STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

DAVID FORD CONSULTING ENGINEERS

Lake Oroville 2018/2019

Flood Operations Plan

Prepared for: DWR

November 1, 2018

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1 Summary

The 1970 United States Army Corps of Engineers (USACE) Lake Oroville Flood [Water] Control Manual (1970 WCM) prescribes how the as-built reservoir must be operated for flood management (USACE 1970). During the 2017 Oroville spillway incident, the gated flood control spillway and the Emergency Spillway were damaged. To maintain dam safety and manage flood risk, the Department of Water Resources (DWR) prepared plans for operating the gated spillway while project facilities are restored.

To maintain dam safety and manage flood risk, operation plans should:

- Meet the USACE's 1970 WCM requirements for flood management.
- Efficiently and effectively use the project features.
- Pass the standard project flood (SPF) without activating the Emergency Spillway. (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.)
- Not increase the frequency at which critical pool elevations are exceeded.
- Not increase the frequency at which critical releases are exceeded (based on release capabilities).
- Not increase the frequency at which critical downstream flow levels are exceeded.

This report describes the DWR flood operation plan for November 2018-June 2019 (2018/2019 Plan). The 2018/2019 Flood Operations Plan is comprised of two primary components: 1) Water operations as described in the Oroville Emergency Recovery – Spillways 2018/2019 Spillway Recommissioning Manual and 2) an interim enhanced flood control diagram as described in this document.

Other key features of the Plan are as follows:

- The maximum preferred Flood Control Outlet (FCO) Spillway release is 150,000 cfs, in line with the 1970 WCM.
- The method for determining the flood management pool size is enhanced. The method considers:
    - *Coincident flows in the Yuba-Feather River system.* For the 2017/2018 Plan, maximum FCO releases were reduced to 100,000 cfs, effectively reducing downstream flows as well. As the maximum FCO release for 2018/2019 will be restored to 150,000 cfs, analysis for the 2019/2018 Plan looks further downstream to avoid exceeding downstream flow targets, accounting for cumulative flow from sources other than Lake Oroville. Cumulative flow includes Lake Oroville outflow, New Bullards Bar Reservoir outflow, and local flows. The 2018/2019 Plan routes SPF flows like the 1970 WCM did, evaluating and selecting appropriate operation from a system perspective.

- *The absence of Marysville Reservoir.* 1970 WCM operation relies on storage anticipated in Marysville Reservoir to meet the operation objective of passing the SPF without use of the Emergency Spillway. However, the reservoir was never constructed. The 1970 WCM system SPF routing centered on the Feather River shows that maximum releases must exceed 150,000 cfs to pass the event with the defined flood pool size and without use of the Emergency Spillway or a release of 150,000 cfs could be maintained by allowing the reservoir to be surcharged – thus activating the Emergency Spillway. In the 2018/2019 Plan, the method for determining the flood pool size recognizes the absence of Marysville Reservoir, and the flood pool is increased accordingly.
- *Variation of wet ground conditions (wet conditions) and dry ground conditions (dry conditions)*. For the 2017/2018 Plan, a single flood pool size was determined based on spillway limitations at that time. Construction has progressed, and the FCO Spillway design release is restored to 150,000 cfs in line with the WCM. In the 2018/2019 Plan, following the 1970 WCM, DWR has allowed for variable flood storage based on wet and dry conditions.

All elevations reported herein refer to the National Geodetic Vertical Datum of 1929 (NGVD29), unless otherwise stated.

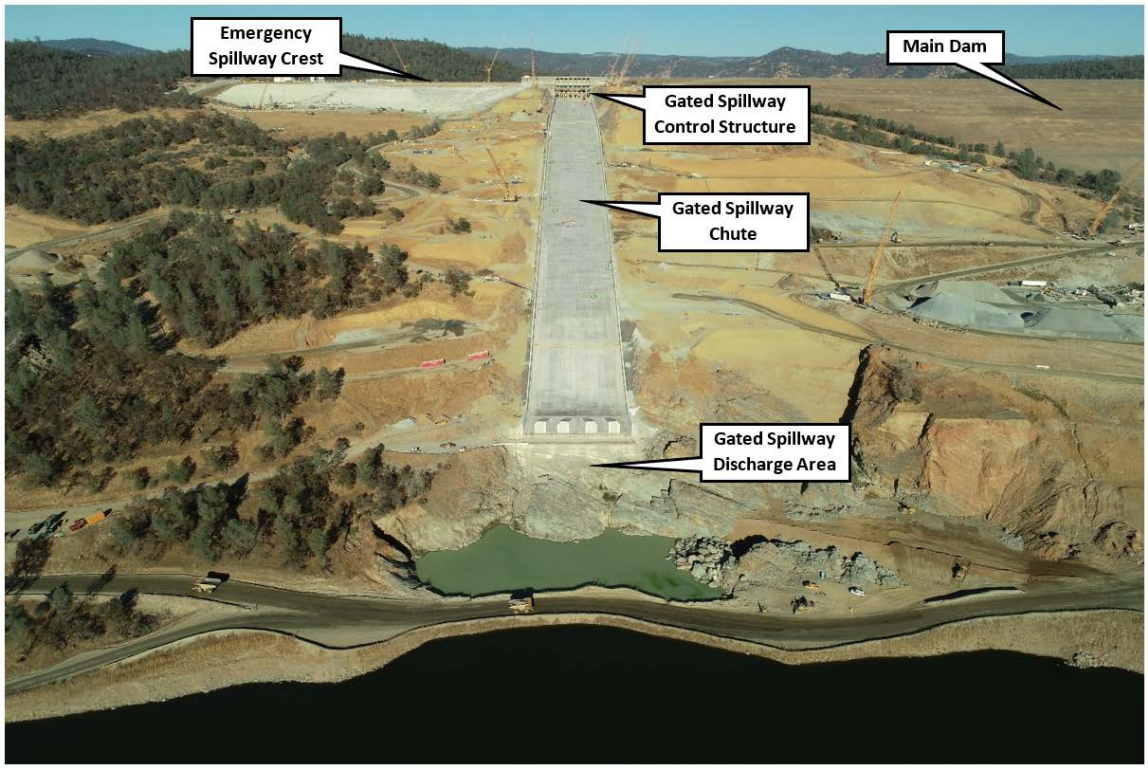
On October 19, DWR reached a target lake elevation of 700 feet, a reasonably low elevation to manage any significant storms until the FCO Spillway is functional. Reservoir operations up to the point the FCO is operational are described in the 2018/2019 Spillway Recommissioning Manual.

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.

2 Oroville Dam and reservoir features

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 and Oroville Dam, shown in Figure 2-1, are located on the Feather River, a major tributary of the Sacramento River, about 6 miles northeast of Oroville in Butte County, California.

Figure 2-1. Features of Oroville Dam and reservoir



Source: DWR

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.

The focus of the 2018/2019 Plan is on flood management, which is governed by the 1970 WCM. In cooperation with USACE, DWR regulates excess inflow to reduce flood damage downstream to the extent practical, storing water and releasing it at a time and rate that would prevent further damage downstream. Planned flood management releases from Lake Oroville are through the FCO, powerplant outlets, and river valve outlet system (RVOS).

