RECLAMATION
Managing Water in the West

Technical Memorandum NO. WHI-8130-IE-2008-1

Evaluation of Environmental Water Program (EWP):

Pilot Re-operation of Whiskeytown Dam

Central Valley Project, California
Mid-Pacific Region

(FINAL DRAFT)
January 2008

U.S. Department of the Interior
Bureau of Reclamation

ESSA Technologies Ltd.

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

This report was prepared jointly by the Bureau of Reclamation and ESSA Technologies Ltd. of Canada under contract with the U.S. Fish and Wildlife Service.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado

Technical Memorandum No. WHI-8130-IE-2008-1

Evaluation of Environmental Water Program (EWP):
Pilot Re-operation of Whiskeytown Dam

Whiskeytown Dam
Central Valley Project, California
Mid-Pacific Region

Prepared: Elisabeth A. Cohen, P.E.
Civil Engineer, Waterways and Concrete Dams Group 86-68130

Prepared: Clint Alexander, MRM
ESSA Technologies Ltd, Canada, www.essa.com

Checker: Ken Bullard, P.E.
Hydraulic Engineer, Hydrology Group 86-68530

Technical Approval: Ken Bullard, P.E.
Hydraulic Engineer, Hydrology Group 86-68530

Peer Review: John H. LaBoon, P.E. Date
Civil Engineer, Waterways and Concrete Dams Group 86-68130

Evaluation of Environmental Water Program (EWP) Pilot Re-operation of Whiskeytown Dam

0. Executive Summary

0.1. Summary

0.1.1 EWP background

The EWP (Environmental Water Program) is part of the California Bay-Delta Authority's (CBDA) Ecosystem Restoration Program (ERP). The U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration Fisheries (NOAA), and the California Department of Fish and Game (CDFG) are designated as the *implementing agencies* for the Ecosystem Restoration Program (ERP Implementing Agencies) and are working, in coordination with the CBDA, to implement pilot water acquisitions in selected watersheds through the EWP. The acquisitions are intended to provide significant biological and ecological benefit, improve the state of scientific knowledge related to the effects of instream flows, and increase knowledge regarding the institutional and social constraints facing environmental water acquisitions.

Clear Creek (Figure 0-1) has been cited as an excellent candidate stream for flow augmentation to achieve several of the objectives of the California Bay Delta Authority (CBDA) Ecosystem Restoration Program. Multi-agency collaborative restoration efforts in Clear Creek have identified a requirement for the release of periodic higher flows to improve aquatic and riparian habitats, but Whiskeytown Dam (WT Dam) operations have significantly reduced the frequency of mid-range flood flows that are essential for forming and maintaining channel and floodplain morphologies on which these habitats and native biota depend. These flows are believed to be a key tool for sustaining and reinforcing the benefits of past and ongoing restoration activities undertaken by the local Clear Creek Restoration Team (CCRT) and their constituent agencies (Reclamation, USFWS, and CDFG).

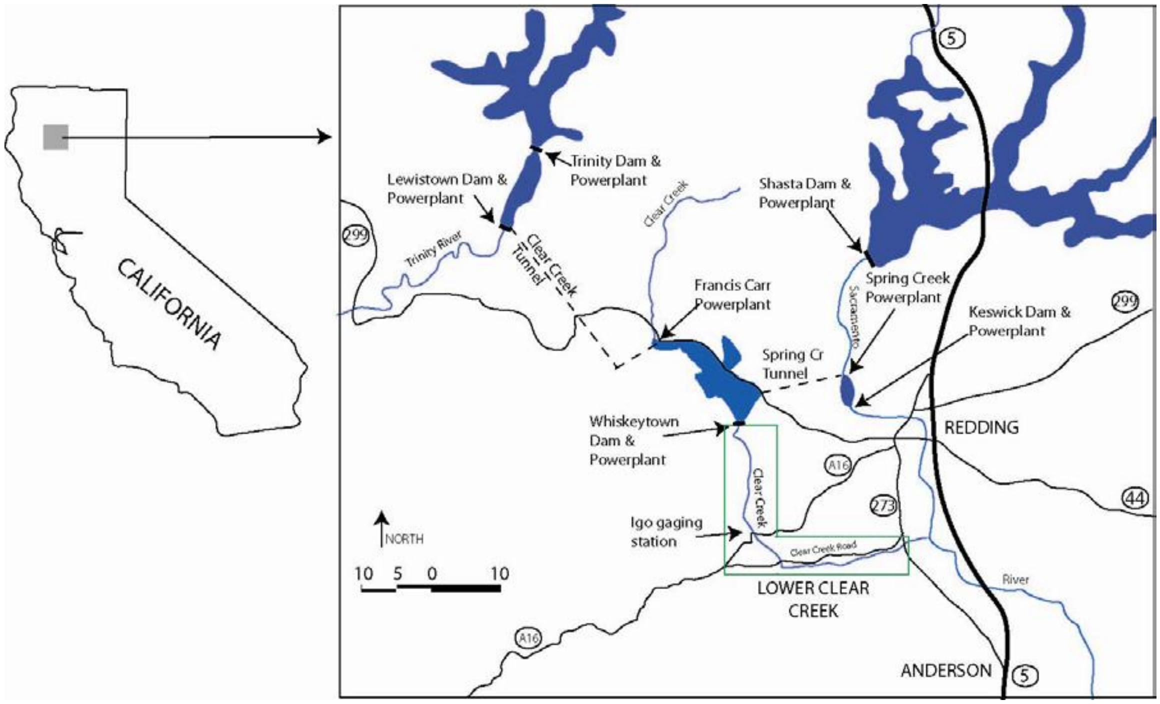


Figure 0-1 Lower Clear Creek Study Area, and major surrounding water supply and power generation infrastructure. *Source*: EWP Concept Proposal, 2004.

A major goal of the overall EWP program for Clear Creek is to implement a pilot re-operation of WT Reservoir over a 10-year trial period. Hence, Reclamation's support to proceed with pilot operational modifications at WT Reservoir is required. For this reason, an evaluation of the feasibility of implementing an EWP pilot program was completed. The next step in this pilot program—if accepted by all Parties—includes steps to develop details of an in-season implementation plan. The implementation plan should build on the modeling performed in this study, including specific tests for initiating and aborting an EWP attempt, quantify impacts, benefits, and additional data required. Upon completion of the 10 year pilot program it should be evaluated prior to any decisions to implement any re-operation on a permanent basis or any modifications to the permanent operation of WT Dam.

0.1.2 General condition

Whiskeytown Dam (also known as Clair A. Hill Whiskeytown Dam, WT Dam) includes a main dam embankment on Clear Creek and two dike embankments on relatively low saddles to the right of the main dam embankment. The dam and dikes are located approximately nine miles west of the city of Redding in northern California. The dam was constructed by the Bureau of Reclamation between 1960 and 1963. The dam is located in the Whiskeytown National Recreation Area operated by the National Park Service. The area is a popular recreation area and heavily used.

The reservoir, Whiskeytown Lake, has an active storage capacity of 241,000 acre-feet at reservoir water surface elevation 1,210.0 ft. Whiskeytown Lake receives water for hydroelectric power generation at the J.F. Carr Powerplant located at the upstream end of the reservoir approximately 7 miles northwest from the dam via the 10.7-mile-long Clear Creek Tunnel and provides water for hydroelectric power generation at the Spring Creek Powerplant located 2.4 miles northeast of the dam via the Spring Creek Tunnel.

The spillway is located near the left abutment of the main dam, and consists of a morning-glory ogee crest structure, a vertical transition curve, a tunnel, and a flip-bucket energy dissipator. The concrete crest structure is at crest elevation 1,210.0.The design discharge capacity of the spillway is 28,650 ft^3/s at reservoir water surface elevation 1,220.5.

Water from the outlet works discharges into Clear Creek immediately downstream from the control structure and to the right of the spillway exit portal. The discharge capacity of the outlet works using the lower intake (with no contribution from the upper intake) is approximately 1,240 ft^3/s at reservoir water surface elevation 1,220.5. The discharge capacity of the outlet works using only the upper intake (with no contribution from the lower intake) is approximately 600 ft^3/s at reservoir water surface elevation 1,220.5.

Table 0-1 Significant features and elevations of WT Dam.

Feature	Design Elevations (ft)
Top of Dam	1,228.0
Design Maximum Water Surface	1,220.5
Spillway Crest	1,210.0
Top of Active Conservation	1,210.0
Winter RWS Elevation	1,198.0
Top of Dead (Outlet Works Sill)	972.0
Streambed at Dam Axis	958.0
Bottom of embankment excavation	946.0

0.2. CCDAM

The Clear Creek Decision Analysis and Adaptive Management Model (CCDAM) is used to evaluate the historical conditions and the potential success for an EWP release (Alexander et al. 2003). The CCDAM model was developed specifically for Clear Creek to address various flow-related ecosystem restoration issues and help design adaptive management experiments. The model consists of submodels that include Dam Operations and Hydrology Power and Lake Recreation (DOHPLR), channel sediment transport dynamics, riparian initiation success, and fish submodels.

0.2.1 Model

The evaluation of the re-operation of WT Dam mainly involved the DOHPLR submodel in CCDAM. Numerous re-operation scenarios were evaluated. The scenario determined to have the greatest potential of success had a target release of 3,250 ft^3/s for 1 day. Three seasons were evaluated with 1) winter being from January 4 through May 15; 2) Spring from March 1 through May 15; and 3) Late Spring from April 1 through May 15. Other variations within the scenarios were initial reservoir water surface elevation, adjusting the power prices from variable to constant, target flow amounts, and target flow durations. The variations on the scenarios were evaluated in detail as described in the body of the Technical Memorandum Evaluation of Environmental Water Program (EWP): Pilot Re-operation of Whiskeytown Dam (this document).

The following table shows some of the details for the runs performed for scenario 3 with an EWP release of 3,250 ft^3/s for 1 day. Scenario 1 had EWP target releases of 4,750 ft^3/s for 3 days, and scenario 2 had EWP target releases of 4,750ft^3/s for 2 days. The details for scenarios 1 and 2 are included in the TM. Scenario 1 and 2 did not have enough successes in operation and were replaced with Scenario 3.

Table 0-2. **Scenario 3** – CCDAM runs with EWP release targets of **3,250 ft^3/s for 1 day.**

Model ID No.	Season	Start date	End date	EWP ready elevation (ft)	Power revenue assumption[1]
15	Spring	March 1	May 15	Historical	no shift
16	**Spring**	**March 1**	**May 15**	**1,204**	**no shift**
17	**Spring**	**March 1**	**May 15**	**1,209.5**	**no shift**
18	Winter	January 7	May 15	Historical	no shift
19	**Winter**	**January 7**	**May 15**	**1,203.5**	**no shift**
20	Late Spring	April 1	May 15	Historical	no shift
21	Late Spring	April 1	May 15	1,204	no shift
22	Late Spring	April 1	May 15	1,209.5	no shift

1 Foregone power costs for a “no shift” condition are based on the assumption that revenue from the production of power is the same regardless of the month; for a “shift” condition, the assumption is that power revenues are greater in the summer than in the spring and that changes made in the winter/spring should be “taxed” to account for foregone revenues under the higher summer prices.

The details of the re-operations are in the Technical Memorandum but significant issues that affected the number of successful attempts are summarized here. Conditions which would result in the termination of an EWP event included:

exceeded 2 attempts per year;

exceeded limit on foregone power cost (maximum of $1,600,000);

exceeded limit on cumulative volume from Whiskeytown Reservoir (preserving volume with a maximum of 84,000 acre-feet used per attempt);

exceeded maximum daily flow in lower Clear Creek that would be unsafe (limited to 9,100 ft^3/s); or

exceeded the maximum number of continuous days attempting an EWP flow without success (limited to 7 days).

Additional constraints that were evaluated in the CCDAM included:

Trinity flood hazard limits;

Shasta encroachment foresight;

maximum flows at Bend Bridge;

J.F. Carr Tunnel minimum and maximum flows;

Spring Creek Tunnel minimum and maximum flows; and

Whiskeytown Dam outlet minimum and maximum flows.

The CCDAM DOHPLR simulations used two fundamental principles: 1) act in the interest of safety first, and 2) act conservatively in terms of (foregone power) calculations and data. The first principle is achieved by checking whether Trinity Reservoir is at a flood stage, Bend Bridge flow is exceeded (65,000+ ft^3/s), or lower Clear Creek Reach 5 flow has hit an emergency stop (9,100+ ft^3/s). These checks are performed for each day in the model simulation. The DOHPLR submodel also acts conservatively in that it defers to using historical data when this differs from the strict course of action defined by the scenario parameters, compensates for flows taken from Trinity and Shasta even if this might not be done in reality, and calculates foregone power to err on the side of costs being higher rather than lower.

The cost for power shifting was evaluated from earlier runs (Scenario 1 and 2) where the same runs were performed with and without a price sift to determine an approximate cost increase when the power cost shifts by month were used (more closely representing the real market demands), see Table 0-4 and Table 0-5.

Since forecasting inflows is a fundamental aspect of deciding whether to initiate EWP re-operations, the CCDAM includes a 5-day advance inflow forecast equation. The equation is based on the preceding 5 day inflow to WT Reservoir and gives a 5-day advance inflow forecast for WT Reservoir.

The Whiskeytown outlets were also used to achieve the EWP release. This reduces the amount of volume needed to buildup the reservoir to achieve a 3,250 ft^3/s outflow solely through the morning glory spillway.

Within the EWP algorithm, the DOHPLR submodel can be in one of 7 states: *AtHistorical*, *BuildtToElevation*, *AtReadyElevation*, *InEWP*, *ReturnToElevation*, *ReturnToHistorical*, *Stopped*. Within the EWP algorithm for a single day, the state can change and tunnels can be re-operated more than once (e.g. may be able to *BuildToElevation*, realize there is an adequate forecast to attempt and release and switch to *InEWP*). The bulk of the EWP code developed by ESSA Technologies Ltd. for this analysis handles these state transitions and tunnel re-operations (Figure 0-2).

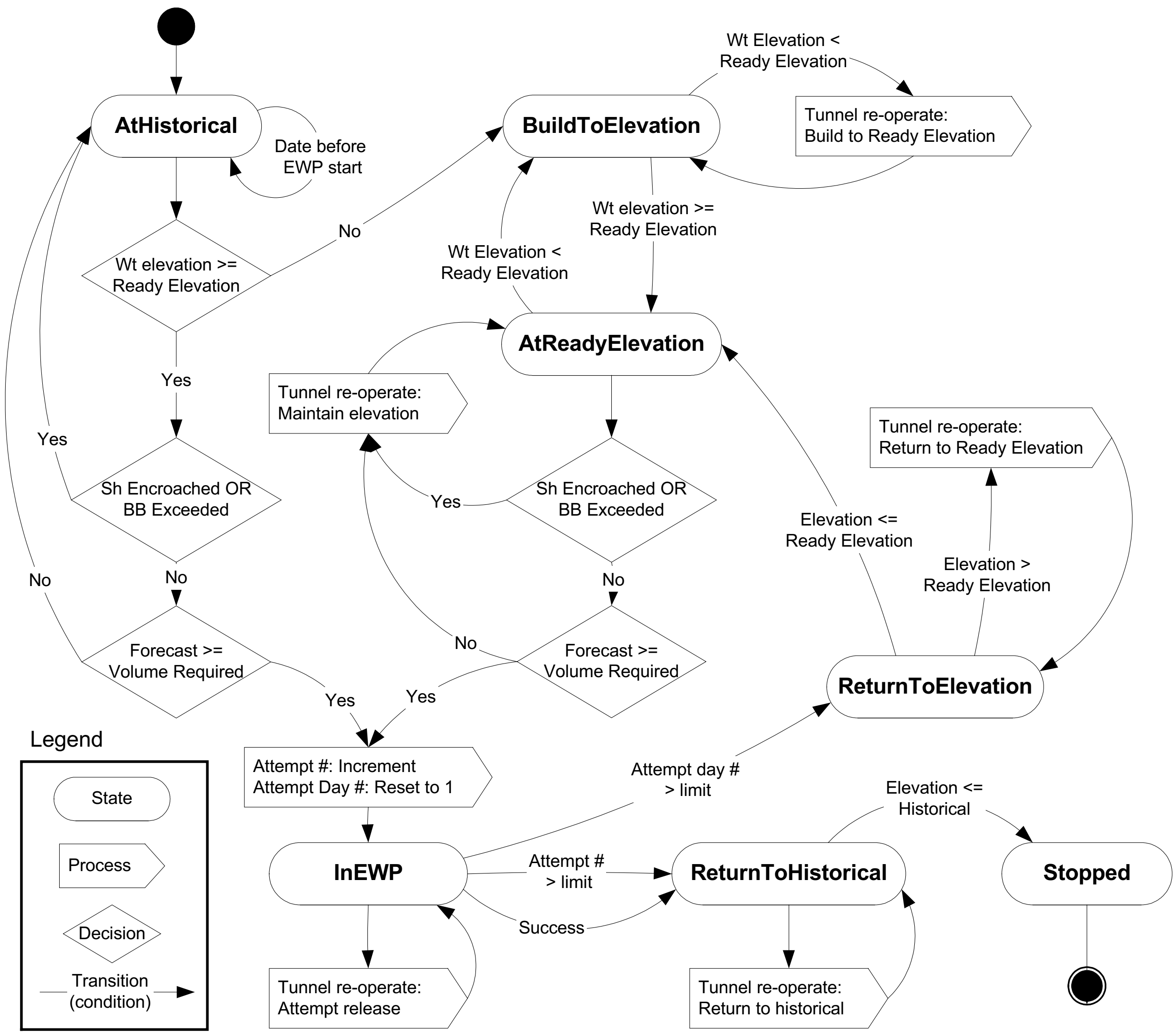


Figure 0-2. EWP algorithm for simulated WT operator behavior in response to daily reservoir elevation, daily advanced inflow forecasts and operating constraints.

0.2.2 Approximation of foregone costs

Foregone power costs are calculated at the end of each day, after any tunnel re-operation has been performed and flows calculated. The cumulative cost is also checked at the end of each day, to make sure that the cost for the year does not exceed the annual budget (e.g., $1.6 million for model ID run no's 15-22) – changing the state to *ReturnToHistorical* if exceeded. In the simulations, foregone power was calculated for all of the generators (Trinity, J.F. Carr, Spring Creek, Shasta, Keswick) except for WT outlet, which was ignored since the costs were estimated to be small and lack of definitive information about the plant.

The *Power*() function differs for each of the generators and are listed in the Technical Memorandum. The first part of the equation deals with the price shift (optional), by taking the product of the maximum yearly price possible and the marginal volume (EWP volume less historical, where negative values ("made money") is allowed) that passed through the generator.

The second part handles the power generated by the powerhouse for the given day, taking the difference between historical and modeled EWP values. The foregone power is calculated for each of the generators daily, and summed.

The set of runs performed includes two basic cases: (a) power price changes each month over the year ("shift"), and (b) where the price remains fixed ("no shift"). For the latter case ("no shift"), the first component in Eqn. 2-6 cancels out the second providing the generator capacity is not exceeded (for the J.F. Carr and Spring Creek Tunnels this is always the case as the maximum flow is equal to the generator capacity)

0.2.3 EWP performance measures

The CCDAM performance measures used to characterize EWP results were selected and defined by Reclamation in collaboration with ESSA's project team. In addition to reporting the number of EWP attempts and successes in each model run, the model also calculated:

the volume of water (acre-ft) spilled through the Glory Hole;

the estimated cost of foregone power; and

the number of EWP attempts stopped for reasons other than success.

0.2.4 Number of successful EWP releases for each CCDAM run

The key performance measure (see glossary for additional clarification of the definitions) used to evaluate performance of alternative scenarios is the number of successful EWP releases in Reach 1. To be a successful candidate re-operation scheme, the number of EWP release successes had to exceed 12 (over a 40 year record where the goal is a minimum of 3 success every 10 years). To provide a "buffer", a minimum number of 18 successes in 40 years was used. This also helps account for the fact that EWP successes are not uniformly distributed in time, giving real-world operators some flexibility to "pass" on EWP attempts in certain years even though conditions may be favorable.

From a Reach 1 EWP success count standpoint (only), the top three model runs were: (rank 1) #3-17 {3,250 ft^3/s × 1 day, spring 1,209.5 ft ready elevation}, (rank 2) #3-19 {3,250 ft^3/s × 1 day, winter 1,203.5ft ready elevation} and (rank 3) #3-16 {3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation} (Table 0-3). All three of these scenarios generated 26 or more successes in 40 years, allowing flexibility to deal with water supply changes, discretionary "spacing" of events through time, and Reclamation operational considerations. Two other scenarios passed the buffered minimum success criteria of 18 or more successes: run #3-22 {3,250 ft^3/s × 1 day, late spring 1,209.5ft ready elevation} and #3-18 {3,250 ft^3/s × 1 day, winter historical ready elevation}. Excluding consideration of flow magnitude for a moment (the most significant variable), the key factors determining success was first the reservoir ready elevation (higher the ready elevation the better) and second the season (winter more favorable than spring).

None of the 4,750 ft^3/s EWP release scenarios met the original unbuffered EWP goal of 12 successes in 40 years in Reach 1 (Table 0-3). However, results using a -5% tolerance on the 4,750 ft^3/s target (i.e., 4,512.5 ft^3/s) yielded 12 or more successes in Reach 1 for runs: #2-10/#2-12 {4,750 ft^3/s × 2 days, winter 1,203.5ft ready elevation} and #2-9/#2-11 {4,750 ft^3/s × 2 days, winter historical ready elevation} illustrating the sensitive nature of the flow target on successes.

In all cases, success counts increased if the river location used to measure success was moved downstream to Reach 5, to allow for accretion flows from Clear Creek's two major tributaries. When Reach 5 was used as the measuring point of success, one 4,750 ft^3/s target flow scenario passed the buffered success criteria of 18 or more successes – run #2-10 {4,750 ft^3/s × 2 days, winter 1,203.5ft ready elevation}.

An additional variable that is useful for 'choosing' amongst scenarios that met the buffered minimum success criteria is the average amount of water required (i.e., Average Glory Hole volume released (acre-ft) during EWP Period). Limiting the choice to the scenarios that met the buffered success goal in Reach 1, run #3-16 {3,250 ft^3/s × 1 day, spring 1,204ft ready elevation} was the best, requiring an **average** of 13,116 acre-ft of water through the Glory Hole spillway (Table 0-3). For comparison run #3-17 {3,250 ft^3/s × 1 day, spring 1,209.5ft ready elevation}, despite being best in terms of successes, on average used over twice the amount of water (26,486 acre-ft) relative to run #3-16 {3,250 ft^3/s × 1 day, spring 1,204ft ready elevation}. This highlights the dynamic nature of the interaction between seasonal water supply and operational strategy. In this case, the routine raising of the reservoir early in the spring to 1,209.5 feet leads to more aborted EWP attempts and explains the higher water use rate associated with scenario #3-17 relative to #3-16.

Table 0-3. Number of historic events (i.e., years in which target flows occurred without operator intervention) and number of successful EWP releases for CCDAM runs from 1965 to 2004. Minimum desired frequency of occurrence is 3 in 10 years, or 12 events in 40 years. The recommended *buffered* minimum success criteria is 18 or more successes in 40 years. SD = standard deviation.

	Without re-operation[δ]			With EWP re-operation						
Scenario and Model ID No. (Rank[ϕ])	No. historic events Oct-1 the year before to start EWP period	No. historic events during entire water year	No. historic events *within* EWP period	No. EWP attempts	No. Successful EWP Releases, Reach 1	No. Successful EWP Releases, Reach 1 with - 5% tolerance	No. Successful EWP Releases, Reach 5	Average Glory Hole volume released (acre-ft) during EWP Period	Average Glory Hole volume released (acre-ft) during EWP Period - 1SD	Average Glory Hole volume released (acre-ft) during EWP Period + 1SD
1-1 (14)				15	2	6	6	58,760	47,642	69,877
1-2 (17)				23	0	5	7	31,320	0	63,889
1-3 (14)				15	2	6	6	57,224	45,455	68,994
1-4 (17)				22	0	3	6	28,984	0	60,387
1-5 (17)				14	0	4	4	23,048	0	55,065
1-6 (17)				36	0	6	6	42,812	5,026	80,598
1-7 (17)	*Cannot be determined without additional dynamic, state-dependent simulations*[γ]			14	0	4	4	22,334	0	53,480
1-8 (17)				32	0	6	6	38,116	4,956	71,276
2-9 (9)				24	7	13	14	55,232	39,018	71,447
2-10 (9)				30	7	15	18	39,019	4,245	73,793
2-11 (11)				24	6	12	13	54,565	39,571	69,559
2-12 (11)				28	6	14	17	35,138	2,811	67,465
2-13 (16)				18	1	7	7	55,047	36,700	73,394
2-14 (13)				24	3	9	12	30,156	0	61,472
3-15 (6)	6	8	3	27	17	26	24	17,673	7,180	28,166
3-16 (3)	6	8	3	32	26	31	31	13,116	0	28,696
3-17 (1)	6	8	3	51	32	39	43	26,486	7,403	45,569
3-18 (5)	1	8	7	33	22	32	30	20,282	5,650	34,913
3-19 (2)	1	8	7	36	28	35	33	16,816	2,264	31,400
3-20 (8)	7	8	2	27	10	25	22	22,140	11,871	32,409
3-21 (7)	7	8	2	30	12	28	23	15,149	1,100	29,198
3-22 (4)	7	8	2	67	23	39	39	36,039	19,566	52,513

ϕ = Rank number for most successful EWP releases in reach 1. Runs with the largest number of reach 1 successes rank the highest.

δ = Number of years within which target flows occurred (one or more times) without operator intervention. This is a comparable value to the values in the "With EWP re-operation" section of the table where we limited the number of successes in Reach 1 to 1 per year (any number of days >= target number of days is still only one success for the year).

γ = Project scope and budget resources did not permit determination of these values.

0.2.5 Approximate Foregone Power Costs

Other factors must be considered in addition to the number of successes in Reach 1 (or Reach 5). One obvious criteria that was used is foregone power cost. As shown in Table 0-4 and Table 0-5, the least costly scenario, whether allowing for a price shifting assumption or not, was run #3-16 {3,250 ft^3/s × 1 day, spring 1,204ft ready elevation}, **averaging** an estimated $312,000 in foregone power costs per attempt. Using the annual results for this run, foregone power costs for successful attempts ranged from a low of $108,000 (1999) to a high of $1.38 million (2002) over the 40 water supply years simulated in the analysis.

On average, the price shifting assumption increased foregone power costs by an estimated 30.5%. Hence, using this average statistic, we would expect scenario #3-16 to on average cost $407,000 per attempt if using price shifting (potentially a more realistic scenario).

Simulation results showed that between year variation in foregone power costs were large, with one standard deviation typically in the $300,000 to $400,000 range for scenario 3. In essence, each year "tells it's own story" in terms of reservoir, tunnel, and downstream outcomes making it somewhat misleading to think too strongly in "average" terms. Furthermore, through inspection of unsuccessful events associated with scenario #3-16, it can be shown that the $312,000 to $407,000 foregone power costs are artificially high. For reasons outlined in the Technical Memorandum, an average expected foregone power estimate of **$200,000 to $300,000** is likely a conservative **average** foregone power cost associated with run #3-16 rules.

Table 0-4 Approximate foregone power costs for CCDAM runs from 1965 to 2004. SD = standard deviation. Note: price shift cases were not evaluated for scenario 3.

	Without price shift			With price shift		
Scenario and Model ID No. (Rank$^{\phi}$)	**Average foregone power cost, $ thousands**	**Foregone power cost - 1SD, $ thousands**	**Foregone power cost + 1SD, $ thousands**	**Average foregone power cost, $ thousands**	**Foregone power cost - 1SD, $ thousands**	**Foregone power cost + 1SD, $ thousands**
1-1 (14)	1,221.03	522.32	1,919.73			
1-2 (10)	758.34	-4.67	1,521.34			
1-3				1,200.03	-801.72	3,201.79
1-4				1,037.80	-226.48	2,302.07
1-5 (5)	428.45	-281.97	1,138.86			
1-6 (13)	1,090.35	144.59	2,036.11			
1-7				481.65	-891.24	1,854.53
1-8				1,262.90	52.80	2,473.00
2-9 (15)	1,241.65	802.32	1,680.99			
2-10 (11)	864.29	90.28	1,638.30			
2-11				1,991.59	800.71	3,182.48
2-12				1,342.59	-345.75	3,030.92
2-13 (16)	1,248.28	775.71	1,720.85			
2-14 (9)	736.99	-54.99	1,528.98			
3-15 (6)	443.39	184.70	702.09			

Scenario and Model ID No. (Rank[ϕ])	Without price shift			With price shift		
	Average foregone power cost, $ thousands	Foregone power cost - 1SD, $ thousands	Foregone power cost + 1SD, $ thousands	Average foregone power cost, $ thousands	Foregone power cost - 1SD, $ thousands	Foregone power cost + 1SD, $ thousands
3-16 (1)	312.52	7.88	617.15			
3-17 (8)	615.41	219.71	1,011.12			
3-18 (4)	404.90	155.14	654.65			
3-19 (2)	336.45	53.62	619.28			
3-20 (7)	560.70	297.70	823.69			
3-21 (3)	355.53	-47.46	758.52			
3-22 (12)	897.51	479.74	1,315.28			

[ϕ] = Rank number for lowest cost of CCDAM run (based on the no price shift case, using the average multi-year cost). Runs with the lowest cost rank the highest.

Table 0-5. Approximate foregone power costs for CCDAM runs from 1965 to 2004 (negative foregone power amounts greater than -$500K considered to be model artifacts and treated as null). SD = standard deviation. Note: price shift cases were not evaluated for scenario 3.

Scenario and Model ID No. (Rank[ϕ])	Without price shift			With price shift		
	Average foregone power cost, $ thousands	Foregone power cost + 1SD, $ thousands	Foregone power cost - 1SD, $ thousands	Average foregone power cost, $ thousands	Foregone power cost - 1SD, $ thousands	Foregone power cost + 1SD, $ thousands
1-1 (14)	1,358.24	887.47	1,829.00			
1-2 (10)	758.34	-4.67	1,521.34			
1-3				1,844.49	873.44	2,815.53
1-4				1,198.28	22.76	2,373.81
1-5 (5)	428.45	-281.97	1,138.86			
1-6 (13)	1,090.35	144.59	2,036.11			
1-7				732.00	-329.40	1,793.40
1-8				1,329.86	181.46	2,478.26
2-9 (15)	1,241.65	802.32	1,680.99			
2-10 (11)	864.29	90.28	1,638.30			
2-11				2,105.19	1,028.67	3,181.71
2-12				1,582.69	78.33	3,087.05
2-13 (16)	1,248.28	775.71	1,720.85			
2-14 (9)	736.99	-54.99	1,528.98			
3-15 (6)	443.39	184.70	702.09			
3-16 (1)	312.52	7.88	617.15			
3-17 (8)	615.41	219.71	1011.12			

Scenario and Model ID No. (Rank$^{\phi}$)	Without price shift: Average foregone power cost, $ thousands	Without price shift: Foregone power cost + 1SD, $ thousands	Without price shift: Foregone power cost - 1SD, $ thousands	With price shift: Average foregone power cost, $ thousands	With price shift: Foregone power cost - 1SD, $ thousands	With price shift: Foregone power cost + 1SD, $ thousands
3-18 (4)	404.90	155.14	654.65			
3-19 (2)	336.45	53.62	619.28			
3-20 (7)	560.70	297.70	823.69			
3-21 (3)	385.59	25.61	745.57			
3-22 (12)	897.51	479.74	1315.28			

$^{\phi}$ = Rank number for lowest cost of CCDAM runs (based on the no price shift case, using the average multi-year cost). Runs with the lowest cost rank the highest.

0.2.6 Failure characteristics

Another factor that must be considered in addition to the number of successes and foregone power costs is the failure characteristics of the different scenarios. These properties help evaluate the odds of starting an attempt that ultimately leads to termination due to lower Clear Creek safety considerations, insufficient water, or excessive cost. Considering the 40 years of simulation per scenario and stopping conditions ‘A’, ‘B’ and ‘C’ in Table 0-6 (see glossary for definitions), the worst performing run was stopped as many as 31 times in 40 years (#3-22 {3,250 $ft^3/s \times 1$ day, late spring 1,209.5ft ready elevation}) while the best was stopped only 5 times in 40 years (#3-16 {3,250 $ft^3/s \times 1$ day, spring 1,204ft ready elevation}). The fact that run #3-22 (1,209.5ft ready elevation) has more stops than run #3-21 (1,204 ft ready elevation) is explained by the fact that a 1,209.5 ft ready elevation typically leads to 2 attempts per year rather than 1 just attempt per year. Inspecting individual year results reveals that in poor water supply years, this nearly doubled the level of false positives for run #3-22.

In summary, given success count rankings, foregone power rankings and now failure characteristic rankings, the overall best scenario was run #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204ft ready elevation).

Given the premium placed on human and property safety, it is likely that any run that generates 2 or more stops in 40 years due to excessive lower Clear Creek flows (9,100 ft^3/s in Reach 5) would be ruled out of contention. This is in some respects an issue of risk tolerance – events that are over 9,100 ft^3/s by a small margin versus those well over this value would be interpreted differently, and need to be evaluated on a case by case basis. The scenario 3 run variants, both the winter runs (#3-18 and #3-19) experience 2 stops in 40 years due to excessive lower Clear Creek flow (Table 0-6).

Table 0-6 “Failure” or “stop” properties for CCDAM runs from 1965 to 2004.

Scenario and Model ID No.	No. EWP attempts	No. Successful EWP Releases, Reach 1	A) No. stopped due to excessive lower Clear Creek flow (and rank$^{\phi}$)	B) No. stopped due to insufficient water (and rank)	C) No. stopped due to cost (and rank)	Total No. of stops, A+B+C (and rank)

1-1	15	2	1 (12)	12 (8)	0 (1)	13 (4)
1-2	23	0	1 (12)	15 (16)	1 (13)	17 (13)
1-3	15	2	1 (12)	10 (4)	3 (15)	14 (6)
1-4	22	0	1 (12)	11 (6)	7 (18)	19 (17)
1-5	14	0	0 (1)	14 (11)	0 (1)	14 (6)
1-6	36	0	0 (1)	21 (22)	0 (1)	21 (19)
1-7	14	0	0 (1)	12 (8)	6 (17)	18 (16)
1-8	32	0	0 (1)	16 (18)	13 (21)	29 (21)
2-9	24	7	3 (21)	14 (11)	0 (1)	17 (13)
2-10	30	7	1 (12)	15 (16)	0 (1)	16 (10)
2-11	24	6	3 (21)	14 (11)	3 (15)	20 (18)
2-12	28	6	1 (12)	13 (10)	10 (20)	24 (20)
2-13	18	1	0 (1)	14 (11)	0 (1)	14 (6)
2-14	24	3	1 (12)	14 (11)	1 (13)	16 (10)
3-15	27	17	0 (1)	10 (4)	0 (1)	10 (3)
3-16	33	25	1 (12)	4 (1)	0 (1)	5 (1)
3-17	51	32	0 (1)	7 (2)	7 (18)	14 (6)
3-18	33	22	2 (19)	11 (6)	0 (1)	13 (4)
3-19	36	28	2 (19)	7 (2)	0 (1)	9 (2)
3-20	27	10	0 (1)	17 (21)	0 (1)	17 (13)
3-21	30	12	0 (1)	16 (18)	0 (1)	16 (10)
3-22	67	23	0 (1)	16 (18)	15 (22)	31 (22)

0.2.7 Successful examples within year daily results for the top performing model run (#3-16)

Figure 0-3 and Figure 0-4 illustrate CCDAM DOHPLR output of the daily consequences of a simulated EWP re-operation (run #3-16) in 2003 leading to a success. Other years are described in the body of the report and daily results for all 40 years for all simulated scenarios can be obtained from ftp://ftp.essa.com/pub/essa/EWP/ ("EWP_DetailedDailyResults.zip"). Given the state-dependent 'if then' nature of simulated re-operations, every year tells it's "own story", making it difficult to describe a 'typical' success. However, the year shown below (2003) is considered adequately representative of the type of re-operation that can be expected under scenario #3-16.

Figure 0-5 provides the 40 year daily pattern of Reach 1 and Reach 5 flows associated with re-operations under the top performing run #3-16. From the Reach 1 plot (top panel in Figure 0-5), it is clear that the re-operation dramatically increases the incidence of EWP successes.

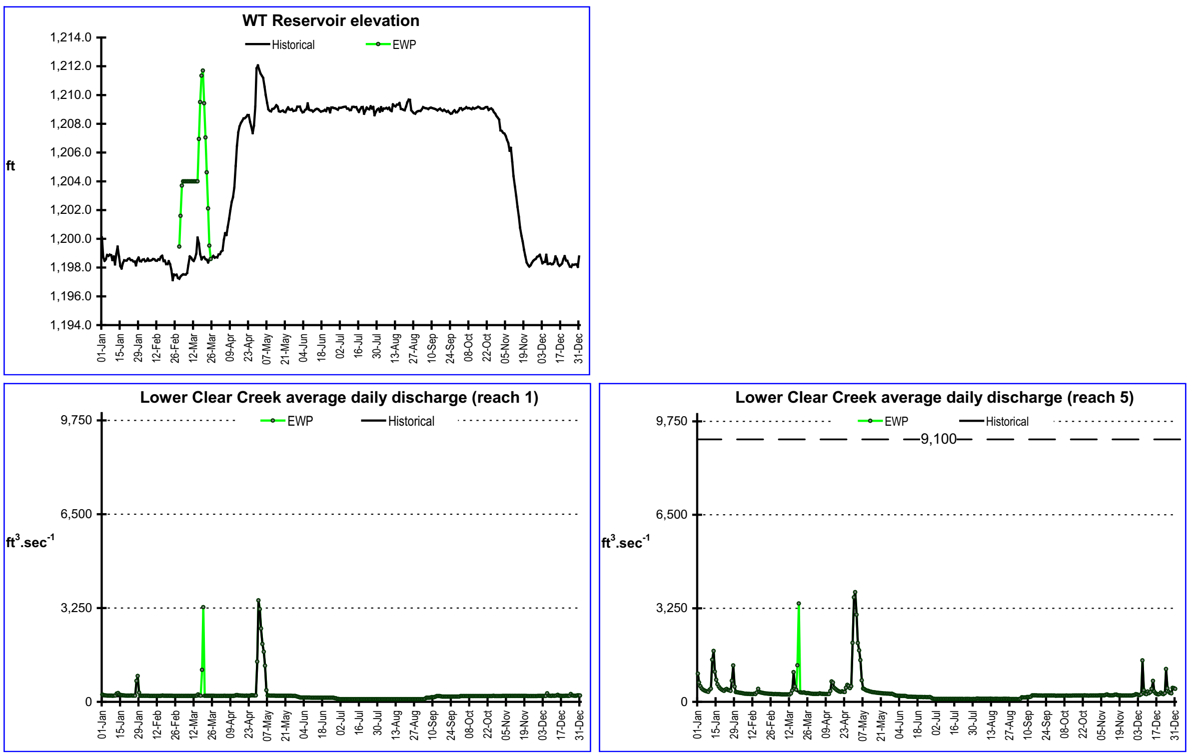


Figure 0-3. Daily results for year **2003**, scenario #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204ft ready elevation) showing a successful Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #3-16 re-operation; Historical = outcome without re-operation, based on historical operating decisions. Note: the EWP operator in this example (as would be the case with a real-world operator) is unaware of the future event that would occur without re-operation.

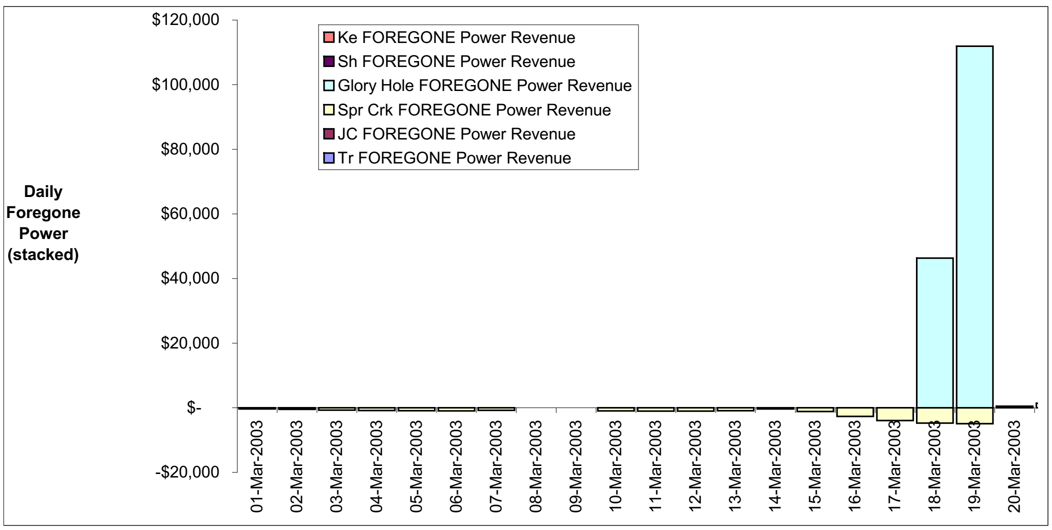


Figure 0-4. Daily foregone power approximation for year **2003**, scenario #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204ft ready elevation) associated with WT Reservoir re-operation. Of the total cumulative foregone power for this event ($131,838), the majority of it occurs on two days in which the water is spilling through WT Glory Hole. This water is not available to flow through either Spring Creek or Keswick power plants.

