fleet" maintenance approach to prioritizing dam safety and other projects within the entire State Water Project (SWP). "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) Clearly, this approach "is not acceptable" to FERC.

[26] Completion of a hillside auxiliary spillway that does not use a bare hillside for spillway discharges or addition of additional low-level outlet facilities useful for forecast-influenced reservoir operations (FIRO) are examples of dam-safety improvements that could improve the floodwater management capabilities of Oroville Dam.