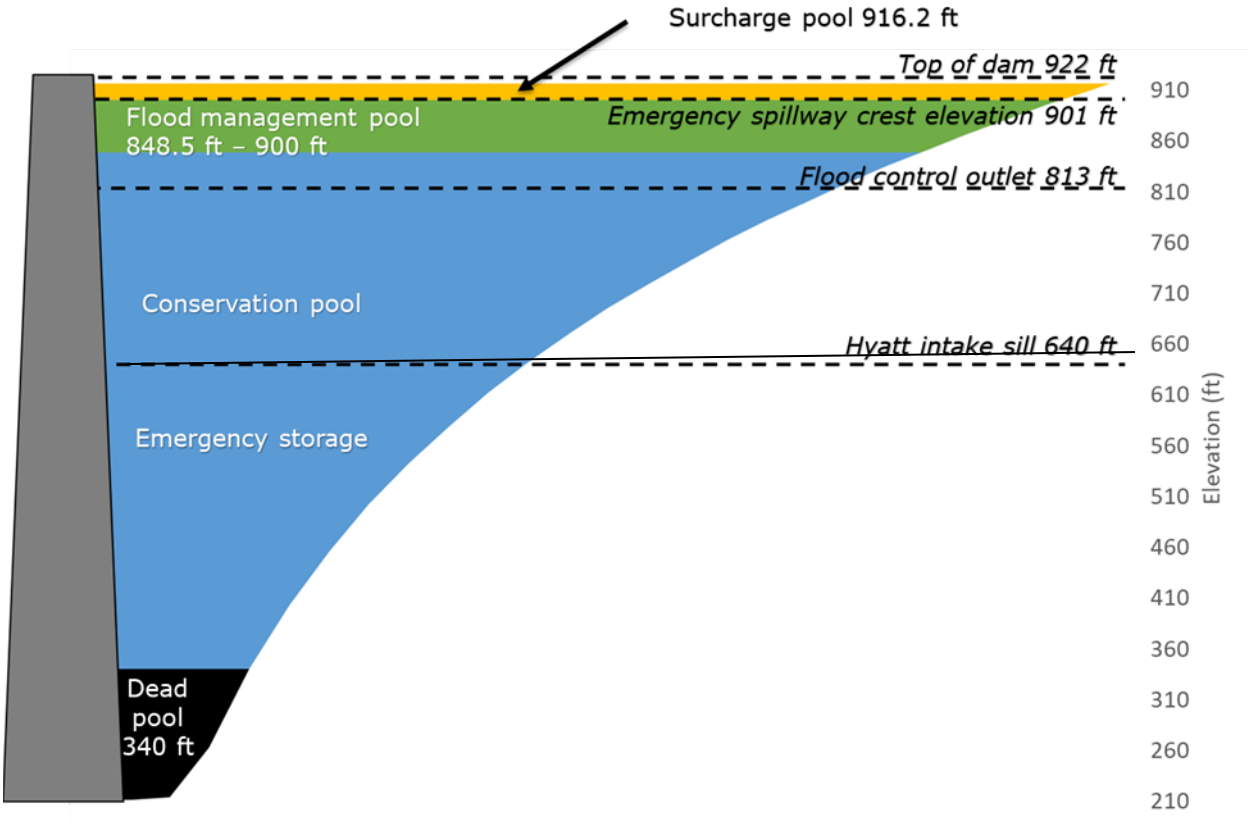
3 1970 WCM operation summary for as-built structure condition

Key features of the 1970 WCM and the operation rules include the following:

1. 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 wetness index that accounts for the runoff response characteristics of the watershed. As less storage is needed for flood management in the late spring months, more storage is made available for conservation.
2. The Hyatt Powerplant, when fully operational, can release up to 17,000 cfs. In addition, the FCO, a 3,055-ft long by 179-ft wide concrete lined chute spillway (as built), can be used when higher releases need to be made. The FCO is designed to have a physical capacity of 296,000 cfs at elevation 916.8 ft as defined in the WCM (USACE 1970).
3. For events greater than the SPF, releases occur over the Emergency Spillway, which has a capacity of 350,000 cfs (USACE 1970). The Emergency Spillway is approximately 1,730 ft long (as built). The left 930 ft is a concrete gravity ogee weir and the right 800 ft is a small broad-crested weir. When the reservoir pool elevation exceeds 901 ft—the Emergency Spillway weir crest elevation—water flows uncontrolled over the ungated spillway and down an unlined hill slope into the Feather River (as built). Use of the ungated spillway is required to pass safely the probable maximum flood (PMF). Use of the ungated spillway was anticipated in the original design for flood events greater than the SPF.
4. 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.
5. When release rules were developed for the 1970 WCM, the maximum non-damaging release rate was considered 150,000 cfs, based on analysis of downstream channel capacity. This maximum operational constraint is inherent in the rules and diagrams.
6. 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. Actual operation has been adjusted as necessary and appropriate to account for this.
7. 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.
8. Use of the ESRD may result in releases greater than 150,000 cfs. At the onset of flow over the Emergency Spillway, the ESRD prescribes reduction of release from

the FCO, thus limiting maximum release to 150,000 cfs until a greater total release is required.

Figure 3-1. Key Elevations of Oroville Reservoir



Source: HDR | David Ford Consulting Engineers

4 2018/2019 Plan development

The 2018/2019 Plan for Oroville reservoir was developed to account for the status of spillways restoration efforts in 2018 and early 2019. In February 2017, during flood operations consistent with the 1970 WCM, the FCO Spillway chute failed. Construction on the FCO and Emergency Spillways commenced in May 2017, repairs were made to prepare the FCO Spillway for the 2017-2018 flood season with an interim capacity of 100,000 cfs. Further repairs are being made to restore the FCO Spillway for the 2018-2019 flood season. The interim enhanced flood pool will take effect upon completion of the construction of the FCO Spillway in the fall/winter of 2018.

4.1 Goals

The goals of the 2018/2019 Plan are to maintain dam safety and provide flood control benefits produced by the reservoir for the period of November 2018 to June 2019.

4.2 Objectives

To meet these goals, the 2018/2019 Plan must satisfy the following objectives:

- Meet the USACE's 1970 WCM requirements for flood management.
- Efficiently and effectively use the project features.
- Pass the SPF without activating the Emergency Spillway.
- Do not increase the frequency at which critical pool elevations are exceeded.
- Do not increase the frequency at which critical releases are exceeded (based on release capabilities).
- Do not increase the frequency at which critical downstream flow levels are exceeded.

4.3 Performance metrics

Fulfillment of the objectives is determined by checking the following:

- Does the interim enhanced flood pool allow the reservoir to pass the SPF without exceeding elevation 901 ft (the Emergency Spillway crest elevation) and without releasing greater than 150,000 cfs from the FCO?
- Does the interim enhanced flood pool avoid increasing maximum pool elevation values significantly on the pool elevation-frequency curves for events that require flood management storage?
- Does the interim enhanced flood pool avoid increasing maximum reservoir outflow values significantly on the outflow-frequency curves for events that require flood management storage?
- Does the interim enhanced flood pool avoid increasing peak flow values significantly on the flow-frequency curves for locations downstream for events that require flood management storage?

4.4 Assumptions

DWR used the following assumptions in developing the 2018/2019 Plan:

- Avoid use of the Emergency Spillway under standard flood operations. Following the approach of the 1970 WCM, DWR developed the 2018/2019 Plan to avoid use of the Emergency Spillway for the SPF and events more likely than the SPF. The goal of the Emergency Spillway repair underway is to provide capability for safe releases of 100,000 cfs, if needed, by March 2019.
- Limit FCO releases to 150,000 cfs for flood management operation (routing of SPF). Operation to protect the integrity of the dam during exceptionally rare events may require larger releases.
- Limit Hyatt Powerplant release capability assuming one of two penstocks is offline. The plan accounts for this outage in anticipation of planned maintenance.
- The RVOS is also assumed not to be used; it is held in reserve for contingencies and temperature management.

4.5 Technical development process overview

The technical development process was as follows.

1. Start with DWR's Oroville reservoir operation model, an HEC-ResSim model, which was used for the 2017/2018 Plan (DWR 2017a).
2. Select a wet system SPF for determining the size of the maximum flood pool from the 1970 WCM and construct a surrogate dry system SPF based on information from the WCM (a dry system SPF is not included in the WCM; only the Oroville inflow component of the SPF is included). For the 2018/2019 Plan, downstream target flows are evaluated from a system perspective, considering not only SPF outflow from Lake Oroville, but also coincident outflow from New Bullards Bar Reservoir on the Yuba River and local flows.
3. Determine the size of the maximum flood pool for wet conditions through an iterative process of increasing the flood pool, routing the wet system SPF with 2018/2019 Plan specifications, and checking whether the reservoir passes the SPF without use of the Emergency Spillway and with a maximum FCO release of 150,000 cfs or less. Also check downstream target flows.
4. Determine the size of the flood pool for drier conditions:
    - Start with the dry SPF routing from the 1970 WCM. Determine the wetness index/1970 WCM flood pool size associated with the dry SPF (DWR found the associated wetness index was 4.1).
    - Start with the 1970 WCM flood pool size associated with the dry SPF (wetness index 4.1). Determine the size of the flood pool for drier conditions through an iterative process of increasing the flood pool, routing the dry system SPF with 2018/2019 Plan specifications, and checking whether the reservoir passes the

SPF without use of the Emergency Spillway and with a maximum FCO release of 150,000 cfs or less. Also check downstream target flows.