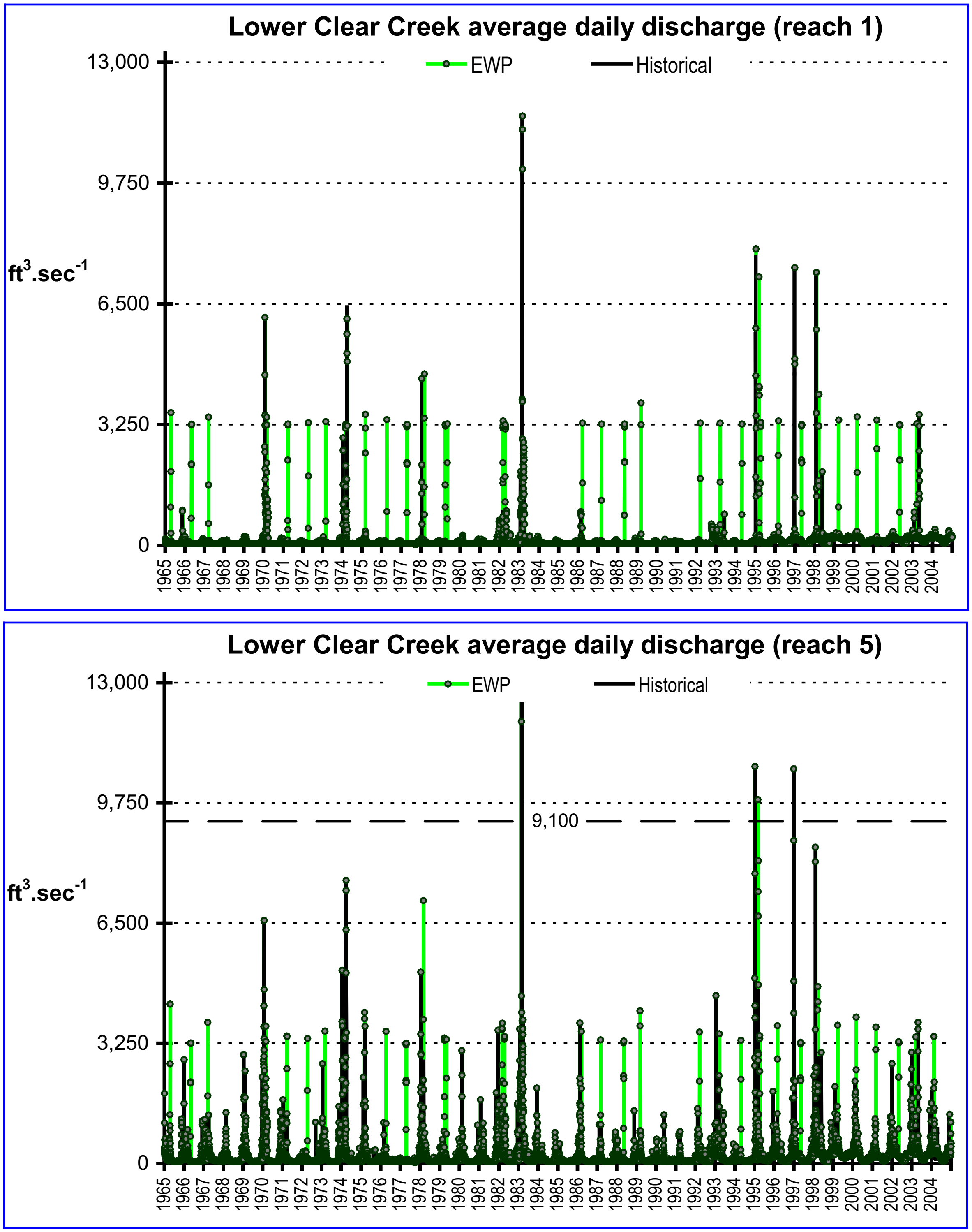


Figure 0-5. Multi-year (1965 to 2004) summary of EWP re-operation outcomes using model run #3-16 (3,250 ft^3/s × 1 day, spring 1,204ft ready elevation) vs. existing historical operations for lower Clear Creek Reach 1 (top panel) and Reach 5 (bottom panel).

0.3. Consequences

0.3.1 Population at risk

The population at risk (PAR) downstream of Whiskeytown Dam consists of persons at the Peltier Bridge camps, the NEED camp, southern Redding, Anderson, Red Bluff, Gerber, Los Molinos/Tehama, and other persons at risk further downstream. In regard to hydrologic failure scenarios, heightened surveillance will be typically undertaken at a Reclamation dam, and onsite inspection will likely occur around the clock. This anticipated surveillance and detection likelihood makes it likely that the dam will be attended and any threats to the structure noted quickly.

The PAR assuming higher flows due to the re-operation of the dam would be significantly less than flows from a dam failure. The population at risk ranges for static, seismic, and hydrologic failure scenarios are shown in Table 0-7, which summarizes the loss of life estimates that were developed using Reclamation's current methodology, Bureau of Reclamation (1999), for the various failure scenarios.

Table 0-7. Loss of Life Estimates

Failure Scenario	Range	Mean
Static Failure Modes		
Zone 1 into Zone 3 or 4	54-369	199
Zone 1 into Foundation	54-369	199
Seismic Failure Modes		
Seismic	54-369	199
Hydrologic Failure Modes		
Overtopping PMF	12-130	69
Piping during PMF	12-130	69

Table 0-8 shows the details for the development of the loss of life due to a hydrologic failure mode for a dam failure and breach condition.

Table 0-8. Loss of life for a dam failure and breach condition during a hydrologic event (from 2006 Decision Document and Report of Findings)

Reach	Severity	Warning	Under-standing	PAR	Fatality Rate L,M,H	Fatalities L,M,H	Mean
Peltier Bridge Primitive Camp	H*	>60 min	Vague	0	.3,.75,1.0	0,0,0	0
NEED Camp at Paige Bar	H	>60 min	Vague	0	.3,.75,1.0	0,0,0	0
Southern Redding	L to M	>60 min	Vague	1,100	0.003, 0.015, 0.03	3,17,33	18
Anderson	L to M	>60 min	Precise	9,130	0.001,0.005, 0.01	9,46,91	49
Red Bluff	L	>60 min	Precise	8,470	0,.0002,.0004	0,2,3	2
Gerber	L	>60 min	Precise	1,050	0,.0002,.0004	0,0,0	0
Los Molinos/Tehama	L	>60 min	Precise	1,880	0,.0002,.0004	0,0,1	0
Further Downstream	L	>60 min	Precise	5,480	0,.0002,.0004	0,1,2	1
Total						12,66,130	69

L = Low, M = Medium, H = High

0.4. Failure modes

The failure modes for Whiskeytown Dam include the static, seismic, and hydrologic loading conditions. The reoperation of the dam mainly impacts the hydrologic risk. The potential hydrologic failure modes are overtopping and breach of the dam or dike during a large flood event which causes the dam or dike to overtop and piping of the embankment due to the higher reservoir water surface elevation. The dam is overtopped during a Probable Maximum Flood (PMF) event by 3.6 feet for approximately 40 hours. This overtopping is expected to lead to breach and dam failure. The hydrologic risk results for the existing baseline condition (current) were developed in a 2006 Issue Evaluation and are shown in Table 0-9.

Table 0-9. Summary of Expected Hydrologic Risks from 2006 Issue Evaluation Study (refer to

Failure Mode	Expected Annual Probability of Failure	Life Loss	Expected Annualized Loss of Life
Static – Zone 1 into Zone 3	1.1E-06	199	2.2E-04
Static – Zone 1 into Foundation	7.0E-07	199	1.4E-04
Static Total	**1.8E-06**	**199**	**3.6E-04**
Seismic Total	**2.0E-07**	**199**	**4.0E-05**
Overtopping Dam/Dike Failure	1.2E-4 (1E-4 – 1.3E-4)	69 (12 – 130)	8.1E-3 (1.2E-3 – 1.7E-2)
Piping of the dam during the PMF	2.0E-6 (7E-7 – 5.0E-64)	69 (12 – 130)	1.4E-4 (8.4E-6 – 6.5E-4)
Hydrologic Total	**1.2E-4** **(1.01E-4 – 1.35E-4)**	**69** **(12 – 130)**	**8.2E-3** **(1.2E-3 – 1.8E-2)**

0.4.1 Summary of risks posed during re-operation

The maximum difference in water surface for different beginning water surface elevations is approximately 0.05 foot (≈5/8 inch) using all beginning reservoir water surfaces for all floods greater than the 100-year return period flood. From this it does not appear that there are any significant increases in the maximum water surface due to these floods for the overtopping potential assuming the spillway does not fail. It does not appear that there is any significant increase in the potential risk of dam overtopping caused by the proposed EWP re-operation based on these numbers.

The peak outflow downstream of the dam depends on the initial reservoir water surface, peak inflow, and shape of the hydrograph. The maximum outflow for a constant 10,000 ft^3/s hydrograph with a beginning reservoir water surface elevation of 1,210 is about 4,000 ft^3/s but the maximum outflow using an assortment of various shaped hydrographs ranged from about 7,660 ft^3/s to about 7,900 ft^3/s. The difference involves nearly 100 percent variation. The outflow from the routings with a beginning reservoir water surface elevation of 1,212 ft was about 6,560 ft^3/s for a constant hydrograph and ranged from about 9,000 ft^3/s to 9,300 ft^3/s for the various shaped hydrographs.

The shape of the hydrograph during an EWP will have a great deal of impact on the outflow, which is directly related to the maximum water surface during the flood event. The peak **hourly** outflows will likely be higher than predicted by the CCDAM DOHPLR submodel and may be as high as double the daily average predicted in the downstream reaches (26% to 60% greater flows in reach 5 than the daily average flow immediately below the dam). The potential variation in outflows is significant from a dam safety perspective when considering the maximum reservoir water surface for the risk analysis and when considering the downstream public risks. The outflow and downstream risks show the importance of determining potential downstream flooding thresholds between the dam and Redding CA and impacts on the downstream channel.

There are increases in the Annual Failure Probability (APF) for the potential internal erosion failure modes due to the increase in percent of time the reservoir water surface is above elevation 1,210 ft but below the top of the dam. These are discussed below.

Dam safety risk analysis calculations were performed for existing conditions and with both the spring and winter EWP re-operation scenarios. Two methods were used to estimate the total hydrologic risk: a hydrologic event tree or a combination of a hydrologic event tree and an internal erosion event tree. The hydrologic loadings were divided into eight branches representing the various loading conditions from the yearly flood up through the 50,000-year return period flood. Flood routings were performed to determine an estimated maximum reservoir water surface for a one-day hydrograph. The response of the structure was estimated when the water surfaces elevations were between 1210 to 1215 feet, 1215 to 1221 feet, 1221 to 1229 feet, and 1229 to 1232 feet. The ranges represent the increase in piping potential for experienced reservoir water surfaces, for first filling conditions, for reservoir water surface elevations between maximum design and top of dam, and overtopping. The AFP was computed using elevation 1198 for the existing condition, initial reservoir water surface elevations 1198, 1203.5, and 1209 for the spring scenario, and for initial reservoir water surface elevations 1198 and 1203.5 for the winter scenarios.

Due to the differences in methodology in computing the risk associated with the dam, the AFP and Annualized Loss of Life (ALOL) are different than computed in the 2006 Risk Analysis. The details for the computations are included in the Technical Memorandum and summarized in Table 0-10. The risk analysis using the hydrologic event tree (2007a) showed an increase for both the APF and the ALL while the risk analysis (2007b) with a hydrologic event tree and an internal erosion event tree showed a minor decrease in the APF and a slightly larger decrease in the ALL.

The selected EWP re-operation scenarios (#3-16, #3-15, #3-17, #3.18 and #3-19) show there is the potential for an increase in the total hydrological risk. The static and seismic risks did not change for this analysis. Reclamation is concerned that the existing total hydrologic risk at Whiskeytown Dam are above Reclamation guidelines. Reclamation is currently re-evaluating the hydrologic probability of loading for Whiskeytown Dam. The results of this evaluation are expected to be completed within the next six months.

Table 0-10 Dam Safety Risks based existing 2006 IE conditions, a revised operation using the hydrologic event tree only (2007a), and a revised operation using both hydrologic and internal erosion event trees.

Loading Condition	Expected Annual Probability of Failure (range)	Expected Consequences Loss of Life (range)	Expected Annual Loss of Life (range)
Total Static – 2006 IE	1.80E-06	199	3.58E-04
Total Seismic – 2006 IE	2.00E-07	199	3.98E-05
Total Hydrologic – 2006 IE	1.19E-04	69	8.215E-03
Revised Total Hydrologic – 2007a	1.18E-04	69	8.14E-03
#3-16 Spring 1204 Ready – 2007a	1.25E-04	69	8.59E-03
#3-15 Spring 1198 Ready – 2007a	1.21E-04	69	8.31E-03
#3-17 Spring 1209 Ready – 2007a	1.30E-04	69	8.94E-03
#3-18 Winter 1198 Ready – 2007a	1.26E-04	69	8.68E-03
Revised Total Hydrologic – 2007b	8.89E-05	69	6.14E-03
#3-16 Spring 1204 Ready – 2007b	8.85E-05	69	6.11E-03
#3-15 Spring 1198 Ready – 2007b	8.85E-05	69	6.11E-03
#3-17 Spring 1209 Ready – 2007b	8.78E-05	69	6.06E-03
#3-18 Winter 1198 Ready – 2007b	8.56E-05	69	5.91E-03

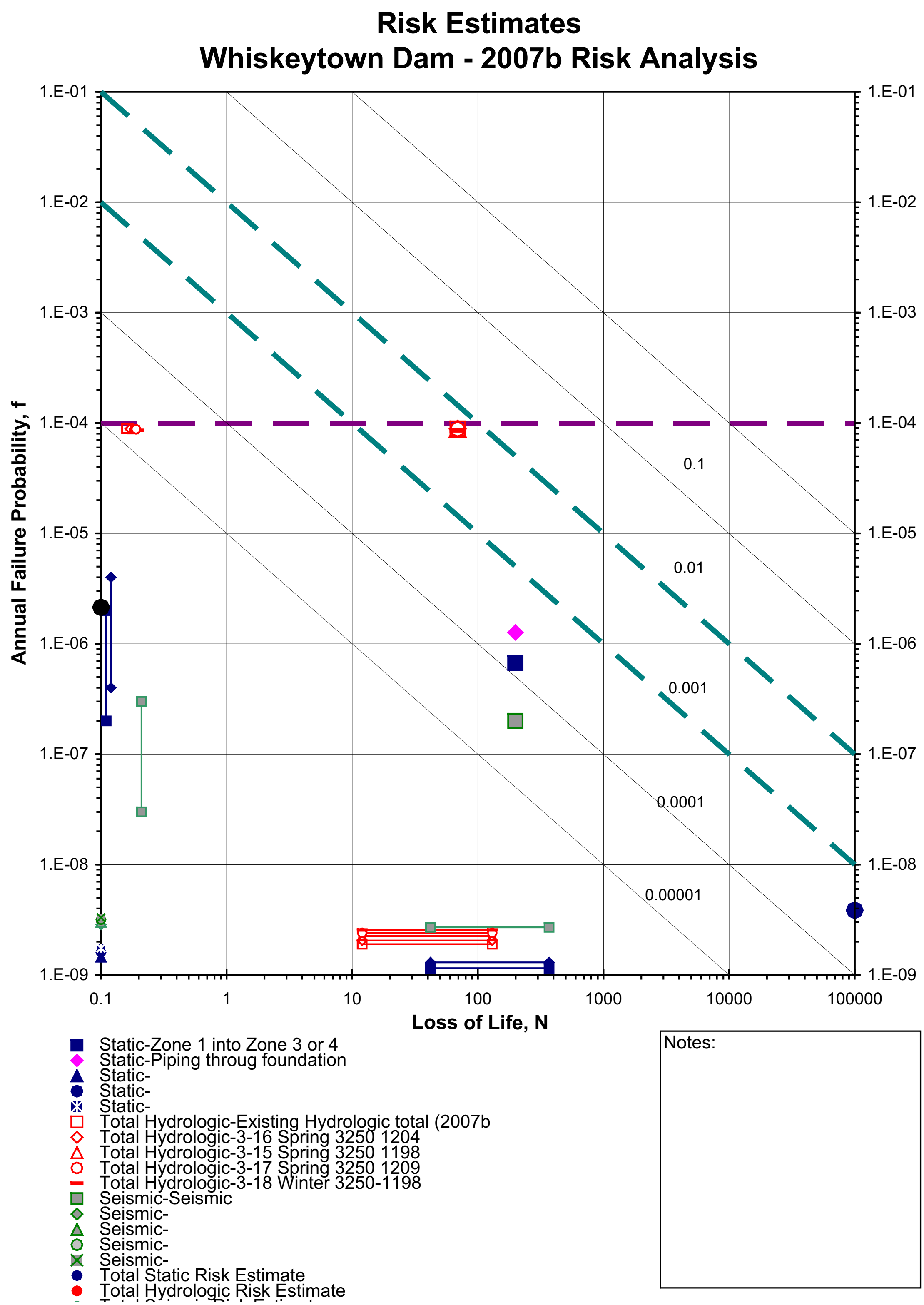


Figure 0-6. Plot of dam safety risks for Whiskeytown Dam.

0.4.2 Operational issues

There is a high probability of setting a new higher maximum historical reservoir water surface elevation during years in the trial period for an EWP release. The peak outflows during an EWP event may be larger than predicted by the CCDAM model, and increase the risk to the dam. The increased maximum water surface for the reservoir will increase the time the reservoir is above historical water surface elevations and also puts the reservoir into a first filling mode. A first filling mode has a higher potential annual probability failure. However, the risks do not pose any significant changes to the safety issues at the dam which would justify rejecting the pilot program proposal. The peak outflows should be compared to any downstream flood threshold and downstream channel impacts. It is estimated that the safe downstream channel capacity is approximately 14,000 ft^3/s based on preliminary studies by Graham Matthews and Associates (Graham Matthews and Associates 2003, 2004, 2005).

The dam safety risks posed between the winter and spring starting elevation are approximately the same, however they may have different operational impacts. Both the winter and spring scenarios have about the same number of days that the predicted reservoir water surface elevation is above elevation 1210. Downstream accretion and instantaneous peak flow risks associated with winter scenarios are expected to be considerably higher than for spring scenarios. Further, the winter scenarios are not considered preferred due to the following intangible factors: the number of days the scenario lasts and impacts the daily operations of Reclamations Central Valley Operations and the number of Reclamation staff on site that will be involved at the various facilities.

0.4.3 Implementation plan

An implementation plan will need to be fully developed prior to on the ground implementation of the pilot program. The U.S. Fish and Wildlife Service will be the lead agency in the development of the implementation plan. Performance measures will be used to evaluate the Pilot Program upon its completion. Some areas of concern for Reclamation need to include:

- Assignment of final authority to attempt and or abort an EWP release (may be a dual decision)
- Impacts to Reclamation daily operations
- Coordination issues with power costumers, irrigation districts, and other stake holders
- Decision mechanism to authorize the EWP attempt

Pilot implementation of EWP operations involves having the mechanism in place to authorize individual EWP attempts and to determine program effectiveness. For example, there are no rain gages upstream of the dam in the Whiskeytown basin. The desired release of 3,250 ft^3/s can nearly be obtained mechanically by increasing the Clear Creek Tunnel to a maximum and closing the Spring Creek Tunnel to a minimum. However, the duration of this filling operation to surcharge the reservoir and achieve equilibrium at the desired outflows will involve higher water volumes. To achieve maximum efficiency it is desired to initiate an EWP attempt at a time when rainfall is occurring or anticipated to fall on the basin. This additional amount of inflow would fill the reservoir more quickly than tunnel diversion flows alone. This requires an approach to inflow forecasting that will involve discussions and analyses by personnel at various

Reclamation facilities. The 5-day multiple regression approach developed for the CCDAM DOHPLR submodel could serve as a helpful starting point.

An in-season operational mechanism will have to be developed to determine when the EWP release attempt is made. In the DOHPLR submodel the attempt is based on estimating rainfall and volumes from the five prior days. Hence, on an in-season basis this would also require the operational forces to review these records daily and make the decision to attempt or pass on the attempt according to a decision algorithm resembling Figure 2-9.

Additional attention to flows and rainfalls would probably be required by Reclamation staff during the EWP attempt to avoid larger than needed flows. This could involve an hourly review to determine how the attempt is going and a status evaluation to initiate, terminate, or to continue the attempt (e.g., building on the stopping and other 'if then' rules included in the CCDAM DOHPLR simulations).

After an attempt was made there has to be some type of review to determine the implementation costs and impacts on other ongoing tasks. The issues associated with water delivery and power production will also require additional efforts during an EWP attempt. The cost and contractual impacts of the loss of power production would have to be determined, the replacement power obtained if operation falls below contracted values. Coordination with the power producers would be required. An accounting of the amount of water and cost to power and additional Reclamation costs would have to be determined after each attempt.

Should EWP releases be implemented on a pilot basis, the time involvement by Reclamation staff is expected to vary dramatically depending on the water year type, the EWP ready elevation, operation of Trinity, J.F. Carr Tunnel, WT Dam, and the Spring Creek Tunnel, and selected scenarios and their respective time periods.

The following are the items which need to be addressed prior to on-the-ground implementation of the pilot program for an EWP attempt:

- Implementation plans coordinated by the USFWS discussed with Reclamation
- Re-evaluation of the hydrologic risk based on hydrology data being collected at this time and to be analyzed by Reclamation (Completion expected within 6 to 9 months)
- Discussions with USFWS should be clear as to who holds final authority to attempt or abort an EWP release
- Determine length of Pilot Program in years (presently 10), number of attempts, or cumulative cost
- Set up in-season operational rules and plans (building on decision algorithm in CCDAM DOHPLR submodel)
- Determine the need for a WT Reservoir inflow forecasting model (e.g., use the model embedded in CCDAM DOHPLR or an as yet developed alternative)
- Hold additional discussions with water users and irrigation districts
- Hold discussions with power customers and power regulators
- After each EWP attempt:

evaluate and prepare plans to mitigate impacts to irrigation districts

evaluate and prepare plans to mitigate impacts to power customers

evaluate and prepare plans to mitigate manpower needs during an EWP attempt

estimate cost to prepare accounting report of EWP attempt

Determined associated costs for above tasks

Ensure a biological and geomorphic effectiveness monitoring plan is in place prior to the first event.

0.4.4 Outstanding SOD recommendation

The following SOD recommendation exists irrespective of the disposition of the contemplated pilot EWP re-operation.

2005-SOD-A Initiate a Corrective Action Study (CAS) to evaluate risk reduction alternatives and prepare a Modification Report.

This work is underway with additional hydrologic studies to define the hydrologic loadings and feasibility designs.

0.5. Conclusions

It is possible to achieve an EWP release at Whiskeytown Dam (WT Dam) by re-operation of Whiskeytown Dam. The most successful re-operation in terms of greatest number of successes, lowest volume, and least foregone power costs is scenario #3-16. This involves a release of 3,250 ft^3/s for 1 day between March 1 and May 15 and with a starting reservoir water surface elevation on March 1 of elevation 1204. Achieving the EWP success will potentially require Reclamation to jointly operate Trinity Dam, J.F. Carr Tunnel, J.F. Carr Power Plant, Whiskeytown Dam, Spring Creek Tunnel, Spring Creek Power Plant, and Keswick Dam.

Based on an integration of success count rankings, foregone power rankings and rankings for failure characteristics, model run #3-16 is the best scenario (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation) for re-operation.

This scenario has a risk for both the APF and the ALL which are above the existing risk. The *existing* dam safety risks are currently above Reclamation guidelines. This risk may increase slightly based on the #3-16 EWP re-operation. The uncertainty with regard to these estimated risks are expected to be improved with the completion of the additional hydrologic study. The uncertainty warrants additional study during real-world implementation. Key factors that lead to this conclusion are:

The dam will be exposed to higher reservoir water surfaces

The dam is expected to fall into a first filling mode due to the re-operation

Table of Contents

List of Figures

List of Tables

Glossary

ALL	Annualized Loss of Life
APF	Annual Probability of Failure
CAS	Corrective Action Study
CBDA	California Bay Delta Authority
CCDAM	Clear Creek Decision Analysis and Adaptive Management Model
CCDAM run	Simulation of reservoir behavior using CCDAM over a 40 year period with predefined EWP flow and duration targets, start and end dates, and other related parameters
CCRT	Clear Creek Restoration Team
CFR	Comprehensive Facility Review
DOHPLR	Dam Operations and Hydrology Power and Lake Recreation submodel of the overall CCDAM simulation model. Note: in parts of this document, CCDAM is used interchangeably with DOHPLR. Given the context of this study, a reference to the "CCDAM" model should be interpreted only as application of one of its four submodels, DOHPLR
EAP	Emergency Action Plan
ERP	CalFed / California Bay Delta Authority Ecosystem Restoration Program
EWP	California Bay Delta Authority Environmental Water Program
EWP attempt	Days during which the CCDAM attempts to make an environmental release from Whiskeytown Reservoir
EWP attempt window	Days during which model is in InEWP state +2 additional days for 3-day scenarios, +1 additional day for 2 day scenarios; additional days included to account for residual hydrological effects; additional days were not included for 1-day scenarios
EWP period	Timeframe of a CCDAM model run within which the DOHPLR submodel evaluates whether to attempt an EWP release, e.g., March 1 - May 15
Foregone power	Power lost due to EWP activity (e.g., EWP Attempt, operator intervention to build reservoir levels to non-historical ready elevation), expressed in the model as year 2005 dollars
Historical success (or event)	Flows that are >= target flows for the required number of days (as defined by each CCDAM run) without operator intervention

IE	Issue Evaluation
InEWP	A CCDAM simulation state in which the DOHPLR submodel modifies historical Whiskeytown Reservoir tunnel operations in an effort to generate a semi-controlled Glory Hole discharge
PMF	Probable Maximum Flood
Reach 1	The first, most upstream of 5 channel segments along Clear Creek in the CCDAM DOHPLR submodel starting at the base of Whiskeytown Dam. The first measured flow after Whiskeytown Dam before the input of any tributary flow, equal to the flow out of the Whiskeytown outlet plus any Glory Hole discharge
Reach 5	The last, most downstream of 5 channel segments in the CCDAM DOHPLR submodel that joins the Sacramento River
Ready elevation	A EWP parameter which defines the elevation that Whiskeytown is raised to prior to attempting a release, to increase the probability of a success. Note: if the historical elevation is higher, this is used instead
Scenario	A set of CCDAM runs that share the same general parameter values, e.g., EWP targets of 4,750 ft^3/s for 2 days
SOD	Safety of Dams
Stop conditions	Conditions under which the DOHPLR submodel stops an EWP attempt, i.e., Lower Clear Creek (Reach 5) flows that exceed a predefined tolerance limit, excessive foregone power cost, continuous days without success (i.e., insufficient water); an EWP Attempt is also stopped when there has been a successful EWP Release
Successful EWP release	Requisite number of days during EWP attempt window with flows >= target flows (i.e., a successful EWP Attempt), e.g., 3 days for 3-day scenario; even if flows >= target occur for more than the required number of days, this still counts as a single EWP Release. Note: days >= target flow **do not** have to be contiguous, just >= target for requisite number of days within EWP attempt window
TSC	Technical Services Center, US Bureau of Reclamation, Denver
WT	Whiskeytown Dam
FWS	U.S. Fish and Wildlife Service

1. Introduction

1.1. General project

Clear Creek has been cited as an excellent candidate stream for flow augmentation to achieve several of the objectives of the California Bay Delta Authority (CBDA) Ecosystem Restoration Program (CALFED 2002; Kimmerer et al. 2002; Stillwater Sciences 2003). Recent multi-agency collaborative restoration efforts in Clear Creek have identified a requirement for the release of periodic higher flows to improve aquatic and riparian habitats, but dam operations have significantly reduced the frequency of mid-range flood flows that are essential for forming and maintaining channel and floodplain morphologies on which these habitats and native biota depend. To increase and sustain the value of other recent restoration activities undertaken by the local Clear Creek Restoration Team (CCRT) whilst balancing socioeconomic considerations and to advance understanding of the science underlying channel-forming and maintenance flow events, a 10-year pilot program has been proposed to deliver the water into the Clear Creek. An evaluation of the pilot program, as described in the report, was completed by U. S. Fish and Wildlife (FWS) Staff, ESSA Technologies, and the Bureau of Reclamation staff in 2007.

The specific objectives of this program are to attempt to reliably and safely create EWP target flows from Whiskeytown Dam between 3,250 ft^3/s and 6,000 ft^3/s for a 1-day duration occurring on average once every two to three years. Part of the program is to evaluate the feasibility, risks, and foregone power revenues posed by such pilot operations.

This is a multiple partner, multi-year study prepared for the U.S. Fish and Wildlife Service (USFSW) with input and review by FWS staff, Reclamation and ESSA Technologies Ltd., Canada. Team members involved in the preparation and review of this report (alphabetical) include:

Diana Abraham, ESSA Technologies Ltd.
*Clint Alexander, ESSA Technologies Ltd.
Don Bader, NCAO Redding, CA
Matt Brown, USFWS
Kenneth Bullard, TSC Denver, CO
David Carr, ESSA Technologies Ltd.
*Elisabeth Cohen, TSC Denver, CO
Jim DeStaso, NCAO Redding, CA
Gary Egan, DSO Sacramento, CA
Paul Fujitani, CVO Sacramento, CA
Joan Goodwin, DSO Sacramento, CA
Roger Guinee, USFWS
Nick Hindman, USFWS
Campbell Ingram, USFWS (now with the Nature Conservancy of California)
John LaBoon, TSC Denver, CO

Kris Mills, DSO Denver, CO
Tom Morestein-Marx, CVO Sacramento, CA
Barry Mortimeyer, CVO Sacramento, CA
Don Reck, NCAO Redding, CA
Robert Swain, TSC Denver, CO
Joseph Wright, TSC Denver, CO

* = Principal Investigators

1.2. Description of Whiskeytown Dam

Whiskeytown Dam (also known as Clair A. Hill Whiskeytown Dam, abbreviated here as WT Dam) includes a main dam embankment on Clear Creek and two dike embankments on relatively low saddles to the right of the main dam embankment. The dam and dikes are located approximately nine miles west of the city of Redding in northern California. The dam was constructed by the Bureau of Reclamation between 1960 and 1963. The dam is located in the Whiskeytown National Recreation Area operated by the National Park Service. The area is a popular recreation area and heavily used.

The reservoir, Whiskeytown Lake, has an active storage capacity of 241,000 acre-feet at reservoir water surface elevation 1,210.0. Whiskeytown Lake receives water for hydroelectric power generation at the J.F. Carr Powerplant located at the upstream end of the reservoir approximately 7 miles northwest from the dam via the 10.7-mile-long Clear Creek Tunnel and provides water for hydroelectric power generation at the Spring Creek Powerplant located 2.4 miles northeast of the dam via the Spring Creek Tunnel. The discharge capacity of the J.F. Carr Powerplant is 3,600 ft^3/sat approximately 712 ft of head and the discharge capacity of the Spring Creek Tunnel is 4,300 ft^3/sat approximately 620 ft of head. Hydroelectric power is also generated at the City of Redding powerplant located immediately downstream from the dam. The reservoir supplies domestic water to the Clear Creek Community Services District (CCCSD), and is a popular recreation destination.

The main dam embankment is a zoned earthfill structure with a structural height of 282 ft, a crest length of approximately 2,250 ft at design elevation 1,228.0, and a crest width of 30 ft (see Figure 1, Appendix D). Dike No. 1 is a modified homogeneous earthfill embankment located to the right of the main dam embankment and Dike No. 2. The dike has a maximum structural height of approximately 25 ft, a crest width of 30 ft, and a crest length of 750 ft at elevation 1,228.0 ft. Dike No. 2 is a zoned earthfill embankment that is located between the main dam embankment and Dike No.1. Dike No. 2 has a maximum structural height of approximately 70 ft, a crest width of 30 ft, and a crest length of 1,000 ft at elevation 1,228.0. Table 1-1 shows the significant elevations of features of the dam.

The spillway is located near the left abutment of the main dam, and consists of a morning-glory ogee crest structure, a vertical transition curve, a tunnel, and a flip-bucket energy dissipator. The concrete crest structure is 92 ft in diameter at crest elevation 1,210.0. The vertical curve transitions to 21 ft in diameter at the upstream end of the tunnel at invert elevation 1,001.12. The 21-foot-diameter tunnel is approximately 1,007 ft long and slopes at 0.04382. A 25-foot-long conduit extends from the tunnel outlet portal to a flip-bucket energy dissipator that discharges into Clear Creek. The design discharge capacity of the spillway is 28,650 ft^3/s at reservoir water surface elevation 1,220.5. The spillway air vent intake is located in the downstream pier at elevation 1,222.

The outlet works consists of a trashracked concrete structure (sill elevation 972 and elevation 1,100, lower and upper intakes, respectively), concrete pressure tunnels, a gate chamber with three high-pressure guard gates, a concrete access tunnel downstream from the guard gate chamber, two steel main pressure pipes within the access tunnel, a downstream control structure with two high-pressure regulating gates, and a steel bypass pipe with jet-flow regulating gate. Water from the outlet works discharges into Clear Creek immediately downstream from the control structure and to the right of the spillway exit portal. The outlet works includes bifurcations from the main steel pressure pipes for a bypass into the Clear Creek, the City of Redding Powerplant, and the Clear Creek Community Services District (CCCSD) withdrawals.

The discharge capacity of the outlet works using the lower intake (with no contribution from the upper intake) is approximately 1,240 ft^3/s at reservoir water surface elevation 1,220.5. The discharge capacity of the outlet works using only the upper intake (with no contribution from the lower intake) is approximately 600 ft^3/s at reservoir water surface elevation 1,220.5. These discharge capacities do not reflect operation of the City of Redding Powerplant or the Clear Creek Community Services District (CCCSD) withdrawals. The discharge capacity of the 10-inch jet-flow gate bypass into Clear Creek is 50 ft^3/s at reservoir water surface elevation 1,220.5. The City of Redding Powerplant was constructed in 1985 and 1986 to the right of the outlet works control structure. The discharge capacity of the City of Redding Powerplant is 200 ft^3/s. It was assumed the relative magnitude of power generated by the various power plants modeled in this study is much greater than the foregone power losses associated with the power plant at WT Dam, so operations at WT were ignored for this study and in the model. Furthermore, the EWP re-operation scenarios considered in this study never dropped flows below 50 ft^3/s (when this lower bound was imposed, it rarely lasted for more than 3-7 days), so it was assumed the release for CCCSO are not impacted.

Table 1-1: Significant features and elevations of WT Dam.

Feature	Design Elevations (ft)
Top of Dam	1,228.0
Design Maximum Water Surface	1,220.5
Spillway Crest	1,210.0
Top of Active Conservation	1,210.0
Winter RWS Elevation	1,198.0
Top of Dead (Outlet Works Sill)	972.0
Streambed at Dam Axis	958.0
Bottom of embankment excavation	946.0

1.3. Hydrology

There is an extensive hydrology study ongoing in Reclamation to determine the peaks and volumes for frequency floods ranging from 500- to 50,000-year return periods. This work will be used in the Corrective Action Study ongoing for WT Dam. The hydrology work will not be completed until 2008. Specific assumptions concerning the EWP re-operation of WT Dam will be updated at the conclusion of the Corrective Action Study. In the meantime, sufficient information exists to evaluate whether or not to move forward with a pilot implementation of EWP re-operation.

1.4. Whiskeytown Reservoir (WT Reservoir): Relevant past and ongoing studies

1.4.1 2003 Comprehensive Facility Review

The 2003 Comprehensive Facility Review (CFR) was transmitted on November 13, 2003 (Comprehensive Facility Review 2003). The CFR included no previous incomplete Safety of Dams (SOD) recommendations but made a new SOD recommendation to re-evaluate the hydrologic hazard and hydrologic risks. This recommendation included developing frequency hydrographs and flood routings and surveying the crest of the dam and dikes to determine where overtopping would initiate.

This recommendation was addressed in an issue evaluation (IE) which followed.

1.4.2 2006 Issue evaluation (IE)

An IE was initiated to study the risks identified in the 2003 CFR. Flood frequency information was developed during the IE, and topography of the top of the dam based on a survey was obtained. The information was used in flood routings and a risk analysis for determining the hydrologic risks. This work is documented in the "Issue Evaluation Decision Document," WT Dam, California, July 2006 (Bureau of Reclamation 2006c); "Whiskeytown Dam Issue Evaluation Flood Routings, Technical Memorandum No. WHI-8130-IE-05-01," Central Valley Project, California, Mid-Pacific Region, August 2005 (Bureau of Reclamation 2005); and "Whiskeytown Dam Issue Evaluation – Risk Analysis, Technical Memorandum No. WHI-8130-IE-2006-01," Central Valley Project, California, Mid-Pacific Region, August 2005 (Bureau of Reclamation 2006a).

The IE used available topography and frequency floods to perform flood routings used in the risk analysis. The risk analysis identified the following failure modes and risks for the existing dam: static failure mode involving piping from the embankment Zone 1 material into the embankment Zone 3 or 4 materials; static failure mode involving piping from the embankment Zone 1 material into the foundation, hydrologic failure mode involving overtopping the dam, hydrologic failure mode involving piping of the embankment during a PMF event, and seismic failure mode involving cracking failure of the dam.

At the completion of the IE Reclamation decided to initiate a Corrective Action Study (CAS) to evaluate risk reduction alternatives and prepare a Modification Report (**2005-SOD-A)**. This work is ongoing.

Static

The expected annual probability of failure for the static failure mode involving piping from the Zone 1 material into the Zone 3 or 4 materials is 1.1E-06. Using an expected mean loss of life of 199, the annualized loss of life (risk) is 2.2E-04. The expected annual probability of failure for the static failure mode involving piping from the Zone 1 material into the foundation is 7.0E-07 , resulting in a risk of 1.4E-04. The static risks are below Reclamation guidelines.

Seismic

The seismic failure mode involves a cracking failure of the dam. The expected annual probability of failure for the seismic failure mode is 2.0E-07. Assuming an expected mean loss of life of 199, the risk is 4.0E-05. The seismic risk is below Reclamation guidelines.

Hydrologic

The identified hydrologic failure modes include overtopping of the dam resulting from a large storm and from internal erosion (piping) due to high reservoir water surface. It was estimated that the probability of dam failure due to overtopping was 1.2E-04 and the probability of dam failure due to internal erosion is two orders of magnitude lower or 2.0E-06. The estimated mean loss of life was 69 people resulting in risk of 8.1E-03 for overtopping or 1.4E-04 for internal erosion due to the high reservoir water surface. The existing combined hydrologic risk is above Reclamation guidelines.

The 2001 Emergency Action Plan (EAP) for WT Dam (Bureau of Reclamation, 2001) describes actions to be taken in unusual conditions (not just Hydrologic) and provides emergency contacts. The EAP includes inundation maps which were prepared in February 2000 for the maximum inundation and flood wave leading edge travel time. The inundation map contains only the maximum inundation based on breach of the main dam and does not include normal operational outflows or breach outflows from either of the dikes. The inundation map notes indicate that the breach scenario is based on a 1994 study, and state the depth of flood water and time for the flood wave leading edge to reach various locations for this condition. The peak breach outflow is predicted to be 2,636,000 ft^3/s for a piping failure and 3,722,000 ft^3/s for a failure during the full PMF from the 1994 inundation study. The study indicated there was a previous 1976 erosion breach failure simulation with an estimated peak outflow of 1,684,000 ft^3/s. Based on the 2000 inundation maps, it will take the leading edge of the flows about 2 hours to reach Redding, 3 hours to reach Anderson, and 10 hours to reach Red Bluff.

Findings

The revised estimated risk indicated little justification for SOD modifications due to static or seismic loading conditions. The risk for the hydrologic loading condition was above Reclamation guidelines and indicated increasing justification to reduce risk.

Based on the risk numbers, a SOD recommendation (2005-SOD-A) was made to initiate and perform a CAS to evaluate risk reduction alternatives and prepare a Modification Report.

1.4.3 Corrective Action Study (CAS)

The CAS was initiated in October 2006. Irrespective of the EWP flow feasibility study, a hydrology study is currently being performed to critically evaluate and refine the hydrologic loadings. The possible alternatives for modification of the dam will be developed and analyzed after the hydrologic loadings are refined. The alternatives could include, but are not limited to:

1. adding an auxiliary spillway;
2. raising the dam;
3. modifying a dike to be a spillway;
3. modifying a dike to be a fuseplug spillway;
4. reservoir restrictions;
5. draining the reservoir; and
6. no action (existing conditions).

The possible alternatives will be discussed, evaluated, and additional alternatives added in a scoping meeting which will be held at a future date.

2. Clear Creek: Evaluating Environmental Water Program Opportunities and Risks

2.1. Background

The EWP (portfolio.jsanet.com/archive/calfed-ewp-original/pilot.html) is part of the California Bay-Delta Authority's (CBDA) Ecosystem Restoration Program (ERP). The U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration Fisheries (NOAA), and the California Department of Fish and Game (CDFG) are designated as the *implementing agencies* for the Ecosystem Restoration Program (ERP Implementing Agencies) and are working, in coordination with the CBDA, to implement pilot water acquisitions in selected watersheds through the EWP. The acquisitions are intended to provide significant biological and ecological benefit, improve the state of scientific knowledge related to the effects of instream flows, and increase knowledge regarding the institutional and social constraints facing environmental water acquisitions.

Clear Creek (Figure 2-1) has been cited as an excellent candidate stream for flow augmentation to achieve several of the objectives of the California Bay Delta Authority (CBDA) Ecosystem Restoration Program (CALFED 2002, Kimmerer et al. 2002, Stillwater Sciences 2003). Multi-agency collaborative restoration efforts in Clear Creek have identified a requirement for the release of periodic higher flows to improve aquatic and riparian habitats, but Whiskeytown Dam (WT Dam) operations have significantly reduced the frequency of mid-range flood flows that are essential for forming and maintaining channel and floodplain morphologies on which these habitats and native biota depend. These flows are believed to be a key tool for sustaining and reinforcing the benefits of past and ongoing restoration activities (totaling millions of dollars since 1995) undertaken by the local Clear Creek Restoration Team (CCRT) and their constituent agencies (Reclamation, USFWS, CDFG, WSRCD).