5. Develop an enhanced FCD by identifying the magnitude of the flood pool for the range of watershed conditions represented by the WCM wetness indices of 3.5 to 11. The range of the pool volume is determined through linear interpolation between the maximum flood pool size (wetness index 11) and the drier condition flood pool size (associated wetness index determined in step 4, 4.1).
6. Evaluate flood management performance of the 2018/2019 Plan with the enhanced FCD. Refine as needed.

4.6 Reservoir operation model development

Under a previous effort to support the Oroville emergency recovery effort, DWR developed a reservoir operation model for the Yuba-Feather river system. That model includes Lake Oroville and New Bullards Bar Reservoir and follows 1970 WCM rules. The model uses HEC-ResSim, the USACE standard-of-practice software (http://www.hec.usace.army.mil/software/hec-ressim/). Given a reservoir network, physical properties, operating rules and constraints, and a set of flows, HEC-ResSim routes the flows through the system, following the rules to select releases for the reservoirs. The model is described in detail in the memorandum, “Reservoir Pool Elevation-Frequency Curves for Long-term Risk Assessment,” SRT-RES-HY-02 (DWR 2017b).

DWR truncated the model to extend from Lake Oroville on the Feather River and New Bullards Bar Reservoir on the Yuba River to Nicolaus downstream. This truncation removed the headwater reservoirs in the Feather River watershed. Operation of these reservoirs is not part of the Oroville plan. However, the boundary conditions used to assess performance account implicitly for performance of the headwaters reservoirs.

To determine the magnitude of the flood pool volume, DWR configured alternatives within the model to reflect candidate 2018/2019 Plans and routed the SPFs. In order to evaluate the performance, DWR used the model to route a range of design events with the selected operation plan and developed frequency curves to compare with the existing 1970 WCM operation frequency curves.

4.7 Determination of flood management pool size

4.7.1 1970 WCM

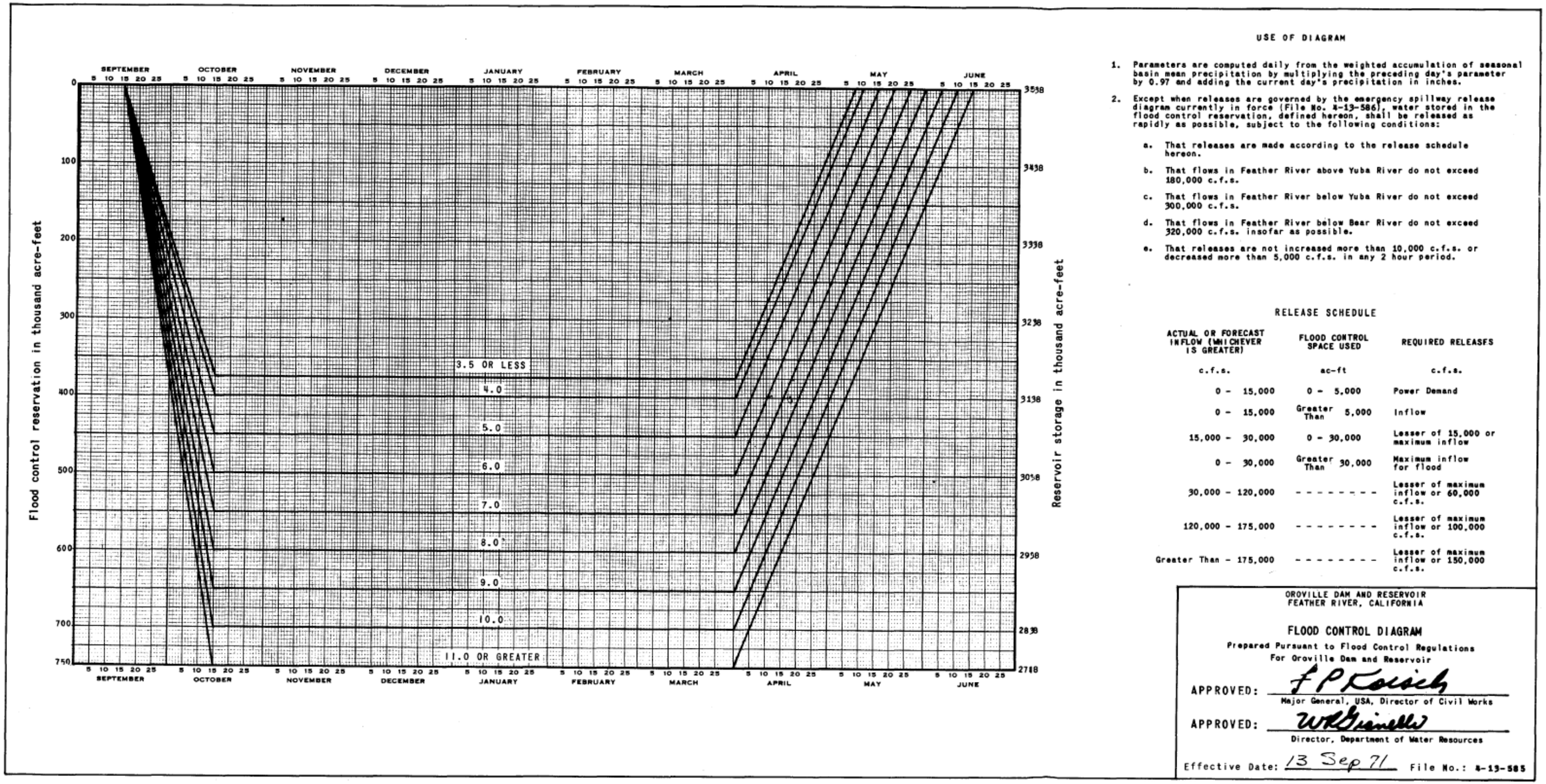
The 1970 WCM was developed such that the reservoir could pass the SPF with a maximum FCO Spillway release of 150,000 cfs without using the Emergency Spillway, assuming Marysville Dam was in place. Reservoir operation rules for flood management were also developed considering seasonal variation of inflow, resulting in varying seasonal flood management storage.

According to the 1970 WCM, large rain storms in the Feather River Basin occur most frequently in the months of November through March and are not known to occur in the months of June through August. For a specified ground condition, the seasonal variation

of rain flood potential is dependent on the seasonal variation of storm potential, which is a function of latitude and the amount of storm precipitation that normally occurs at any location.

The 1970 WCM includes a storage management plan that assigns available storage at Oroville for conservation purposes (water supply, hydropower production, recreation, and environmental protection) or flood management as needed. This plan is represented with the flood control diagram shown in Figure 4-1, which shows a set of rule curves ranging from wet ground conditions (bottom curve) to dry ground conditions (top curve). The storage above the solid line is allocated to flood management on the day shown, and the storage below is allocated to conservation. For example, for wet conditions (wetness index 11) from October 15 through April 1, 750,000 acre-feet is allocated for flood management. From April 1 through June 15, the reservoir is allowed to refill, and by June 15, the allocation for flood management is reduced to 0 acre-feet.

Figure 4-1. Lake Oroville Flood Control Diagram



USE OF DIAGRAM

1. Parameters are computed daily from the weighted accumulation of seasonal basin mean precipitation by multiplying the preceding day's parameter by 0.97 and adding the current day's precipitation in inches.

2. Except when releases are governed by the emergency spillway release diagram currently in force (File No. 4-13-586), water stored in the flood control reservation, defined hereon, shall be released as rapidly as possible, subject to the following conditions:

   a. That releases are made according to the release schedule hereon.

   b. That flows in Feather River above Yuba River do not exceed 180,000 c.f.s.

   c. That flows in Feather River below Yuba River do not exceed 300,000 c.f.s.

   d. That flows in Feather River below Bear River do not exceed 320,000 c.f.s. insofar as possible.

   e. That releases are not increased more than 10,000 c.f.s. or decreased more than 5,000 c.f.s. in any 2 hour period.

RELEASE SCHEDULE

ACTUAL OR FORECAST INFLOW (WHICHEVER IS GREATER) c.f.s.	FLOOD CONTROL SPACE USED ac-ft	REQUIRED RELEASES c.f.s.
0 - 15,000	0 - 5,000	Power Demand
0 - 15,000	Greater Than 5,000	Inflow
15,000 - 30,000	0 - 30,000	Lesser of 15,000 or maximum inflow
0 - 30,000	Greater Than 30,000	Maximum inflow for flood
30,000 - 120,000	- - - - - - - -	Lesser of maximum inflow or 60,000 c.f.s.
120,000 - 175,000	- - - - - - - -	Lesser of maximum inflow or 100,000 c.f.s.
Greater Than - 175,000	- - - - - - - -	Lesser of maximum inflow or 150,000 c.f.s.

OROVILLE DAM AND RESERVOIR
FEATHER RIVER, CALIFORNIA

FLOOD CONTROL DIAGRAM

Prepared Pursuant to Flood Control Regulations
For Oroville Dam and Reservoir

APPROVED: F P Koisch
Major General, USA, Director of Civil Works

APPROVED: W R Gianelli
Director, Department of Water Resources

Effective Date: 13 Sep 71 File No.: 4-13-585

Source: USACE 1970

4.7.2 Approach to determine enhanced flood pool

To maintain WCM operation—given the current state of the project features and the absence of Marysville Dam—the volume used for flood management storage must be increased for the range of ground conditions (wetness index 3.5 to 11). As described in the following sections, for the 2018/2019 Plan, DWR determined the size of the maximum flood pool (wetness index 11) by routing a wet system SPF and a flood pool for drier conditions by routing a dry system SPF. DWR used linear interpolation between these values to determine the magnitude of the flood pool for the range of ground conditions. (The 1970 WCM flood pool sizes are also linearly related.)

4.7.3 SPF for wet and dry conditions

The standard project flood is a severe event developed based on the standard project storm, which reflects observed conditions reasonably characteristic of the hydrologic region. Prior to construction of Oroville Dam, USACE developed the standard project storm and routed it under different conditions to compute inflow into Lake Oroville and throughout the system. Table 4-1 shows a list of SPF routings included in the 1970 WCM and how they were applied for this analysis. Figure 4-2 to Figure 4-4 show the 1970 WCM routings.

These routings inform determination of the enhanced flood pool size as follows:

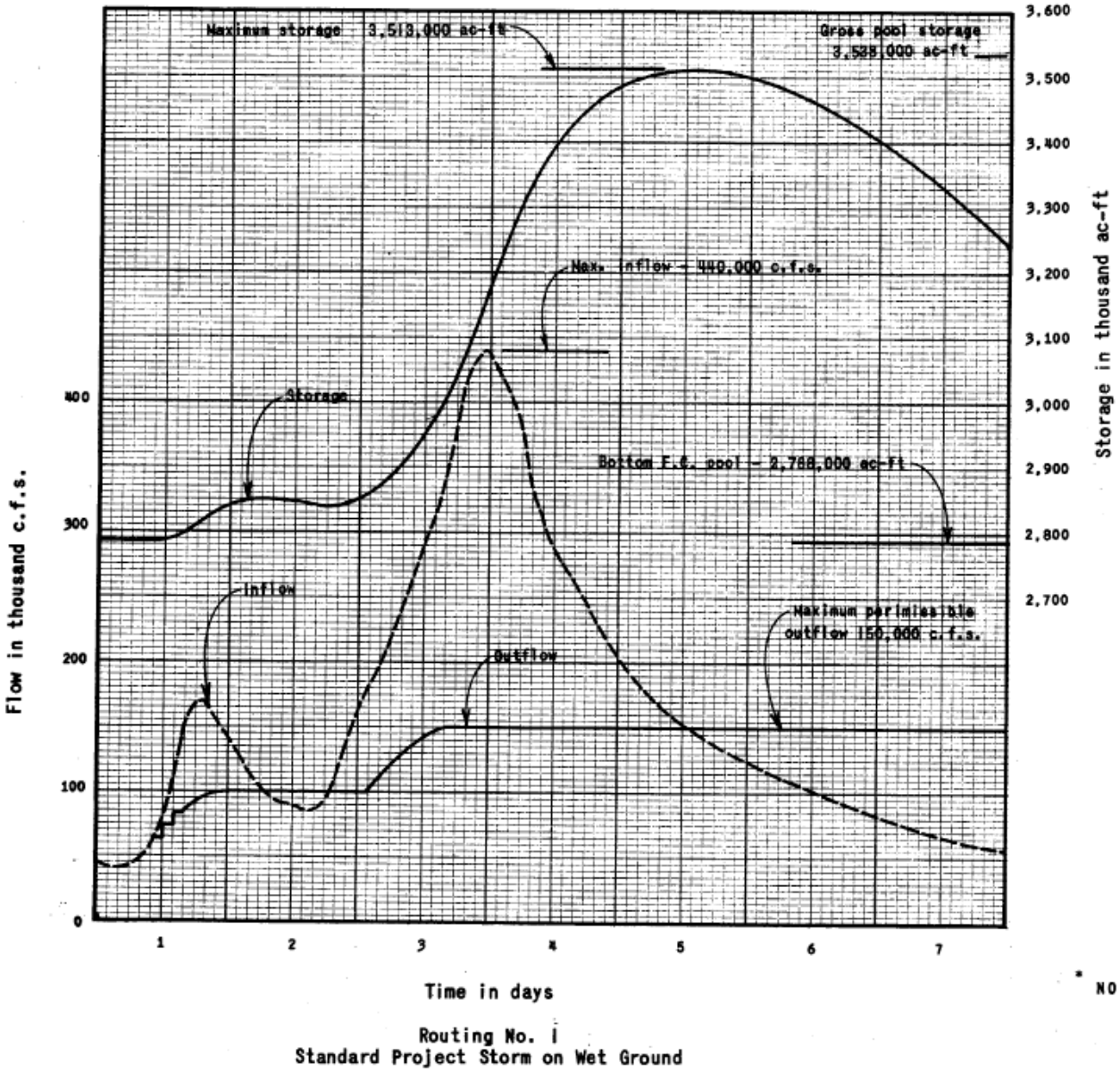
- The system routing centered on the Feather River above Oroville Dam without Marysville Dam shows that WCM operation yields maximum releases above the target 150,000 cfs. This demonstrates the need to reevaluate the flood pool size in the absence of Marysville Dam.
- The system routings centered on the Yuba River below New Bullards Bar Dam with and without Marysville Dam show that during peak inflow with Marysville Dam, releases can be sustained rather than cut back further for downstream flow considerations. These routings demonstrate the necessity of reevaluating the flood pool size in the absence of Marysville Dam from a system perspective.

The 1970 WCM does not include a system SPF routing for dry conditions to determine the appropriate flood pool for drier conditions. Therefore, DWR constructed a surrogate dry system SPF based on the wet system SPF centered on the Feather River above Oroville Dam. After calculating the ratio of Oroville peak inflow for the dry SPF to Oroville peak inflow to the wet SPF, DWR applied this ratio, 0.81, to scale local flows and New Bullards Bar Reservoir inflow to develop a dry system SPF.

Table 4-1. SPF routings included in the 1970 WCM and application for current plan