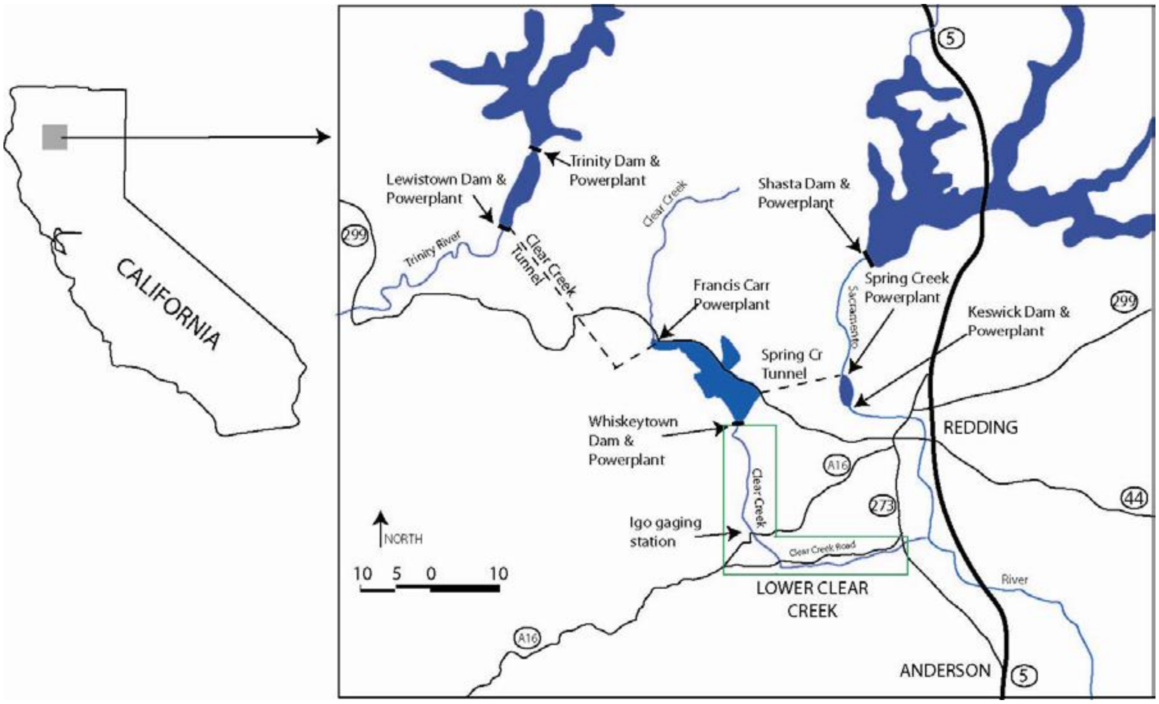


Figure 2-1. Lower Clear Creek Study Area, and approximately locations of major surrounding water supply and power generation infrastructure. *Source*: EWP Concept Proposal, 2004.

A **Concept Proposal** for water acquisition in Clear Creek was completed by EWP Staff and the EWP Lead Science Team on behalf of the Clear Creek Local Preparation Proposal Team (Local Team) in August 2004 (EWP 2004). Considerable input and review of the Concept Proposal was completed by the Local Team consisting of a variety of stakeholders who attended numerous participatory meetings. These meetings encompassed the review and discussion of existing information, the identification of species of concern and biological objectives, identification of existing tools to help with implementation design and evaluation (such as the CCDAM). The proposal was subsequently approved by the ERP Selection Panel and Implementing Agency managers supported contracts to move forward with further analysis via (*i*) a **Feasibility & Dam Safety Study** (documented in this report) and (*ii*) a **Full Proposal** under preparation by Stillwater Sciences (expected to be complete in February 2008).

A Concept Proposal and CCDAM suitability meeting was held February 15, 2005 in Denver and the project initiation and scoping workshop was held in Denver October 26-28 2005 (ESSA 2005).[1] A subsequent CCDAM DOHPLR code review was provided by Denver TSC staff. After two years of work by the Reclamation-ESSA team, this report provides detailed descriptions of candidate scenarios, modeling methods and results, dam safety risks, impacts to the project, and other impacts as best can be determined at this time. A major function of the overall EWP program for Clear Creek is to implement a pilot re-operation of WT Reservoir over a 10-year trial period starting no later than water year 2010. Hence, Reclamation's approval from a Dam Safety perspective to proceed with pilot operational modifications at WT Reservoir is required.

[1] This detailed technical memo (dated November 14, 2005) and workshop summary provides important context on scoping decisions made by the Reclamation-ESSA team for this project and report.

For this reason, the end product of our Clear Creek Feasibility & Dam Safety Study is a **formal Decision** — "a go or no go" on whether pilot water acquisitions can move forward in Clear Creek. This report encompasses the critical details and evidence that will be used to make an informed decision. The pilot program—if accepted by all Parties—will then be used to test predicted impacts, learn, determine benefits, and provide additional data to determine if the pilot program should be implemented on a permanent basis or otherwise incorporated into the permanent operation of WT Dam.

2.1.1 EWP release targets

The EWP Concept Proposal for Clear Creek (EWP 2004) provided the initial context for the release targets that were evaluated in this study. Key statements from this document guiding the Clear Creek modeling included:

"…the magnitude of the experimental flow releases will need to be in excess of 3,200 ft^3/s to allow at least for partial bed mobility. To achieve full bed mobility and notable coarse sediment transport, flow releases will need to be even greater" (pg. 29, EWP 2004);

"Sediment transport modeling using the Shields equation found that, in general, critical discharge was approximately 3,000–3,500 ft^3/s, although thresholds were much lower in Renshaw Riffle…" (pg. 29, EWP 2004);

"…McBain and Trush (2001) estimated that the majority of the bed was in motion at this site [Igo gauge] at about 4,000 ft^3/s" (pg. 30, EWP 2004);

"Bedload transport modeling using the Parker equation at the Peltier Valley Bridge site (in reach 1) indicate that transport begins at about 3,700 ft^3/s and significant transport (transport greater than about 1 ton/day) begins at about 5,500 ft^3/s" (pg. 30, EWP 2004);

"In their conclusion McBain and Trush (2001) recommended release of a somewhat higher high flow magnitude (>5,000 ft^3/s) partly to mobilize a greater size range of particles and initiate alluvial processes such as periodic scour of alternate bars, channel migration, and floodplain inundation (McBain and Trush 2001, p. 96), and partly in an attempt to offset riparian vegetation encroachment that leads to deeper, simplified habitat (Kondolf and Williams 1999, p. 6)" (pg. 30, EWP 2004);

"Bed mobility modeling … predicted mobility of D84 at the floodplain restoration sites at 3,100 ft^3/s, and approximately 50 percent of D84 particles were mobilized at 3,200 ft^3/s. Inundation occurred at the 2002 floodplain restoration site, with bank overtopping occurring at 3,000–3,400 ft^3/s. Monitoring has also shown that a flow in excess of 3,000 ft^3/s is necessary to recruit augmented gravels from floodplain staging sites, particularly the augmented gravels input directly below Whiskeytown Dam" (pg. 31, EWP 2004);

"**The overall implication of these experiments is that the required flow magnitude should be in the range 4,000–6,000 ft^3/s to achieve sediment transport sufficient to re-arrange channel habitats**" (emphasis added, pg. 31, EWP 2004).

"Based on this information related to gravel mobilization (and, by implication, to habitat change), and being conscious of the costs of obtaining large volumes of water over extended time periods, **a provisional recommendation is that the flow duration should peak over a 2-day period**" (emphasis added, pg. 31, EWP 2004).

"Relative to the provisional recommendations for flow magnitude and duration of 4,000 to 6,000 ft^3/s for two days, **it is suggested that a flow of around or in excess of 5,000 ft^3/s be obtained no less than once in every three years**" (emphasis added, pg. 33, EWP 2004).

During the October 2005 initiation and scoping workshop these statements were reviewed, and the study team settled on evaluating base targets of **4,750 ft^3/s for 3 days and 4,750 ft^3/s for 2 days**. Subsequent reviews of modeling results for these scenarios in February 2007 by Matt Brown (USFWS), who obtained an opinion from geomorphologists currently working in Clear Creek (Graham Matthews and Associates 2003, 2004, 2005) led to a third general target of **3,250 ft^3/s for 1 day**. Considering that some downstream accretion flows are expected below the dam, this lower flow was deemed adequate to achieve geomorphic and ecological needs. It also falls in-bounds with some of the comments identified above from the Concept Proposal.

To route the target discharges of 3,250 or 4,750 ft^3/s through the Glory Hole structure into the Clear Creek channel, two basic operational strategies for WT Reservoir were explored. The first is the "**winter strategy**", which involves increasing the target elevation of the reservoir during winter months (January through May) above the current winter target of 1,198 ft. This would allow natural inflows associated with storm events to fill the reservoir more quickly with some of the surplus inflow passing through the Glory Hole. The second "**spring strategy**", builds on the current operation of WT Reservoir during the spring months (March to May), when operators begin to fill the reservoir to maximum pool (1,209.5 ft to 1,210 ft). This later strategy relies principally on temporarily ceasing diversions from the WT Reservoir through the Spring Creek Tunnel, so that Trinity River water routed through the J.F. Carr Tunnel, along with natural inflows, would be allowed to fill the reservoir until its elevation exceeded the crest of the Glory Hole structure, thereby spilling into the Clear Creek channel. Our study quantifies the trade-offs associated with these two strategies (e.g., success rates, foregone power costs, dam safety risks).

EWP scientists identified a minimum goal of achieving 3 EWP releases every 10 years. Over the 40 year historical dataset used in our study, this translates to a minimum of 12 successes in these 40 years. For reasons outlined later, we suggest using a "buffer" beyond the lower-bound 12 successes in 40 year goal. The exact number is a matter judgment, but for purposes of evaluating different re-operation scenarios, we recommend a minimum number of **18 successes in 40 years**. (This does not mean that real-world operators would pursue more than 3 successes in 10 years in practice).

2.1.2 Comparison of historical flows with EWP release targets

A logical initial question is to ask how many EWP target events would have occurred naturally over the 40 years of record (1965–2005) if WT Dam were not in place? Figure 2-2 shows the historical outflows from WT Dam. The basic context stemming from the Concept Proposal (EWP 2004) is that the target flow and duration should be realized 3 times in 10 years – equivalent to 12 times in 40 years. Historically, between 1965 and 2005 there were 8 instances (1970, 1974, 1978, 1983, 1995, 1997, 1998, 2003) when the outflows in Reach 1 exceeded 3,250 ft^3/s for 1 day or more and only 5 instances when the Reach 1 flows were 4,750 ft^3/s or more for at least 2 days (fewer still if considering a 3 day duration). In one case, 12 consecutive years elapsed (1983 to 1995) before even the smaller of these two target flows were observed.

Figure 2-3 shows the plot of the natural daily inflow (for comparison purposes in discharge rather than volume units) into WT Reservoir. In contrast to the Clear Creek *outflows* below WT Dam, there were approximately 54 occurrences (on distinct calendar days) when the historical *natural* inflows (not including J.F. Carr/Trinity River diversions) exceeded 3,250 ft^3/s for 1 day or more between 1965 and 2005. This straightforward observation supports the goal that there should be more instances of these kinds of flows reaching lower Clear Creek (below WT Dam).

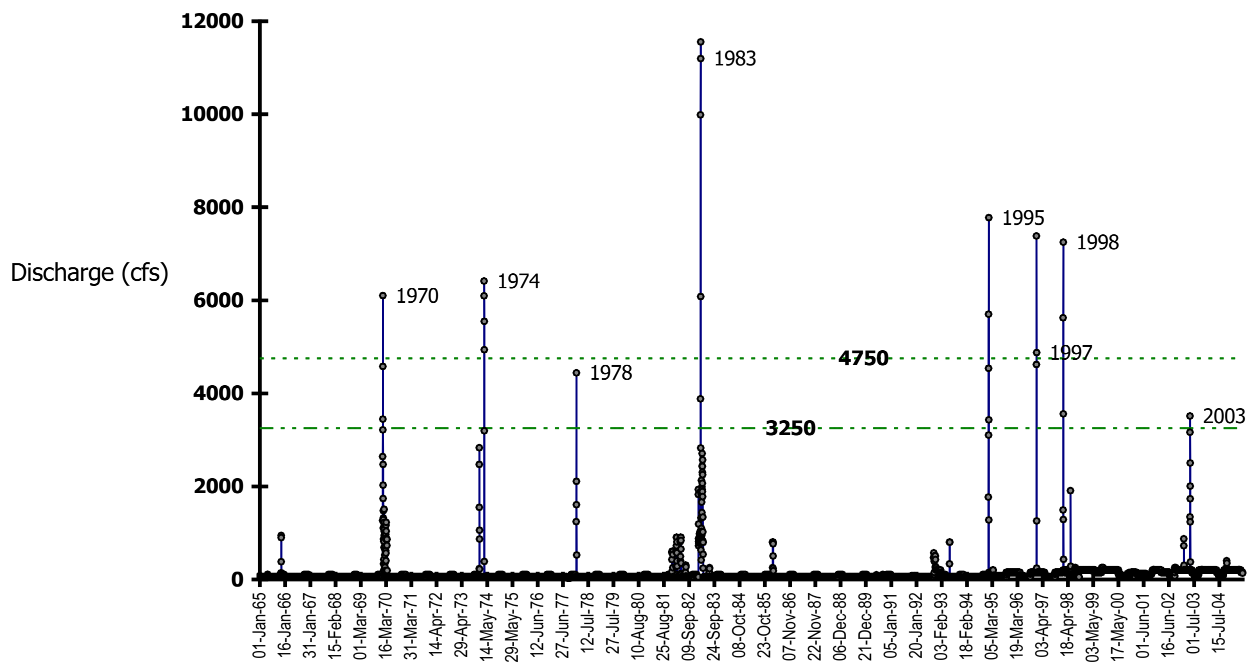


Figure 2-2: Clear Creek, below WT Dam (Reach 1), historical flow record, 1965 to 2005 (40 years of record).

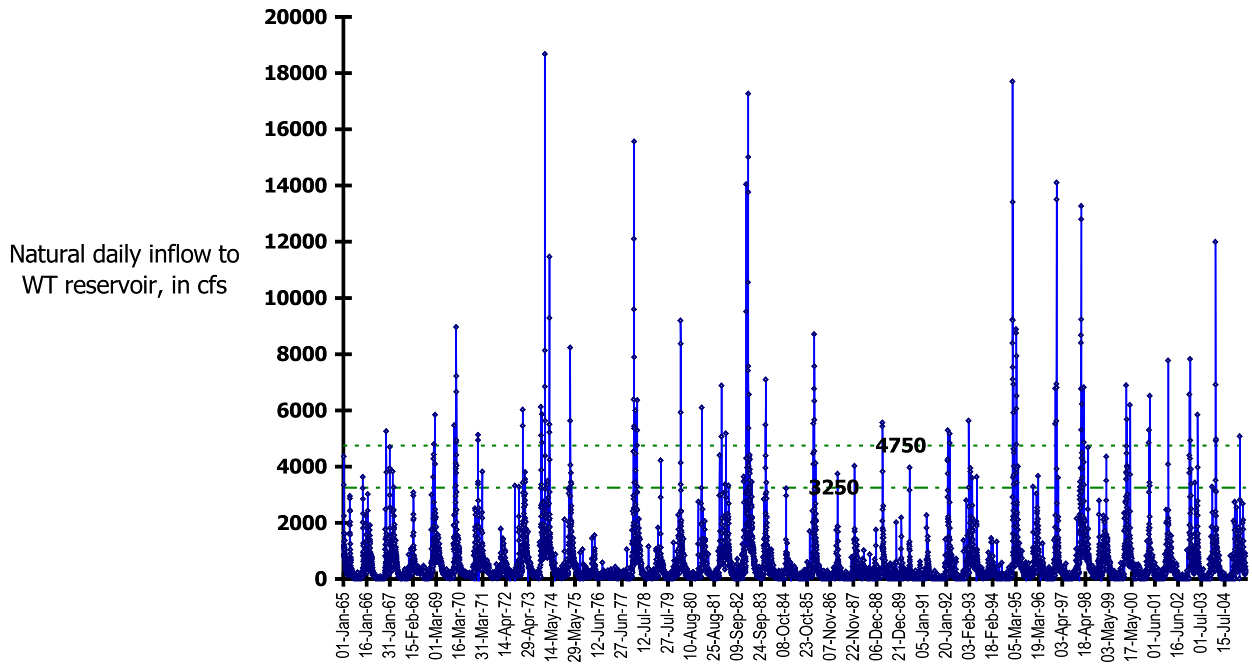


Figure 2-3: Historical natural daily inflows to Whiskeytown Reservoir, 1965 to 2005 (40 years of record).

2.2. Retrospective identification of event opportunities: Clear Creek Decision Analysis and Adaptive Management Model (CCDAM)

The method used to study pilot re-operation and EWP event opportunities was based on a simulation model developed by ESSA Technologies Ltd. between 2000 and 2003 (Alexander et al. 2003). Specifically, this study uses the Dam Operations, Hydrology, Power and Lake Recreation (DOHPLR) submodel of CCDAM, which was significantly enhanced to meet the needs of this study. The modified DOHPLR submodel was specifically designed around WT Dam, and implicitly considers the operation of Trinity Dam, Shasta Dam, Keswick Dam and flows at Bend Bridge on the Sacramento River. Though not used in this study, the overall CCDAM model also provides the ability to study the management of gravel in the Clear Creek from Whiskeytown to the junction with the Sacramento River (Alexander 2006), scouring processes, riparian initiation, and impacts to fish (temperature, spawning, rearing, and return).

For this study the DOHPLR submodel provided EWP analysis capabilities such as:

- natural inflow forecasting to WT Reservoir,
- improved Glory Hole discharge modeling,
- stopping conditions,
- a 'ready elevation' to raise Whiskeytown elevation to increase the probability of achieving a success, and
- simulation of WT Dam operator behavior as different states within the EWP process, under which different tunnel operations apply.

Using 40 years of historical data from 1965 to 2004 (January 1, 1965 to December 31, 2004), the model was run with different operational scenarios (described in detail in 2.2.6). As with any retrospective modeling approach, we have assumed future conditions are reasonably well approximated by the historical distribution of different kinds of water years (5 standard classifications of 'Critically Dry', 'Dry', 'Normal', 'Wet', and 'Extremely Wet') and past 'out-of-basin' conditions (e.g., encroachment states, Sacramento River flow rates) in Trinity and Shasta Reservoirs. The scenarios differed in the window of opportunity to consider an EWP release, the target flow, duration of this flow, and the WT Reservoir 'ready elevation'. All of these variations hope to encompass the range of natural variation that will occur in the future, along with the different options available to re-operate WT Reservoir in an attempt to achieve a safe Glory Hole release.

Climate change raises uncertainties with respect to the assumption of stationarity (historical flows same as future flows) given the expectation from Western North American Global Circulation Model runs of a higher frequency of drier conditions. To help ameliorate this concern, we use a "buffer" beyond the lower-bound 12 successes in 40 years goal to account for the expected increase in the frequency of dry years in decades ahead.

Likewise, any contemplated supply side hydrosystem changes in Northern California (Sites Reservoir, raising Shasta Dam) were beyond the scope of this study.

2.2.1 Spatial resolution and hydraulic components

The geographic area of interest, as mentioned above (Figure 2-1), spans from Trinity Dam to the northwest, Shasta Dam to the northeast, and Bend Bridge to the south (off map, SSE of the confluence of Clear Creek and the Sacramento River, ~ 32 miles downstream).

For modeling purposes, lower Clear Creek below WT Dam was subdivided into five reaches (Figure 2-4, Table 2-1) during a workshop bounding exercise completed in 2000 (Alexander et al. 2003). These mainstem reaches approximate the geomorphic characteristics (e.g., channel slope and confinement, alluvial vs. bedrock channel, etc.) of the four reaches defined in McBain and Trush (2001) but include slightly different breaks anchored to two major tributary junctions and culturally significant places such as former Saeltzer Dam. The major consideration for defining these reach breaks relate to the CCDAM channel submodel's needs for volumetric sediment budget modeling where it is preferable to have reaches of generally equal flow and gradient.

The DOHPLR submodel considers there to be an EWP success when the desired flow target is achieved at Reach 1, however due to the additional inflows to Clear Creek below WT Dam it is possible to achieve the desired EWP release in Reach 5 when it was not achieved in Reach 1. For this reason our analysis of model results also considered the estimated flow conditions in Reach 5.

Table 2-1. Individual reaches comprising the CCDAM channel submodel.

Reach	Description	Approx. river miles
1	Whiskeytown to the confluence with Paige Boulder Creek	17.5–16.3
2	Paige Boulder Creek to the confluence with South Fork Clear Creek (slightly upstream of USGS Gauging station)	16.3–10.9
3	South Fork Clear Creek to the Clear Creek road bridge	10.9–8.5
4	Clear Creek road bridge to former Saeltzer Dam site	8.5–6.5
5	Former Saeltzer Dam site to the confluence with the Sacramento River	6.5–0.0

Beyond Clear Creek itself there are various hydraulic elements that are considered to various degrees (whether explicit or implicit) by the DOHPLR submodel during a simulation. These major features are identified in Figure 2-5. All of the other powerhouses (Trinity, J.F. Carr, Spring Creek, Shasta, and Keswick) are used in the calculation of foregone power. Note: Lewiston Dam is shown for illustration purposes but is considered for neither the hydraulic modeling nor the foregone power calculations. Likewise the small powerhouse that exists at WT Dam was ignored due to its minimal generation capacity relative to other power houses included.

The model is capable of considering whether there is a flood hazard with the Trinity Reservoir and whether Shasta is encroached when making decisions about hydraulic re-operation of WT Dam, however an explicit volume balance is not performed on these 'out-of-basin' reservoirs (i.e. reducing or increasing the flow at Shasta/Trinity has no effect on the reservoir's elevation in our model). An explicit volume balance *is* performed on WT Reservoir, taking into account the flows arriving from J.F. Carr Tunnel plus natural inflows, as well as the outflows through Spring Creek Tunnel, the WT outlet, and of course the Glory Hole. Evaporative losses on the water surface itself are implicitly accounted for inside a net flow concept.[2] East of WT Reservoir, foregone power is considered through Spring Creek, Shasta, and Keswick power plants, however an *explicit* volume balance is not performed on water once it has left through Spring Creek.

[2] The historical data used in the study include daily reservoir storage and surface elevations, which integrates inflows, outflows and evaporative losses from the lake surface.

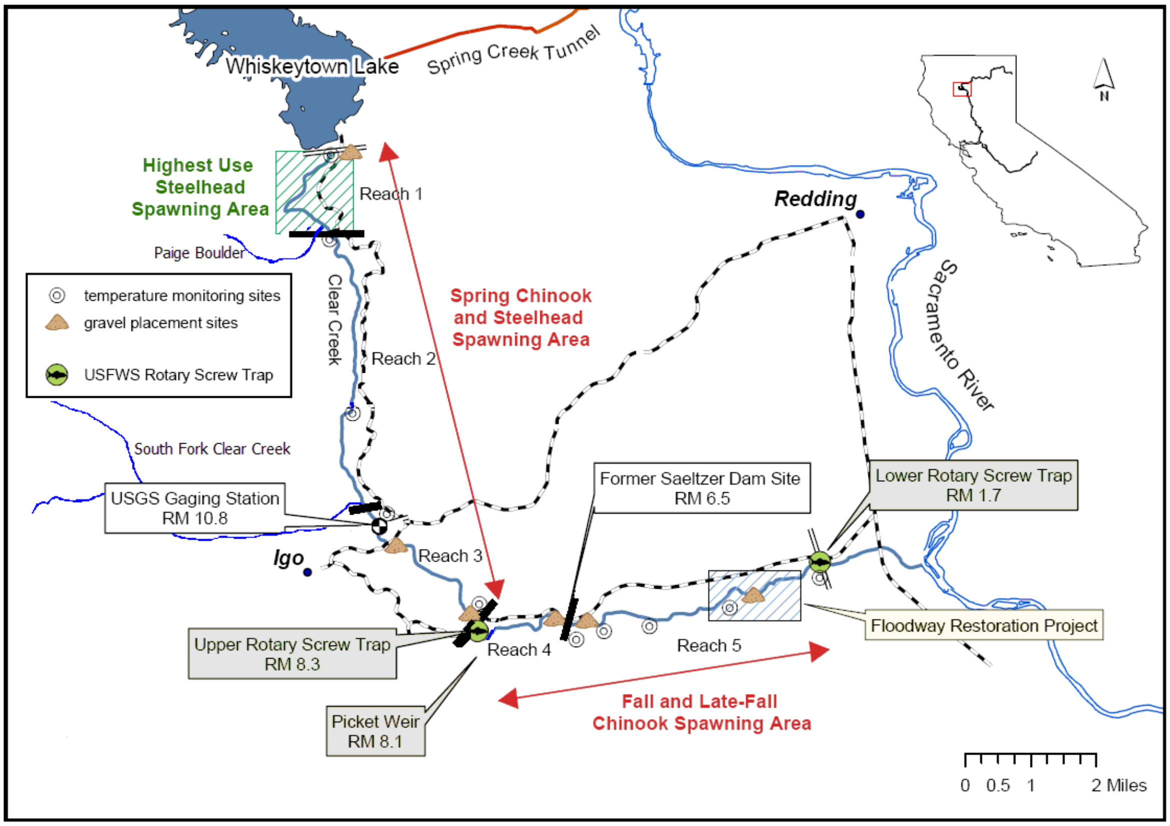


Figure 2-4. Lower Clear Creek downstream of WT Dam showing CCDAM reach definitions. (Original image created by Sarah Giovannetti of the US Fish and Wildlife Service. The image has been modified from the original for purposes of this report).

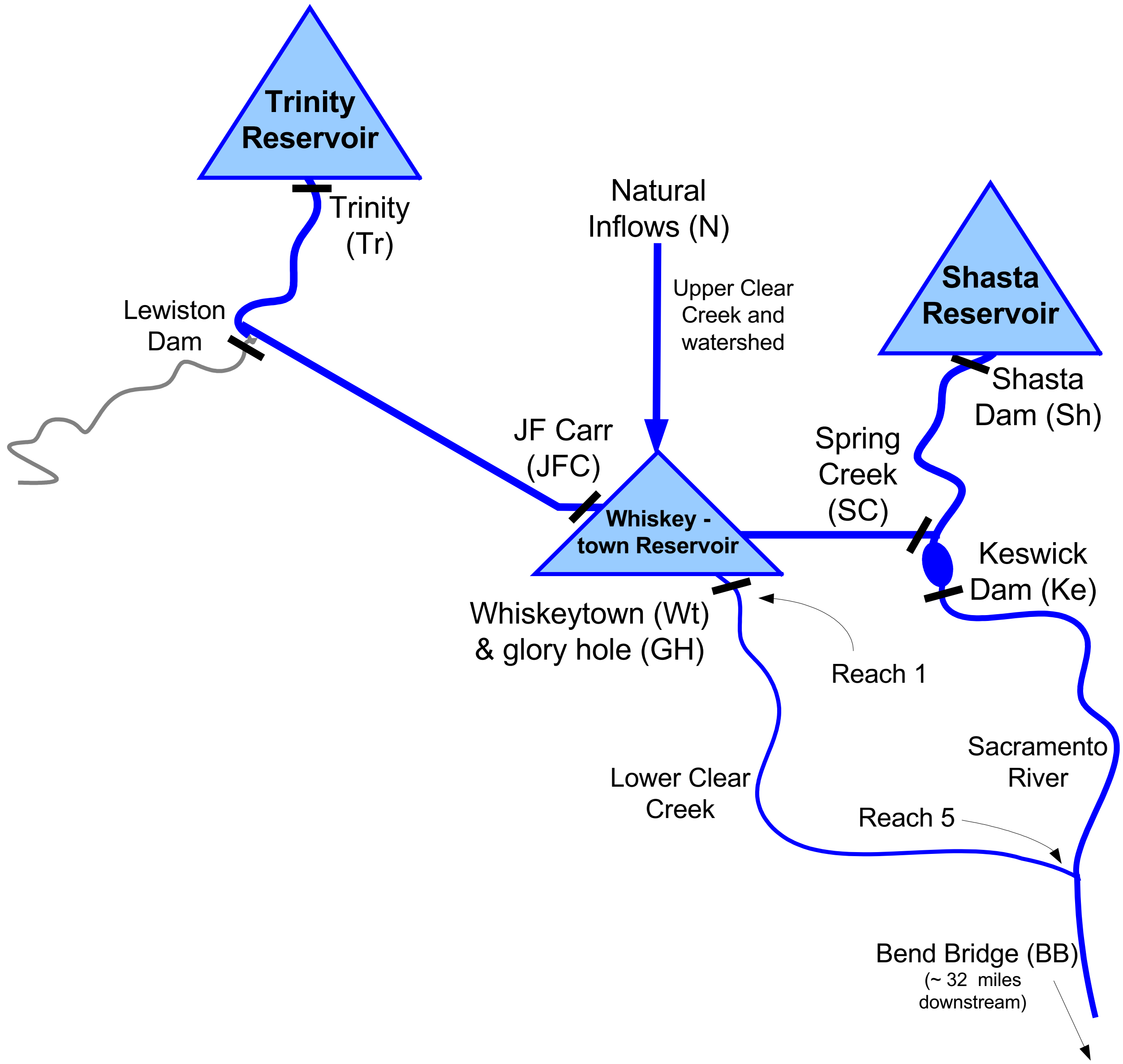


Figure 2-5: Hydraulic features considered by the CCDAM DOHPLR submodel.

In addition to the capability of taking into account the flood hazard and encroachment of Trinity and Shasta, respectively, for WT Dam re-operation, the DOHPLR submodel is also capable of responding to whether Reach 5 or Bend Bridge flows exceed a prescribed limit.

2.2.2 Temporal horizon and resolution

The CCDAM DOHPLR submodel calculates daily WT Reservoir elevations, tunnel flows and downstream daily average flows in each of CCDAM's 5 mainstem reaches.

The temporal horizon of model runs in this study was 40 years using historical daily average data for all hydraulic components. Each run started January 1, 1965, and ran through to December 31, 2004.

The EWP algorithm within the DOHPLR submodel performs many steps and checks (described in detail in section 2.2.7). It is important to note that the order of these steps imply the passing of time within a single day, where a day's starting conditions are the final values at the end of the prior day. When the model is **not** re-operating WT Reservoir (typically 95% or more of the time) it simply re-iterates historical data, outputting it directly without changes.

2.2.3 Data sources

All historical daily reservoir and flow data (Trinity River, J.F. Carr Tunnel, natural inflow to WT Reservoir, Trinity/WT Reservoir elevations, WT outlet flow, WT Dam Glory Hole flows, Igo gage flows, Spring Creek Tunnel flows, Shasta Dam, Keswick, Sacramento River at Bend Bridge) used in this study were either already included in the model, were provided by the Bureau of Reclamation, Denver Technical Services Center or were obtained from USGS/NWIS web sites.

The WT Reservoir rating table data used in modeling were taken from the original Technical Record of Design and Construction documents for the Trinity River Division Features of the Central Valley Project (Bureau of Reclamation 1965).

Glory Hole discharge vs. reservoir surface elevation lookup tables used by the DOHPLR submodel were supplied by Elisabeth Cohen, using the Bureau of Reclamation's flood routing for dams program.

Power output vs. 75th percentile exceedance head (power house efficiency vs. reservoir elevation) relationships for all of the powerhouses in this study were provided by Kim Nguyen, Central Valley Operations. Power prices used in the study were taken from the CAISO monthly average prices for 2005. The prices for September, October, November, and December were adjusted down from the actual 2005 prices as these values were believed to have had high natural gas price effects.

2.2.4 Treatment of out-of-basin reservoirs

As identified above, CCDAM simulates WT Dam re-operation based upon historical data. One well known difference between the historical data and present day is the way in which Trinity Dam is operated following the Trinity River Record of Decision (ROD). While historical Trinity flows were not changed in our simulations, the CCDAM foregone power calculations take a conservative approach (i.e. more costly) in an attempt to recognize shifts in operational rules.

CCDAM assumes that both Trinity and Shasta Reservoirs are infinite pools, where any *change* in water volume through the Trinity or Shasta Dams does not affect their elevation (i.e. no volume balance). In our simulations we introduced a "guaranteed delivery" of water down the Trinity River, that is, CCDAM assumes that if more water is required in WT Reservoir—such as when building elevation by increasing flows through the J.F. Carr tunnel—then additional flow must be brought through Trinity Dam. For example, if 8,000 ft^3/s was historically flowing through Trinity and 1,000 ft^3/s flowing through J.F. Carr, and it is necessary to increase the flow through

J.F. Carr to 3,000 ft^3/s for purposes of achieving a Glory Hole release at WT Dam, the Trinity flow must be increased to 10,000 ft^3/s. Assuming no losses, this guarantees that the 7,000 ft^3/s that historically passed through Lewiston Dam down the Trinity River continues to do so.

This approach has implications for the calculation of foregone power. Taking the peak generating capacity of Trinity Dam of 4,000 ft^3/s, it is assumed that only the available capacity can generate revenue. Following the example from above, if 8,000 ft^3/s were flowing through Trinity the full generating capacity would already be exceeded, thus the additional 2,000 ft^3/s brought through J.F. Carr—thus raising the Trinity flow to 10,000 ft^3/s in an effort to maintain the historical Trinity flows—would likewise generate no additional revenue. Another example would be if the DOHPLR submodel increased flows by 2,000 ft^3/s through J.F. Carr when Trinity Dam historically had 3,000 ft^3/s flowing. In this situation, only half of the 2,000 ft^3/s could be used to generate power, and the remaining 1,000 ft^3/s of the 2,000 ft^3/s would be assumed to be brought through the spillway.

In conclusion, while historical data does not capture the current operation of the Trinity according to the ROD, the foregone power calculations take a conservative approach generating costs on the high side. This is particularly true for the "price shifting" foregone power method (described in section 2.2.8), where the additional flows moved through to Clear Creek for EWP purposes is assumed to have been prematurely released, assumed to have otherwise been available for use at peak season (summer period) prices.

An analogous approach is used when setting flows and calculating foregone power at the Shasta/Keswick power plants.

2.2.5 Considerations in WT Dam re-operation scenarios

Scenarios were developed around several conditions including the EWP period (start and end dates), EWP duration (3, 2, or 1 day events), number of EWP attempts per year, initial WT Reservoir water surface elevation during the EWP period ("ready elevation"), stopping conditions, and power revenue considerations.

Time period for event

Two general periods, winter and spring, were initially defined as periods when the EWP flows would occur. The **spring** period was eventually refined for a spring (March 1 to May 15) and **late spring** (April 1 to May 15) period. The **winter** period is January 7th or 21st to May 15th. The two winter period start dates were used to obtain insights on the significance of large January storms for sensitivity analysis purposes. As all of the scenarios have the same end date of May 15th, the winter scenarios actually encompass the spring and late spring scenarios, and similarly the spring scenarios encompass the late spring scenarios.

Duration

The duration of an EWP scenario is a critical part of the functioning of the DOHPLR submodel and reaching an EWP success. Achieving 4,750 ft^3/s for 3 days is less probable than 4,750 ft^3/s for 2 days over the same window. While reaching 4,750 ft^3/s for 3 days might be the geomorphic ideal for certain geomorphic processes, achieving this flow for fewer days would still have benefit. For context, it is also important to recognize that DOHPLR submodel flows are *daily* *averages*, and do not show any within-day flow variability (actual peak hourly flows may be 26% to 60% higher). Thus, varying the duration provides a degree of insight into sensitivity analysis for these parameters, and at the same time raising awareness about the kinds of opportunities that may exist for flows of different durations.

Number of attempts per year

The simulations considered up to 2 attempts at achieving a EWP flow in any one year. This was implemented to capture the opportunity that may exist within the EWP period, should an initial attempt fail (e.g., due to a transient lack of natural inflows). For example, if only 1 attempt per year was allowed for a scenario starting April 1st, if an attempt failed at the outset, but conditions emerged in mid-April enabling success, we would have never captured this in our simulations. Providing the simulated WT Dam operator the ability to go for a second attempt within the year allows for this possibility. Of course, this will increase the number of successes in the model, with a corresponding cost increase to follow in some years.

Note that if the first attempt was a success, then the model tries to return the operations back to their historical state, and no additional attempts are made within the same year.

Two attempts per year were therefore chosen as a good compromise to handle inflow variability while not overly incurring failures and accelerating foregone power costs. As natural inflow over short time periods are an autocorrelated process, failure to achieve a success after 1-2 attempts is a (albeit imperfect) sign to the simulated WT Dam operator that “this might not be the best year for this”.

Starting reservoir water surface elevation

In addition to being a recreational destination, WT Reservoir is essentially a transfer point for water between the Trinity and Shasta basins and secondarily a flood control storage pool. WT Dam is operated to provide power generation at opportune times. Once summer arrives the reservoir has an additional goal: meeting recreational values for the public. To meet this need historically, the reservoir is brought to full pool (1,209.5 ft) by Memorial Day (last Monday of May) weekend.

It should come as little surprise that the probability of an EWP success is inversely related to the volume of water required to reach 1,210 ft (height of the Glory Hole spillway). Thus if the WT Reservoir elevation can be raised earlier in the season when significant winter run-off and spring precipitation is more frequent—this will increase the probability of an EWP success. For this reason, some of our scenarios were designed with a higher “ready elevation” to provide information on how varying Whiskeytown elevation affects the EWP process.

It was also important to be able to compare model output without having any change to the way the reservoir elevation has been historically operated. CCDAM achieves this goal by setting the ready elevation to an arbitrarily low elevation of 1,170 ft (well below that observed historically, 1,176 ft). Because the model includes a rule to never operate the reservoir to go *below* that which occurred historically, scenarios with a ready elevation of 1,170 ft are referred to as using a ‘historical’ ready elevation. Hence, *unless* a WT Reservoir inflow forecast predicts there may be sufficient water to attempt a EWP release, the model will track the historical elevation if using a historical ready elevation.

Three additional general WT Reservoir water surface "ready elevations" were evaluated: elevation 1,203.5/1,204, elevation 1,206, and elevation 1,209.5. The highest elevation considered (1,209.5 ft) reflects the maximum reservoir water surface that might be contemplated by more risk taking operators having only minimal storage in the reservoir for flood control events, and elevation 1,203.5/1,204 was selected as a low-intermediate elevation which provides reasonable flood control space but a more plausible achievable volume for obtaining the target Glory Hole release. Elevation 1,206 serves as a midpoint for analysis, to illustrate sensitivity between the higher and lower elevations.

Stopping conditions

During the October 2005 project initiation and scoping workshop (ESSA 2005), expert participants (including a senior Central Valley operator) discussed a number of conditions that could occur that would lead to termination of EWP operations at WT Dam. These "stopping conditions" were based on:

foregone power cost;

placing a limit on cumulative volume released from WT Reservoir (i.e., recognizing a likely lack of inflow);

a maximum daily flow in lower the Clear Creek (Reach 5) that would be unsafe; and

the maximum number of continuous days attempting an EWP flow without success.

The values for these parameters used in our simulations are shown in Table 2-2. These values in Table 2-2 were not *routinely* surpassed, rather, they were used as upper limits to keep modeling results within a reasonable range. Furthermore, simulated EWP operations were always terminated if they realized "success", with no further attempts occurring within the year.

Table 2-2: Stopping conditions used in EWP simulations. Note: run numbers are defined below.

	All CCDAM Runs	Runs 1-14	Runs 15-22
Max lower Clear Creek (Reach 5) daily flow	9,100 ft^3/s		
Max cost for the year		$2,600,000	$1,600,000
Max cumulative spill for the attempt	84,000 acre-feet		
Max continuous days without success		10 days	7 days

The EWP algorithm, at the end of the processing of a day, examines the total cost that has been incurred since the start of the EWP period. This is to simulate the notion of an annual budget that cannot be exceeded. If it has been exceeded, re-operation is finished for the year, and CCDAM returns to historical elevation levels. If it has not been exceeded, the model then examines whether the total volume spilled for this attempt is greater than or equal to the 84,000 acre-feet. If 84,000 or more acre-feet have been spilled through the Whiskeytown outlet (taking the difference of Whiskeytown outlet's historical flow) plus the volume through the Glory Hole, then this attempt is likewise terminated. The model then returns to the historical elevation. The maximum continuous days without success is handled in the same way as the cumulative spill, in that once an attempt has started the days are counted. Once day 10 (or day 7 for the single day runs 15-22) has been reached, the attempt is terminated, and the model returns to the ready elevation (or historical levels if this was the second attempt).

The lower Clear Creek flow at Reach 5 is handled somewhat differently by the DOHPLR algorithm because of the inherent flood safety issues. Within the model, the flows from the Whiskeytown outlet are set, and the Glory Hole flows calculated to generate a Reach 1 flow. The DOHPLR model's final step for the day is to then add downstream accretions to arrive at a Reach 5 flow. To shut down operations as quickly as possible when the lower Clear Creek flow reaches or surpasses 9,100 ft^3/s, the model checks this value at the start of the next day. If exceeded—regardless of whether attempting an EWP release or not, the model returns to historical levels and no further attempts are made in that simulation year.

The recorded safe channel capacity is 1,250 ft^3/s. The background on how this value was labeled as a "safe channel capacity" is vague, but it in reality it appears to be the maximum controlled outlet release capacity of WT Dam itself, without consideration of additional flow from Glory Hole releases. *Numerous* flows have occurred historically on lower Clear Creek well in excess of 1,250 ft^3/s without producing any reports of flooding. Peak flows at the dam have been 7,775 ft^3/s which was recorded on January 13, 1995, 7,384 ft^3/s on January 2, 1997, 7,250 ft^3/s on February 8, 1998, **and the maximum outflow from Whiskeytown was 11,553 ft^3/s on March 2-3, 1983**. Based on the accretion flow rules used in the DOHPLR submodel that estimate downstream accretions from tributaries, the maximum flow at the lower end of reach 5 for the 11,533 ft^3/s dam outflow may have been as high as **16,703 ft^3/s** and modeled reach 5 flows consisted of 10,730 ft^3/s on January 13, 1995, 10,661 ft^3/s on January 1, 1997, and 8,548 ft^3/s on February 8, 1998.

Figure 2-6: A focal area of concern for evaluating lower Clear Creek flood risk.

Topographic data used in *preliminary* 1-D HEC-RAS modeling suggests that Clear Creek near the confluence with the Sacramento River (Figure 2-6) reaches top of bank height at approximately 14,000 ft^3/s (i.e., 54% more than our 9,100 ft^3/s stopping rule)[3]. However, this does not take into account the hydrologic effects of this type of flow were it concomitant with high flows on the Sacramento River (i.e., back-water effects). Given that the lower Clear Creek safe channel flow used in simulations (9,100 ft^3/s) is lower than the historical maximum outflow from the dam (11,553 ft^3/s) and below 14,000 ft^3/s top of bank flow, it offers a reasonable initial rule. **Any real-world EWP operations should consider further development of this rule considering Sacramento River backwater effects and other risk considerations**.