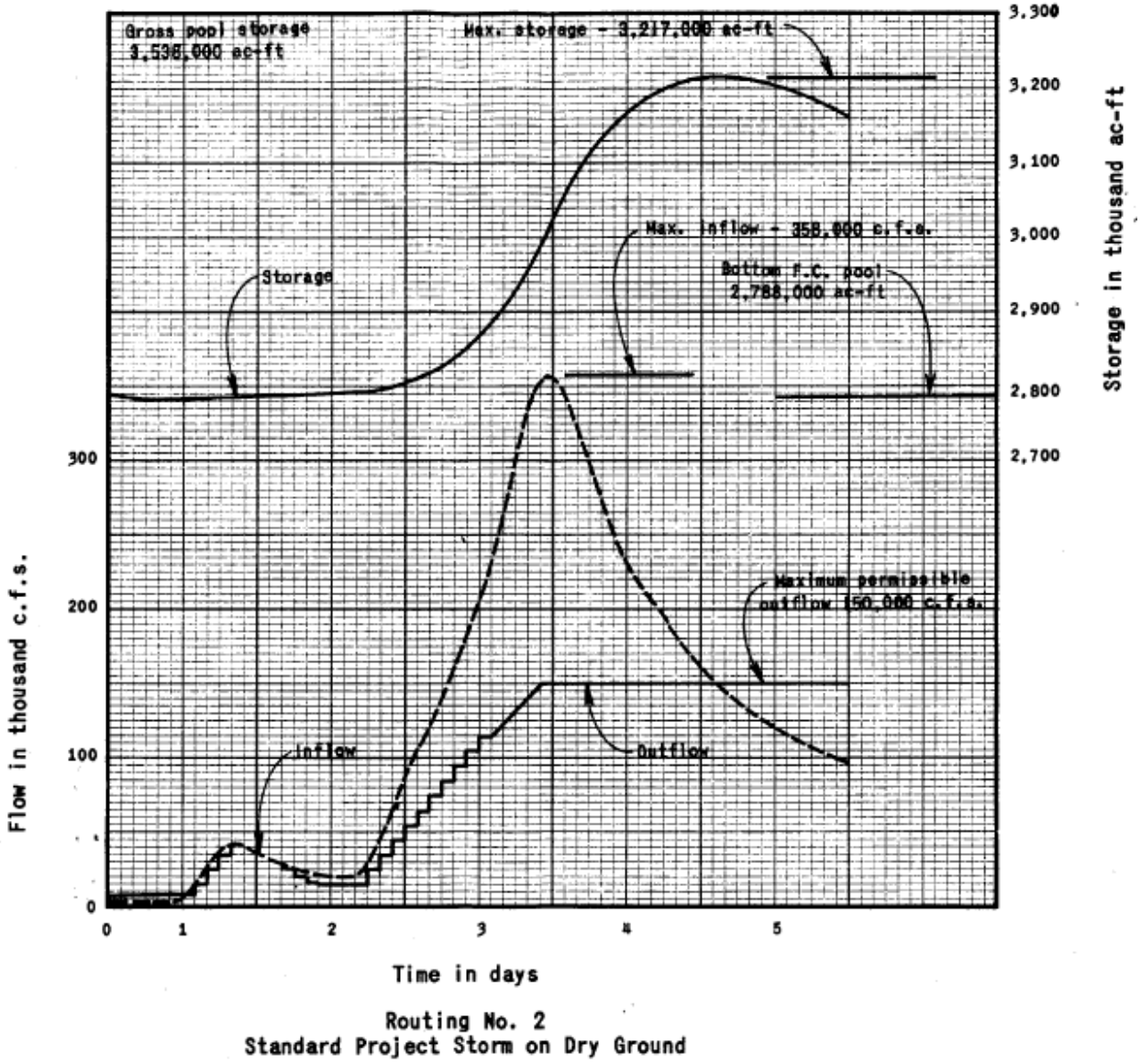
Routing	WCM Chart No. Routing No.	Description	Application for current plan
Wet SPF	11-1 (Figure 4-2)	Oroville component only. Pertains to 1970 WCM determination of flood control space requirement. Oroville inflow here is the same as the inflow of the system SPF centered on the Feather River above Oroville Dam.	Used to evaluate performance of enhanced maximum flood pool (wet conditions)
Dry SPF	11-2 (Figure 4-3)	Oroville component only. Pertains to 1970 WCM determination of flood control space requirement.	Used as a basis for development of a surrogate dry system SPF for determining enhanced flood pool size for drier conditions Also used to evaluate performance of enhanced flood pool for drier conditions
Primary standard project storm centered on Feather River above Oroville Dam – present conditions, wet	32-1 (Figure 4-4, Routing 1)	System routing without Marysville Dam showing maximum release of 170,000 cfs. Shows runoff hydrographs for various portions of the watershed.	Used to determine size of enhanced maximum flood pool (wet conditions) Also used as a basis for development of a surrogate dry system SPF for determining enhanced flood pool size for drier conditions
Primary standard project storm centered on Yuba River below New Bullards Bar Dam – present conditions, wet	32-2 (Figure 4-4, Routing 2)	System routing without Marysville Dam showing reduced releases during inflow peak for downstream flow considerations. Shows runoff hydrographs for various portions of the watershed.	Used to evaluate performance of enhanced maximum flood pool (wet conditions)
Primary standard project storm centered on Yuba River below New Bullards Bar Dam – future conditions, wet	32-3 (Figure 4-4, Routing 3)	System routing with Marysville Dam showing relatively sustained releases during inflow peak due to additional storage capacity in Marysville Dam. Shows runoff hydrographs for various portions of the watershed.	n/a

Figure 4-2. 1970 WCM wet SPF routing pertaining to determination of flood control space requirement



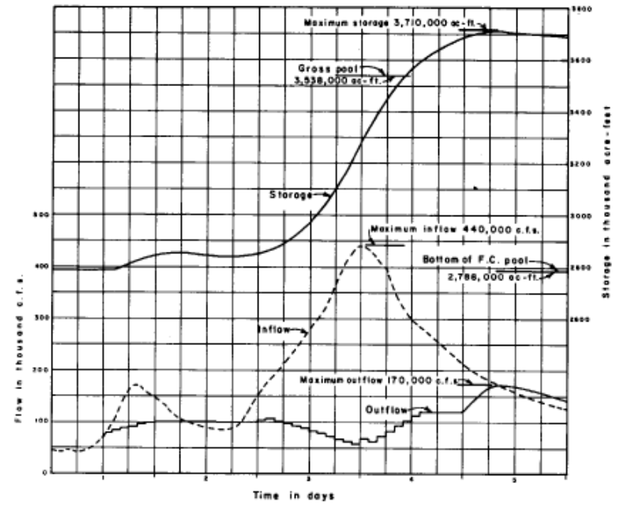
Source: USACE 1970

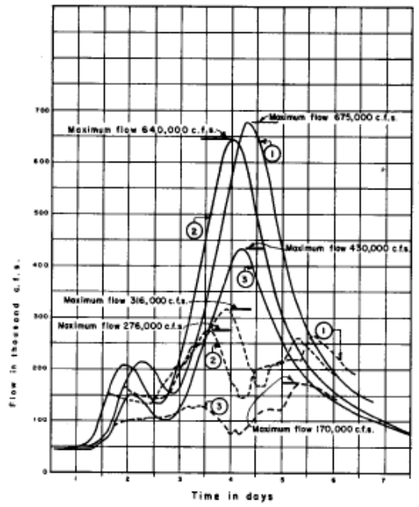
Figure 4-3. 1970 WCM dry SPF routing pertaining to determination of flood control space requirement



Source: USACE 1970

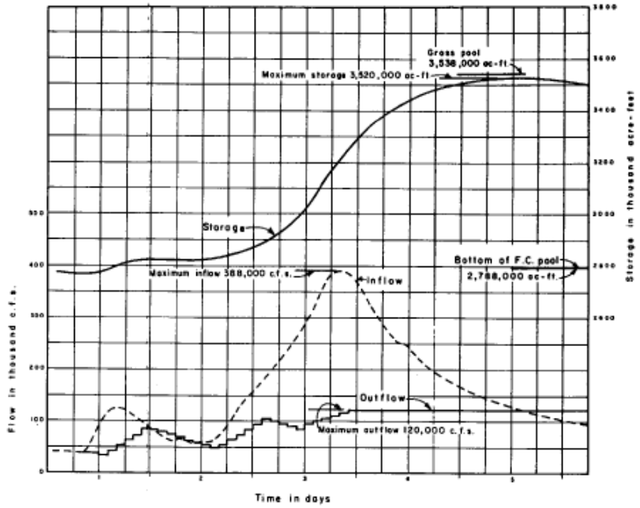
Figure 4-4. 1970 WCM wet system SPF routings

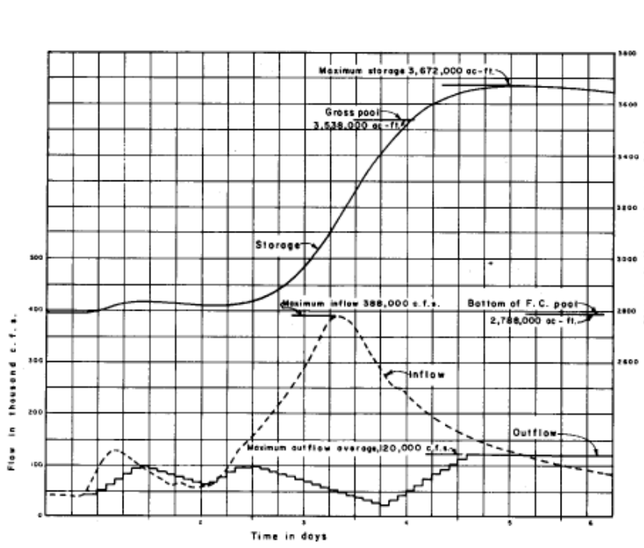


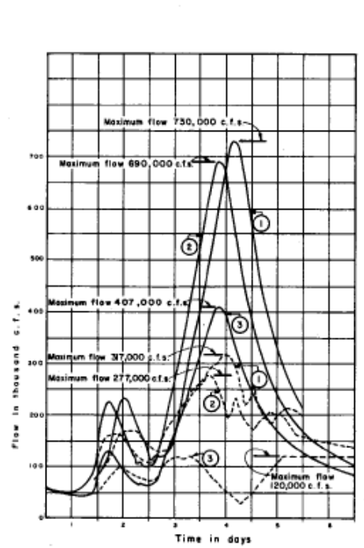


ROUTING NO. 1 (PRESENT CONDITIONS)

(Primary standard project storm centered on Feather River above Oroville Dam)
(Regulation by Oroville and New Bullards Bar Reservoirs)

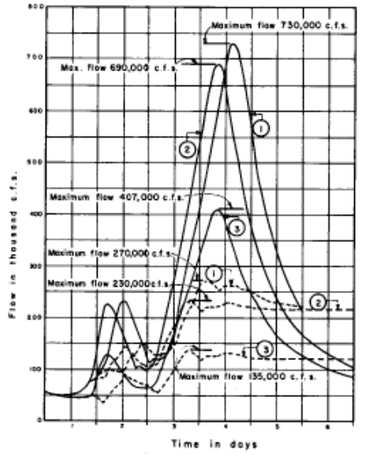






ROUTING NO. 2 (PRESENT CONDITIONS)

(Primary standard project storm centered on Yuba River below New Bullards Bar Dam)
(Regulation by Oroville and New Bullards Bar Reservoirs)



ROUTING NO. 3 (FUTURE CONDITIONS)

(Primary standard project storm centered on Yuba River below New Bullards Bar Dam)
(Regulation by Oroville, New Bullards Bar and Marysville Reservoirs)

LEGEND

Regulated _ _ _ _ Unregulated _____

① Feather River below Bear River
② Feather River below Yuba River
③ Feather River above Yuba River

NOTES:

1. All Oroville routings are based on criteria on Chart A-1 and in paragraph 16.
2. The following assumptions were made to allow for contingencies of operation:
   (a) 25 percent error in forecasting of Yuba River local flow below Marysville Reservoir.
   (b) 80 percent of objective flows (Feather River = 120.000 c.f.s.; Yuba River = 96.000 c.f.s.)
3. Maximum Bear River flow assumed = 40.000 c.f.s.

Source: USACE 1970

4.7.4 Determination of enhanced maximum flood pool size

To determine the maximum flood pool size, DWR:

- Started with the 1970 WCM operation configured in the HEC-ResSim model, which allocates 750,000 acre-feet for flood storage (wetness index 11).
- Increased the flood pool volume configured in the model.
- Routed the wet system SPF with specifications for the 2018/2019 Plan: FCO release is limited to 150,000 cfs, only 3 of the 6 powerhouse units can release water, and flow through the RVOS is 0 cfs. To determine the maximum flood pool size, DWR used the wet system SPF centered on the Feather River above Oroville Dam. This system SPF is more challenging to pass than the system SPF centered on the Yuba River below New Bullards Bar Dam.
- Reviewed results and checked whether the Emergency Spillway crest elevation, 901 feet, is exceeded. Also checked whether channel capacities at Yuba City and Marysville (180,000 cfs), the Yuba-Feather River confluence (300,000 cfs), and Nicolaus (320,000 cfs) are exceeded. If so, increased the flood pool volume incrementally and repeated.
- Selected the flood pool volume that allows passage of the SPF without use of the Emergency Spillway and without exceeding downstream flow targets. This volume was 920,000 acre-feet (elevation 835.5 feet).

Table 4-2 shows a summary of the routing results.

Table 4-2. Summary of wet SPF routing results for enhanced maximum flood pool compared with results based on 1970 WCM flood pool

SPF	1970 WCM (as built condition) [TOC 848.5 ft, flood management storage 750,000 ac ft]			Enhanced flood management pool [enhanced pool elev. = 835.5 ft, flood management storage 920,000 ac ft]		
	Maximum pool elevation (ft)	Maximum storage (1,000 ac ft)	Maximum outflow from dam (1,000 cfs)	Maximum pool elevation (ft)	Maximum storage (1,000 ac ft)	Maximum outflow from dam (1,000 cfs)
Wet, Oroville inflow component only[a]	901.09	3,555	151	897.36	3,497	150
System, Feather River above Oroville Dam[b]	903.77	3,598	172	900.89	3,552	150
System, Yuba River below New Bullards Bar Dam[b]	900.87	3,551	150	897.92	3,505	150

Source: HDR | David Ford Consulting Engineers

[a] DWR digitized the SPF information from Chart 11 of the 1970 WCM and estimated values shown on the chart.

[b] DWR digitized the SPF information from Chart 32 of the 1970 WCM and estimated values shown on the chart.

4.7.5 Determination of enhanced flood pool size for drier conditions

To determine the size of the flood pool for drier conditions, DWR:

- Determined the wetness index/1970 WCM flood pool size associated with the dry SPF. As shown in Figure 4-3, the flood pool volume for the 1970 WCM dry SPF routing is 750,000 acre-feet, the maximum flood pool (wetness index 11). The routing shows that the event is passed at an elevation significantly below the Emergency Spillway elevation. This suggests that the 1970 WCM flood pool size associated with passing the dry SPF just below the Emergency Spillway elevation is smaller than the maximum flood pool. To determine the associated wetness index/1970 WCM flood pool size for the dry SPF, DWR:
    - Started with the maximum flood volume of 750,000 acre-feet configured in the HEC-ResSim model.
    - Iteratively decreased the flood pool volume and routed the dry SPF (Oroville inflow component only) with 1970 WCM operation until the maximum pool elevation was just below 901 feet. The identified flood pool volume was 405,000 acre-feet (elevation 873.3 feet).
    - Used the 1970 WCM FCD to determine that 405,000 acre-feet correlates with a wetness index of 4.1.
- Determined the 2018/2019 Plan flood pool size for a wetness index of 4.1, the wetness index associated with the dry SPF. To do this, DWR:
    - Configured the 1970 WCM flood pool size for wetness index 4.1 in the HEC-ResSim model, 405,000 acre-feet.
    - Increased the flood pool volume configured in the model.
    - Routed the dry system SPF with specifications for the 2018/2019 Plan: FCO release is limited to 150,000 cfs, only 3 of the 6 Hyatt Powerplant's units can release water, and flow through the RVOS is 0 cfs. The dry system SPF includes the Oroville inflow component as well as downstream local flows.
    - Reviewed results and checked whether the Emergency Spillway crest elevation, 901 feet, is exceeded. Also checked whether channel capacities at Yuba City and Marysville (180,000 cfs), the Yuba-Feather River confluence (300,000 cfs), and Nicolaus (320,000 cfs) are exceeded. If so, increased the flood pool volume incrementally and repeated.
    - Selected the flood pool volume that allows passage of the SPF without use of the Emergency Spillway and without exceeding downstream flow targets. This volume was 453,000 acre-feet (elevation 870.0 feet).

Table 4-3 shows a summary of the routing results.

Table 4-3. Summary of dry SPF routing results for enhanced flood pool compared with results based on 1970 WCM flood pool associated with a wetness index of 4.1

SPF	1970 WCM (as built condition) [TOC 873.3 ft, flood management storage 405,000 ac ft]			Enhanced flood management pool [enhanced pool elev. = 870.0 ft, flood management storage 453,000 ac ft]		
	Maximum pool elevation (ft)	Maximum storage (1,000 ac ft)	Maximum outflow from dam (1,000 cfs)	Maximum pool elevation (ft)	Maximum storage (1,000 ac ft)	Maximum outflow from dam (1,000 cfs)
Dry, Oroville inflow component only[a]	900.82	3,551	150	899.54	3,531	150
Dry[a] with system components[b]	903.11	3,552	165	900.81	3,531	150

Source: HDR | David Ford Consulting Engineers

[a] DWR digitized the SPF information from Chart 11 of the 1970 WCM and estimated values shown on the chart.