Operational constraints and J.F. Carr and Spring Creek tunnel outlet limits

The CCDAM DOHPLR submodel provides the ability to specify various operational settings and constraints for the EWP model. For our analysis, all of the scenarios used the same parameters

[3] Technical memorandum to Smokey Pittman, Graham Matthews and Associates, dated August 31 2007, from Bonnie Pryor and Jeffrey Anderson, Jeff Anderson & Associates, P.O. Box 841 Arcata California, 95518. (Phone 707.822.5444).

(Table 2-3). These values were recommended and accepted by expert participants at the project initiation and scoping workshop held in Denver October 26–28, 2005 (ESSA 2005).

Additional details on parameters and their values internal to the model are listed in Appendix A.

Table 2-3: Operational settings and constraints used in EWP simulations.

Parameters	Value
Trinity flood hazard limits	Nov. 1st – Mar. 31st: 2,345 ft Apr. 1st – Sep. 30th: 2,373.5 ft
Shasta encroachment foresight	0 days (preliminary sensitivity runs performed using 5 days)
Max. flow at Bend Bridge	65,000 $ft^3.s^{-1}$
J.F. Carr Tunnel [min, max]	[60; 3,400] $ft^3.s^{-1}$
Spring Creek Tunnel [min, max]	[200; 4,300] $ft^3.s^{-1}$
Whiskeytown outlet [min, max]	[50; 1,100] $ft^3.s^{-1}$

The Trinity flood hazard limits affect the minimum flow through the J.F. Carr tunnel. Each day the historical elevation is compared against the appropriate flood hazard limit. If the historical elevation is greater than this limit, then there is a Trinity flood hazard. J.F. Carr's minimum tunnel flow is then temporarily adjusted for the day—set to the maximum of the historical tunnel flow or the parameter minimum. While this does not typically have any effect when attempting or within an EWP release, it may hamper the model's ability to reduce Whiskeytown elevation back to the ready elevation or historical levels when working to end an EWP attempt.

The DOHPLR submodel includes a 'Shasta encroachment foresight' parameter to simulate the short-term forecast knowledge real-world dam operators have. The model can use this parameter to look ahead in time *n* days, where if *n* is 1, then the model examines the current day, if 2 then the current day and the next, and so on. If the Shasta storage level is greater than its permissible storage (both of these are daily historical values available to the DOHPLR submodel) then Shasta is deemed to be encroached. However, for purpose of our analysis, this Shasta encroachment concept was turned off in order to expose all possible EWP successes and limit interpretational confusion this parameter introduced with respect to foregone power estimates. Further, it was decided following sensitivity analysis tests that the key EWP successes that dropped out of the more open analysis could then be better analyzed for flood safety issues using Reclamation's standard procedures. Furthermore, sensitivity analyses using this rule showed that it tended to place a disproportionate burden of flood risk mitigation within Clear Creek relative to the Sacramento River. That is, when used, if a simulated WT operator entered into an EWP event and subsequently Shasta reservoir became encroached, the model operator lost the ability to use Spring Creek tunnel to evacuate flows if conditions in WT exceeded safety limits. In practice, we believe real-world operators would be more willing to tolerate an extra 1,000 to 5,000 ft^3/s in the Sacramento River at Keswick rather than in a relatively small tributary like Clear Creek – particularly as the flows will end up in the Sacramento River anyway.

The reader should recognize that any "in-season" (real-world) implementation of pilot WT Dam re-operations would consider factors such as the flood states on other reservoirs (esp. Shasta) and use this information to make real-time decisions. While many were accounted for in our analysis, attempting to accommodate *every* "if then" rule that enters into real-world operational decision-making in the CCDAM DOHPLR submodel was beyond the budgetary resources of this study.

The flow at Bend Bridge was also identified as a factor that should have an effect on the simulated operator behavior. Thus, if the daily historical value for the flow at Bend Bridge is greater than 65,000 ft^3/s, then Bend Bridge is considered to be exceeded.

Shasta encroachment and Bend Bridge flow exceedances affect the model in the same way. If either of these are true, the DOHPLR will not enter into an EWP attempt, and the Spring Creek flow maximum is temporarily set to the maximum of either the Spring Creek minimum (e.g. 200 ft^3/s) or the historical Spring Creek flow. Thus, under either of these conditions the model adjusts Spring Creek tunnel to prevent additional flows (such as when trying to reduce WT Reservoir elevation) from entering the Sacramento River. Of course, this is a fallacy should WT Dam be in the middle of a large Glory Hole release—the water simply arrives at the Sacramento River at a few miles further downstream.

The J.F. Carr and Spring Creek Tunnel have physical and operational limits. Note that this is not the same as the generating capacity—these are internal parameters in the software. The limits above (Table 2-3) were used across all runs in this analysis.

2.2.6 EWP scenarios performed

Three general scenarios were defined and performed for this project. Each of these "general scenarios" has several variants (termed model runs) based on different EWP start and end dates, reservoir ready elevation, and foregone power assumptions. The initial scenario defined at the October 2005 project initiation and scoping workshop called for a EWP flow target of 4,750 ft^3/s for 3 days, and 8 CCDAM model runs were conducted under these conditions. Scenario 1 (Model ID No. 1-8) is shown in Table 2-4.

Table 2-4: **Scenario 1** – CCDAM runs with EWP release targets of **4,750 ft^3/s for 3 days.**

Model ID No.	Season	Start date	End date	EWP ready elevation (ft)	Power revenue assumption[1]
1	Spring	March 1	May 15	Historical (elevation 1,170)	no shift
2	Spring	March 1	May 15	1,204	no shift
3	Spring	March 1	May 15	Historical (elevation 1,170)	shift
4	Spring	March 1	May 15	1,204	shift
5	Late Spring	April 1	May 15	1,206	no shift
6	Late Spring	April 1	May 15	1,209.5	no shift
7	Late Spring	April 1	May 15	1,206	shift
8	Late Spring	April 1	May 15	1,209.5	shift

1 Foregone power costs for a "no shift" condition are based on the assumption that revenue from the production of power is the same regardless of the month; for a "shift" condition, the assumption is that power revenues are greater in the summer than in the spring and that changes made in the winter/spring should be "taxed" to account for foregone revenues under the higher summer prices.

The second scenario (Model ID No. 9-14, Table 2-5) shared the same EWP flow target as Scenario 1 (4,750 ft^3/s) but the number of days was reduced from 3 to **2 days**.

Table 2-5: **Scenario 2** – CCDAM runs with EWP release targets of **4,750 ft^3/s for 2 days.**

Model ID No.	Season	Start date	End date	EWP ready elevation (ft)	Power revenue assumption[1]
9	Winter	January 7	May 15	Historical	no shift
10	Winter	January 21	May 15	1,203.5	no shift
11	Winter	January 7	May 15	Historical	shift
12	Winter	January 21	May 15	1,203.5	shift
13	Spring	March 1	May 15	Historical	no shift
14	Spring	March 1	May 15	1,204	no shift

1 Foregone power costs for a "no shift" condition are based on the assumption that revenue from the production of power is the same regardless of the month; for a "shift" condition, the assumption is that power revenues are greater in the summer than in the spring and that changes made in the winter/spring should be "taxed" to account for foregone revenues under the higher summer prices.

Scenario 3 (Model ID No. 15-22, Table 2-6) reduced the EWP flow target to 3,250 ft^3/s and further reduced the target number of days from 2 to 1 day. These changes were made based on the (2007) recommendations of Matt Brown (USFWS) and Graham Matthews and Associates geomorphologists who believe that a 1-day flow exiting WT Dam of 3,250 ft^3/s should be a sufficient minimum target for meeting aquatic and riparian habitat improvement goals. It was assumed that accretions in downstream reaches would contribute to higher flows in reach 5 where much of the geomorphic work is targeted. These recommendations were made based on biological and geomorphological information generated since the Concept Proposal was written. These more recent analyses suggest that the WT Glory Hole spill of 2003 met many of the project goals and so a spill of this magnitude (3,250 ft^3/s) could be used as a minimum EWP target. The Glory Hole spill moved considerable amounts of sand, and redistributed large amounts of spawning gravel, greatly improving the amount of spawning habitat downstream. Significant amounts of sand remaining in lower Clear Creek continue to negatively impact fall Chinook production. It was accepted that some objectives might not always be achieved by the 3,250 ft^3/s minimum flow target. Some of the project objectives have higher flow thresholds and are not required as often (Kondolf and Williams 1999). It was assumed that some of the successes would achieve flows higher than the minimum target and would meet the needs of objectives with higher flow thresholds, such as channel avulsion.

Table 2-6: **Scenario 3** – CCDAM runs with EWP release targets of **3,250 ft^3/s for 1 day.**

Model ID No.	Season	Start date	End date	EWP ready elevation (ft)	Power revenue assumption[1]
15	Spring	March 1	May 15	Historical	no shift
16	**Spring**	**March 1**	**May 15**	**1,204**	**no shift**
17	**Spring**	**March 1**	**May 15**	**1,209.5**	**no shift**
18	Winter	January 7	May 15	Historical	no shift
19	**Winter**	**January 7**	**May 15**	**1,203.5**	**no shift**
20	Late Spring	April 1	May 15	Historical	no shift
21	Late Spring	April 1	May 15	1,204	no shift
22	Late Spring	April 1	May 15	1,209.5	no shift

1 Foregone power costs for a "no shift" condition are based on the assumption that revenue from the production of power is the same regardless of the month; for a "shift" condition, the assumption is that power revenues are greater in the summer than in the spring and that changes made in the winter/spring should be "taxed" to account for foregone revenues under the higher summer prices.

2.2.7 Simulated Whiskeytown operator behavior, clear creek flows and reservoir response

WT Dam operator behavior is simulated within the DOHPLR submodel using rule-based deterministic logic. The rules operate using two fundamental principles:

act in the interest of safety first

act conservatively in terms of (foregone power) calculations and data.

The first principle is achieved by checking whether Trinity Reservoir is at a flood stage (Table 2-3), Bend Bridge flow is exceeded (65,000+ ft^3/s), or lower Clear Creek Reach 5 flow has hit an emergency stop (9,100+ ft^3/s). These checks are performed each day in the model, and also repeatedly through the algorithm. The DOHPLR submodel also acts conservatively in that it defers to using historical data when this differs from the strict course of action defined by the scenario parameters, compensates for flows taken from Trinity and Shasta even if this might not be done in reality, and calculates foregone power to err on the side of costs being higher rather than lower (esp. in the "shift" power assumption cases).

The overall EWP algorithm has 5 key components in order to simulate WT Dam operator behavior:

WT Reservoir inflow forecasting

WT Reservoir elevation-storage lookup

Glory Hole discharge calculations

utilization of the Whiskeytown outlet

downstream flow and accretion model (unchanged, original CCDAM code)

Inside this algorithm a volume balance is maintained for WT Reservoir.

5-day advance inflow forecasting

Tunnel re-operation alone can bring Whiskeytown to full pool by minimizing Spring Creek and maximizing J.F. Carr but cannot easily yield a Reach 1 target flow of 3,250 ft^3/s let alone 4,750 ft^3/s. Thus, it was also advantageous to have naturally occurring inflows at the same time an EWP release was occurring in the study.

For this reason, the TSC Flood Hydrology and Meteorology Group developed a 5-day advance inflow forecast equation for WT Reservoir:

$$Q_{T5} = C * \left[b + (S_{-1} * Q_{-1}) + (S_{-2} * Q_{-2}) + (S_{-3} * Q_{-3}) + (S_{-4} * Q_{-4}) + (S_{-5} * Q_{-5})\right] \qquad \text{(Eqn. 2-1)}$$

where Q_{T5} is the total forecasted natural inflow for the next 5 days, Q_{-1} is the actual natural inflow from yesterday, Q_{-2} the natural inflow from 2 days ago, and so on. Parameter C, b, and S_{-n} are all fitted constants.

The historical data was then analyzed and an appropriate temporal and water year grouping applied. Due to the variable nature of natural inflows during the winter (up until March 31st), a set of fitted constants were determined separately for this period. After March 31st (springtime) the natural inflows were totaled for each water year and categorized into 5 different kinds of water years: Critically Dry, Dry, Normal, Wet, and Extremely Wet (Figure 2-7). The historical daily data for the spring period were extracted, properly lagged and binned according to their water year types and a multiple regression conducted to obtain values of the various coefficients. All positive y-axis intercepts (b) were then given a bias adjustment equal to 50% of the initial b value determined by multiple regression. This was done to reduce over-estimation bias at low inflows (where the highest density of data points typically existed). Next a correction factor (C) was applied (Eqn. 2-4) that achieved an overall *under*-prediction rate of 20%. The R^2 values on these adjusted multiple regression equations was in the 0.52 to 0.60 range. (The raw multiple regression equations without prediction rate adjustments had adjusted R^2 values in the range of 0.57 to 0.70). For our runs, the b and S_{-n} coefficients and the C values are the same for all runs within water year categories.

There is also a 'Volume Scalar' parameter expressed as a percent available to the model. This multiplies Q_{T5}, allowing the user to tweak the forecast: increasing above 100% to overpredict more often, or reducing below 100% to underpredict[4]. For this analysis, the Volume Scalar was kept at 100% (i.e. no effect on Q_{T5}) for all runs except runs 20-22 inclusive, where it was set to 125%. Thus for runs 20-22, it is expected that the number of attempts would be equal to or greater than the number of attempts for runs 15-17 (and by extension the number of successes), respectively, for the same period (runs 15-17 start 1 month earlier).

[4] CCDAM software gives the user the ability to change the *C* and *Volume Scalar* values through portions of the reservoir control user interface.

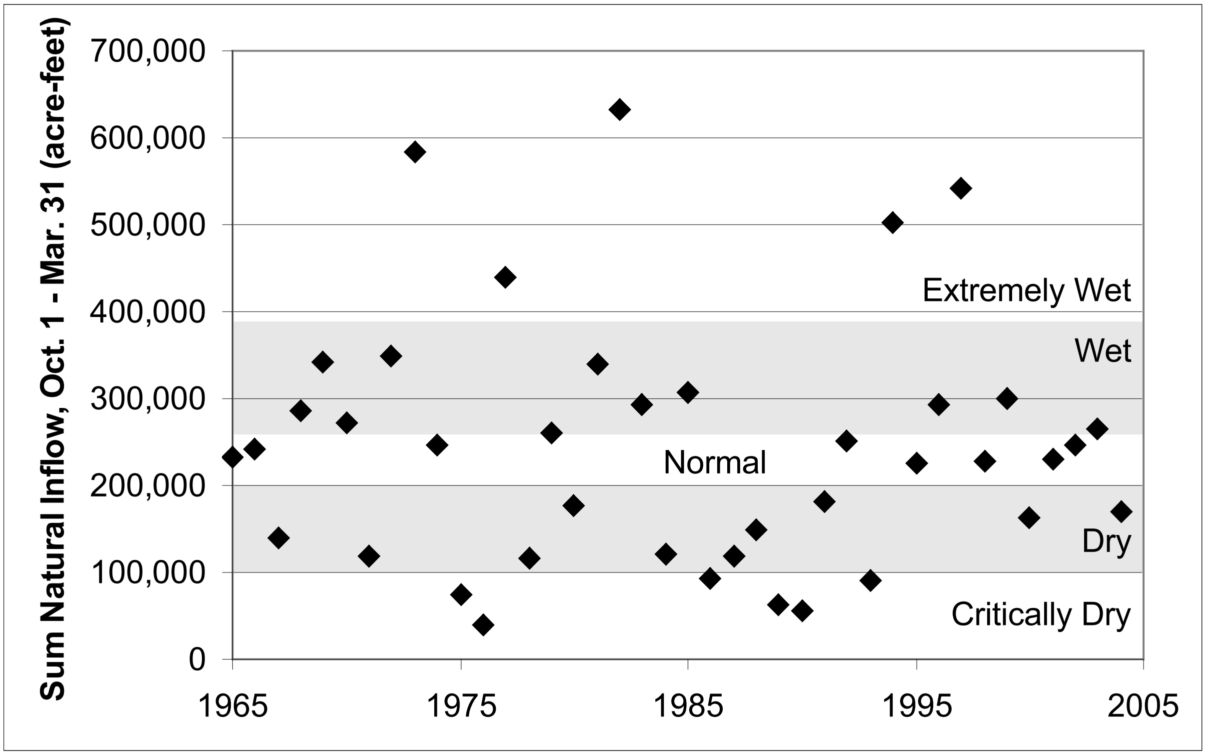


Figure 2-7: WT Reservoir / Clear Creek water year designations used in the study.

Each day of an EWP period Q_{T5} was calculated by the model. Q_{T5} was then divided by 5 to obtain the daily forecast, and used to decide whether the expected natural inflows were sufficient to make an EWP attempt, based on considering the current reservoir elevation, and diversion flows available from J.F. Carr Tunnel.

Whiskeytown elevation-storage lookup

As the model operates using a volume balance, internally the WT storage level in acre-feet is used rather than elevation. This conversion is performed using linear interpolation on a lookup table (database table tblDOHPLRWtElevationStorage) of paired (elevation, storage) values ranging from (1,086.7 ft, 18,631 acre-feet) to (1,228 ft, 301,764 acre-feet). Values up to 1,222.9 ft are based upon the Record of Design elevation-capacity values (Bureau of Reclamation 1965), and those in the range [1,223 to 1,228 ft] have been extrapolated using the equation:

$$WtStorage = (3363 * WtElevation) - 3\,828\,000 \qquad \text{(Eqn. 2-2)}$$

Whiskeytown Glory Hole discharge

There are two aspects in modeling the Glory Hole discharge: determining the elevation to achieve the required steady state Glory Hole discharge, and calculating flows and changes in elevation through the building and falling of the reservoir throughout the EWP release.

The steady state Glory Hole discharge is modeled using a simple equation that is referred to as the "falling limb" equation, where the Glory Hole flow Q is a function of the elevation, H:

$$Q(ft^3/s) = (308.36 * H^2) + (942.37 * H) \qquad \text{(Eqn. 2-3)}$$

This equation is also used to determine what the necessary elevation is to achieve the desired steady state Glory Hole flow. To do this, a quadratic solver calculates the roots of the equation to solve H for a given Q.

Modeling Glory Hole discharge *as it builds* and reaches a steady state proved to be challenging. The hydraulic process involved is highly non-linear and dynamic as the water reaches the top of the Glory Hole spillway and WT Reservoir elevation builds while water continues to spill.

After a family of curves approach was attempted, a decision was reached to abandon this method and use the best available data, namely the output from Reclamation's Flood Routing model, which resolves calculations on a 15-minute time step. The Flood Routing model was run for 11 different net inflows to WT Reservoir and 9 different starting WT elevations, generating 99 records of data with matching end elevation and average daily Glory Hole flows (Table 2-7).

Table 2-7: WT Dam Glory Hole lookup-up table matrix definition, provided by Reclamation's Flood Routing Model.

Parameter	Values	Description
WtNetFlow	{-1,100, 0, 1,000, 2,000, 3,500, 5,000, 7,500, 10,000, 15,000, 20,000, 30,000} ft^3/s	The net inflow into WT Reservoir excluding the Glory Hole (i.e. WtNetFlow = N + J.F. Carr tunnel – Spring Creek tunnel – Wt)
WtStartElevation	{1,210, 1,211, 1,212, 1,212.5, 1,213, 1,215, 1,217, 1,219, 1,221} ft	Whiskeytown starting elevation
WtEndElevation	Set of computed values, ft	Whiskeytown elevation after 24 hours of a net inflow given by WtNetFlow, with an initial elevation of WtStartElevation
WtGHFlow	Set of computed values, ft^3/s	The average Glory Hole flow over the day for an initial elevation of WtStartElevation and a net inflow of WtNetFlow.

The resultant data can be visualized in Figure 2-8. To use this lookup data within the DOHPLR submodel, a 'Glory Hole calculator' was created. Internally within the calculator code, bilinear interpolation[5] is used to calculate any value from any pair of parameters.

[5] More sophisticated numerical methods (e.g. a cubic spline) could have also been employed, however it was decided that bilinear interpolation was adequate and within the degree of accuracy for this analysis.

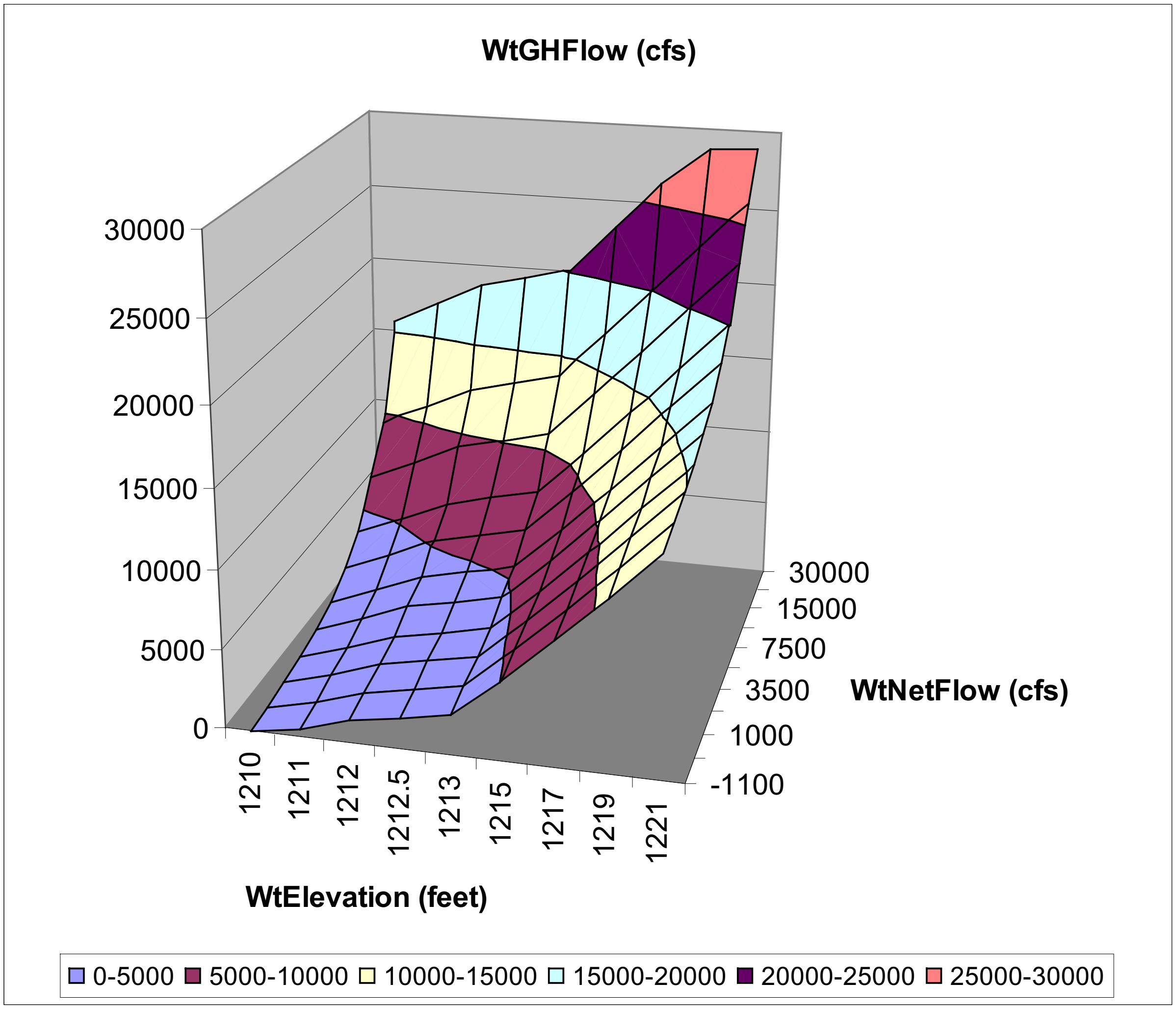


Figure 2-8: WT Glory Hole discharge, reservoir surface elevation, net inflow to WT Reservoir, and resultant daily average Glory Hole flow.

Maximizing usage of Whiskeytown outlet

CCDAM has the capability to set a monthly minimum flow for the WT outlet, and a single annual maximum. For our analysis, all months and all runs used the same range of 50 to 1,100 ft^3/s. The WT outlet is important, because it gives the model greater freedom to achieve its target flow rate. It also reduces the amount of spill that occurs when having to drive the WT elevation higher to obtain the commensurate higher Glory Hole flow.

In our simulations, the WT outlet can be opened and closed within the ranges specified in the operational settings and constraints (Table 2-3). For the purposes of this analysis, the range was fixed at 50 to 1,100 ft^3/s[6].

[6] Note: in practice the USFWS attempts to maintain at least 200 ft^3/s most of the year to provide suitable conditions for salmon and steelhead. In practice, were an actual EWP release attempted, it would be strongly desirable to avoid reducing flows below this level even for a short duration, particularly if accretions in close proximity to the Dam did not afford cut-backs from the 200 ft^3/s target.

In order to achieve a target Reach 1 flow, the elevation of WT must be raised to an elevation above the Glory Hole. Due to the physics of this process, the elevation must actually be initially raised higher than the elevation where a steady state is achieved (i.e. inflows are equal to outflows). Throughout this period—at the moment water starts to trickle down the Glory Hole and until the target flow is achieved—water is effectively being "wasted" as it empties down the Glory Hole. Discharges during this time period are often referred to as "ramping flows." Minimizing the required ramping volume and height above the Glory Hole achieves two objectives:

improves dam safety; and

reduces foregone power by reducing the cumulative volume spilled.

When calculating the necessary Glory Hole flow, WT outlet is set to the target flow less the WT outlet's maximum flow of 1,100 ft^3/s. This reduces the elevation that WT must be driven to if the Glory Hole alone were to be used to achieve the target flow.

For example, consider an EWP target flow of 4,750 ft^3/s with a starting WT Reservoir elevation of 1,210 ft. If the WT outlet is left at its minimum 50 ft^3/s, then the Glory Hole needs to provide 4,700 ft^3/s. Using the DOHPLR Glory Hole calculator, we can determine that this would require an 11,488 ft^3/s net inflow to WT Reservoir in a single day in order to realize a daily average Glory Hole release of 4,700 ft^3/s. So adding the 50 ft^3/s for Whiskeytown and subtracting Spring Creek tunnel's minimum outflow of 200 ft^3/s means J.F. Carr and natural inflows need to be **11,738 ft^3/s** in order to achieve the target EWP release.

Next, consider the situation where we maximize WT outlet releases (1,100 ft^3/s). With these flows, the Glory Hole discharge requirement falls to 3,650 ft^3/s (4,750 less 1,100). This reduces the net inflow requirement to WT Reservoir to 9,375 ft^3/s. Now, adding 1,100 ft^3/s for WT outlet releases and subtracting 200 ft^3/s for Spring Creek tunnel outflows means that J.F. Carr and natural inflows need to provide **10,675 ft^3/s.** This is a significant reduction of over 1,000 ft^3/s that would not be available without leveraging flows out of WT outlet.

Hence, maximizing the usage of the WT outlet will improve dam safety and reduce foregone power costs. It also will increase the number of chances to attempt an EWP release, as well as the probability of success.

Operational states

Within the EWP algorithm, the DOHPLR submodel can be in one of 7 states: *AtHistorical*, *BuildtToElevation*, *AtReadyElevation*, *InEWP*, *ReturnToElevation*, *ReturnToHistorical*, *Stopped*. Within the EWP algorithm for a single day, the state can change and tunnels can be re-operated more than once (e.g. may be able to *BuildToElevation*, realize there is an adequate forecast to attempt and release and switch to *InEWP*). The bulk of the EWP code developed for this analysis handles these state transitions and tunnel re-operations (Figure 2-9).

50 cfs, even for a couple of days. When we actually attempt a pulse flow we'll need to maintain the 200 cfs WT outlet release unless accretions in close proximity to the dam allow us to cut back.

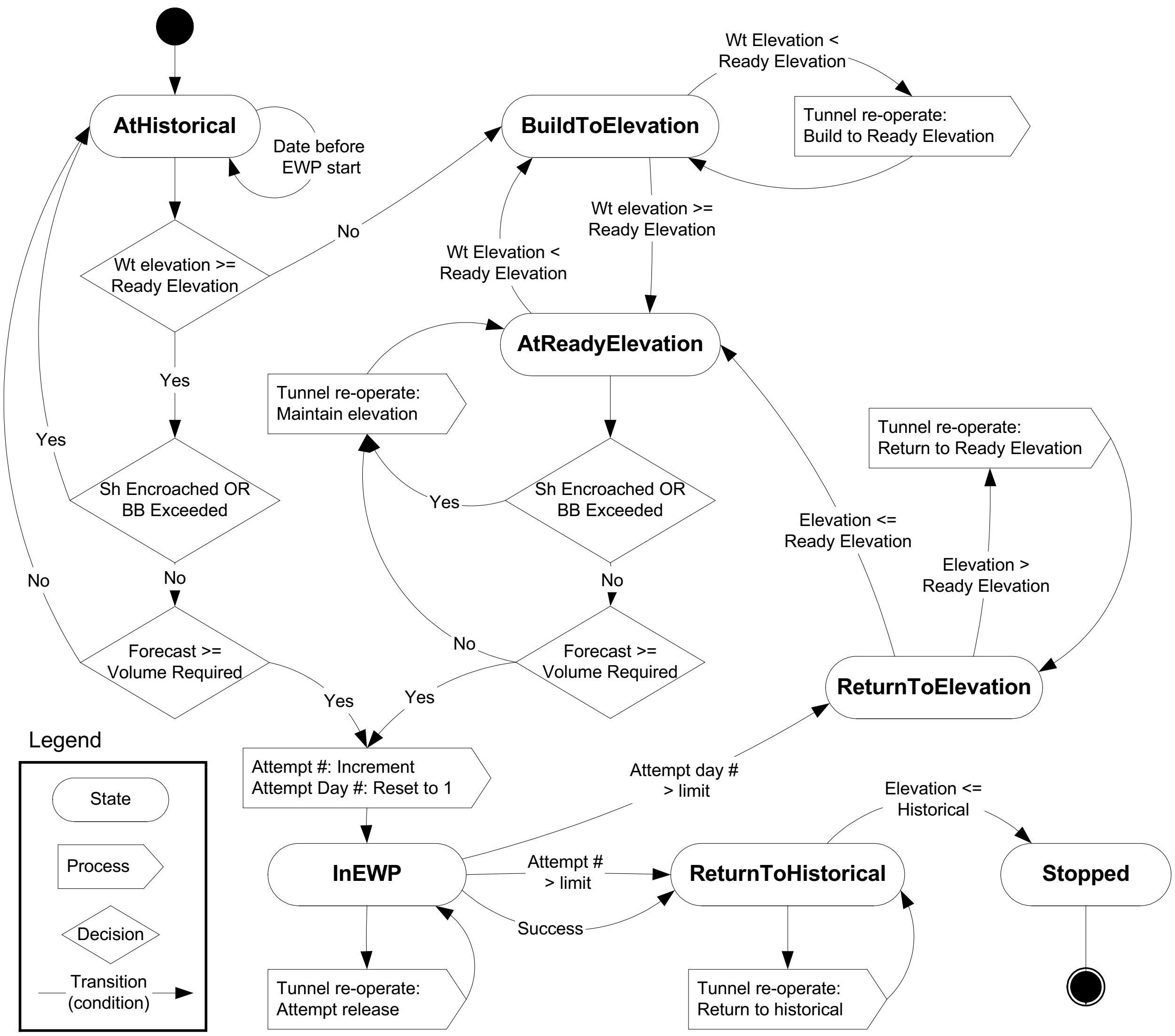


Figure 2-9: EWP algorithm for simulated WT operator behavior in response to daily reservoir elevation, daily advanced inflow forecasts and operating constraints.

The DOHPLR submodel's initial state at the beginning of every water year is *AtHistorical* (water years are treated independently), and remains at this state from January 1st until at least the start of the EWP period. The DOHPLR submodel does not leave *AtHistorical* unless conditions are favorable to do so or it needs to build to the ready elevation. The initial check on the elevation allows the model to stay in this state when using a historical ready elevation, or if Whiskeytown's historical elevation is already high (e.g. flood conditions, or late in season and building to full pool).

The *BuildToElevation* state is typically the first state transition to occur, unless within a single day the forecast is sufficient to transition immediately to *InEWP* to attempt a Glory Hole release. Otherwise, the *BuildToElevation* state is where the model will increase the elevation of WT Reservoir to the specified ready elevation.

Once the ready elevation has been reached, the model transitions to *AtReadyElevation*. Here, the model maintains elevation until there are no simulated stopping conditions and the WT Reservoir inflow forecast (plus diversion flows from J.F. Carr Tunnel) predicts enough flow and volume to attempt a release. When these conditions are met, the model transitions to *InEWP*.

In the *InEWP* state, the model tries to achieve an EWP success as quickly as possible by attempting the release in the fewest days. This process is repeated until success is achieved or a stopping condition is reached. The state then transitions to *ReturnToElevation* or *ReturnToHistorical*. These latter states simply drive down the elevation to their associated levels. When desired elevation has been reached, there is an immediate transition to *AtReadyElevation* or *Stopped*.

Modified operational constraints and states

On any given day if there is a flood hazard at Trinity or Bend Bridge flows are exceeded, the operational limits are changed per Table 2-2/Table 2-3. When the state is *AtHistorical* or *AtReadyElevation*, checks are made again on Bend Bridge before proceeding as can be seen in Figure 2-9.

The state *InEWP* differs in that once a EWP attempt has been *started*, the Bend Bridge exceeded check does not prevent the model from continuing with the attempt. Sensitivity analyses show that modified operational constraints would typically have little to no effect when *InEWP*. When *InEWP*, J.F. Carr Tunnel is typically opened to it's maximum (3,400 ft^3/s) and Spring Creek tunnel outflows are throttled to their minimum (200 ft^3/s) to obtain the required Glory Hole flows. In our simulations, if Trinity reservoir was in flood hazard, only J.F. Carr Tunnel's minimum inflows are modified (set to the maximum of its minimum or historical flow), with no effect on J.F. Carr's maximum. A similar but converse situation applies to Spring Creek, where if Bend Bridge is exceeded, Spring Creek Tunnel's outflows are set to the maximum of its minimum or the historical value, with no change on its minimum.

Modified operational constraints do, however, have a strong effect when the state is *ReturnToElevation* or *ReturnToHistorical*. In these states, the model will typically be trying to reduce J.F. Carr Tunnel to its minimum and increase Spring Creek Tunnel to its maximum, to bring down Whiskeytown Reservoir's water surface elevation as quickly as possible. If the tunnel limits have been modified by constraints, this will prolong the time required to decrease the elevation. This in turn will likely increase foregone power costs, especially if water is spilling through the Glory Hole at a faster rate (due to an elevated WT Reservoir elevation).

Tunnel re-operation processes

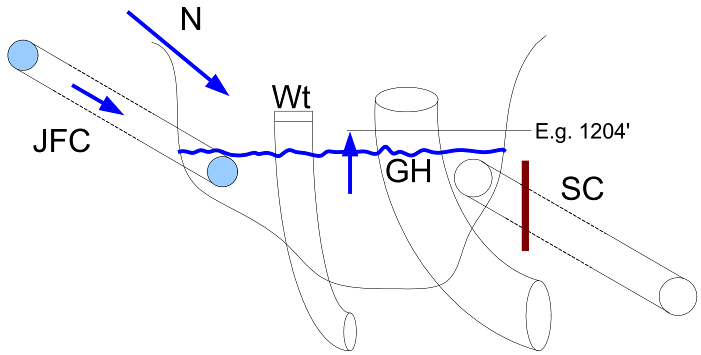
The process of 'Tunnel Re-operation', as shown in Figure 2-9, has different forms depending upon the state the model is in at the time. The following figures illustrate the actions that are taken. Note that the adjusted operational constraints are **always** in effect (e.g. if Bend Bridge flows are exceeded, then Spring Creek's maximum is not 4,300 ft^3/s but rather the maximum of its 200 ft^3/s and the historical value for the day). Further, these are descriptions of the process itself where the model must have entered the state first (e.g. the process of attempting a release is always preceded by checking whether Bend Bridge flows are exceeded, in addition to there being an adequate inflow forecast).

Below, a series of diagrams are used to illustrate reservoir states and tunnel re-operation processes.

Process: Maintain Elevation

For this process, J.F. Carr and Spring Creek Tunnels are set based upon the predicted daily forecast of natural inflows, in order to maintain the elevation of WT Reservoir.

Process: Build to ready elevation



Objective: Build to ready elevation (or historical, whichever is higher).

Safety Constraints: BB cannot be exceeded.

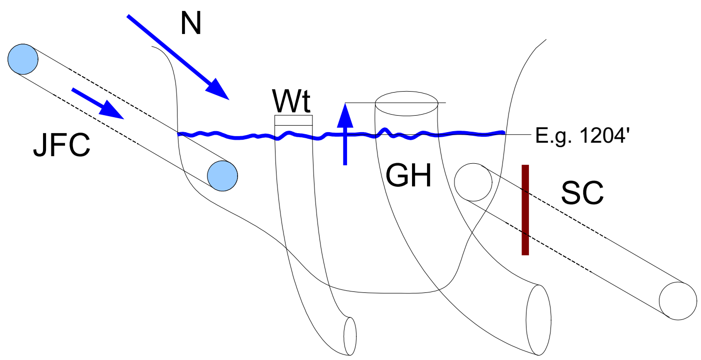
Actions:

J.F. Carr tunnel – opened to its maximum

Spring Creek tunnel – reduced to its minimum.

WT – Minimize WT outlet releases.

Process: Attempt EWP release – Step 1



Objective: Build to the top of the Glory Hole.

Requirements: WT inflow forecast plus diversion flows from J.F. Carr must be adequate.

Actions:

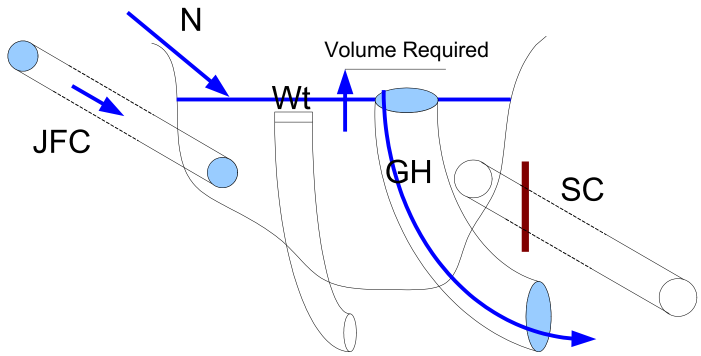
J.F. Carr tunnel – open to its maximum.

Spring Creek tunnel – reduce to its minimum.

Shasta – Maintain volume balance on Sacramento (typically requires increasing Shasta/Keswick flows).

WT – Minimize WT outlet releases.

Process: Attempt Release - Step 2



Objective: Build to the required height above Glory Hole to achieve target flow.

Requirements: WT inflow forecast plus diversion flows from J.F. Carr must be adequate.

Actions:

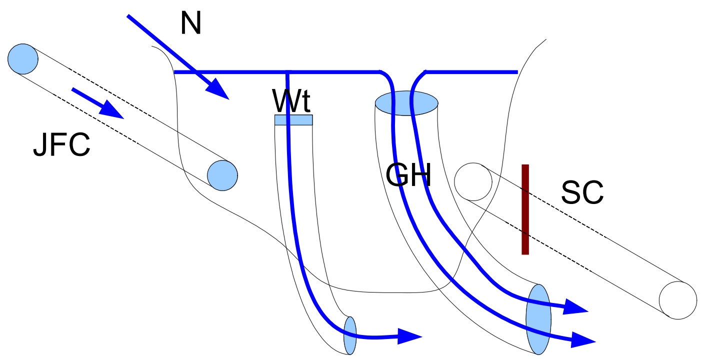
J.F. Carr tunnel – open to its maximum.

Spring Creek tunnel – reduce to its minimum.

Shasta – Maintain volume balance on Sacramento (typically requires increasing Shasta/Keswick flows).

WT – Minimize WT outlet releases until reach reservoir elevation target.

Process: Attempt Release - Step 3



Objective: Sustain the required height above Glory Hole to achieve target flow.

Requirements: WT inflow forecast plus diversion flows from J.F. Carr must be adequate.

Actions:

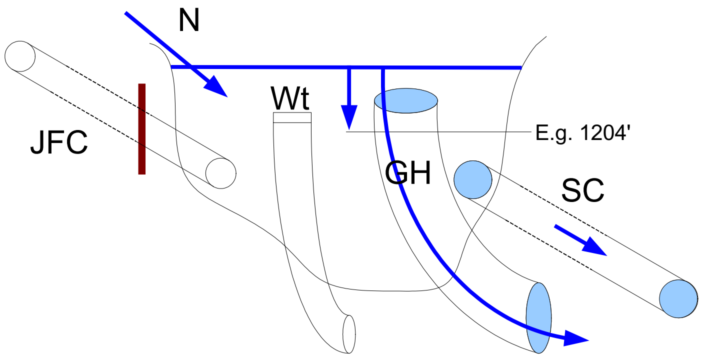
J.F. Carr tunnel – open to its maximum.

Spring Creek tunnel – reduce to its minimum.

WT – Maximize WT outlet.

Shasta – Maintain volume balance on Sacramento (typically requires increasing Shasta/Keswick flows).

Process: Return to ready elevation



Objective: Reduce as quickly as possible to ready elevation.

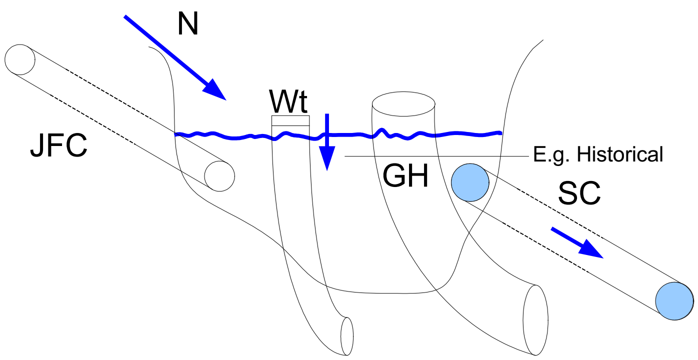
Requirements: None.