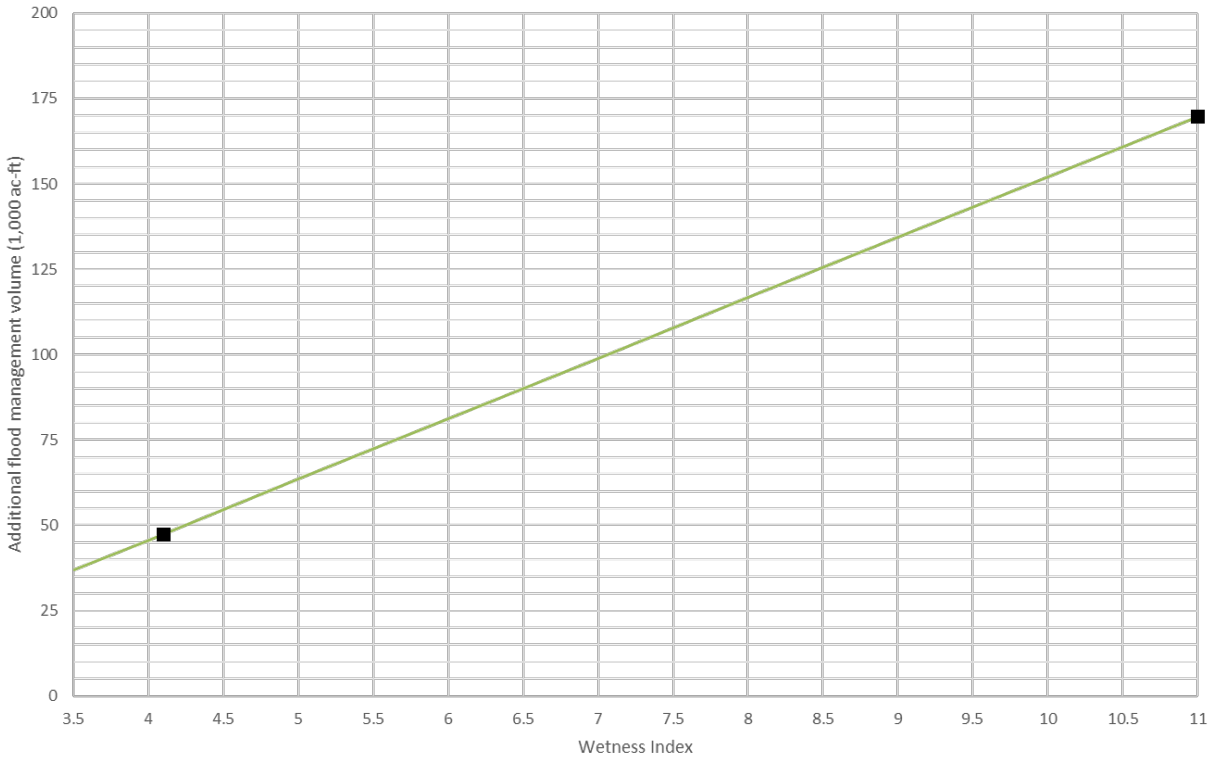
[b] System components were configured as 81% of the SPF system routing centered on the Feather River above Oroville Dam. 81% is the ratio between the peak Oroville inflow for the dry SPF (358,000 cfs) and peak Oroville inflow for the SPF system routing (440,000 cfs).

4.8 Enhanced flood control diagram

To develop the enhanced FCD for wetness indices ranging from 3.5 to 11, we linearly interpolated between the enhanced maximum flood pool volume (wetness index 11) and the enhanced flood pool volume for wetness index 4.1. Figure 4-5 shows the linear interpolation in terms of additional storage from the 1970 WCM FCD. At a wetness index of 3.5, an additional volume of 37,000 acre-feet was identified, thereby increasing the flood pool from 375,000 acre-feet (elevation 875.4 feet) to 412,000 acre-feet (elevation 872.8 feet). At a wetness index of 11 or greater, an additional volume of 170,000 acre-feet was identified, increasing the flood pool from 750,000 acre-feet (elevation 848.5 feet) to 920,000 acre-feet (elevation 835.5 feet).

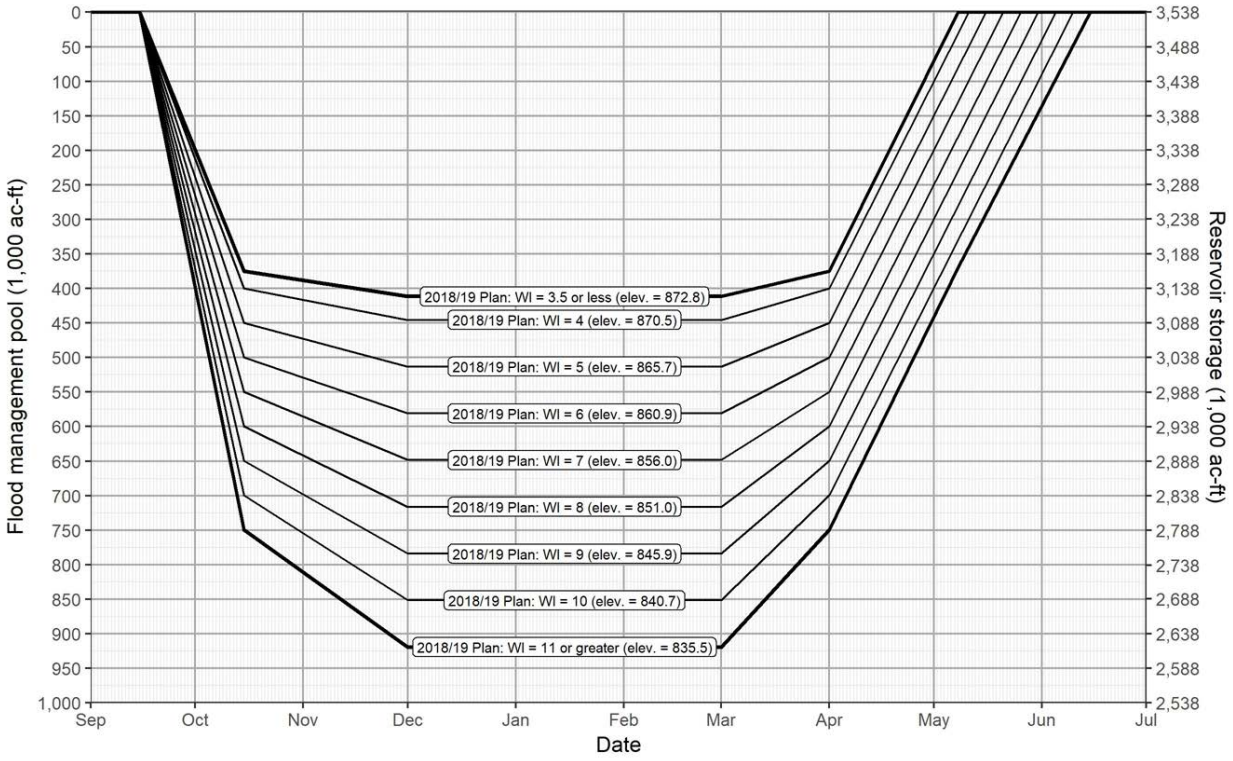
The enhanced FCD is shown in Figure 4-6. The fall drawdown and spring refill portions of the curves are retained from the 1970 WCM.

Figure 4-5. Linear interpolation to determine additional flood management storage for the range of wetness indices for the enhanced FCD



Source: HDR | David Ford Consulting Engineers and USACE 1970

Figure 4-6. Interim Enhanced Flood Pool



Source: HDR | David Ford Consulting Engineers

4.9 Reservoir releases

The 1970 WCM release schedule shown in Table 4-4 was incorporated into the development of the enhanced flood pool and will be adhered to during all flood control operations. No changes to the release schedule from the 1970 WCM are included in the 2018/2019 Plan. As indicated in Figure 4-1, these releases are dictated by a combination of volume of encroachment and forecasted inflows. For interim operations, the level of encroachment will be measured against the interim enhanced flood pool. Because the capacity of the FCO gates are a function of reservoir elevation, high releases are not achievable within the enhanced flood pool space. Should the forecast call for a release of 100,000 cfs to 150,000 cfs, when the elevation of the pool is within the enhanced flood pool space (835.5 to 848.5 feet), releases will be maximized. Release capacity limitations were incorporated into the enhanced flood pool design and will not impact the ability to pass the SPF.

DWR plans to adhere to the ramping rates outlined in the 1970 WCM of no more than 10,000 cfs every two hours for an increase, and no greater decrease than 5,000 cfs every two hours.