Actions:

- J.F. Carr tunnel – reduce to its minimum.
- Spring Creek tunnel – open to its maximum.
- WT outlet – reduce to its historical flow[7].
- Shasta – Maintain volume balance on Sacramento (typically requires decreasing Shasta/Keswick flows).

Within this process, the desire is to reduce the elevation as quickly as possible to maximize dam safety. As well, this approach minimizes foregone power costs—the more water pushed through Spring Creek, the less that is passively spilled through the Glory Hole.

Process: Return to Historical



Objective: Reduce as quickly as possible to historical elevation.

Requirements: None.

Actions:

- J.F. Carr tunnel – Reduce to its minimum.
- Spring Creek tunnel – Open to its maximum.
- WT outlet – Reduce to its historical flow.
- Shasta – Maintain volume balance on Sacramento (typically requires decreasing Shasta/Keswick flows).

Note that the historical elevation may actually be at or above the ready elevation. If so, then from the state transition diagram (Figure 2-9) the state immediately changes to *Stopped,* and the EWP algorithm is finished for the water year.

[7] Note: in practice a real-world operator may choose to open WT outlet to it's maximum during the return to ready or return to historical phases. We did not do this in our simulations, as we found that using Spring Creek had the benefit of generating more power revenues (reducing foregone power) than if this flow were passed through WT outlet.

Case study

Prior to attempting an EWP release the DOHPLR submodel must first determine if there is adequate inflows forecast that will yield the desired Reach 1 flow. If the WT Reservoir elevation is lower than the top of the Glory Hole, the first step is to calculate the volume of water necessary to bring it to 1,210 ft. Next the model uses the quadratic solver on the falling limb equation to calculate the elevation required for the steady state target Glory Hole flow, Q. If we wanted a flow of 3,270 ft^3/s, then the corresponding steady state elevation is approximately 1,212 ft. With the target WT Reservoir elevation known, the Glory Hole calculator determines the net inflow required from natural inflow and diversion flows given the current reservoir elevation.

Assuming a starting WT Reservoir elevation of 1,210 ft, the Glory Hole calculator determines that a net inflow of 4,853 ft^3/s would be required to reach an elevation of 1,212 ft at the end of the day. (During this initial 'ramping' phase, the model also accounts for an average daily Glory Hole flow on that day of 1,555 ft^3/s)

If the target duration is 2 days, then the total volume required would be the sum of the 4,853 ft^3/s ramping flow plus $2 \times 3{,}270$ ft^3/s for the 2-day duration, converted into acre-feet. The expected inflow volume is calculated by diverting as much flow as possible through tunnel re-operation (i.e. increasing J.F. Carr Tunnel flows and reducing Spring Creek Tunnel), plus the expected forecast for the next 5 days. If this expected volume is greater than or equal to the total volume required, then the model changes state to *InEWP*.

If the state is already *InEWP*, the Glory Hole calculator is used right away. In any case, once the state is *InEWP* the Glory Hole calculates the net inflow based upon the known reservoir start elevation and target Glory Hole flow. Tunnels are then re-operated based upon the net inflow required and the expected daily forecast. Once this step has been performed where tunnel flows are set, the actual historical natural inflow is added and the true Glory Hole discharge calculated. The process of setting the tunnel flows based upon the expected forecast, and then determining the actual Glory Hole discharge subsequently helps account for the uncertainty that would be faced by a real-world operator.

Intra-day sequence of events

Table 2-8 provides the full sequence of events that occurs each day, with the handling of state transitions and tunnel re-operations.

Table 2-8: Intra-day sequence of events for handling state transitions and tunnel re-operations.

a)	Review Operational Constraints	Whiskeytown elevation allowed to rise to the max(historical, ready elevation) Whiskeytown outlet minimum flow = max(50, historical) Determine if Trinity has a flood hazard or Bend Bridge exceeded. Adjust J.F. Carr Tunnel's minimum and Spring Creek Tunnel's maximum accordingly.
b)	Calculate WT Reservoir inflow forecast	Based upon prior 5 days Convert to expected daily volume
c)	Reach 5 Emergency Stop?	If lower Clear Creek Reach 5 flow exceeds 9,100 ft^3/s, bring operations to a halt for the year. Set state = *ReturnToHistorical*.
d)	Verify AtHistorical/ AtReadyElevation	If elevation is below ready elevation and *AtHistorical* or *AtReadyElevation*, set state = *BuildToElevation*.
e)	Verify InEWP	Evaluate if a success has occurred. If so, set state = *ReturnToHistorical*. If not, determine the remaining volume required for success[8]. Increment attempt day #
f)	Transition States and Process	Algorithm to move through state transition diagram, processing and re-operating tunnels for what is possible within a 24 period.
g)	Set J.F. Carr Tunnel, WT outlet, Spring Creek Tunnel	If have not yet left *AtHistorical* state (i.e. State = *AtHistorical*), then simply output the historical data. Otherwise, use the values set in (f).
h)	Calculate Glory Hole flow	Using the Glory Hole calculator, determine what if any flow passes through the Glory Hole
i)	Adjust Shasta flows	Attempt to maintain a volume balance on the Sacramento River by adjusting Shasta / Keswick flows
j)	Foregone Power	Calculate foregone power
k)	Stopping Conditions	Check the stopping conditions and set state accordingly Stop on Cost -> *ReturnToHistorical* Stop on Volume -> *ReturnToElevation* Stop on Continuous Days -> *ReturnToElevation*
l)	Check # of attempts	If number of attempts has been exceeded, set state = *ReturnToHistorical*

Flow downstream of WT Dam

Calculation of daily average flow in each of CCDAM's 5 reaches is also the responsibility of the DOHPLR submodel. This includes calculation of downstream accretion flows and water temperatures (Alexander et al. 2003). DOHPLR incorporates historical daily data on inflows and outflows from WT Reservoir from January 1965 onwards together with stream gage measurements at Igo gage and a proportionate drainage-area based reconstruction of daily run-off to the 5 downstream reaches.

Accretion flows in each reach of Clear Creek downstream from WT Dam are based on estimated tributary inputs between WT Dam and Igo gage (reaches 1 to 3). These values are available from the historical record. Accretion inflows to each reach are adjusted based on the drainage areas of each reach relative to the drainage area between Whiskeytown and Igo gage, and a "runoff adjustment" to account for spatial differences in precipitation (Eqn. 2-4).

[8] Note that this is conservative as it is based upon the forecast at the start of the day where in reality the Operator would dynamically re-operate over the course of the day.

$TRIBFLOW_{i,d} = AREA_i / AREA_{WTtoIGO} * TRIB_{WTtoIGO,HIST,d} * RUNOFFADJ_{i,m}$ Eqn. 2-4

where:

TRIBFLOWi,d	=	daily mean tributary/catchment inflow to reach i (ft^3/s);
AREAi	=	area (hectares) of drainage for reach i
TRIBWTtoIGO,HIST,d	=	daily mean tributary inflow between Whiskeytown and IGO (ft^3/s)
RUNOFFADJi,m	=	runoff adjustment for reach *i*, month *m*. DOHPLR computes a month and reach-specific adjustment factor as the average precipitation in reach *i*, month *m* ÷ ave. precipitation in reaches 1-3, month *m*. Monthly average precipitation in each reach was interpolated from the precipitation data from stations at WT Dam (1993-2001) and Redding Fire Station (1989-2001), adjusted by the relative distance of each reach relative to these two measuring points. We note other reach-specific factors will also affect the relative accretion inflow to each reach. For example, reaches with steeper terrain and less permeable geology would likely have higher tributary inflows. Our precipitation-based runoff adjustment factors do not consider such factors, but they can be calibrated with information from new downstream gages.

The total flow in a particular day and reach is:

FLOWi,d = TRIBFLOWi,d + FLOWi-1,d Eqn. 2-5

where:

$TRIBFLOW_{i,d}$	=	daily mean tributary inflow to reach i (ft^3/s) from Eqn. 2-4;
$FLOW_{i-1,d}$	=	daily mean flow in the reach immediately upstream from reach i (ft^3/s). For reach 1 (the reach just below WT Dam), $FLOW_{i-1,d}$ = $CLEAR_{OUT}$, the flow released from Whiskeytown given the inflows for that day and the WT Dam operator rules specified by the user.

Reviewers of this approach have noted that it would be valuable to have a gage lower down in the river (e.g., near the Anderson Cottonwood Irrigation District (A.C.I.D.) siphon) to calibrate the assumed inflows from the watershed in reaches 4 and 5. Graham Matthews and Associates observed accretion flows during storms (>2,000 ft^3/s) between Igo and CCDAM reach 5 in the range of 20%. CCDAM model accretion flows between reach 2 and 5 (Eqn. 2-5) typically vary between 6% to 23% depending on time of year.

2.2.8 Approximation of foregone power costs

Foregone power costs refer to the cost associated with water that was spilled down the Glory Hole (and WT outlet) during an EWP attempt which could have otherwise been used to generate power through various tunnels and power plants directly linked with WT Reservoir. Five power plants are considered in these calculations: Spring Creek, J.F. Carr, Trinity Dam, Shasta Dam and Keswick Dam. Another factor considered is timing, in that the model can look at the cost of re-operating tunnels at a time in the winter or spring when power rates are lower than utilizing the same volume of water when rates are highest (e.g., summer).

While an explicit volume balance is not performed on the actual Trinity / Shasta Reservoirs themselves, the DOHPLR submodel does assume that the Trinity River and Sacramento River *flows* are kept *constant* as a result of any of J.F. Carr or Spring Creek Tunnel re-operations. On the Trinity River side, this means that the model can only utilize the Trinity generator capacity left after removing the historical flow. Water used in excess of the generator capacity generates no revenue.

For the Shasta / Keswick system, the difference between the modeled and historical net flow through Spring Creek and Clear Creek must be compensated by bringing more or less water through Shasta and on to Keswick in order to maintain a "volume balance" on the Sacramento River. Similar to the Trinity generator, if more water is required through either of these generators than they have capacity for in order to volume balance the Sacramento, then the model generates no revenue for this surplus water.

Foregone power costs are calculated at the end of each day, after any tunnel re-operation has been performed and flows calculated. The cumulative cost is also checked at the end of each day, to make sure that the cost for the year does not exceed the annual budget (e.g., \$2.6 million for runs 1-14) – changing the state to *ReturnToHistorical* if exceeded. In our simulations, we calculated foregone power for all of the generators (Trinity, J.F. Carr, Spring Creek, Shasta, Keswick) except for WT outlet, which was ignored due to its relatively small power generation capability and the limited change to these flows in our simulations. The general form of the equation is:

$$\$\mathrm{Foregone}_d = [\mathrm{Price}_{MAX} \times \mathit{Power}(V_{EWP} - V_{Hist})] + [\mathrm{Price}_d \times \{\mathit{Power}(V_{Hist}) - \mathit{Power}(V_{EWP})\}] \qquad \text{Eqn. 2-6}$$

where:

Price_{MAX}	=	Maximum price possible for the year (\$/MWhr).
Price_d	=	Price on the given day, *d* (\$/MWhr).
V_{EWP}	=	Modeled volume of water through generator, limited to generator capacity (for Trinity/Shasta/Keswick, generator capacity is reduced by V_{Hist}) (acre-feet).
V_{Hist}	=	Historical volume of water through generator, limited to generator capacity (acre-feet).
Power(Volume)	=	Generator-specific function that determines power output based upon gross head and volume of water (MWhr).

The *Power* function differs for each of the generators and have been listed in Appendix A. The first part of the equation deals with the price shift (optional), by taking the product of the maximum yearly price possible and the marginal volume (EWP volume less historical, where negative values ("made money") is allowed) that passed through the generator. The second part handles the power generated by the powerhouse for the given day, taking the difference between historical and modeled EWP values. The foregone power is calculated for each of the generators daily, and summed.

The set of runs performed includes two basic cases: (a) power price changes over the year ("shift"), and (b) where the price remains fixed ("no shift"). For the latter case ("no shift"), the first component in Eqn. 2-6 cancels out providing the generator capacity is not exceeded (for the J.F. Carr and Spring Creek Tunnels this is always the case as the maximum flow is equal to the generator capacity).

2.2.9 EWP performance measures

The CCDAM performance measures used to characterize EWP results were selected and defined by Reclamation in collaboration with ESSA's project team. In addition to reporting the number of EWP attempts and successes in each model run, we also tracked:

- the volume of water (acre-ft) spilled through the Glory Hole;
- the estimated cost of foregone power; and
- the number of EWP attempts stopped for reasons other than success.

Each performance measure, along with a brief description, is listed in Table 2-9.

Table 2-9: CCDAM performance measures.

Performance Measure	Units	Description
EWP Attempts	#	The number of times over the 40 years of a model run where the dam operator tries to achieve defined EWP target flows during the EWP Period; if an EWP Attempt succeeds in lower Clear Creek Reach 1 (LCC1), no further attempts will be made during that Period; if the first attempt fails in LCC1, a second EWP Attempt in that same Period can be made (maximum of 2 EWP Attempts per EWP Period).
Successful EWP Releases – Lower Clear Creek Reach 1 (LCC1)	#	The number of times over the 40 years of a model run where an EWP Attempt is successful in LCC1; during the EWP Period of any given year, there can only be one successful EWP Release in Reach 1.
Successful EWP Releases – Lower Clear Creek Reach 5 (LCC5)	#	The number of times over the 40 years of a model run where an EWP Attempt is successful in LCC5; during the EWP Period of any given year, there can be a maximum of two successful EWP Releases in Reach 5.
Glory Hole Volume Released during EWP Period	acre-ft	The total volume of water spilled through the Glory Hole during the EWP Period for each year in the 40 years of a model run; values of 0 are treated as null only if there is no operator intervention during the EWP Period (i.e., the reservoir is at historical levels throughout).
Foregone Power Cost	$ (thousands)	The total cost in foregone power for each year in the 40 years of a model run; for years with successful EWP Releases in LCC1 (i.e., when the model is stopped by success), foregone power is summed from the start of the EWP Period to the end of the EWP Attempt + 1 day; for years with failed EWP Attempts in LCC1, foregone power is summed over the entire EWP Period; for runs based on non-historical ready elevations where no EWP Attempt is made, foregone power costs are summed from the start of the EWP Period to the end of the build-to-elevation phase +1 day; values of 0 are treated as null only if there is no operator intervention during the EWP Period (i.e., the reservoir is at historical levels throughout).
Foregone Power Costs with *profits* over $500K omitted	$ (thousands)	Same reporting rules as for Foregone Power Costs above, but with values < -$500,000 omitted from the analysis.
EWP Attempt Stopped by Lower Clear Creek Flows	#	The number of times over a 40 year model run where an EWP Attempt was stopped because flows on Lower Clear Creek exceeded defined tolerance limits (9,100 ft^3/s).
EWP Attempt Stopped by Insufficient Water	#	The number of times over a 40 year model run where an EWP Attempt was stopped because the number of continuous days without success exceeded defined tolerance limits.
EWP Attempt Stopped by Cost	#	The number of times over a 40 year model run where an EWP Attempt was stopped because the cost of foregone power exceeded defined tolerance limits.

2.3. Determination of dam safety risks owing to EWP events

2.3.1 Dam safety risk analysis methodology

This section is intended to provide a summary on the dam safety methodology which is documented in ***Dam Safety Risk Analysis Methodology*** (Bureau of Reclamation, 2003a) and ***Guidelines for Achieving Public Protection in Dam Safety Decision Making*** (Bureau of Reclamation, 2003b). The objective of Reclamation's Dam Safety Program is to ensure that Reclamation water impounding structures do not create unacceptable risks to public safety and welfare, property, the environment, and cultural resources. This objective is aimed at fulfilling the Federal Government's trust responsibilities for the safety and welfare of the downstream public. In a dam safety context, the event of interest is an uncontrolled release of the reservoir and the resulting consequences which may include loss of life, economic loss, or other adverse consequences. Quantitative estimates of dam failure risk require quantifying the likelihood of loads, adverse responses given the load, and adverse consequences given a failure occurs, as well as the uncertainties associated with each. The quantitative measure of risk is computed by the following equation:

Risk = P[load] x P[Adverse Response given the load] x Adverse Consequence given the failure

Eqn. 2-7

The dam safety risks are the potential risks associated with operating WT Dam according to its current criteria or using modified criteria. For the purposes of the analysis of risk, as discussed by Reclamation (Bureau of Reclamation 2003), Annual Failure Probability (APF) is defined as (Probability of Load or *P[load]*) x (Probability of Failure Given the Load or *P[Adverse Response given the load]*). Annualized Loss of Life is defined as (Annual Failure Probability) x (Fatalities Given Failure). By definition, risk includes both likelihood of failure and consequences. Therefore, Annualized Loss of Life is sometimes referred to as "risk" in this section. The risk can be plotted in a log-log chart (f-N) showing annual probability of failure (f) on the ordinate and loss of life (N) on the abscissa.

The potential failure modes are determined to clarify the load and potential responses for a structure. The potential failure modes are associated with operation during normal conditions (static), flood loadings (hydrologic), and earthquake (seismic) loadings. The Issue Evaluation (Bureau of Reclamation 2006a) indicated two potential failure modes with static loadings, two potential failure modes associated with hydrologic loadings, and one potential failure mode associated with seismic loadings.

The methodology associated with computing the potential loss of life is determined using the methodology presented in "A Procedure for Estimating Loss of Life Caused by Dam Failure," (Bureau of Reclamation, 1999).

Reclamation generally uses an event tree approach to estimate the risk. An event tree is the specific identified failure mechanism for a structure and encompasses the load, the response of the structure, and the consequences. In the re-operation of Whiskeytown Dam, the potential increase in risk is due to hydrologic loading and the potential piping through the embankment when the reservoir is above the spillway crest, elevation 1210. A generic example of a static internal erosion event tree is as follows (see Figure 2-10):

↳Reservoir Rises

↳Initiation – Flaw exists

↳Initiation – Erosion starts

↳Continuation – Unfiltered exit exists (consider: no erosion/some erosion/excessive erosion/continuing erosion)

↳Progression – Roof forms

↳Progression – Upstream zone fails to crack stop

↳Progression – Upstream zone fails to limit flows

↳Intervention fails

↳Dam breaches (consider all likely breach mechanisms)

↳Consequences occur

Figure 2-10: Example Event Tree for Static Internal Erosion.

A specific event tree is developed for each loading condition (static, hydrologic, and seismic) and each potential failure mode with branches on the event tree for the different levels of loading, and different responses. The development of event trees can become complicated; therefore this investigation attempts to develop event trees suitable for evaluating the effects of the re-operation plan without getting too detailed. Each event tree for each potential failure mode is somewhat unique due to specific conditions at that dam. In this study for WT Dam, the static condition is considered for all reservoir water surface elevations up to the morning glory spillway crest, elevation 1210. There are two potential static failure modes: one involves piping of the embankment Zone 1 material through the Zone 3 and Zone 4 material and the second involves piping of the embankment Zone 1 material through discontinuities in the foundation rock.

When the reservoir water surface exceeds the spillway crest, the risks are developed from the potential hydrologic loading case. Two potential hydrologic failure modes were identified for Whiskeytown Dam – overtopping induced failure of the dam and failure of the dam, and piping through the embankment due to elevated reservoir water surface elevations during flooding when the reservoir water surface is above the elevation of the spillway crest, elevation 1210. A hydrologic loading involves the determination of a flood and its return period which is routed through the reservoir to determine an associated maximum reservoir water surface elevation. The response of the dam is estimated by examining each component of the dam failure process to determine the dam failure probability if the load were to occur. Lastly, the consequences for each potential failure mode are determined.

The hydrologic loading ranges from the reservoir water surface just above the spillway crest up to overtopping of the dam during extremely large floods. Reclamation has developed methodology for determining the Probable Maximum Floods (PMFs) based on meteorological conditions and stream gage data (Bureau of Reclamation 1987). The PMFs have no associated return period and are typically reported for design and comparison to the frequency floods. Reclamation develops a hydrologic hazard analysis to define floods and their frequency occurrence (100- to 10,000,000-year and greater return periods). The hydrologic hazard analysis is based on collected information from stream gage data, paleohydrology data, and PMF data to develop the frequency floods. The hydrologic loading event tree is then developed to include all levels of flood loading. The floods are routed through the dam using operational information, reservoir capacity data, and release capacity to determine the impacts on the dam. The behavior of the reservoir is used to develop the structural response probability for various loadings. The time or duration the reservoir is above a specified elevation is considered in preparing estimates of the potential response of the structure.

The seismic loading results from the frequency of various earthquakes. The seismic dam failure probability combines the seismic hazard curve with the associated response of the dam including seepage erosion through cracks resulting from the shaking. The seismic risk results from multiplying the seismic dam failure probability by the potential consequences.

There is uncertainty associated with computations of the Annual Probability of Failure (APF) and the Annualized Loss of Life (ALL). Reclamation uses an f-N chart to graphically display the expected APF and the expected ALL as well as the uncertainty associated with each. The f-N plot for WT Dam is shown in Figure 2-11 with the ALL on the abscissa and APF on the ordinate. The estimated probable uncertainty bands are plotted next to the axis.

The f-N plot also shows the Reclamation guidelines. The horizontal dashed line at an APF of 0.0001 is the Reclamation guideline. If the expected APF is greater than 0.0001, the justification to implement risk reduction actions increases as the estimates become greater than 0.0001. If the expected APF is less than 0.0001 then the justification to implement risk reduction actions diminishes as the estimates become smaller. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decision-making. Actions considered reasonable and prudent should be contemplated for implementation when the APF is greater than 0.0001 (i.e., higher than the guideline).

The dashed lines from the upper left to lower right of the f-N chart show the guidelines for the ALL which is a product of the APF and the Loss of Life. Reclamation considers that there is justification for taking expedited action to reduce risk if the estimated risk is portrayed to be greater than 0.01 lives/year. If the estimated risk is portrayed between 0.01 and 0.001 lives/year Reclamation considers that there is justification for taking action to reduce risk. When the range of risk estimates falls in the range of 0.01 to 0.001, there are a wide variety of possible actions which may be appropriate. However, the actions can be scheduled into the dam safety program and coordinated with other needs at the facility or at other facilities. Actions to reduce risk should be implemented on a schedule that is consistent with budgeting and appropriations processes. If the estimated risk is portrayed to be less than 0.001 lives/year, the justification to implement risk reduction actions or conduct additional studies diminishes. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decision-making. Actions considered reasonable and prudent should be considered for implementation when the risk is less than 0.001.

2.3.2 Dam safety risks - existing

Consequences

As indicated in previous sections, there are three parts to estimating the risk at a structure: the load probability, the response of the structure, and the consequences. The consequences downstream of Whiskeytown Dam (WT) were developed for the 2003 Comprehensive Facility Review (CFR) (Bureau of Reclamation 2003c) and reviewed during an Issue Evaluation (IE) study performed for Whiskeytown Dam (Bureau of Reclamation 2006a) There are three areas where there is the potential for significant consequences based on less than 2 hours flood wave travel time:

1. a primitive campground and an environmental camp (N.E.E.D.) for grade school children located in the canyon near the river just downstream of the dam;
2. a population at risk at the southern end of Redding with a newly constructed casino adjacent to the river; and
3. the town of Anderson (population over 9,000) may be inundated at low to medium severity for a "sunny day" failure.

These and additional location specific consequences are provided in Table 2-10 for the hydrologic loading condition only. The estimated loss of life for a hydrologic event ranges from 12 to 130 with an expected mean of 69. Table 2.10 indicates how the consequences were determined and where the greatest number of potential lives will be lost. The estimated loss of life for a static or seismic event was computed similarly and ranges from 42 to 369 with an expected mean of 199. These values are the same as in the 2006 CFR, but show an increase for the hydrologic event from the 2003 CFR.

Table 2-10: Loss of life for a dam failure and breach condition during a hydrologic event (from 2006 Decision Document and Report of Findings)

Reach	Severity	Warning	Under-standing of Warning	PAR	Fatality Rate L,M,H	Fatalities L,M,H	Mean
Peltier Bridge Primitive Camp	H*	>60 min	Vague	0	.3,.75,1.0	0,0,0	0
NEED Camp at Paige Bar	H	>60 min	Vague	0	.3,.75,1.0	0,0,0	0
Southern Redding	L to M	>60 min	Vague	1,100	0.003, 0.015, 0.03	3,17,33	18
Anderson	L to M	>60 min	Precise	9,130	0.001,0.005, 0.01	9,46,91	49
Red Bluff	L	>60 min	Precise	8,470	0,.0002,.0004	0,2,3	2
Gerber	L	>60 min	Precise	1,050	0,.0002,.0004	0,0,0	0
Los Molinos/Tehama	L	>60 min	Precise	1,880	0,.0002,.0004	0,0,1	0
Further Downstream	L	>60 min	Precise	5,480	0,.0002,.0004	0,1,2	1
Total						12,66,130	69

L = Low, M = Medium, H = High

Annual Probability of Failure and Annualized Loss of Life (Risk)

The total risk at WT Dam is comprised of the sum of the static risk, the hydrologic risk and the seismic risk. The largest contributor to the risk at WT is due to the hydrologic loading failure modes, as both the overtopping during a large flood and piping due to high reservoir water surface elevations. The estimated *existing* annual probability of failure due to the hydrologic loading of WT Dam from the 2006 IE is 1.19×10^{-4} and the annualized loss of life (based on the expected mean consequence estimate of 69) is 8.21×10^{-3}. This risk is similar to that developed during the 2003 CFR (annual probability of failure was 3×10^{-4} and annualized loss of life of 5.5E-03) and is based on the failure of the main dam with its resulting breach outflows. The 2006 (current) expected static, hydrologic, and seismic risks are shown in figure (see Table 2-11 is a summary of the risks, Figure 2-11 is the f-N plot, and Table 2-12 show the details of the calculations from the 2006 IE). As a comparison the 2003 CFR risk plot and details are shown in

Table 2.11 also shows Reclamation guidelines. The hydrologic risk for WT is in an area where there is increasing justification to take action for both the AFP and ALL.

Table 2-11: Reclamation guidelines and existing risks based on current operation (based on 2006 IE).

Loading Condition	Expected Annual Probability of Failure (range)	Expected Consequences Loss of Life (range)	Expected Annual Loss of Life (range)
Total Static	1.80E-06	199	3.58E-04
Total Seismic	2.0E-07	199	3.98E-05
Total Hydrologic	1.19E-04	69	8.21E-03
Guidelines	**1.0E-04**		**1.0E-03**

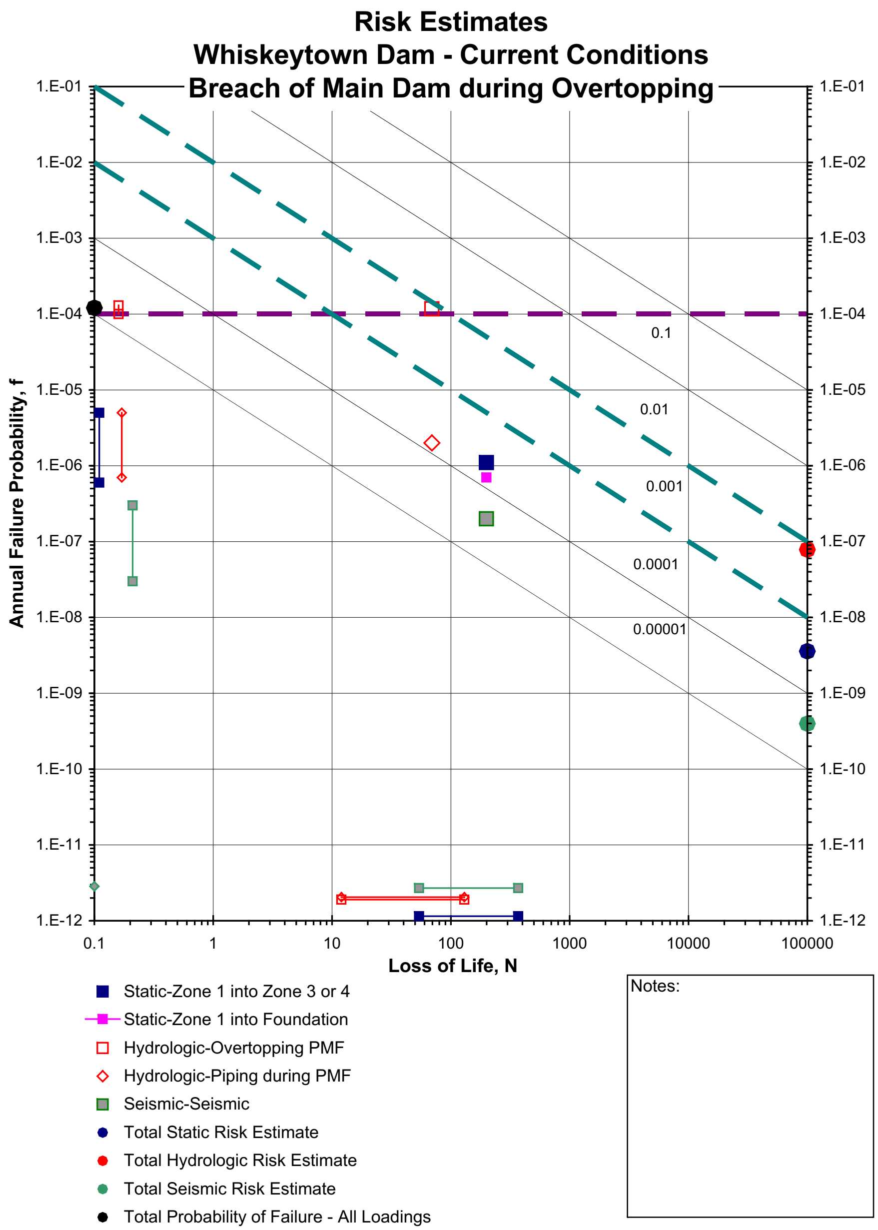


Figure 2-11: 2006 IE Portrayal of risks for existing conditions at WT Dam.

Risk Results

Facility	WHISKEYTOWN	Author	E.A. Cohen
Region	MP	Checked	
Product	IE	Notes	Recreated from IE by EAC on 12/5/2007
Source Document	2006 IE and Decision D(		
Date of Chart	05-12-2007 Redrawn by EAC		

Analysis of Risk From Source Document

Failure Mode	Mean Probability of Failure Estimate			Mean Loss of Life Estimate			Mean Total Risk Estimate		
	Low	Expected	High	Low	Expected	High	Low	Expected	High
Static									
1 Zone 1 into Zone 3 or 4	6.00E-07	1.10E-06	5.00E-06	54	199	369	3.24E-05	2.19E-04	1.85E-03
2 Zone 1 into foundation	6.00E-07	7.00E-07	5.00E-06	54	199	369	3.24E-05	1.39E-04	1.85E-03
Total	1.20E-06	1.80E-06	1.00E-05	54	199	369	6.48E-05	3.58E-04	3.69E-03
Hydrologic									
1 Overtopping PMF	1.00E-04	1.17E-04	1.30E-04	12	69	130	1.20E-03	8.07E-03	1.69E-02
2 Piping PMF	7.00E-07	2.00E-06	5.00E-06	12	69	130	8.40E-06	1.39E-04	6.50E-04
Total	1.01E-04	1.19E-04	1.35E-04	12	69	130	1.21E-03	8.21E-03	1.76E-02
Seismic									
1 Seimsic - crack erosion	3.00E-08	2.00E-07	3.00E-07	54	199	369	1.62E-06	3.98E-05	1.11E-04
Total	3.00E-08	2.00E-07	3.00E-07	54	199	369	1.62E-06	3.98E-05	1.11E-04

Table 2-12 2006 IE Risk Calculations

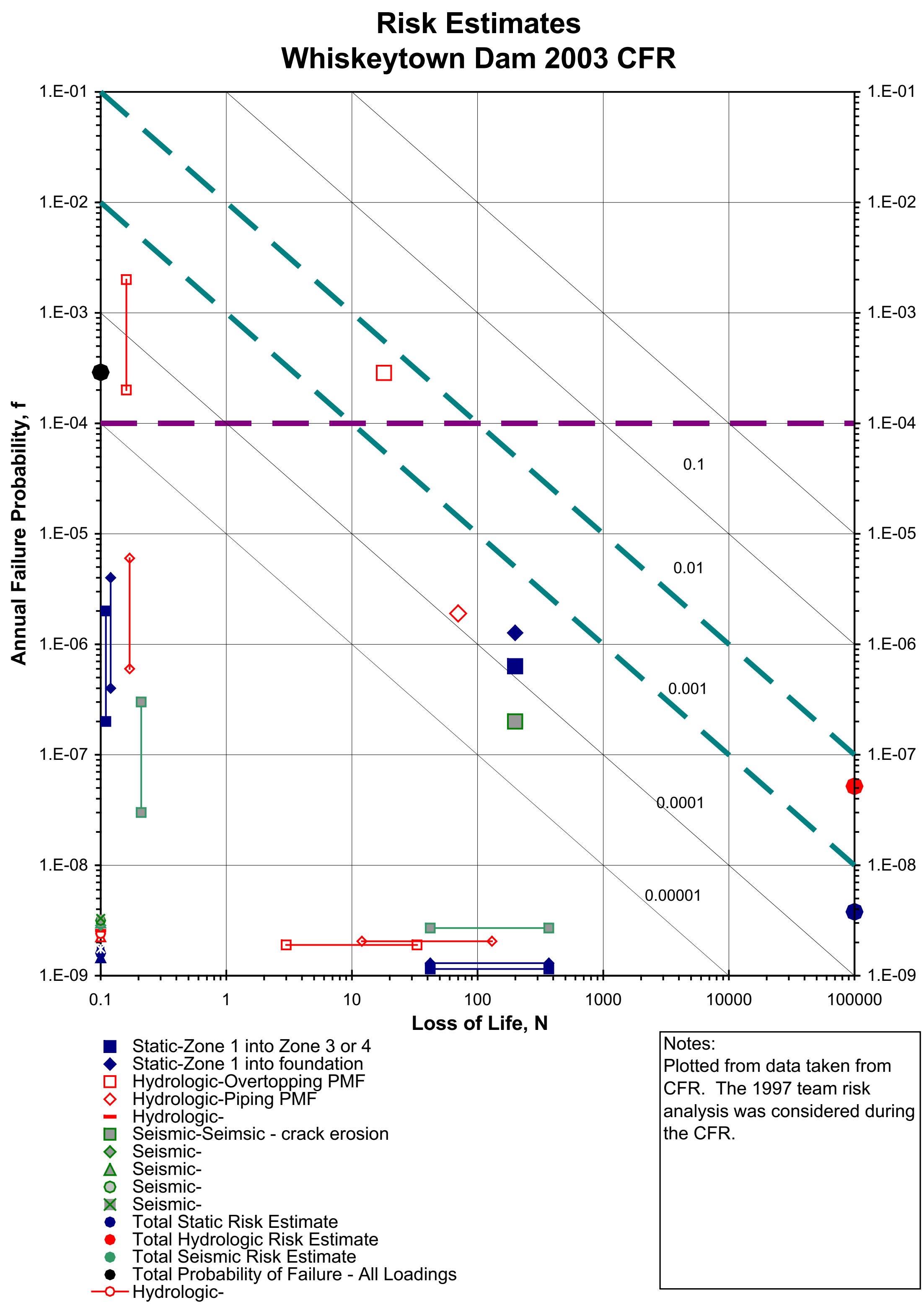


Figure 2-12 2003 CFR f-N plot showing Risks

Risk Results

Facility	WHISKEYTOWN	Author	Gregg Scott
Region	MP	Checked	
Product	CFR	Notes	Recreated from CFR by EAC on 12/5/2007
Source Document	17-11-2003		
Date of Chart	05-12-2007 Redrawn by EAC		

Analysis of Risk From Source Document

Failure Mode	Mean Probability of Failure Estimate			Mean Loss of Life Estimate			Mean Total Risk Estimate		
	Low	Expected	High	Low	Expected	High	Low	Expected	High
Static									
1 Zone 1 into Zone 3 or 4	2.00E-07	6.32E-07	2.00E-06	42	199	369	8.40E-06	1.26E-04	7.38E-04
2 Zone 1 into foundation	4.00E-07	1.27E-06	4.00E-06	42	199	369	1.68E-05	2.53E-04	1.48E-03
Total	6.00E-07	1.90E-06	6.00E-06	42	199	369	2.52E-05	3.78E-04	2.21E-03
Hydrologic									
1 Overtopping PMF	2.00E-04	2.86E-04	2.00E-03	3	18	33	6.00E-04	5.15E-03	6.60E-02
2 Piping PMF	6.00E-07	1.90E-06	6.00E-06	12	70	130	7.20E-06	1.33E-04	7.80E-04
Total	2.01E-04	2.88E-04	2.01E-03	3	18	130	6.07E-04	5.28E-03	6.68E-02
Seismic									
1 Seimsic - crack erosion	3.00E-08	2.00E-07	3.00E-07	42	199	369	1.26E-06	3.98E-05	1.11E-04
Total	3.00E-08	2.00E-07	3.00E-07	42	199	369	1.26E-06	3.98E-05	1.11E-04

Table 2-13 2003 CFR Risk Calculations

2.3.3 Exceedance curves based on EWP re-operation scenarios

Exceedance curves are used in determining the response of a structure due to time dependent events (for example, the number of years a maximum annual reservoir elevation exceeds a given elevation for static conditions for a specified period and the percent of time the reservoir is above a given elevation for seismic and hydrologic risks analyses). WT Dam has more than 40 years of operation with a total of 14,791 days of record that were used in this study. In the historical record the minimum reservoir water surface since January 1, 1965 occurred on December 27, 1991 with a reservoir water surface elevation of 1,176.05 ft.

The maximum historical reservoir water surface elevation occurred on March 2, 1983 with a reservoir water surface elevation of 1,215.33. Based on historical exceedance curves, the reservoir is above elevation 1,210 about one percent of the time (0.0095). It is above elevation 1210 about three percent (0.0290) of the time using the historical record with EWP re-operation releases using the most extreme reservoir ready elevation case of 1,209.5 ft. The number of days when the reservoir is above elevation 1,210 increased from 141 days to 429 days over 40 years. The exceedance curves and the following discussion were developed using the results from the CCDAM DOHPLR submodel.

Plots showing the exceedance curves for the historical record and EWP runs #3-15, #3-16, #3-17, #3-18, #3-19, #3-20 and #2-10 are shown in Appendix C. A summary of the data is shown in Table 2-14 (EWP #3-15 through #3-20 are highlighted in yellow). This data was used in determining the probability of the loading and structural response in the risk analysis.

Using the historical record, the number of days the reservoir water surface is above elevation 1,210 is less than one percent of the time, but the reservoir water surface is above elevation 1,204 about 53.5 percent of the time. All of the modifications to the operation of WT Dam increase the amount of time the reservoir is above elevation 1,210 and elevation 1,204. The increase depends on the selection of the reservoir operating criteria.

The recommended operation (#3-16) using historical reservoir water surface elevations increases the number of times the reservoir water surface is above elevation 1210 by a total of 153 days over 40 years. The EWP re-operation will potentially increase the maximum reservoir water surface from elevation 1215.33 to a single day maximum elevation of as high as 1,221.9 under a water year like that which occurred in 1983. These factors were considered during development of the probability of response of the reservoir. The 1,221.9 ft simulated elevation is a relatively crude estimate because of the DOHPLR submodel's daily time-step and volume balance rules, and is potentially an overestimate relative to what would occur under more finely controlled tunnel operations.

Table 2-14: WT Dam elevation changes in exceedance (Taken from WTEceedanceCurves_ Additional.xls (June 13, 2007) and WTExceedance Curves.xls (19-Jan-2007).

Case	% time above El 1,204	% time above El 1,206	% time above El 1,209	% time above El 1,210	No. of Days above El 1,210	Increase in No. of Days above El 1,210	Maximum Elevation*
Historical	53.47	49.23	24.19	0.95	141	-	1,215.33
#1-1	54.07	49.84	25.58	1.73	256	115	1,221.93
#1-2	63.85	50.56	26.10	2.22	329	188	1,221.93
#1-5	57.15	54.13	25.71	1.91	283	142	1,215.33
#1-6	57.00	53.70	31.87	2.90	429	288	1,215.33
#2-9	54.99	50.65	26.14	2.22	328	187	1,218.61
#2-10	55.61	51.27	26.69	2.62	388	247	1,215.53
#2-13	54.38	50.17	25.82	1.92	285	144	1,221.93
#2-14	63.52	50.69	25.15	2.25	333	192	1,221.93
#3-15	54.01	49.79	25.42	1.68	250	109	1,221.93
#3-16	**61.68**	**50.35**	**25.79**	**1.98**	**294**	**153**	**1,221.93**
#3-17	56.82	52.35	27.25	2.83	420	279	1,221.93
#3-18	54.35	50.11	25.58	1.79	266	125	1,221.93
#3-19	54.84	50.55	25.83	1.95	290	149	1,219.66
#3-20	53.50	49.37	25.57	1.95	288	147	1,221.93

* In the case of the 1,221.93 elevation – under an extreme inflow water year like that which occurred in 1983. This is not the average or expected maximum reservoir elevation for a typical event. The 1,221.93 ft simulated elevation is a relatively crude estimate because of the DOHPLR submodel's daily time-step and volume balance rules, and is potentially an overestimate relative to what would occur under more finely controlled tunnel operations. Furthermore, real-world operators would in many cases have the opportunity to "pass" on attempting EWP flows in these types of extreme water years.

3. Results and Discussion

3.1. General

The daily information provided in the output from the model runs are extensive and cannot be fully captured here. Selected results are drawn from the simulation analysis and summarized for purposes of evaluating the ability of alternative WT Dam re-operation scenarios to meet Clear Creek EWP objectives within the defined operating constraints. Though anticipated to be modest, the real world implementation plan for the re-operation of WT Dam should be reviewed in greater detail for the specific impacts to the Redding Power Plant and the Clear Creek Community Services District. This level of detail was beyond the scope of this study.

Detailed daily simulation results can be obtained from the following electronic archive: ftp://ftp.essa.com/pub/essa/EWP/ (file: "EWP_DetailedDailyResults.zip").

3.2. Retrospective analysis of event opportunities and outcomes

For each model run, results are shown at three levels of aggregation: (i) a summary rolling up performance over 40 years, (ii) a listing of *annual* summary results, and (iii) select examples of *daily* results for selected years and model runs. Given the vast quantity of output generated by our analysis, the focus in this report is on understanding the emergent properties of the various runs performed at the multi-year summary level. Readers interested in obtaining annual and daily details can consult the electronic archive (ftp://ftp.essa.com/pub/essa/EWP/).

3.2.1 Multi-year summary: roll-up of 1965–2004

Number of successful EWP releases for each CCDAM run

The key performance measure (see Table 2-9 for definitions) used to evaluate performance of alternative scenarios is the number of successful EWP releases in Reach 1. To be a successful candidate re-operation scheme, the number of EWP release successes had to exceed 12 (40 years with a minimum of 3 success every 10 years for a total of 12 successes). Continuing climate change raises doubts with respect to our assumption that past water supply conditions will be representative of those in the future. To ameliorate this concern, we suggest using a "buffer" beyond the lower-bound 12 successes in 40 year goal. The exact number is a matter judgment, so for purposes of this report, we suggest a minimum number of **18 successes in 40 years**. In addition to climate change effects (increase in frequency of drier conditions in the future), this also helps account for the fact that EWP successes are not uniformly distributed in time, giving real-world operators some flexibility to "pass" on EWP attempts in certain years even though conditions may be favorable.

From a Reach 1 EWP success standpoint, the top three model runs were: **(rank 1) #3-17** {3,250 ft^3/s × 1 day, spring 1,209.5 ft ready elevation}, **(rank 2) #3-19** {3,250 ft^3/s × 1 day, winter 1,203.5 ft ready elevation} and **(rank 3) #3-16** {3,250 ft^3/s × 1 day, spring 1,204ft ready elevation} (Table 3-1). All three of these scenarios generated 26 or more successes in 40 years, allowing flexibility to deal with future climate change, water supply changes and discretionary "spacing" of events through time. Two other scenarios passed our buffered minimum success criteria of 18 or more successes: run #3-22 {3,250 ft^3/s × 1 day, late spring 1,209.5ft ready elevation} and #3-18 {3,250 ft^3/s × 1 day, winter historical ready elevation}. Excluding consideration of flow magnitude for a moment (the most significant variable), the key factors determining success was first the reservoir ready elevation (higher the ready elevation the better) and second the season (winter more favorable than spring).

None of the 4,750 ft^3/s EWP release scenarios met our buffered minimum success criteria of 18 or more successes (Table 3-1). Likewise, even reverting to the original unbuffered EWP goal of 12 successes in 40 years, no 4,750 ft^3/s scenario met this goal in Reach 1 (highest Reach 1 success counts for the larger flow target scenarios was 7 for runs #2-9 {4,750 ft^3/s × 2 days, winter historical ready elevation} and #2-10 {4,750 ft^3/s × 2 days, winter 1,203.5ft ready elevation}). **However, results using a -5% tolerance on the 4,750 ft^3/s target (i.e., 4,512.5 ft^3/s) yielded 12 or more successes in Reach 1 for runs: #2-10/#2-12 {4,750 ft^3/s × 2 days, winter 1,203.5ft ready elevation} and #2-9/#2-11 {4,750 ft^3/s × 2 days, winter historical ready elevation}** illustrating the 'knife-edge' nature of the flow target on successes.

In all cases, success counts increased if the river location used to measure success was moved downstream to Reach 5, to allow for accretion flows from Clear Creek's two major tributaries. **When Reach 5 was used as the measuring point of success, one 4,750 ft^3/s target flow scenario passed the buffered success criteria of 18 or more successes – run #2-10 {4,750 ft^3/s × 2 days, winter 1,203.5 ft ready elevation}.**

None of the 4,750 ft^3/s × 3 day target flow scenarios achieved even the minimum 12 in 40 year success target whether measured with a -5% tolerance or measured in Reach 5.

An additional variable that is useful for 'choosing' amongst scenarios that met our buffered minimum success criteria is the average amount of water required (i.e., Average Glory Hole volume released (acre-ft) during EWP Period). Limiting our choice to the scenarios that met the buffered success goal in Reach 1, run **#3-16 {3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation}** is the best, requiring an average of 13,116 acre-ft of water through the Glory Hole spillway (Table 3-1). For comparison run #3-17 {3,250 ft^3/s × 1 day, spring 1,209.5 ft ready elevation}, despite being best in terms of successes, required on average over twice the amount of water (26,486 acre-ft) relative to run #3-16 {3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation}. This highlights the dynamic nature of the interaction between seasonal water supply and operational strategy. In this case, the routine raising of the reservoir early in the spring to 1,209.5 ft explains the higher water use rate associated with scenario #3-17 relative to #3-16.

Table 3-1: Number of historic events (i.e., years in which target flows occurred without operator intervention) and number of successful EWP releases for CCDAM runs from 1965 to 2004. Minimum desired frequency of occurrence is 3 in 10 years, or 12 events in 40 years. The recommended *buffered* minimum success criteria is 18 or more successes in 40 years. SD = standard deviation.

	Without re-operation[δ]			With EWP re-operation						
Scenario and Model ID No. (Rank[ϕ])	No. historic events Oct-1 the year before to start EWP period	No. historic events during entire water year	No. historic events *within* EWP period	No. EWP attempts	No. Successful EWP Releases, Reach 1	No. Successful EWP Releases, Reach 1 with - 5% tolerance	No. Successful EWP Releases, Reach 5	Average Glory Hole volume released (acre-ft) during EWP Period	Average Glory Hole volume released (acre-ft) during EWP Period - 1SD	Average Glory Hole volume released (acre-ft) during EWP Period + 1SD
1-1 (14)	*Cannot be determined without additional dynamic, state-dependent simulations*[γ]			15	2	6	6	58,760	47,642	69,877
1-2 (17)				23	0	5	7	31,320	0	63,889
1-3 (14)				15	2	6	6	57,224	45,455	68,994
1-4 (17)				22	0	3	6	28,984	0	60,387
1-5 (17)				14	0	4	4	23,048	0	55,065
1-6 (17)				36	0	6	6	42,812	5,026	80,598
1-7 (17)				14	0	4	4	22,334	0	53,480
1-8 (17)				32	0	6	6	38,116	4,956	71,276
2-9 (9)				24	7	13	14	55,232	39,018	71,447
2-10 (9)				**30**	**7**	**15**	**18**	**39,019**	**4,245**	**73,793**
2-11 (11)				24	6	12	13	54,565	39,571	69,559
2-12 (11)				28	6	14	17	35,138	2,811	67,465
2-13 (16)				18	1	7	7	55,047	36,700	73,394
2-14 (13)				24	3	9	12	30,156	0	61,472
3-15 (6)	6	8	3	27	17	26	24	17,673	7,180	28,166
3-16 (3)	**6**	**8**	**3**	**32**	**26**	**31**	**31**	**13,116**	**0**	**28,696**
3-17 (1)	**6**	**8**	**3**	**51**	**32**	**39**	**43**	**26,486**	**7,403**	**45,569**
3-18 (5)	1	8	7	33	22	32	30	20,282	5,650	34,913
3-19 (2)	**1**	**8**	**7**	**36**	**28**	**35**	**33**	**16,816**	**2,264**	**31,400**
3-20 (8)	7	8	2	27	10	25	22	22,140	11,871	32,409
3-21 (7)	7	8	2	30	12	28	23	15,149	1,100	29,198
3-22 (4)	7	8	2	67	23	39	39	36,039	19,566	52,513

ϕ = Rank number for most successful EWP releases in reach 1. Runs with the largest number of reach 1 successes rank the highest.

δ = Number of years within which target flows occurred (one or more times) without operator intervention. This is a comparable value to the values in the "With EWP re-operation" section of the table where we limited the number of successes in Reach 1 to 1 per year (any number of days >= target number of days is still only one success for the year).

γ = Project scope and budget resources did not permit determination of these values.

Approximate foregone power costs

Other factors must be considered in addition to the number of successes in Reach 1 (or Reach 5). Given that multiple scenarios are capable of meeting both the buffered and unbuffered success criteria, we need to look at other properties of these releases. One obvious criteria that many decision makers will focus on is foregone power cost. Having established success criteria in terms of counts (Table 3-1), a sensible question to ask is: "which of these scenarios is least costly in terms of foregone power generation opportunities"? As shown in Table 3-2 and Table 3-3, the least costly scenario, whether allowing for a price shifting assumption or not, was run #3-16 {3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation}, averaging $312,000 in foregone power costs per attempt. Considering the annual results (next section) for this run, foregone power costs for successful attempts ranged from a low of $108,000 (1999) to a high of $1.38 million (2002) over the 40 water supply years simulated in our analysis.

Importantly, as illustrated by inspection of Table 3-2 and Table 3-3, **the use of price shifting or no price shifting did not affect the rank-order performance of the model scenarios.** Likewise, eliminating "made money" (negative foregone power values) cases of -$500,000 or more did not change the rank order performance of model scenarios. However, on average, the price shifting assumption increased foregone power costs by 30.5%. Hence, using this average statistic, we would expect scenario #3-16 to on average cost $407,000 per attempt if using price shifting.

Simulation results showed that between year variation in foregone power costs were large, with one standard deviation typically in the $300,000 to $400,000 range for scenario 3. In essence, each year "tells it's own story" in terms of reservoir, tunnel, and downstream outcomes making it somewhat misleading to think too strongly in "average" terms. Furthermore, as illustrated later when looking at unsuccessful events associated with scenario #3-16, it can be shown that foregone power costs are artificially high. **In summary, an average foregone power estimate of $200,000 to $300,000 is likely a more realistic average foregone power cost associated with run #3-16 rules** (about $261,000 to $392,000 if accepting the price shifting assumption).

Table 3-2: Approximate foregone power costs for CCDAM runs from 1965 to 2004. SD = standard deviation. Note: price shift cases were not evaluated for scenario 3.

	Without price shift			With price shift		
Scenario and Model ID No. (Rank$^{\phi}$)	**Average foregone power cost, $ thousands**	**Foregone power cost - 1SD, $ thousands**	**Foregone power cost + 1SD, $ thousands**	**Average foregone power cost, $ thousands**	**Foregone power cost - 1SD, $ thousands**	**Foregone power cost + 1SD, $ thousands**
1-1 (14)	1,221.03	522.32	1,919.73			
1-2 (10)	758.34	-4.67	1,521.34			
1-3				1,200.03	-801.72	3,201.79
1-4				1,037.80	-226.48	2,302.07
1-5 (5)	428.45	-281.97	1,138.86			
1-6 (13)	1,090.35	144.59	2,036.11			
1-7				481.65	-891.24	1,854.53
1-8				1,262.90	52.80	2,473.00
2-9 (15)	1,241.65	802.32	1,680.99			
2-10 (11)	864.29	90.28	1,638.30			
2-11				1,991.59	800.71	3,182.48
2-12				1,342.59	-345.75	3,030.92
2-13 (16)	1,248.28	775.71	1,720.85			
2-14 (9)	736.99	-54.99	1,528.98			
3-15 (6)	443.39	184.70	702.09			
3-16 (1)	**312.52**	**7.88**	**617.15**			
3-17 (8)	615.41	219.71	1,011.12			
3-18 (4)	404.90	155.14	654.65			
3-19 (2)	**336.45**	**53.62**	**619.28**			
3-20 (7)	560.70	297.70	823.69			
3-21 (3)	**355.53**	**-47.46**	**758.52**			
3-22 (12)	897.51	479.74	1,315.28			

$^{\phi}$ = Rank number for lowest cost of CCDAM run (based on the no price shift case, using the average multi-year cost). Runs with the lowest cost rank the highest.

Table 3-3: Approximate foregone power costs for CCDAM runs from 1965 to 2004 (negative foregone power amounts greater than -$500K considered to be model artifacts and treated as null). SD = standard deviation. Note: price shift cases were not evaluated for scenario 3.

	Without price shift			With price shift		
Scenario and Model ID No. (Rank^ϕ^)	Average foregone power cost, $ thousands	Foregone power cost + 1SD, $ thousands	Foregone power cost - 1SD, $ thousands	Average foregone power cost, $ thousands	Foregone power cost - 1SD, $ thousands	Foregone power cost + 1SD, $ thousands
1-1 (14)	1,358.24	887.47	1,829.00			
1-2 (10)	758.34	-4.67	1,521.34			
1-3				1,844.49	873.44	2,815.53
1-4				1,198.28	22.76	2,373.81
1-5 (5)	428.45	-281.97	1,138.86			
1-6 (13)	1,090.35	144.59	2,036.11			
1-7				732.00	-329.40	1,793.40
1-8				1,329.86	181.46	2,478.26
2-9 (15)	1,241.65	802.32	1,680.99			
2-10 (11)	864.29	90.28	1,638.30			
2-11				2,105.19	1,028.67	3,181.71
2-12				1,582.69	78.33	3,087.05
2-13 (16)	1,248.28	775.71	1,720.85			
2-14 (9)	736.99	-54.99	1,528.98			
3-15 (6)	443.39	184.70	702.09			
3-16 (1)	**312.52**	**7.88**	**617.15**			
3-17 (8)	615.41	219.71	1011.12			
3-18 (4)	404.90	155.14	654.65			
3-19 (2)	**336.45**	**53.62**	**619.28**			
3-20 (7)	560.70	297.70	823.69			
3-21 (3)	**385.59**	**25.61**	**745.57**			
3-22 (12)	897.51	479.74	1315.28			

ϕ = Rank number for lowest cost of CCDAM runs (based on the no price shift case, using the average multi-year cost). Runs with the lowest cost rank the highest.

Failure characteristics

Another factor that must be considered in addition to the number of successes and foregone power costs is the failure characteristics of the different scenarios. These properties help evaluate the odds of starting an attempt that ultimately leads to termination due to lower Clear Creek safety considerations, insufficient water, or excessive cost. Considering the 40 years of simulation per scenario and stopping conditions ‘A’, ‘B’ and ‘C’ in Table 3-4 (see Table 2-9 for definitions), the worst performing run was stopped as many as 31 times in 40 years (#3-22 {3,250 ft^3/s × 1 day, late spring 1,209.5 ft ready elevation}) **while the best was stopped only 5**

times in 40 years (#3-16 {3,250 $ft^3/s \times$ 1 day, spring 1,204 ft ready elevation}). Note, the fact that run #3-22 (1,209.5 ft ready elevation) has more stops than it's relative run #3-21 (1,204 ft ready elevation) is explained by the fact that a 1,209.5 ft ready elevation typically leads to 2 attempts per year rather than 1 just attempt per year. Inspecting individual year results reveals that in poor water supply years, this near doubles the level of false positives for run #3-22.

Given success count rankings, foregone power rankings and now failure characteristic rankings the overall best scenario was run #3-16 (3,250 $ft^3/s \times$ 1 day, spring 1,204ft ready elevation).

Note: given the premium placed on human and property safety, it is likely that any run that generates 2 or more stops in 40 years due to excessive lower Clear Creek flows (9,100 ft^3/s in Reach 5) would be ruled out of contention. This is in some respects an issue of risk tolerance – events that are over 9,100 ft^3/s by a small margin vs. those well over this value would be interpreted differently, and need to be evaluated on a case by case basis. **The scenario 3 run variants, both the winter runs (#3-18 and #3-19) experience 2 stops in 40 years due to excessive lower Clear Creek flow (Table 3-4).**

Table 3-4: “Failure” or “stop” properties for CCDAM runs from 1965 to 2004.

Scenario and Model ID No.	No. EWP attempts	No. Successful EWP Releases, Reach 1	A) No. stopped due to excessive lower Clear Creek flow (and rank$^{\phi}$)	B) No. stopped due to insufficient water (and rank)	C) No. stopped due to cost (and rank)	Total No. of stops, A+B+C (and rank)
1-1	15	2	1 (12)	12 (8)	0 (1)	13 (4)
1-2	23	0	1 (12)	15 (16)	1 (13)	17 (13)
1-3	15	2	1 (12)	10 (4)	3 (15)	14 (6)
1-4	22	0	1 (12)	11 (6)	7 (18)	19 (17)
1-5	14	0	0 (1)	14 (11)	0 (1)	14 (6)
1-6	36	0	0 (1)	21 (22)	0 (1)	21 (19)
1-7	14	0	0 (1)	12 (8)	6 (17)	18 (16)
1-8	32	0	0 (1)	16 (18)	13 (21)	29 (21)
2-9	24	7	3 (21)	14 (11)	0 (1)	17 (13)
2-10	30	7	1 (12)	15 (16)	0 (1)	16 (10)
2-11	24	6	3 (21)	14 (11)	3 (15)	20 (18)
2-12	28	6	1 (12)	13 (10)	10 (20)	24 (20)
2-13	18	1	0 (1)	14 (11)	0 (1)	14 (6)
2-14	24	3	1 (12)	14 (11)	1 (13)	16 (10)
3-15	**27**	**17**	**0 (1)**	**10 (4)**	**0 (1)**	**10 (3)**
3-16	**33**	**25**	**1 (12)**	**4 (1)**	**0 (1)**	**5 (1)**
3-17	51	32	0 (1)	7 (2)	7 (18)	14 (6)
3-18	33	22	2 (19)	11 (6)	0 (1)	13 (4)
3-19	**36**	**28**	**2 (19)**	**7 (2)**	**0 (1)**	**9 (2)**
3-20	27	10	0 (1)	17 (21)	0 (1)	17 (13)
3-21	30	12	0 (1)	16 (18)	0 (1)	16 (10)
3-22	67	23	0 (1)	16 (18)	15 (22)	31 (22)

3.2.2 Annual results: 1965–2004

Table 3-5 provides a listing of *annual* summary results for our top performing run, #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation) for the 40 years of record evaluated. For this scenario, there were only 10 years in 40 when an EWP attempt was not made. Of these cases, the longest stretch of years without an attempt was 3 years (1983 to 1985). Hence, even during dry cycles or unfavorable seasonal water supply periods, this scenario under past water supply conditions and dam operations, does not experience an excessive gap between EWP attempts. This is a useful consideration in that certain geomorphic and ecological attributes improved by environmental releases have time expiration characteristics (e.g., obtaining 12 out of 40 years of EWP successes in the first 12 consecutive years with no attendant successes thereafter would likely be considered a failure).

It is noted that even for the top performing scenario (#3-16), dry seasonal cycles should be expected to eliminate new/surplus EWP opportunities (witness the absence of Reach 1 successes between 1980 to 1985 period) (Table 3-5). **On average however, scenario #3-16 yielded a successful release every 1–2 years**. **This in principle would give WT Dam operators the opportunity to forego attempts even when conditions were favorable on the assumption that the next available opportunity will be typically only 1 to 2 years away**. This flexibility would be valuable in practice if for example bridge repair or other infrastructure work were needed in Clear Creek, or if spot power market conditions were likely to result in foregone power costs well in excess of what was permissible under EWP budgets.

Appendix B provides a full listing of annual summary results for all model runs performed for the 1965 to 2004 period. This data is also available electronically from the electronic repository at ftp://ftp.essa.com/pub/essa/EWP/ (file: "EWP_CCDAM_SummaryResults.xls")

Table 3-5: Annual results summary for top performing model run #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation), 1965 to 2004.

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
3 - 3250 ft^3/s x 1 day	16	1965	1	1	1	10,887	$207,160	$207,160	0	0	0
		1966	1	0	0	26,793	$525,512	$525,512	0	1	0
		1967	1	1	1	8,739	$198,687	$198,687	0	0	0
		1968	**0**	0	0						
		1969	**0**	0	0						
		1970	1	1	1	18,842	$454,243	$454,243	0	0	0
		1971	1	1	1	14,774	$345,555	$345,555	0	0	0
		1972	1	1	1	8,724	$218,188	$218,188	0	0	0
		1973	1	1	1	6,707	$123,008	$123,008	0	0	0
		1974	1	1	1	82,328	$319,374	$319,374	0	0	0
		1975	1	1	1	14,041	$326,292	$326,292	0	0	0
		1976	1	1	1	6,175	$138,904	$138,904	0	0	0
		1977	1	0	0	27,083	$680,164	$680,164	0	1	0
		1978	1	1	1	17,531	$396,613	$396,613	0	0	0
		1979	2	1	2	9,894	$820,355	$820,355	0	0	0
		1980	**0**	0	0						
		1981	**0**	0	0						
		1982	1	1	2	40,505	$752,564	$752,564	0	0	0
		1983	**0**	**0**	0						
		1984	**0**	**0**	0						
		1985	**0**	**0**	0						
		1986	1	1	1	8,240	$810,698	$810,698	0	0	0
		1987	1	1	1	6,584	$160,801	$160,801	0	0	0
		1988	1	1	1	18,580	$489,774	$489,774	0	0	0
		1989	1	1	1	9,990	$258,207	$258,207	0	0	0
		1990	**0**	0	0						
		1991	**0**	0	0						
		1992	1	1	1	7,711	$183,710	$183,710	0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1993	1	1	1	8,303	$204,286	$204,286	0	0	0
		1994	1	1	1	10,079	$342,718	$342,718	0	0	0
		1995	1	1	1	42,047	$410,346	$410,346	1	0	0
		1996	1	1	1	9,894	$253,329	$253,329	0	0	0
		1997	1	0	1	26,989	$810,530	$810,530	0	1	0
		1998	1	1	1	15,172	$126,453	$126,453	0	0	0
		1999	1	1	1	6,213	$107,765	$107,765	0	0	0
		2000	1	1	1	8,305	$663,155	$663,155	0	0	0
		2001	1	1	1	7,450	$181,460	$181,460	0	0	0
		2002	1	0	1	26,880	$1,377,188	$1,377,188	0	1	0
		2003	1	1	1	6,077	$131,838	$131,838	0	0	0
		2004	**0**	0	0						

[1] No. of EWP Releases for Reach 1, i.e., X days >= target flow during EWP Attempt window

[2] No. of EWP Releases for Reach 5, i.e., X days >= target flow during EWP Attempt window

[3] Glory Hole spill for entire EWP Period; treat 0 values as null if state is AtHistorical throughout

[4] Cost in foregone power over the entire EWP Period (to InEWP+1 if stopped on success); always report cost when an EWP Attempt is made; for non-historical runs in which no EWP Attempt is made, report costs from the start of the EWP Period through BuildToElevation +1 day

[5] Foregone Power as in Column I, but with negative foregone power values greater than -$500K considered to be artifacts and treated as null

3.2.3 Example within year daily results for the top performing model run (#3-16)

Successful

Figure 3-1 and Figure 3-2 illustrate CCDAM DOHPLR output of the daily consequences of a simulated EWP re-operation (run #3-16) in 2003 leading to a success, as do Figure 3-3 and Figure 3-4 for 2000, and Figure 3-5 and Figure 3-6 for 1971. Given the state-dependent 'if then' nature of simulated re-operations, every year tells it's "own story", making it difficult to describe a 'typical' success. However, the years shown below (2003, 2000 and 1971) are considered adequately representative of the type of re-operation that can be expected under scenario #3-16.

Figure 3-7 provides the 40 year daily pattern of Reach 1 and Reach 5 flows associated with re-operations under the top performing run #3-16. From the Reach 1 plot (top panel in Figure 3-7), it is clear that the re-operation dramatically increases the incidence of EWP successes.

Daily results for all model runs can be obtained from the electronic repository for this study: ftp://ftp.essa.com/pub/essa/EWP/ (file: "EWP_DetailedDailyResults.zip").

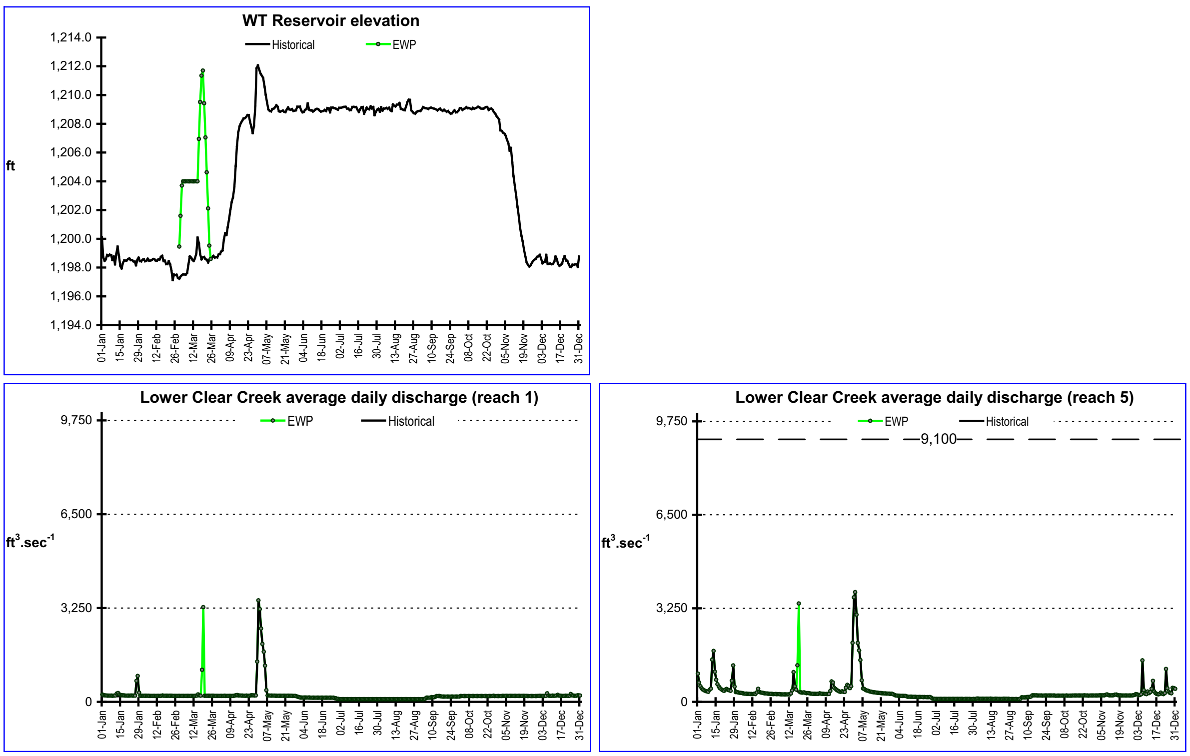


Figure 3-1: Daily results for year **2003**, scenario #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation) showing a successful Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #3-16 re-operation; Historical = outcome without re-operation, based on historical operating decisions. Note: the EWP operator in this example (as would be the case with a real-world operator) is unaware of the future event that would occur without re-operation.

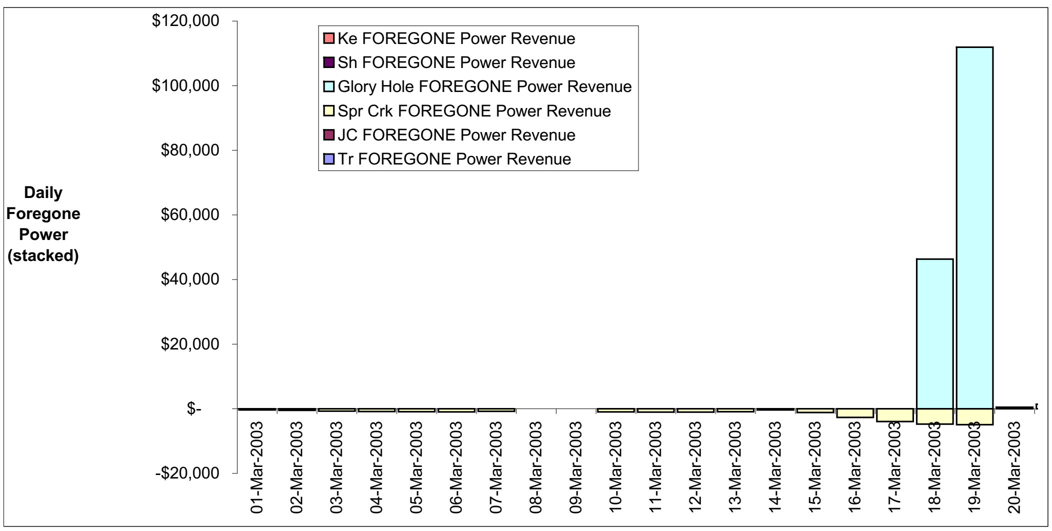


Figure 3-2: Daily foregone power approximation for year **2003**, scenario #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) associated with WT Reservoir re-operation. Of the total cumulative foregone power for this event ($131,838), the majority of it occurs on two days in which the water is spilling through WT Glory Hole. This water is not available to flow through either Spring Creek or Keswick power plants.

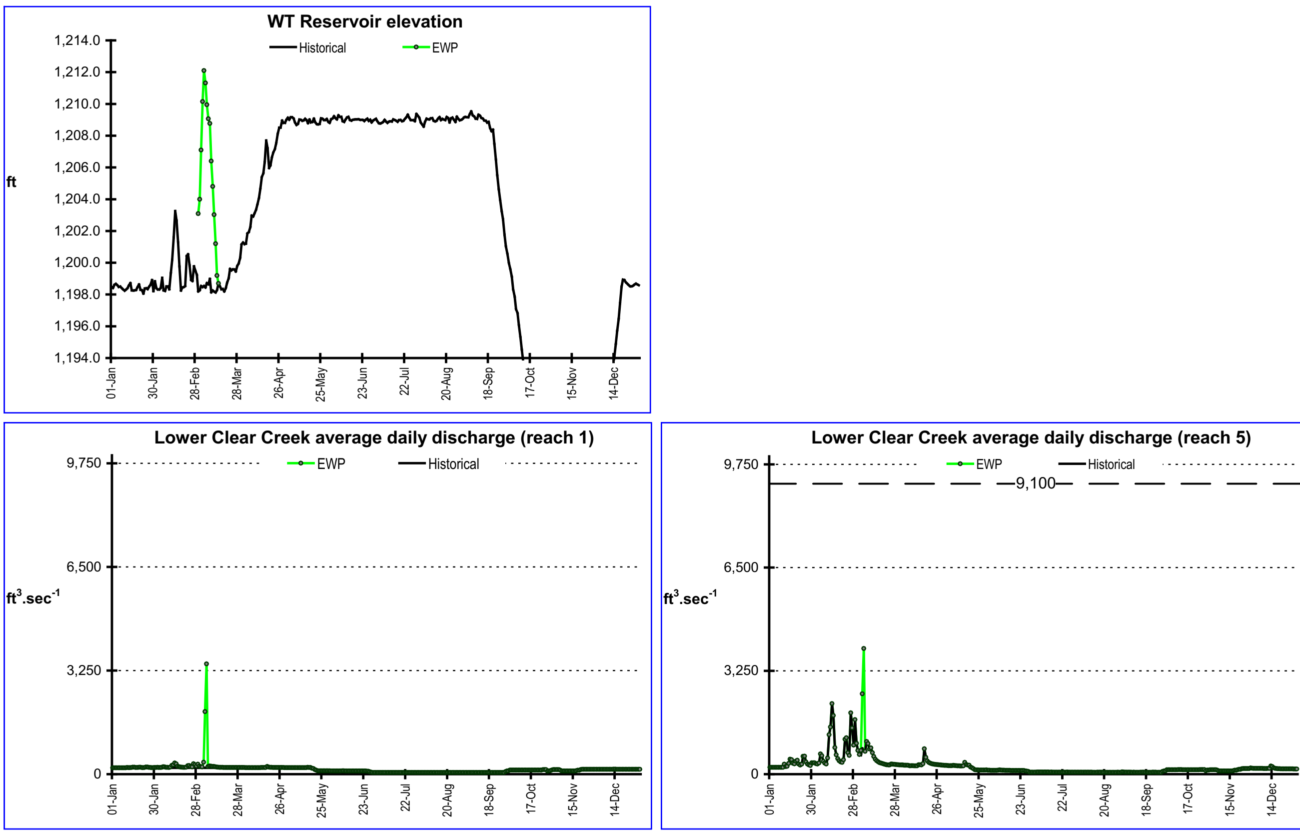


Figure 3-3: Daily results for year **2000**, scenario #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation) showing a successful Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #3-16 re-operation; Historical = outcome without re-operation, based on historical operating decisions.

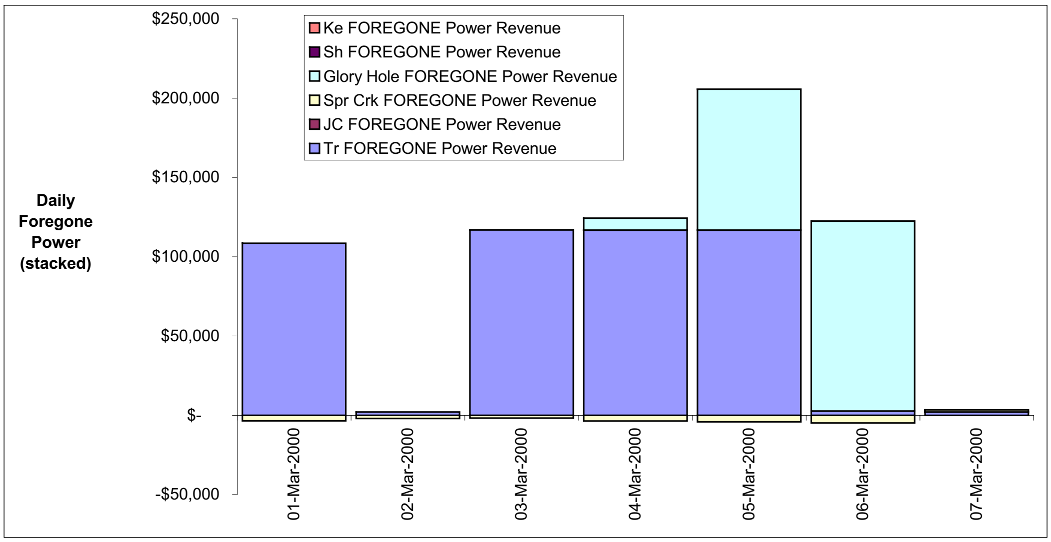


Figure 3-4: Daily foregone power approximation for year **2000**, scenario #3-16 (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation) associated with WT Reservoir re-operation. Of the total cumulative foregone power for this event ($663,155), a significant proportion of it is associated with foregone power on Trinity reservoir*.

*To understand why the foregone power for the Trinity exceeds $100, 000 on March 1st and the 3rd through to the 5th, it is necessary to refer back to section 2.2.7. The Trinity, Shasta, and Keswick differ from the tunnels in that the flow can be increased beyond the generator capacity (for our model, the tunnels' generating capacity is the same as the maximum flow), however any marginal flow above the generator capacity does not generate any revenue whatsoever. As well, any change through J.F. Carr must be matched with the same change in the Trinity flow, to ensure that there is no effective change in flow down the Trinity River (i.e., flow balancing assumption on two major external river systems).

In this case, the Trinity had a historical flow of 3,752 ft^3/s on March 1st, and over 5,000 ft^3/s from March 2nd through to March 9th**. The Trinity's generator capacity, however, is only 4000 ft^3/s. So on March 1st, there was only 248 ft^3/s of generating capacity (i.e. revenue-generating potential) left and 0 left on the other days. Also, the historical flow at J.F. Carr from February 27th through to March 9th inclusive was 0 cfs.

Now the model determined that an EWP attempt was possible and it adjusted the J.F. Carr flows to 3,400 ft^3/s on the 4 days, leaving it down at 60 ft^3/s on March 2nd as the ready elevation had already been reached. To maintain the Trinity River flow, Trinity Dam releases were increased to 7,152 ft^3/s (3,752 + 3,400) and 8,400+ for the other days. Revenue was only generated for the 248 ft^3/s on March 1st, but nothing more on that day and $0 at all on the other days. Based upon the power calculation for the Trinity using the historical elevation for head, these increased flows end up costing approximately $100, 000 per day.

**Although not relevant to foregone power calculations, with a winter encroachment limit of 2345' the Trinity was encroached throughout this EWP attempt.

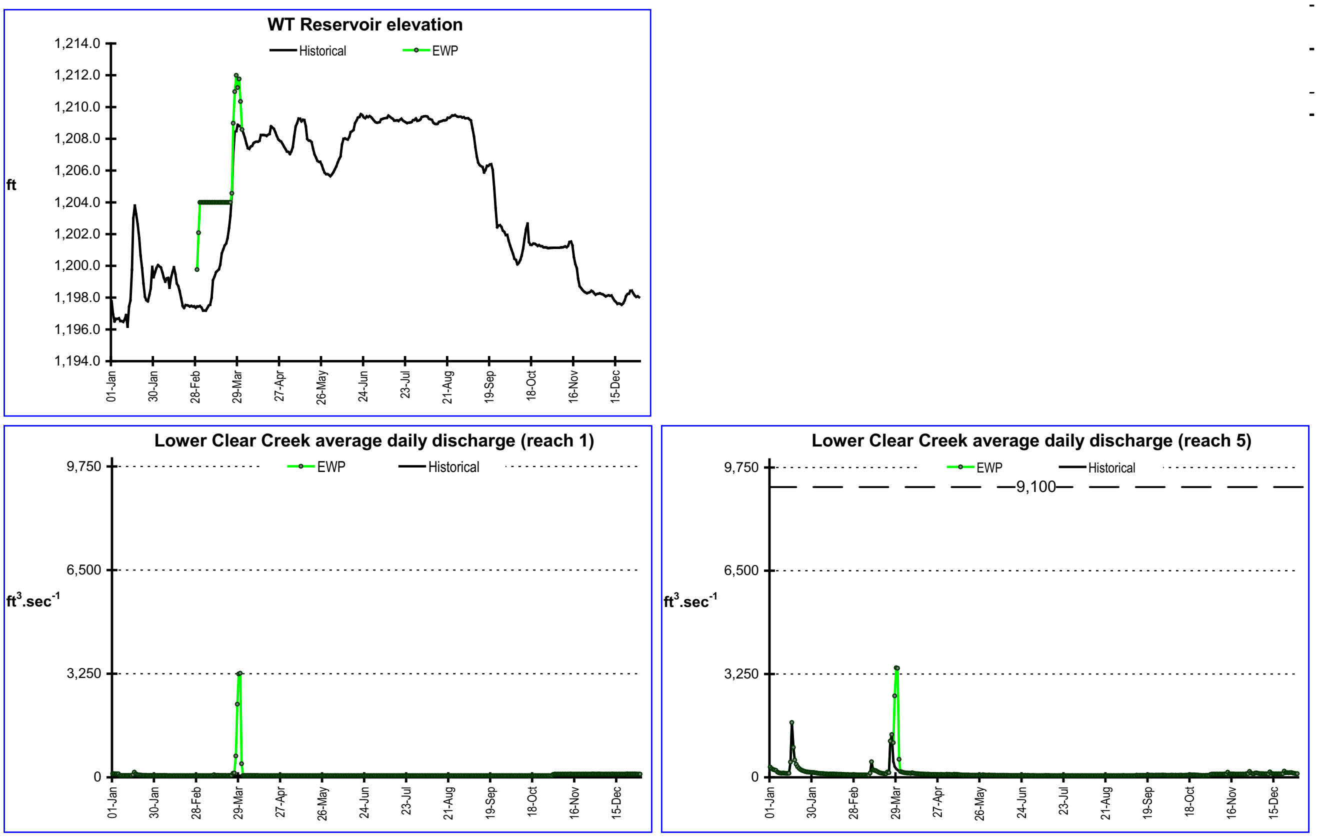


Figure 3-5: Daily results for year **1971**, scenario #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) showing a successful Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #3-16 re-operation; Historical = outcome without re-operation, based on historical operating decisions.

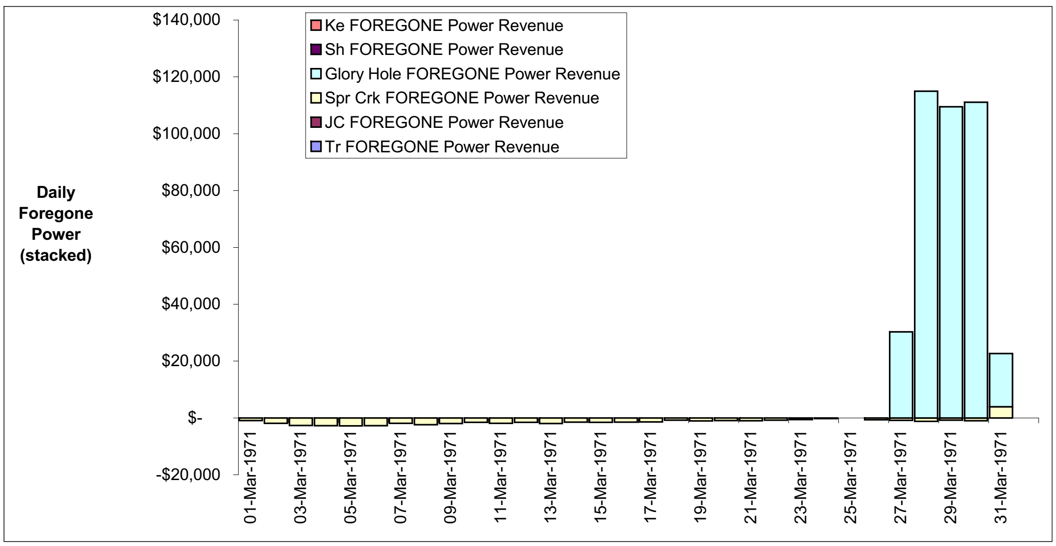


Figure 3-6: Daily foregone power approximation for year **1971**, scenario #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) associated with WT Reservoir re-operation. Of the total cumulative foregone power for this event ($345,555), the majority of it is associated with water spilled through WT Glory Hole. This water is not available to flow through either Spring Creek or Keswick power plants.