Table 4-4. Planned release schedule

Actual or Forecasted Inflow (cfs)	Enhanced Flood Control Space Used (TAF)	Planned Release
0 – 15,000	0 – 5	Power Demand
0 – 15,000	Greater than 5	Inflow
15,000 – 30,000	0 - 30	Lesser of 15,000 cfs or maximum inflow
0 – 30,000	Greater than 30	Maximum inflow for flood
30,000 – 120,000	---------	Lesser of maximum inflow or 60,000 cfs
120,000 – 175,000	---------	Lesser of maximum inflow or 100,000 cfs
Greater than 175,000	---------	Lesser of maximum inflow or 150,000 cfs

Source: USACE 1970

4.10 Wetness index calculation

The wetness index calculation is consistent with the calculation in the 1970 WCM. The ground wetness index is calculated from accumulated basin mean precipitation, which directly relates flood potential to wetness of the drainage basin. The adopted ground wetness index incorporates a daily reduction in the weight given previously occurring precipitation and will be computed each day by multiplying the preceding day's index by 0.97 and adding the current day's precipitation in inches:

WI = WI' x 0.97 + Precip

WI = ground wetness index for the present day's operation

WI' = previous day's index

Precip = precipitation occurring since WI' was calculated

4.11 2018/2019 Plan criteria

In summary, the 2018/2019 Plan allows for variable flood management storage based on dry and wet ground conditions. As determined through our analysis, storage ranges from 412,000 acre-feet (elevation 872.8 feet) to 920,000 acre-feet (elevation 835.5 feet) through February as dictated by the enhanced FCD shown in Figure 4-6. Elevations taper up to the 1970 WCM elevations at the end of March, and then the refill period starts.

Other key aspects of the plan are in line with the modeling assumptions described in Section 4.4:

- Avoids use of the Emergency Spillway for the SPF and events more likely than the SPF.
- Limits FCO releases to 150,000 cfs for flood management operation (routing of SPF). Operation to protect the integrity of the dam during exceptionally rare events (greater than SPF) may require larger releases.
- Limits Hyatt Powerplant release capability assuming one of two penstocks is offline. The plan accounts for this outage in anticipation of planned maintenance.
- The RVOS is also assumed not to be used; it is held in reserve for contingencies and temperature management.

4.12 Performance evaluation

To evaluate the performance of the 2018/2019 Plan, DWR developed pool elevation-frequency, reservoir outflow-frequency, and downstream flow-frequency curves based on the plan and compared those to frequency curves based on 1970 WCM operation. DWR developed the WCM operation curves under the previous Oroville emergency recovery analysis described in SRT-RES-HY-02 (DWR 2017). Comparison of frequency curves, specifically comparing whether values for the 2018/2019 Plan are equal to or lower than values for the 1970 WCM, allowed DWR to determine whether flood management objectives, and in turn the flood management goal, were satisfied.

To develop the frequency curves for the 2018/2019 Plan, DWR:

- Configured the 2018/2019 Plan in the HEC-ResSim model with the enhanced FCD (maximum flood pool of 920,000 acre-feet). Just as in the simulations for flood pool sizing, FCO release is limited to 150,000 cfs, only 3 of the 6 powerhouse units can release water, and flow through the RVOS is 0 cfs.
- Routed a set of balanced hydrographs associated with a range of frequencies through Lake Oroville (a risk-informed approach that considers uncertainty). DWR developed the balanced hydrographs under the previous Oroville emergency recovery analysis described in SRT-RES-HY-02. The hydrographs are representative of design events with return intervals of 5, 10, 25, 50, 100, and 200 years. For pool elevation and outflow results, these balanced hydrographs with frequencies specific for the months of November through May are used. For flow at downstream locations, scaled historical hydrographs developed based on annual frequency statistics are used consistent with the Central Valley Hydrology Study (CVHS) (DWR 2015).
- Compiled the set of pool elevation, outflow, and downstream flow results for the design events of each frequency and compared them to the values determined previously for WCM operation.
- Reviewed results to confirm the 2018/2019 Plan satisfied objectives.

5 2018/2019 Plan performance

DWR confirmed that the 2018/2019 Plan satisfies the objectives as indicated by Table 5-1 to Table 5-3:

- The 2018/2019 Plan avoids increasing peak flow values significantly on the peak flow-frequency curves for locations downstream for events that require flood management storage.
- The 2018/2019 Plan allows the reservoir to pass the SPF without exceeding the Emergency Spillway crest elevation of 901 feet and without releasing greater than 150,000 cfs from the FCO .
- The 2018/2019 Plan avoids increasing pool elevation values significantly on the reservoir pool elevation-frequency curves for events that require flood management storage.
- The 2018/2019 Plan avoids increasing outflow values significantly on the reservoir outflow-frequency curves for events that require flood management storage.

Table 5-1. Downstream flow-frequency curve values for 1970 WCM operation and 2018/2019 Plan

Annual chance exceedence (CE)	Peak regulated flow (1,000 cfs) at given location: 1970 WCM operation[a,b]				Peak regulated flow (1,000 cfs) at given location: 2018/2019 Plan[a,c]			
	Marysville[d]	Yuba City[d]	Feather Yuba confluence[e]	Nicolaus[f]	Marysville[d]	Yuba City[d]	Feather Yuba confluence[e]	Nicolaus[f]
20%	49	91	134	151	49	73	119	136
10%	70	112	174	197	70	94	155	180
4%	108	145	239	266	108	129	218	245
2%	141	160	277	306	141	153	264	296
1%	174	170	290	321	171	164	289	320
0.5%	200	185	309	352	197	179	300	338

Source: HDR | David Ford Consulting Engineers

[a] These results are based on the reservoir routings of the scaled hydrographs from the CHVS flow dataset for entire system (DWR 2015).

[b] 1970 WCM: 6 powerhouse units available and RVOS flows = 0 cfs.

[c] Restricted pool elevation = 835.5 feet, FCO capped at 150,000 cfs, 3 powerhouse units available (penstock 2 is offline), and RVOS flows = 0 cfs.

[d] The maximum target flow at Marysville and Yuba City is 180,000 cfs.

[e] The maximum target flow at the confluence of the Feather and Yuba rivers is 300,000 cfs.

[f] The maximum target flow at Nicolaus, just downstream of the confluence of the Feather and Bear rivers, is 320,000 cfs.

Table 5-2. Oroville reservoir frequency curve values for 1970 WCM operation: Operation follows the 1970 WCM for the as-built condition

Design event chance exceedence (CE)[a]	Maximum pool elevation (ft)[b]							Maximum outflow (1,000 cfs)[b]						
	Nov	Dec	Jan	Feb	Mar	Apr[c]	May[c]	Nov	Dec	Jan	Feb	Mar	Apr	May
20%	849	854	854	854	853	873	894	27	67	67	67	60	41	27
10%	849	852	852	852	854	873	894	40	98	98	98	65	59	36
4%	849	858	858	858	852	873	894	60	124	124	124	96	72	48
2%	851	867	867	867	858	873	894	60	149	149	149	100	100	59
1%	856	878	878	878	863	873	894	100	150	150	150	138	102	69
0.5%	857	894	894	894	871	873	894	122	150	150	150	150	150	80

Source: HDR | David Ford Consulting Engineers

[a] For example, 1% means the pool elevation would exceed 856 feet in 1 out of 100 Novembers.

[b] These results are based on the reservoir routings of balanced inflow hydrographs. These routings do not account for downstream control.

[c] Maximum elevation equals the elevation at the bottom of flood management volume near the end of the month.

Table 5-3. Oroville reservoir frequency curve values for 2018/2019 Plan

Design event chance exceedence (CE)[a]	Maximum pool elevation (ft)[b]							Maximum outflow (1,000 cfs)[b]						
	Nov	Dec	Jan	Feb	Mar	Apr[c]	May[c]	Nov	Dec	Jan	Feb	Mar	Apr	May
20%	836	842	842	842	852	873	894	27	60	60	60	57	41	27
10%	836	846	846	846	852	873	894	40	79	79	79	63	59	36
4%	836	854	854	854	852	873	894	52	109	109	109	83	72	48
2%	839	861	861	861	853	873	894	60	138	138	138	100	100	59
1%	845	871	871	871	859	873	894	75	150	150	150	128	102	69
0.5%	851	886	886	886	868	873	894	95	150	150	150	150	150	80

Source: HDR | David Ford Consulting Engineers

[a] For example, 1% means the pool elevation would exceed 845 feet in 1 out of 100 Novembers.

[b] These results are based on the reservoir routings of balanced inflow hydrographs. These routings do not account for downstream control.

[c] Maximum elevation equals the elevation at the bottom of flood management volume near the end of the month.

6 References

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