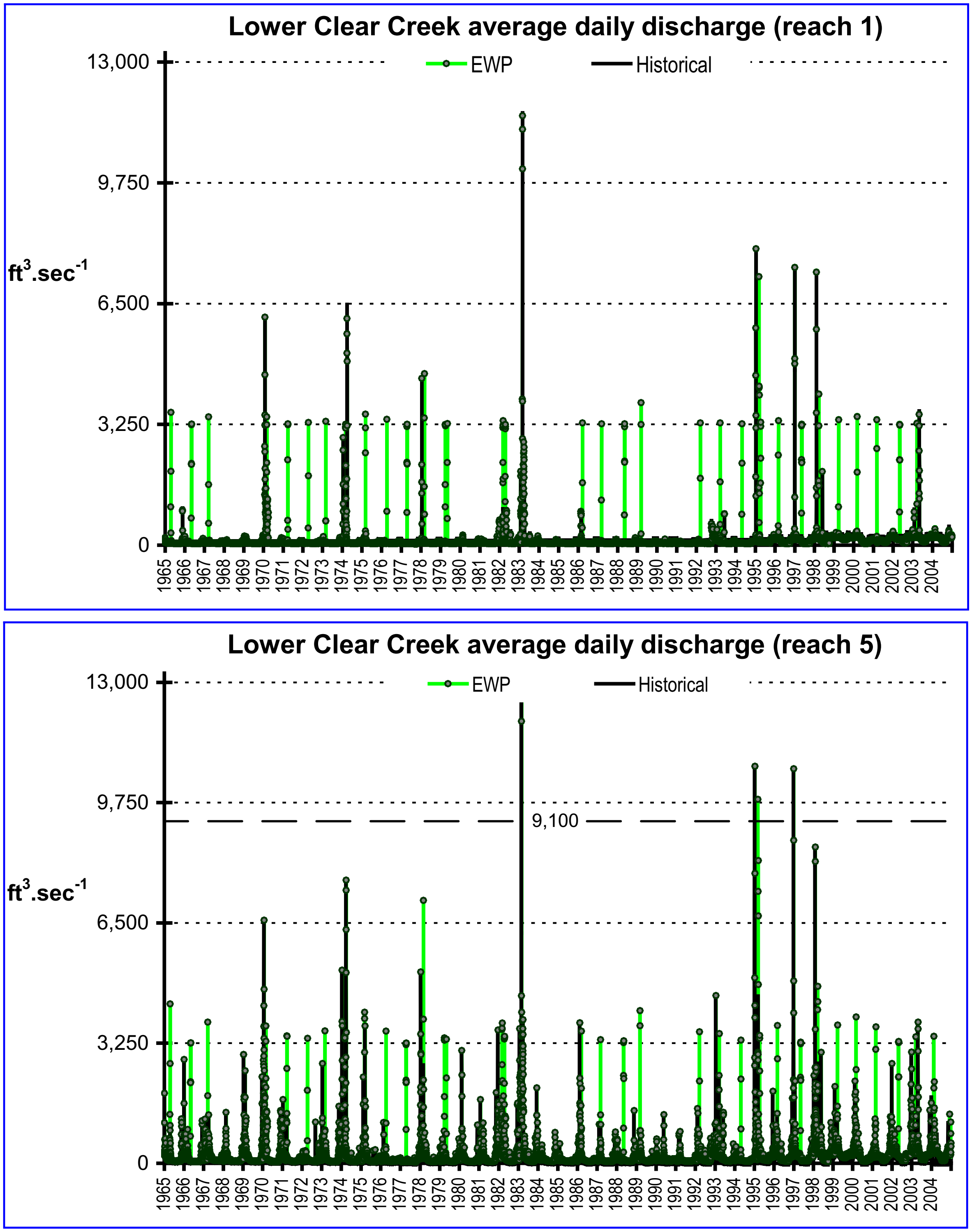


Figure 3-7: Multi-year (1965 to 2004) summary of EWP re-operation outcomes using model run #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) vs. existing historical operations for lower Clear Creek Reach 1 (top panel) and Reach 5 (bottom panel).

Unsuccessful

Figure 3-8 and Figure 3-9 illustrate CCDAM DOHPLR output of the daily consequences of a simulated EWP re-operation (run #3-16) in 1997 leading to a failed attempt. **As simulation model rules were deterministic, they can become artificially precise—in this case as in all failures for the #3-16 scenario, the realized Reach 1 flows were within 2 ft^3/s of the 3,250 ft^3/s target! In this context, it is important to realize that scenario #3-16 failures and resultant foregone power costs for years 1966, 1977, 1997 and 2002 are overstated.**

This problem is not generally true of failed attempts for 4,750 ft^3/s scenarios, which depend more heavily on natural inflows than J.F. Carr Tunnel diversions (e.g., Figure 3-10).

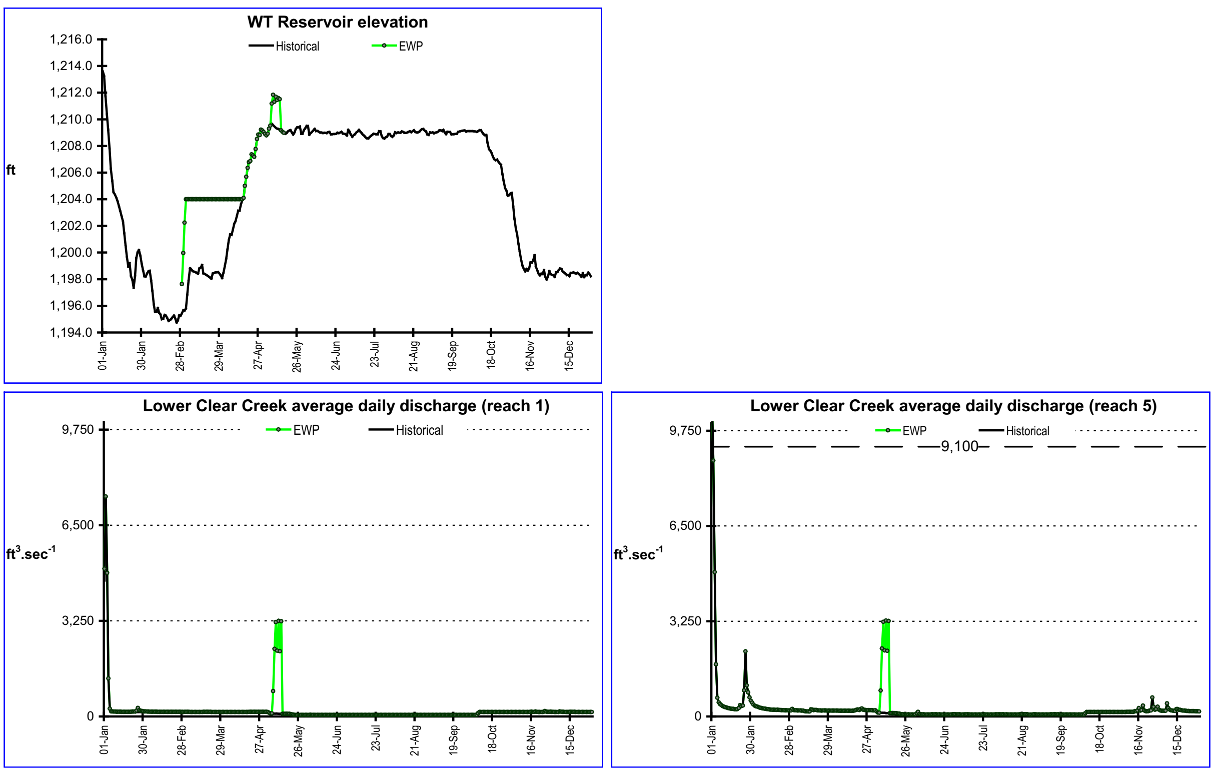


Figure 3-8: Daily results for year **1997**, scenario #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) showing an *unsuccessful* Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #3-16 re-operation; Historical = outcome without re-operation, based on historical operating decisions. As simulation model rules are deterministic, they can become artificially precise – in this case as in all failures for the #3-16 scenario, the realized Reach 1 flows were within 2 ft^3/s of the 3,250 ft^3/s target.

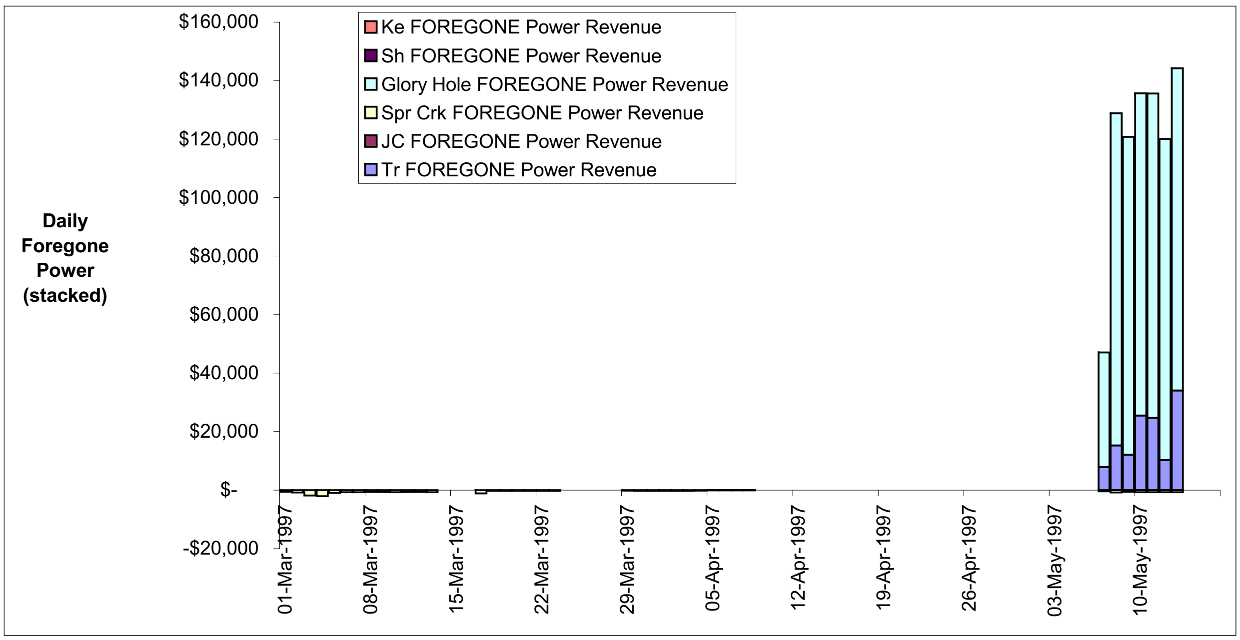


Figure 3-9: Daily foregone power approximation for year **1997**, scenario #3-16 (3,250 ft^3/s × 1 day, spring 1,204 ft ready elevation) associated ('by the book') with unsuccessful WT Reservoir re-operation. The total foregone power revenue in this case ($810,530) is overstated, as the event in practice would have ended at least 4-5 days earlier than shown when Reach 1 flows were within 1 ft^3/s of the 3,250 ft^3/s target.

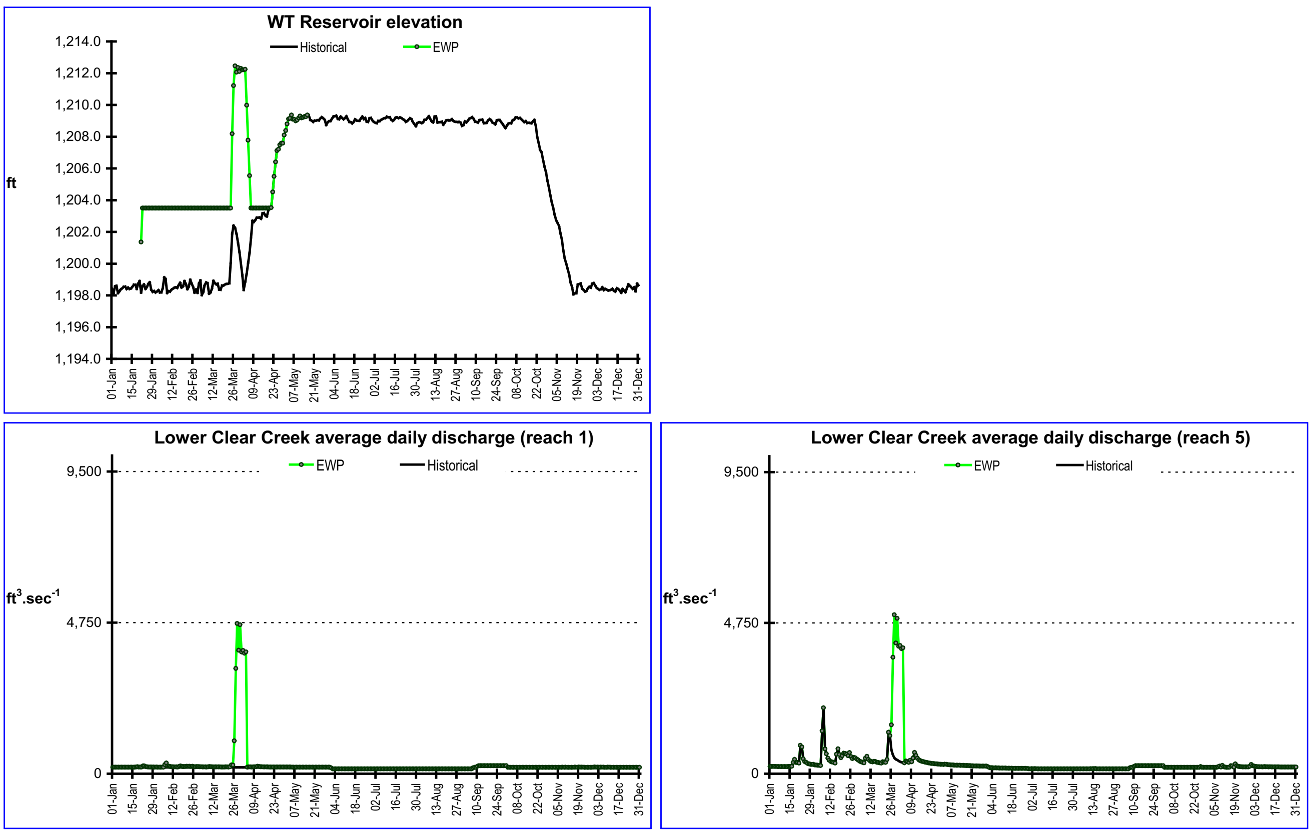


Figure 3-10: Daily results for year **1999**, scenario #2-10 (4,750 ft^3/s × 2 day, winter 1,203.5 ft ready elevation) showing an *unsuccessful* Reach 1 event and the associated WT Reservoir re-operation (top panel). EWP = outcome with scenario #2-10 re-operation; Historical = outcome without re-operation, based on historical operating decisions.

3.3. Dam safety risks and impacts to operation

3.3.1 Dam safety issue - maximum Whiskeytown Reservoir water surface elevations

The potential hydrologic failure modes are overtopping of the dam and piping due to elevated reservoir water surfaces above the spillway crest. The design maximum reservoir water surface elevation for WT Reservoir is 1,220.5 ft, and the historical maximum reservoir water surface occurred on March 2, 1983 with an elevation 1,215.3. The maximum reservoir water surface for all EWP model analyses is elevation 1,221.9 which occurs on March 2, 1983 (see Table 2-14). This indicates that there is a large potential for higher maximum reservoir water surface elevations during re-operation attempts than has been experienced in the past. The operation of the reservoir for EWP releases potentially increases the risk of piping during a hydrologic event due to the duration the reservoir will be above the spillway crest. This is also a situation that increases the failure potential as the embankment is in a "first filling" period for all reservoir water surface elevations above 1215.3 ft. (The 1,221.9 ft elevation simulated by DOHPLR for the 1983 water year is a relatively crude estimate because of the submodel's daily time-step and volume balance rules, and is potentially an overestimate relative to what would occur under more finely controlled tunnel operations).

The re-operation also increases the overtopping potential due to the potential for damage and failure of the spillway which increases the potential for dam overtopping failure. The spillway failure potential is increased when the reservoir water surface seals off the air vent for the morning glory spillway. The vent is located at elevation 1,222. In addition there is the potential for an increase in risk due to undesired operation and damages to the spillway. This may cause some operational issues that will have to be addressed during the pilot program period.

The higher reservoir water surface elevations and operation will also have to be evaluated for impacts to any modifications developed during the Corrective Action Study, if a decision is made to proceed with a plan to implement or an implementation of the EWP re-operation pilot program.

3.3.2 Dam safety issue - higher beginning reservoir water surface

The latest flood frequency data (hydrologic hazard analysis) were developed by Reclamation in 2005 and 2006 (Bureau of Reclamation 2006b). Additional hydrologic data is being collected and reviewed at this time. The 2006 floods were routed past WT Dam, and results were documented in a Technical Memorandum which was completed in August 2005 (Bureau of Reclamation 2005). The routings were performed using 100-, 200-, 500-, 1,000-, 2,000-, 5,000-, 10,000-, 20,000-, 50,000-year frequency floods, plus the PMF General Storm with 100-year snowmelt, the PMF General Storm with 100-year antecedent rain, and the PMF Local Thunderstorm. The frequency flood inflow peaks range from 13,400 ft^3/s for the 100-year return period to 118,600 ft^3/s for the 50,000-year return period and 118,600 ft^3/s the PMF General Storm with 100-year snowmelt. The routings were performed with three initial starting reservoir water surface elevations; 1,198-, 1204-, and 1209-feet, to determine the effect on the maximum reservoir water surface elevation.

Table 3-6: Maximum WT Reservoir water surface elevations for various beginning water surface elevations and various (hypothetical) floods. The 1983 storm of record is included in the table for comparison purposes.

		Beginning RWS El. 1,198		Beginning RWS El. 1,204		Beginning RWS El. 1,209	
Flood Recurrence Interval	**Inflow ft³/s**	**Outflow ft³/s**	**Elevation (feet)**	**Outflow ft³/s**	**Elevation (feet)**	**Outflow ft³/s**	**Elevation (feet)**
100	13,394	8,222	1,213.84	8,223	1,213.88	8,233	1,213.89
1983 storm of record	**14,000 ft³/s observed inflow**		**Observed dam outflow - 11,553 ft³/s**		**Observed dam elevation – 1,215.33 ft**		
500	28,100	19,188	1,216.84	19,270	1,216.86	19,277	1,216.86
1000	37,363	26,764	1,218.54	26,829	1,218.55	26,835	1,218.56
Dam crest			**1,228**		**1,228**		**1,228**
5000	68,364	47,987	1,229.36	68,364	1,229.36	48,110	1,229.36
10000	86,935	76,560	1,230.5	76,763	1,230.51	76,779	1,230.51
20000	109,465	106,199	1,231.46	106,236	1,231.46	106,239	1,231.46
50000	118,600	115,988	1,231.75	116,000	1,231.75	116,001	1,231.75
GenSnowStd_PMF	118,559	115,944	1,231.74	115,957	1,231.74	115,958	1,231.81
GenRainStd_PMF	124,305	120,094	1,231.86	120,101	1,231.86	120,101	1,231.86

Using the data from Table 3-6, it is observed that the maximum difference in reservoir water surface for different beginning water surface elevations is 0.05 feet (≈5/8 inch) using all beginning reservoir water surfaces for all floods equal to or greater than the 100-year return period flood. From this it does not appear that there are any significant increases in the maximum reservoir water surface due to these floods for the overtopping potential assuming the spillway does not fail. Maximum reservoir water surface elevation versus return period was plotted (Figure 3-11) and shows that there will potentially be some decrease in the return period for the threshold flood with a higher starting reservoir water surface with the available data. The detail of the available data precludes determining how much this increase will be. Polynomial equations were developed to evaluate the increase and showed that overtopping might occur five to 15 years earlier for about a 4000-year return period flood. Reclamation is in the process of developing more detailed hydrology to address this issue. Until the study is completed, there is the potential for an increase in risk but the amount of the increase is not available and is not obvious in the probability of load for the risk calculation.

It does not appear that there is any significant increase in the potential risk of dam overtopping based on these numbers although there is the potential for a risk increase.

There are increases in the annual probability of failure due to the piping potential with the increase in percent of time the reservoir water surface is above elevation 1,210. These are discussed below.

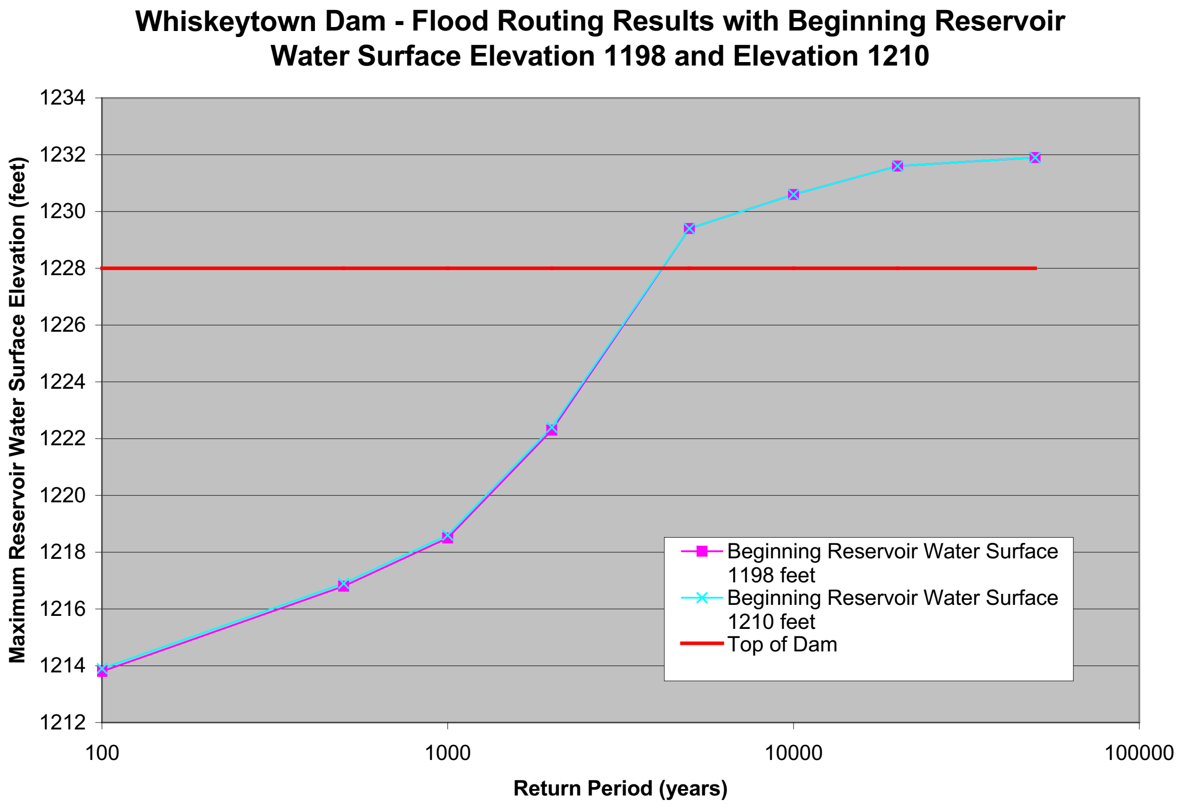


Figure 3-11 - Maximum water surface elevation versus return period for existing dam using existing frequency flood hydrology and varying the beginning reservoir water surface elevation.

3.3.3 Dam safety issue - peak hourly outflows vs. mean daily outflows

The Whiskeytown basin is relatively small and storms in the area can produce reservoir inflow hydrographs that are sharply peaked. It is expected that the peak inflow using smaller time increments will be larger then the peak based on a daily time step. The CCDAM DOHPLR simulation analysis was based on daily average flows. A review of the peak outflow versus mean daily outflow was performed to determine if there are additional risks associated with the instantaneous maximum reservoir water surface or the peak downstream flows and variations in the reservoir water surface elevation within a given day.

The maximum reservoir water surface elevations and peak outflows reported with the CCDAM DOHPLR submodel presented in this report are based on a mean daily flow and mean daily routing. The CCDAM DOHPLR assumes the flow is constant the entire day. However, given the small drainage basin for WT Dam and flashy nature of rainfall in the area, the actual inflow hydrograph is not accurately represented by a mean daily inflow which is an average of the daily instantaneous inflow. The peak inflow may actually be significantly higher. This is a function of the precipitation and rainfall-runoff transformations which results in a specific shape of the inflow hydrograph. The range in potential one-day hydrograph shapes is large and determining the maximum reservoir water surface elevation and the peak outflow from the uncontrolled spillway is difficult since the spillway responds quickly to raises in reservoir water surface elevations.

An assortment of hypothetical one day hydrograph shapes were developed based on available WT Dam flood frequency hydrograph shapes. This was achieved by extracting from the frequency floods, the 24 hour period with the most rapid inflow changes. The shape of these 24-hour periods from the frequency floods were used as representative shapes for a one-day flood hydrograph by maintaining the average daily flow and volume. It is recognized that these hydrographs do not reflect the full variation in potential hydrograph shapes.

The developed one-day frequency flood hydrograph shapes from the 100-year up through the 50,000-year were used as a representation of the potential shape of the hydrographs versus a constant one day flow. The flow was varied throughout the day to maintain the mean daily volume. With the daily volume held constant, the derived hourly inflows for each of the hydrographs were developed as a ratio of the maximum daily flow to the maximum flow in the section of the hydrograph extracted from the frequency floods. The derived maximum peak **hourly** inflows were between 26- to 60-percent greater than the mean daily inflow. The peak hourly to mean daily flow ratio varied depending on the shape of the hydrograph. Flow comparisons were based on the estimated 1,000-, 3,250-, 10,000-, 20,000- and 50,000 ft^3/s mean daily flows and used in evaluating the increase in dam safety risk, section 3.3.4.

Routing results for the 1,000 ft^3/s and the 10,000 ft^3/s hourly routings are shown in Table 3-7 and discussed in the following paragraphs.

Table 3-7: Comparative results from routings for 1,000 ft^3/s and 10,000 ft^3/s WT Reservoir inflows. Note: these results have no specific relationship to EWP scenarios performed. They are based on picking a reservoir starting elevation, and then shape and magnitude of flood hydrograph.

	Shape of Hydrographs based on Frequency Flood								
	Flat	**100-yr**	**500-yr**	**1000-yr**	**2000-yr**	**5000-yr**	**10,000-yr**	**20,000-yr**	**50,000-yr**
Beginning RWS 1210									
1000 ft^3/s									
Maximum Water Surface (ft)	1,210.45	1,210.46	1,210.46	1,210.46	1,210.46	1,210.46	1,210.46	1,210.46	1,210.46
Peak Inflow (Q ft^3/s)	1,000	1,602	1,483	1,439	1,398	1,349	1,312	1,279	1,270
Peak Outflow (Q ft^3/s)	480	490	492	492	493	494	494	495	496
Average Outflow (Q ft^3/s)	266								
10,000 ft^3/s *(~1983 storm)*									
Maximum Water Surface (ft)	1,213.64	1,213.7	1,213.73	1,213.73	1,213.74	1,213.76	1,213.76	1,213.77	1,213.78
Peak Inflow (Q ft^3/s)	10,000	16,016	14,834	14,392	13,983	13,489	13,125	12,788	12,695
Peak Outflow (Q ft^3/s)	7,501	7,659	7,747	7,777	7,806	7,844	7,859	7,876	7,899
Average Outflow (Q ft^3/s)	3,956								
Beginning RWS 1212									
1000 ft^3/s									
Maximum Water Surface (ft)	1,211.28	1,211.31	1,211.31	1,211.31	1,211.31	1,211.31	1,211.31	1,211.31	1,211.31
Peak Inflow (Q ft^3/s)	1,000	1,602	1,483	1,439	1,398	1,349	1,312	1,279	1,270
Peak Outflow (Q ft^3/s)	3,031	3,031	3,031	3,031	3,031	3,031	3,031	3,031	3,031
Average Outflow (Q ft^3/s)	2,192								
10,000 ft^3/s *(~1983 storm)*									
Maximum Water Surface (ft)	1,214.06	1,214.13	1,214.16	1,214.17	1,214.18	1,214.19	1,214.2	1,214.21	1,214.21
Peak Inflow (Q ft^3/s)	10,000	16,016	14,834	14,392	13,983	13,489	13,125	12,788	12,695
Peak Outflow (Q ft^3/s)	8,761	9,022	9,113	9,151	9,186	9,233	9,253	9,276	9,301
Average Outflow (Q ft^3/s)	6,556								

Routings were conducted for the 1,000 ft^3/s constant inflow hydrograph and the equivalent 1,000 ft^3/s flood volume with various shaped one-day hydrographs. The results were compared with the beginning reservoir water surface elevations of 1,210 ft and 1,212 ft. The peak inflow of the one-day hydrographs occurred at hour 13 (middle of the day) and ranged from 1,602 ft^3/s to 1,270 ft^3/s as compared to the mean daily flow of 1,000 ft^3/s. There was no significant difference in the maximum reservoir water surface elevations (1,210.45 ft versus 1,210.46 ft) with a beginning reservoir water surface elevation 1,210 ft. The outflow was 480 ft^3/s for the constant inflow hydrograph and ranged from 490 ft^3/s to 496 ft^3/s for the various shaped one-day hydrographs.

The routing results were similar for the 1,000 ft^3/s constant inflow versus the one-day hydrographs with starting reservoir water surface at 1,212 ft. These were similar because at this starting reservoir water surface the morning glory spillway outflow is greater than the inflow. The beginning reservoir water surface elevation 1,212 ft resulted in a minimum reservoir water surface of 1,211.31 ft at the end of the routing and a peak outflow of 3,031 ft^3/s (the initial discharge at water surface elevation 1,212 ft).

The routing results are slightly different for a 10,000 ft^3/s inflow. The one-day hydrographs were developed from the constant 10,000 ft^3/s inflow daily volume. The hydrograph shapes are similar to the 100-year, the 500-year, the 1,000-year, the 2,000-year, the 5,000-year, the 10,000-year, the 20,000-year, and the 50,000 year hydrographs. The peak hourly inflow ranged from 16,016 ft^3/s for the 100-year hydrograph shape, to 12,695 ft^3/s for the 50,000-year hydrograph shape, to 10,000 ft^3/s for the constant inflow hydrograph. The maximum reservoir water surface elevation using a beginning reservoir water surface of elevation 1,210 ft changed by 0.14 ft (about 1 ¾ inches) for the various hydrographs, elevation 1,213.64 ft for the constant inflow hydrograph to elevation 1,213.78 for the 50,000-year shaped hydrograph. With a beginning reservoir water surface of elevation 1,212 ft, the change in maximum water surface is about the same (from elevation 1,214.06 ft to 1,214.21 ft).

The peak outflow varies depending on the hydrograph shape and the beginning initial reservoir water surface. The average outflow is about 4,000 ft^3/s for the constant inflow 10,000 ft^3/s hydrograph and a beginning reservoir water surface elevation of 1,210; while the maximum outflow for the various shaped hydrographs ranged from about **7,500 ft^3/s to about 7,900 ft^3/s.** The difference involves nearly 90-percent variation in the reported outflow at Whiskeytown Dam. The outflow is about 6,560 ft^3/s for a constant inflow hydrograph with a beginning reservoir water surface elevation of 1,212 ft and ranged from about **9,000 ft^3/s to 9,300 ft^3/s** for the various shaped hydrographs.

Therefore, it appears that the increase in maximum reservoir water surface elevation during an EWP event attempt will not be significantly different regardless of the shape of the hydrographs. **What is significant is the peak hourly outflows will likely be higher than the daily outflow (average outflow) predicted by the CCDAM DOHPLR submodel and may be as much as double the predicted value in the downstream reaches**. The potential variation in outflows is significant from a safety perspective when considering the downstream risks to the public and shows the importance of determining potential downstream flooding thresholds between the dam and Redding CA and impacts on the downstream channel.

3.3.4 Dam Safety Risk analysis summary for EWP re-operation #3-16 (spring scenario 3,250 ft^3/s x 1 day, 1,204 ft ready elevation)

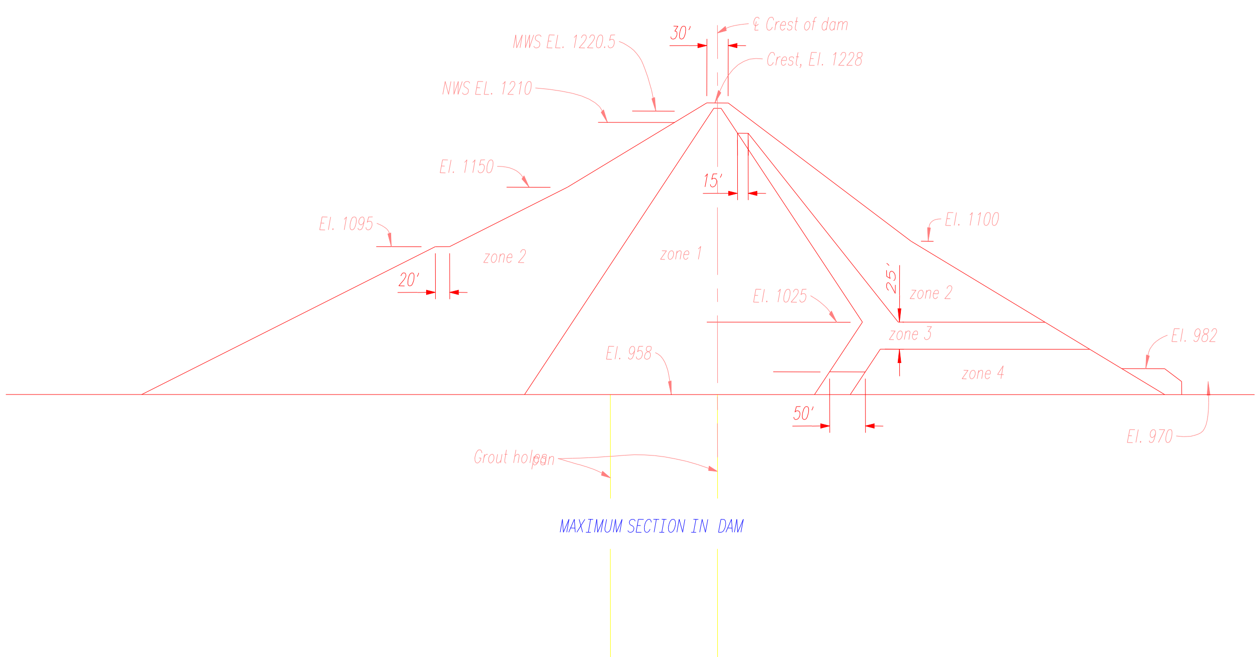
For the re-operation scenarios, a review of the potential failure modes was addressed. The failure modes for Whiskeytown Dam are identified as:

1. This failure is under normal conditions and involves piping of the Zone 1 material through Zone 3 and Zone 4 materials and downstream.
2. This failure is under normal conditions and involves piping of Zone 1 through discontinuities in the foundation rock.
3. This failure mode is overtopping during the PMF
4. This failure mode is a piping related failure mode during hydrologic loadings.
5. This failure mode is a seismic failure mode with seepage erosion through cracks resulting from strong shaking.

Re-operation of Whiskeytown Dam will involve these same failure modes. The analysis of risk due to re-operation involved the development of a finer breakdown of the hydrologic failure modes as discussed below.

Failure modes No. 1 and 4 include static and hydraulic conditions with piping of embankment Zone 1 or Zone 2 material through the Zone 3 transition and the Zone 4 rockfill toe into the downstream channel, resulting in headcutting to the reservoir and breach of the dam depending on the triggering event. The Zone 3 material does not strictly satisfy the “no erosion” filter criteria, but is anticipated to plug off and not allow continuing erosion of Zone 1 [Bureau of Reclamation 2003c]. Any material moving through the Zone 3 and Zone 4 would probably exit at the toe of the dam in the channel area, and probably be undetected. There is no toe drain system at WhiskeytownDam.

Figure 3-12 Maximum cross section, Whiskeytown Dam



Failure mode No. 1 is the static condition and includes all reservoir water surface (RWS) elevations below elevation 1211 in this study. Failure mode No. 4 involves the hydrologic loading on these static conditions. This failure mode was broken down into event trees for both of the risk analyses (2007a and 2007b) to evaluate the risk due to the various re-operation scenarios.

The first risk analysis (2007a) is based on developing simplified hydrologic event trees that involve two nodes. The details of the event trees and risk calculations are in Appendix E. The first node is the hydrologic loading. The probability of the loading is determined from the interval between end flood events (for example, the frequency from a 500- to a 1000-year flood). The hydrologic loading was divided into eight branches representing the various loading conditions from the yearly flood up through the 50,000-year return period flood. Flood routings were performed to determine an estimated maximum reservoir water surface. The second node captures the structural response of the dam for the loading. This node includes in a global manner consideration for the maximum reservoir water surface, duration of the high reservoir water surface, and structural response. The response of the structure was generally estimated when the reservoir water surfaces elevations were below 1210, 1210 to 1215 ft, 1215 to 1221 ft, 1221 to 1229 ft, and 1229 to 1232 ft. The first three levels of hydrologic loadings represent the reservoir with a maximum water surface below design maximum reservoir water surface, the next level represents loading the embankment above design level, and the last level involves direct overtopping of the dam. This node indirectly considers the increase in piping potential for known reservoir water surfaces or for first filling conditions. The base Annual Probability of Failure (APF) of all potential hydrologic failure modes was considered to be 1 in 10,000 if the reservoir water surface elevation was below 1215 feet., increased to 1 in 1,000 when the reservoir was between 1215 feet and 1221 feet, and became 1 in 100 when the reservoir water surface elevation was at or above elevation 1228. The APF was increased as the reservoir water surfaces rose, especially when the reservoir water surface was above historical. Adverse factors that make this potential failure mode more likely include the frequent loading at elevations below elevation 1221, first loading conditions when the reservoir is above elevation 1215.3, the dam was not designed for a reservoir water surface above elevation 1220.5, plugging of the spillway when the reservoir water surface is above elevation 1222, and the lack of designed filters. Positive factors that make this potential failure mode less likely include a dam that has performed well over the life, a well designed dam, and a dam that was constructed using modern methods with a zoned embankment. The AFP was computed for the various EWP model IDs with initial reservoir water surface elevations 1198 (historical), 1204, and 1209.5 for the spring scenario and for initial reservoir water surface elevations 1198 (historical) and 1203.5 for the winter scenarios, see Figure 3-13 and in Table 3-10.

The 2007a risk analysis determined an APF of 1.18E-04 and an ALL of 8.1E-03 for the historical condition and an APF range of 1.21E-04 to 1.30E-04 with an ALL range of 8.3E-03 to 8.9E-03 for the various EWP scenarios. This APF was compared to the information to the 2006 IE flood routings and risk analysis. The 2006 risk indicated an APF of 1.19E-04 with an ALL of 8.2E-03 (Figure 2-11). The 2003 CFR APF and ALL are of a similar order of magnitude (Figure 2-12). The 2006 IE used a simplified hydrologic event tree and the 2003 CFR used a different methodology which did not involve event trees. While not validating the 2007a risk analysis, these earlier studies indicated that the risks as defined in the 2007a risk analysis show there is a potential for a slight to negligable increase in the annual probability of failure. The ALL for the 2007a risk analysis also shows a potential increase with an ALL of 8.3E-03 to 8.9E-03 depending on the EWP scenario.

The simplified risk event tree (2007a) does not consider the internal erosion event tree which could be potentially more accurate for the potential failure conditions when the dam does not overtop. A second risk analysis (2007b, see Appendix F) was then developed to evaluated the potential increase in risk using an internal erosion event tree (see Figure 2-10) for the hydrologic loadings between elevation 1210 (spillway crest) and elevation 1228 (top of dam) and with a hydrologic event tree for overtopping flows. The use of the additional nodes in the internal erosion event tree potentially provide clarification of the risk the dam is exposed to and is a more current Reclamation method to evaluate the risk when the dam is not overtopping and the potential failure mode involves internal piping. The seismic risks were not increased for either analysis (2007a or 2007b). The seismic event tree as developed for the 2007b risk analysis is shown in appendix F and is the same (2.0E-07) as earlier risk analyses.

The potential hydrologic failure mode involves both internal erosion and overtopping of the dam. There are nine nodes for the internal erosion event tree. The internal erosion event tree nodes are: reservoir water surface rises to a specified elevation, initiation with a concentrated leak, continuation with a deficient filter, progression due to a supported roof for the leak, progression with no limits to the flow, progression with an erodible core, failure of early intervention, dam breach, and heroic measures fail to stop dam failure. In setting up the event tree with the various branches, the probabilities for each node could vary based on the reservoir water surface elevation for that branch of the event tree. However, once the probabilities for the existing condition were set up, the EWP scenarios were evaluated by changing the probability of the reservoir water surface using the exceedance information from the EWP model runs.

Adverse factors that make this potential failure mode more likely include more frequent periods with higher reservoir water surface elevations, operations that will put the reservoir water surface above historical elevations, and the dam will be in a first filling condition. Positive factors that make this potential failure mode less likely include a dam that has performed well over the past 40 years, has experienced a maximum reservoir water surface elevation 1215.3, a dam that was designed and constructed using modern methods, and has a design reservoir water surface elevation 1220.5 with an additional 7.5 feet of freeboard. Individual factors for the nodes are included in the worksheets in Appendix F, which show the details for the existing condition.

Table 3-8 shows the verbal descriptors and their associated probability as used in the 2007b methodology.

Table 3-8: Probabilities using verbal descriptors in risk methodology

Verbal Descriptors	Probability
Virtually certain	0.999
Very likely	0.99
Likely	0.9
Neutal	0.5
Unlikely	0.1
Very unlikely	0.01
Virtually impossible	0.001

The APF for the static condition with piping from Zone 1 into Zone 3 or Zone 4 is 6.7E-07, and the APF for piping through the foundation is 1.3E-06. The seismic APF is 2.0E-07

The ALL for the static potential failure modes of Zone 1 into Zone 3 or Zone 4 is 1.3E-04 and for piping through the foundation is 2.5E-04. The seismic ALL is 4.0E-05.

Due to the detail in developing the event trees and computing the risk associated with the dam, the AFP and Annualized Loss of Life (ALL) for the existing total hydrologic loading condition are slightly different than computed in the 2006 Risk Analysis. The existing total hydrologic APF is 8.9E-05 with an ALL of 6.1E-03. This is in the area of increasing justification to take action. The APF for the various EWP scenarios ranges from 8.6 to 8.9E-05 with ALL ranging 5.9E-03 to 6.1E-03. The ALL for the EWP scenarios is in an area of increasing justification to take action to reduce risk. The details for the computations are included in Appendix F for the historical condition and the results are summarized in the f-N chart, Figure 3-14, and in Table 3-11. In general it appears that the finer detail from the 2007b methodology potentially reduced both the APF and the ALL but not enough so either the APF or the ALL is below Reclamation guidelines.

The selected EWP re-operation scenarios (#3-16, #3-15, #3-17, and #3.18) using the hydrologic event tree only (2007a) or both an internal erosion and a hydrologic event tree (2007b) show there is a small change in hydrological risk (compare Table 2-11 and Table 3-9). The greater detail from the 2007b analysis shows a slight decrease in the ALL for all conditions.

The f-N chart for the EWP re-operation plan using 2007a is shown on Figure 3-13 and the table is shown in Table 3-10 while the f-N chart using 2007b is shown in Figure 3-14 and the table is shown in Table 3-11.

Risk methodology is continually developing. The various methods used to evaluate the risks have been used at Whiskeytown Dam and show the variation. The 2003 CFR used the UNSW method, the 2006 IE used a hydrology event tree, the 2007a used a 2-node hydrology event tree, and the 2007b method used the hydrology event tree, the internal erosion event tree, and a seismic event tree. The UNSW method is currently under further development to improve the internal erosion event trees. Reclamation is currently working to improve the state of knowledge regarding the probability of the hydrologic loadings at Whiskeytown Dam. This additional information could change the risk as understood at Whiskeytown Dam. The greatest area of concern is that in all evaluated scenarios, the hydrologic ALL is above Reclamation guidelines and the use of the revised UNSW method in conjunction with the revised hydrologic loadings should be considered prior to any permanent changes in operation at Whiskeytown Dam.

Table 3-9: Dam safety risks showing existing 2006 IE conditions, a revised operation using the hydrologic event tree only (2007a), and a revised operation using both hydrologic and internal erosion event trees (2007b).

Loading Condition	Expected Annual Probability of Failure (range)	Expected Consequences Loss of Life (range)	Expected Annual Loss of Life (range)
Total Static – 2006 IE	1.80E-06	199	3.58E-04
Total Seismic – 2006 IE	2.00E-07	199	3.98E-05
Total Hydrologic – 2006 IE	1.19E-04	69	8.215E-03
Revised Total Hydrologic – 2007a	1.18E-04	69	8.14E-03
#3-16 Spring 1204 Ready – 2007a	1.25E-04	69	8.59E-03
#3-15 Spring 1198 Ready – 2007a	1.21E-04	69	8.31E-03
#3-17 Spring 1209 Ready – 2007a	1.30E-04	69	8.94E-03
#3-18 Winter 1198 Ready – 2007a	1.26E-04	69	8.68E-03
Revised Total Hydrologic – 2007b	8.89E-05	69	6.14E-03
#3-16 Spring 1204 Ready – 2007b	8.85E-05	69	6.11E-03
#3-15 Spring 1198 Ready – 2007b	8.85E-05	69	6.11E-03
#3-17 Spring 1209 Ready – 2007b	8.78E-05	69	6.06E-03
#3-18 Winter 1198 Ready – 2007b	8.56E-05	69	5.91E-03

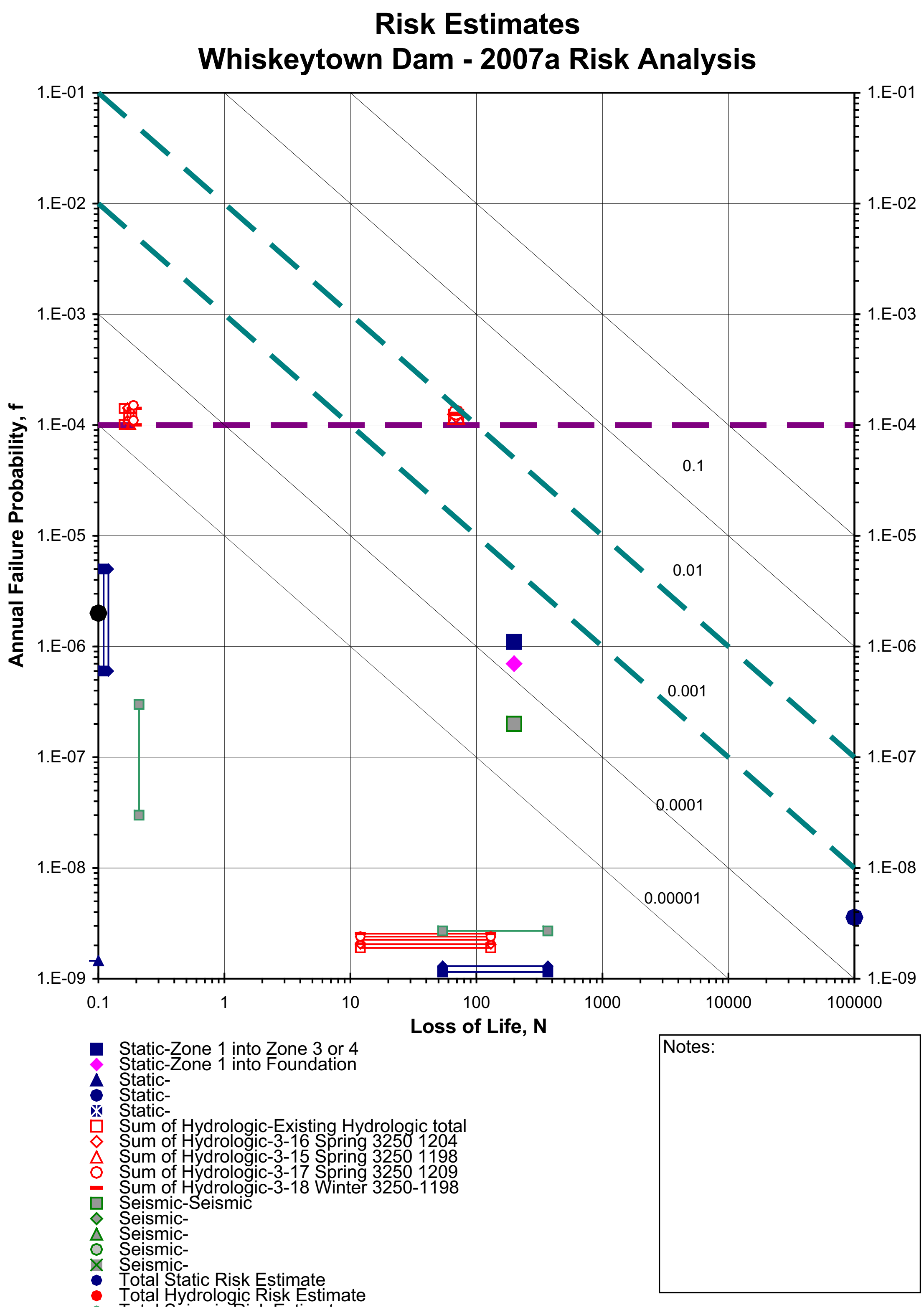


Figure 3-13: Annualized risk plot 2007a for current and EWP re-operation scenarios (#3-15, #3-16, #3-17, and #3-18) using a hydrologic event tree to determine risks.

Risk Results

Facility	WHISKEYTOWN	Author	E.A. Cohen
Region	MP	Checked	
Product	Other EWP Evaluation	Notes	
Source Document	12-12-2007		
Date of Chart	12-17-2007		

Analysis of Risk From Source Document

Failure Mode	Mean Probability of Failure Estimate			Mean Loss of Life Estimate			Mean Total Risk Estimate		
	Low	Expected	High	Low	Expected	High	Low	Expected	High
Static									
1 Zone 1 into Zone 3 or 4	6.00E-07	1.10E-06	5.00E-06	54	199	369	3.24E-05	2.19E-04	1.85E-03
2 Zone 1 into Foundation	6.00E-07	7.00E-07	5.00E-06	54	199	369	3.24E-05	1.39E-04	1.85E-03
Total	1.20E-06	1.80E-06	1.00E-05	54	199	369	6.48E-05	3.58E-04	3.69E-03
Sum of Hydrologic									
1 Existing Hydrologic tota	1.01E-04	1.18E-04	1.41E-04	12	69	130	6.97E-03	8.14E-03	9.71E-03
2 3-16 Spring 3250 1204	1.10E-04	1.25E-04	1.43E-04	12	69	130	7.59E-03	8.59E-03	9.83E-03
3 3-15 Spring 3250 1198	1.01E-04	1.21E-04	1.41E-04	12	69	130	6.97E-03	8.31E-03	9.71E-03
4 3-17 Spring 3250 1209	1.10E-04	1.30E-04	1.51E-04	12	69	130	7.59E-03	8.94E-03	1.04E-02
5 3-18 Winter 3250-1198	1.00E-04	1.26E-04	1.41E-04	12	69	130	6.91E-03	8.68E-03	9.73E-03
Total				12	69	130			
Seismic									
1 Seismic	3.00E-08	2.00E-07	3.00E-07	54	199	369	1.62E-06	3.98E-05	1.11E-04
Total	3.00E-08	2.00E-07	3.00E-07	54	199	369	1.62E-06	3.98E-05	1.11E-04

Table 3-10 – Risk results 2007a using a hydrologic event tree only (details in Appendix E)

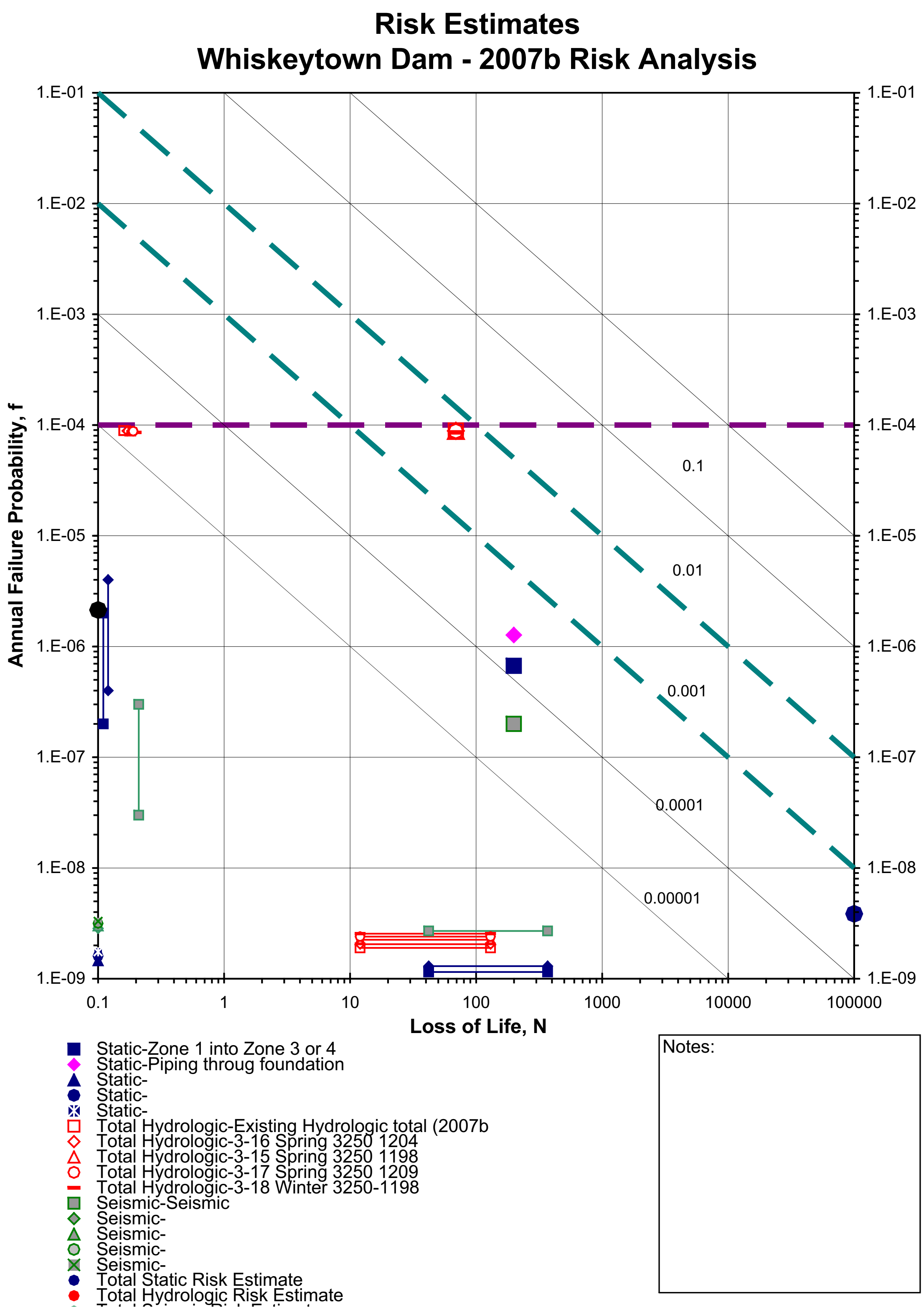


Figure 3-14 - Annualized risk plot 2007b for current and EWP re-operation scenarios (#3-15, #3-16, #3-17, and #3-18) using both the internal erosion event tree and the hydrologic event tree.

Risk Results

Facility	WHISKEYTOWN	Author	E.A. Cohen
Region	MP	Checked	
Product	Other Re-operation Study 2007b	Notes	
Source Document	17-01-2008		
Date of Chart	17-01-2008		

Analysis of Risk From Source Document

Failure Mode	Mean Probability of Failure Estimate			Mean Loss of Life Estimate			Mean Total Risk Estimate		
	Low	Expected	High	Low	Expected	High	Low	Expected	High
Static									
1 Zone 1 into Zone 3 or 4	2.00E-07	6.69E-07	2.00E-06	42	199	369	8.40E-06	1.33E-04	7.38E-04
2 Piping throug foundatior	4.00E-07	1.27E-06	4.00E-06	42	199	369	1.68E-05	2.53E-04	1.48E-03
3									
4									
5									
Total	6.00E-07	1.94E-06	6.00E-06	42	199	369	2.52E-05	3.86E-04	2.21E-03
Total Hydrologic									
1 Existing Hydrologic total (2007b		8.89E-05		12	69	130		6.14E-03	
2 3-16 Spring 3250 1204		8.85E-05		12	69	130		6.11E-03	
3 3-15 Spring 3250 1198		8.85E-05		12	69	130		6.11E-03	
4 3-17 Spring 3250 1209		8.78E-05		12	69	130		6.08E-03	
5 3-18 Winter 3250-1198		8.56E-05		12	69	130		5.90E-03	
Total									
Seismic									
1 Seismic	3.00E-08	2.00E-07	3.00E-07	42	199	369	1.26E-06	3.98E-05	1.11E-04
2									
3									
4									
5									
Total	3.00E-08	2.00E-07	3.00E-07	42	199	369	1.26E-06	3.98E-05	1.11E-04

Table 3-11 - Risk results 2007b using both the internal erosion event tree and a hydrologic event tree (details are in the appendix)

3.3.5 Operational impacts

The operational impacts are a Reclamation concern since the highest ranking option (#3-16) represents a temporary departure from normal operating rules at WT Reservoir. The operational impacts involve having the mechanism in place to authorize the EWP attempt. There are no rain gages upstream of the dam in the Whiskeytown basin, so presumably the inflow forecasting model used in this study or an improved version would need to be used in-season. The desired release of 3,250 ft^3/s can be obtained mechanically by increasing the J.F. Carr Tunnel to a maximum and closing the Spring Creek Tunnel to a minimum. However, the filling operation required to surcharge the reservoir and achieve equilibrium at the desired outflows will potentially have a longer duration and involve higher water volumes.

The period of attempts (March 1 to May 15) is also a time when the Reclamation staff are carefully monitoring flows and reservoir storage volumes and adjusting them to prevent flooding. While flood control is not an authorized project benefit at Whiskeytown Dam, the reservoir is drawn down to elevation 1198 during the flood season to provide up to an estimated 35,000 acre-feet flood control pool. The selection of #3-16 results in the loss of an estimated 18,100 acre-feet of volume that is used for flood control or approximately 51 percent of the flood control pool.

To achieve maximum efficiency, it is desired to initiate an EWP attempt at a time when there is some rainfall occurring on the basin which could fill the reservoir quicker than tunnel diversion inflows. This raises some issues of determining how large the rain storm will be in the basin and if it will be too large or too small (a consideration built into the CCDAM DOHPLR submodel).

An operational process will have to be in-place to determine when the EWP release attempt is made. In the model this is based on estimating rainfall and volumes from the five prior days. For this to be effective in practice requires extracting and incorporating into operations the inflow forecast model in DOHPLR or developing a more refined in-season real-time computer program to predict future inflows. This would necessarily require operating personnel to review the records daily during the EWP period and make daily (or hourly) decisions whether to make an EWP attempt or not (which would not necessarily be every year).

Additional attention to flows and rainfalls would be required by Reclamation staff during the EWP attempt. This could involve an hourly review to determine how the attempt is going and to make any decisions to terminate or to continue the attempt. After an attempt was made there has to be some type of review to determine the implementation and effects of the operation on other ongoing tasks. The issues associated with power production will also require additional efforts during an EWP attempt. The effect of the loss of power production would have to be mitigated, and the replacement power obtained if operation falls below contracted values. Coordination with the power producers would be required. An accounting of the amount of water lost and the cost of power lost and additional Reclamation costs would have to be determined after each attempt.

The accretion of flow in the downstream sections of Clear Creek has to be considered in relation to impacts in Redding and the surrounding developments. The backwater effects of the Sacramento River will have to be taken into account and further refined prior to real world implementation of the pilot program (i.e., is 14,000 ft^3/s the appropriate lower Clear Creek safe channel capacity under high flows on the Sacramento River).

The time involvement by Reclamation staff can vary dramatically depending on the water year type, the EWP Ready elevation, and operation of Trinity, J.F. Carr Tunnel, J.F. Powerplant, WT Dam, Spring Creek Powerplant, and the Spring Creek Tunnel.

Steps required by Reclamation prior to accepting full implementation of the Pilot Program for an EWP attempt:

Implementation plans coordinated by the USFWS discussed with Reclamation

Reclamation will re-evaluate the APF and ALL using the hydrology data and frequency information planned for completion in 2008 and potentially the new UNSW internal erosion event tree

Discussions with USFWS should be clear as to who holds final authority to attempt or abort an EWP release (may be a dual decision)

Finalize the length of the Pilot Program in years (presently 10), number of attempts, or cumulative cost

Set up in-season operational rules and plans (building on decision algorithm in CCDAM DOHPLR submodel)

Determine the need for a more refined WT Reservoir inflow forecasting model (e.g., use the model embedded in CCDAM DOHPLR or an as yet developed alternative)

Hold additional discussions with water users and irrigation districts

Hold discussions with power customers and power regulators

After each EWP attempt

- evaluate and prepare plans to mitigate impacts to irrigation districts
- evaluate and prepare plans to mitigate impacts to power customers
- evaluate and prepare plans to mitigate manpower needs during an EWP attempt
- estimate cost to prepare accounting report of EWP attempt

Determined associated costs for above tasks

Ensure a biological and geomorphic effectiveness monitoring plan is in place prior to the first event.

4. Summary and Recommendations

An EWP release at Whiskeytown Dam (WT Dam) is achievable by re-operation of WT Dam assuming that success is measured as a number of days when the flow in Clear Creek are equal to or greater than the target flow. Achieving the EWP success will also require the re-operation to involve the joint operation of Trinity Dam, J.F. Carr Tunnel, J.F. Carr Powerplant, WT Dam, Spring Creek Tunnel, Spring Creek Powerplant, and Keswick Dam. There are operational impacts on water deliveries and power production that will have to be addressed in order to achieve the EWP release.

There is a high probability of setting a new higher maximum historical reservoir water surface elevation during the trial period of the EWP attempts. The peak outflows during an EWP event may be larger than predicted by the CCDAM model. The design discharge capacity of the spillway is 28,650 ft^3/s at reservoir water surface elevation 1,220.5. The peak outflows should be compared to any downstream flood threshold and downstream channel impacts. It is estimated that the safe downstream channel capacity is approximately 14,000 ft^3/s based on preliminary studies by USFWS (these do not take into account Sacramento River back-water effects).

The total hydrologic APF is above guidelines for the 2006 IE and the 2007a risk analysis. The total hydrologic APF for the 2007b dropped just below guidelines based on the use of the additional detailed event trees. The ALL for all risk analyses and all conditions both existing and for the EWP re-operation scenarios are above Reclamation's guidelines. This is an area of concern and Reclamation is currently studying the probabilities of the hydrologic loading.

4.1. Most promising scenario

Based on an integration of success count rankings, foregone power rankings and rankings for failure characteristics, model run #3-16 is the best scenario (3,250 $ft^3/s \times 1$ day, spring 1,204 ft ready elevation).

This scenario shows negligible change in the risk for either the Annual Failure Probability or the Annualized Loss of Life. The *existing* total hydrologic dam safety risk and the risks under the EWP re-operation scenarios are currently above Reclamation guidelines. The expected potential Annual Failure Probability is either above or just below the guidelines depending on the risk analysis methodology. The expected potential Annualized Loss of Life is above Reclamation guidelines for all analyses.

4.2. Winter scenarios

The risks posed between the winter and spring starting elevation are approximately equal. Both the winter and spring scenarios have about the same number of days that the predicted reservoir water surface elevation is above elevation 1210 ft. The winter scenarios are not considered to be the preferred option due to intangible factors: the number of days the scenario lasts, impacts on the daily operations of Reclamations Central Valley Operations, and impacts to the Reclamation staff on site at the various facilities. Furthermore, risks related to peak downstream flows are expected to be greater with winter scenarios. However, any naturally occurring floods during the winter period may eliminate the need for an EWP release that year.

4.3. Real-time, in-season implementation plan

Pilot implementation of EWP operations involves having the mechanism in place to determine estimated effectiveness and to authorize the EWP attempt. There are no rain gages upstream of the dam in the Whiskeytown basin. The desired release of 3,250 ft^3/s can nearly be obtained mechanically by increasing the Clear Creek Tunnel to a maximum and closing the Spring Creek Tunnel to a minimum, but using only the tunnels for surcharging the reservoir will involve higher water volume losses. The optimum method to achieve an EWP release is to attempt it during a hydrologic event, at a time when rainfall is occurring or anticipated to fall on the basin. This additional amount of volume would add to the EWP and would fill the reservoir quicker than operational inflows alone. This requires a method to approach the issue of estimating precipitation and runoff and one method is along the lines of what was implemented in CCDAM DOHPLR submodel or some other approach.

An in-season operational plan will have to be developed to determine when the EWP release attempt is made and who will be making the final decision to make the attempt. In the DOHPLR submodel the attempt is based on estimating rainfall and volumes from the five prior days. Hence, on an in-season basis this would also require the operational personnel to review these records daily and make the decision to attempt or pass on the attempt according to a decision algorithm resembling Figure 2-9 (and described in detail in section 2). Additional rain and/or stream gages might be desirable to assist with runoff forecasting and the decision to attempt an EWP release.

Additional attention to flows and rainfalls would be required by Reclamation staff during the EWP attempt to avoid larger than needed flows. This could involve an hourly review to determine how the attempt is going and a status evaluation to terminate or to continue the attempt. After an attempt was made there has to be some type of review to determine the implementation costs and impacts on other ongoing tasks. The issues associated with power production will also require additional efforts during an EWP attempt. The cost and contractual impacts of the loss of power production would have to be determined, and the replacement power obtained if operation falls below contracted values. Coordination with the power producers would be required. An accounting of the amount of water and power lost and the associated costs would have to be determined after each attempt.

The implementation plan should also be coordinated with the gravel replacement program and biological and habitat assessment programs to determine the effectiveness of the releases and to avoid making an attempt while other studies or activities are taking place on the river.

4.4. Reclamation requirements for implementing pilot EWP re-operation

Should EWP releases be implemented on a pilot basis, the time involvement by Reclamation staff is expected to vary dramatically depending on the water year type, the EWP ready elevation, and operation of Trinity, J.F. Carr Tunnel, WT Dam, and the Spring Creek Tunnel.

The following are the items which need to be addressed prior to on the ground implementation of the pilot program for an EWP attempt:

- Discussions with USFWS should be clear as to who holds final authority to attempt or abort an EWP release
- Determine length of Pilot Program in years (presently 10 years), number of attempts, or cumulative cost
- Set up in-season operational rules and plans (building on decision algorithm in CCDAM DOHPLR submodel)
- Determine the need for a WT Reservoir inflow forecasting model (e.g., use the model embedded in CCDAM DOHPLR or an as yet developed alternative)
- Hold additional discussions with water users and irrigation districts
- Hold discussions with power customers and power regulators
- After each EWP attempt
    - evaluate and prepare plans to mitigate impacts to irrigation districts
    - evaluate and prepare plans to mitigate impacts to power customers
    - evaluate and prepare plans to mitigate manpower needs during an EWP attempt
    - estimate cost to prepare accounting report of EWP attempt
- Determined associated costs for above tasks
- Ensure a biological and geomorphic effectiveness monitoring plan is in place prior to the first event.

The following are a few of the initial discussion items that will be discussed after the Pilot Program has lasted ten years and the steps required by Reclamation prior to accepting full implementation of the program for an EWP releases:

- Recognize that acceptance of the Pilot Program does not mean Reclamation will accept a full program
- Review impacts, costs, and details of Pilot Program
- Determine final impacts to Reclamation
- Determine final impacts to irrigation districts and water users
- Determine final impacts to power customers

References and Further Reading

Adaptive Management Forum. 2004. Adaptive Management Forum For Large-Scale Channel and Riverine Habitat Restoration Projects, Final Report. Prepared by the Adaptive Management Forum Scientific and Technical Panel and Information Center for the Environment, Department of Environmental Science and Policy, University of California, Davis for USFWS Anadromous Fish Restoration Program and CALFED Bay-Delta Program, CA. 45 pp.

Alexander, C.A.D, C.N. Peters, D.R. Marmorek and P. Higgins. 2006. A decision analysis of flow management experiments for Columbia River mountain whitefish (*Prosopium williamsoni*) management. Can. J. Fish. Aquat. Sci. 63 (5): 1142-1156.

Alexander, C.A.D. 2006. A model-based analysis of gravel augmentation below Whiskeytown Dam, California. Draft report prepared by ESSA Technologies Ltd., Kelowna, B.C. for the Bureau of Reclamation, Shasta Lake, CA. 56 pp.

Alexander, C.A.D., D.R. Marmorek, C.N. Peters and M. Porter. 2003. Clear Creek Decision Analysis and Adaptive Management Model: Design Document, Draft 1.5. Draft report prepared by ESSA Technologies Ltd., Vancouver, BC for U.S. Bureau of Reclamation, Shasta Lake, CA. 116 pp + appendices.

Bureau of Reclamation. 1965. Trinity River Division Features of the Central Valley Project: Technical Record of Design and Construction. Vol. 1. Bureau of Reclamation, Denver, CO.

Bureau of Reclamation. 1987. Design of Small Dams, U.S. Department of the Interior, Bureau of Reclamation, Third Edition, 1987. Bureau of Reclamation, Denver, CO.

Bureau of Reclamation. 1999. "A Procedure for Estimating Loss of Life Caused by Dam Failure," DSO-99-06, Bureau of Reclamation, Denver, CO. September 1999

Bureau of Reclamation. 2001. Emergency Preparedness Plan for Whiskeytown Dam, Standing Operating Procedures, 2006. Bureau of Reclamation, Denver, CO.

Bureau of Reclamation. 2003a. Dam Safety Risk Analysis Methodology, Version 3.3.1, US Department of the Interior, May 2003. Bureau of Reclamation, Denver, CO. 48 p

Bureau of Reclamation. 2003b. Guidelines for Achieving Public Protection in Dam Safety Decision Making, US Department of the Interior, Bureau of Reclamation, June 15, 2003. 19 p

Bureau of Reclamation. 2003c. Clair A. Hill Whiskeytown Dam Comprehensive Facility Review, Central Valley Project, California, Mid-Pacific Region, US Department of the Interior, Bureau of Reclamation, November 2003.

Bureau of Reclamation. 2005. Whiskeytown Dam Issue Evaluation – Flood Routings, Technical Memorandum No. WHI-8130-IE-TM-2005-1, US Department of the Interior, Bureau of Reclamation, April 2005

Bureau of Reclamation. 2006a. Whiskeytown Dam Issue Evaluation – Risk Analysis, Technical Memorandum No. WHI-8130-IE-TM-2006-1, US Department of the Interior, Bureau of Reclamation, April 2006

Bureau of Reclamation. 2006b. Hydrologic Hazard, Whiskeytown Dam, California, Mid-Pacific Region, Central Valley Project, Denver Colorado, April 24, 2006.

Bureau of Reclamation. 2006c. Decision Document, Whiskeytown Dam, California, Mid-Pacific Region, Central Valley Project, Denver Colorado, July 14, 2006.

CALFED. 2002. Executive summary of the Pilot Watershed Acquisition Program's stream selection recommendations. CALFED, Sacramento, California.

Comprehensive Facility Review (CFR) for Clair A. Hill Whiskeytown Dam – Safety Evaluation of Existing Dams (SEED) and Review of Operation and Maintenance (RO&M) Programs – Central Valley Project, California, Bureau of Reclamation, Denver Colorado, November 14, 2003.

DWR. 1986. Clear Creek Fishery Study. March 1986. California Department of Water Resources.

Graham Matthews and Associates. 2003. "WY2003 Geomorphic monitoring report, Clear Creek Floodplain Rehabilitation Project," July.

Graham Matthews and Associates. 2004. "WY2004 Geomorphic monitoring report, Clear Creek Floodplain Rehabilitation Project," June.

Graham Matthews and Associates. 2005. "WY2005 Geomorphic monitoring report, Clear Creek Floodplain Rehabilitation Project," December.

Kondolf G.M. and P.R. Wilcock. 1996. The flushing flow problem: defining and evaluating objectives. *Wat. Resourc. Res*. **32(8)**: 2589-2599.

Kondolf G.M. and J.G. Williams. 1999. Flushing Flows: A review of concepts relevant to Clear Creek, California. Prepared for the U.S. Fish and Wildlife Service, Red Bluff, CA. August 9, 1999.

Environmental Water Program. August 2004. Pilot Flow Augmentation Project: Concept Proposal or Flow Acquisition on Lower Clear Creek. Prepared by Stillwater Sciences, Berkeley, CA for California Bay Delta Authority Ecosytem Restoration Program, CA. 57 pp + appendices.

Kimmerer, W., B. Cavallo, F. Ligon, S. McBain, C. Stevens, J. Williams, and S. Birk. 2002. CALFED Adaptive Management Workshop March 19–20, 2002, Topic area summary report: Flow manipulation.

McBain and Trush. 2001. "Final report: geomorphic evaluation of Lower Clear Creek downstream of Whiskeytown Dam, California," November.

Stillwater Sciences. 2003. Environmental Water Program: Restoring Ecosystem Processes Through Geomorphic High Flow Prescriptions. Final Report. Prepared for CALFED Bay-Delta Program and Jones and Stokes. March 2003.

Appendix A: Summary of CCDAM DOHPLR Parameter Values

Table A1 below summarizes the fixed value parameters required by the DOHPLR submodel design, and the parameter values used in our simulations.

Table A1: CCDAM DOHPLR model parameter values used in EWP analysis.

Functional Relationship	Eq #	Parameter	Prelim. Value	Comments
Operational constraints				
Whiskeytown Glory Hole top	2-2 /2-3	Elevation (ft) Storage equivalent (acre-feet)	1,210 241,096	www.usbr.gov/dataweb/dams/ca10204.htm
Trinity flood hazard limits (ft)		Winter (Nov. 1st – Mar. 31st) Summer (Apr. 1st – Sep. 30th)	2,345.0 2,373.5	DB tblDOHPLRTunnelScenario TrLimitWinter and TrLimitSummer
Shasta encroachment foresight (true/false)			false	DB tblDOHPLRTunnelScenario SheEncroachSuspends
Bend Bridge max. flow (ft^3/s)			65,000	DB tblDOHPLRTunnelScenario BBFlowMax
J.F. Carr tunnel limits (ft^3/s)			[60, 3,400]	DB tblDOHPLRTunnelScenario JCFlowMin and JCFlowMax
Spring Creek tunnel limits (ft^3/s)			[200, 4,300]	DB tblDOHPLRTunnelScenario SCFlowMin and SCFlowMax
Whiskeytown outlet limits (ft^3/s)			[50, 1,100]	DB tblDOHPLRTunnelMonthly.WtFlowMin for all months where TunnelScenarioID = 5, and tblDOHPLRTunnelScenario.WtFloxMax
5-day advance inflow forecasting[9]				
Water Year type limits, acre-feet		Critically Dry Dry Normal Wet Extremely Wet	[-100,000, 100,000] (100,000, 200,000] (200,000, 255,000] (255,000, 393,000] (393,000, 700,000]	As set by Dam Operations' Hydrology Group

[9] The forecast coefficients C, b, S_{-n} were determined through analysis contained in file: CCDAM.ForecastC.r9.xls.

Functional Relationship	Eq #	Parameter	Prelim. Value	Comments
Water Year cumulative volumes (Oct. 1- Mar. 31) by year, acre-feet		1965, 232 469, Normal 1966, 40 835, Normal 1967, 138 799, Dry 1968, 287 145, Wet 1969, 341 792, Wet 1970, 272 696, Wet 1971, 119 258, Dry 1972, 349 454, Wet 1973, 583 987, Extremely Wet 1974, 247 363, Normal 1975, 73 958, Critically Dry 1976, 40 161, Critically Dry 1977, 438 843, Extremely Wet 1978, 116 400, Dry 1979, 260 914, Wet 1980, 175 964, Dry 1981, 338 454, Wet 1982, 632 658, Extremely Wet 1983, 292 931, Wet 1984, 119 950, Dry 1985, 306 401, Wet 1986, 92 214, Critically Dry 1987, 118 905, Dry 1988, 148 891, Dry 1989, 61 880, Critically Dry 1990, 55 813, Critically Dry 1991, 181 402, Dry 1992, 250 407, Normal 1993, 91 384, Critically Dry 1994, 501 794, Extremely Wet 1995, 226 471, Normal 1996, 293 956, Wet 1997, 542 592, Extremely Wet 1998, 228 269, Normal 1999, 299 972, Wet 2000, 163 607, Dry 2001, 229 275, Normal 2002, 247 521, Normal 2003, 265 539, Wet 2004, 169 720, Dry		Computed values using historical data, query DOHPLRNaWaterYear
Forecast Coefficients - Winter	2-1	C	2.5107646413223	DB tblDOHPLREWPScenario.ForecastCWinter
		b	651.377	Hard-coded constants mk_dWinterOffset and mk_dWinterSn[1-5] in CDOHPLRNaWaterYear (module DOHPLRNaWaterYear.cls), determined through analysis contained in file: CCDAM.ForecastC.r9.xls
		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	3.165594742 -0.647428715 0.187012619 -0.056354493 0.355235573	
Forecast Coefficients – Critically Dry (DB WaterYearType.WaterYearTypeID = 1)	2-1	C	2.36211915173554	DB tblDOHPLREWPScenario.ForecastCSpringDry
		b	95.765524	DB WaterYearType.Offset
		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	2.962669935 0.340106302 0.116030264 -0.166738905 -0.04166655	DB WaterYearType.Sn[1-5]
Forecast Coefficients – Dry (DB	2-1	C	2.47248014677686	DB tblDOHPLREWPScenario.ForecastCSpringDry
		b	137.6776583	DB WaterYearType.Offset

Functional Relationship	Eq #	Parameter	Prelim. Value	Comments
WaterYearType.WaterYearTypeID = 2)		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	2.87139047 -0.101982316 0.577515701 -0.127584267 0.106966709	DB WaterYearType.Sn[1-5]
Forecast Coefficients – Normal (DB WaterYearType.WaterYearTypeID = 3)	2-1	C	2.39207452958678	DB tblDOHPLREWPScenario.ForecastCSpringNormal
		b	152.537802	DB WaterYearType.Offset
		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	3.154570772 -0.508172907 0.65736822 0.17318419 0.121365877	DB WaterYearType.Sn[1-5]
Forecast Coefficients – Wet (DB WaterYearType.WaterYearTypeID = 4)	2-1	C	2.4878562585124	DB tblDOHPLREWPScenario.ForecastCSpringWet
		b	116.23782	DB WaterYearType.Offset
		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	2.240202271 0.328008681 0.096277669 0.234464462 0.500262419	DB WaterYearType.Sn[1-5]
Forecast Coefficients – Extremely Wet (DB WaterYearType.WaterYearTypeID = 5)	2-1	C	1.205089561	DB tblDOHPLREWPScenario.ForecastCSpringExtWet
		b	2507.774	DB WaterYearType.Offset
		S_{-1} S_{-2} S_{-3} S_{-4} S_{-5}	4.961572609 0.448007524 -0.066126548 -0.259190422 0.204879095	DB WaterYearType.Sn[1-5]
Approximation of foregone power costs				
Trinity generator parameters	2-6	Maximum flow (ft^3/s)	4000	CTrinity.mk_dGenMaxFlow in Trinity.cls
		Tail elevation (ft)	1902	CTrinity.mk_dTailElevation in Trinity.cls
		Gross Head	calculated	DB tblDOHPLRHistorical.TrElevation – tail elevation (i.e. 1902) CTrinity.GrossHead() in Trinity.cls
		Power(Vol. acre-ft)	calculated	((1.193 * dGrossHead) - 142.109) * 0.001 * dAcreFt CTrinity.PowerOutput() in Trinity.cls
J.F. Carr generator parameters	2-6	Max. flow (ft^3/s)	3400	CJFCarr.mk_dGenMaxFlow in JFCarr.cls
		Tail elevation (ft)	n/a	Not needed by model in order to computer power
		Gross Head	n/a	Not needed by model in order to computer power
		Power (Vol. acre-ft)	calculated	0.51075 * dAcreFt CJFCarr.PowerOutput() in JFCarr.cls
Spring Creek generator parameters	2-6	Max. flow (ft^3/s)	4200	CSpringCreek.mk_dGenMaxFlow in SpringCreek.cls
		Tail elevation (ft)	585	CSpringCreek.mk_dTailElevation in SpringCreek.cls
		Gross Head	calculated	Current or historical Whiskeytown elevation – tail elevation (i.e. 585) CSpringCreek.GrossHead() in SpringCreek.cls
		Power(Vol. acre-ft)	calculated	((1.967 * dGrossHead) - 717.169) * 0.001 * dAcreFt CSpringCreek.PowerOutput() in SpringCreek.cls

Functional Relationship	Eq #	Parameter	Prelim. Value	Comments
Shasta generator parameters	2-6	Max. flow (ft^3/s)	17 000	CShasta.mk_dGenMaxFlow in Shasta.cls
		Tail elevation (ft)	587	CShasta.mk_dTailElevation in Shasta.cls
		Gross Head	calculated	DB tblDOHPLRHistorical.ShElevation – tail elevation (i.e. 587) CShasta.GrossHead() in Shasta.cls
		Power(Vol. acre-ft)	calculated	1.045 * ((0.835 * dGrossHead) + 30.532) * 0.001 * dAcreFt CShasta.PowerOutput() in Shasta.cls
Keswick generator parameters	2-6	Max. flow (ft^3/s)	15 000	CShasta.mk_dGenMaxFlow in Shasta.cls
		Tail elevation (ft)	493	CShasta.mk_dTailElevation in Shasta.cls
		Gross Head	94	CShasta.mk_dGrossHead in Shasta.cls This is fixed as the difference between the tail elevation of Shasta and Keswick
		Power(Vol. acre-ft)	calculated	((0.704 * mk_dGrossHead) + 9.477) * 0.001 * dAcreFt CShasta.PowerOutput() in Shasta.cls
Power price – No Shift ($/MWHr)	2-6	Constant for all months of the year	$44.05	DB tblDOHPLRPowerMonthly for DOHPLRPowerScenarioID = 6 for all months This corresponds to the tblDOHPLRPowerScenario 'NO MARGINAL' with a description "Eliminate marginal price shift, to put lower bound on event costs"
Power price – Shift ($/MWHr)	2-6	January February March April May June July August September October November December	$44.73 $39.06 $37.10 $44.05 $31.99 $40.28 $50.60 $59.36 $37.25 $42.40 $47.39	DB tblDOHPLRPowerMonthly for DOHPLRPowerScenarioID = 4 for all months This corresponds to the tblDOHPLRPowerScenario 'EWP DEFAULT' with a description "CAISO monthly average power prices for 2005. Note prices for Sept, Oct, Nov, and Dec were adjusted down from the actual 2005 prices. Believe 2005 prices had high natural gas price effects."

Appendix B: Detailed CCDAM EWP Simulation Results

Due to the extensive volume of results produced by our analysis, readers interested in further details are directed to the electronic repository available at: ftp://ftp.essa.com/pub/essa/EWP/.

Table B1 below (next page) provides a full listing of annual summary results for all model scenarios over 40 years. The daily results for each of these scenarios and years is included in the electronic repository.

Table B1: Annual results summary for all model runs, 1965 to 2004. Refer to Table 2-4, Table 2-5 and Table 2-6 for run definitions, and see Table 2-9 for performance measure definitions.

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
1 - 4750 (ft^3/s) x 3 day	1	1965	1	0	0	58,813	$1,531,695	$1,531,695	0	1	0
		1966	0	0	0				0	0	0
		1967	0	0	0				0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,908,128	$1,908,128	0	1	0
		1971	1	0	0	61,717	$1,602,975	$1,602,975	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	60,201	$1,559,923	$1,559,923	0	1	0
		1974	1	1	1	56,148	$424,646	$424,646	1	0	0
		1975	1	0	1	67,071	$1,674,470	$1,674,470	0	1	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	0	0	59,582	$1,501,597	$1,501,597	0	1	0
		1979	0	0	0				0	0	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	0	0	0				0	0	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	0	0	0				0	0	0
		1989	1	0	1	60,862	$1,580,289	$1,580,289	0	1	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	58,284	$1,491,398	$1,491,398	0	1	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	1	1	51,879	$1,140,446	$1,140,446	0	0	0
		1996	1	0	0	52,961	$1,293,645	$1,293,645	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	1	59,438	-$699,899		0	1	0
		1999	0	0	0				0	0	0
		2000	1	0	0	65,661	$1,701,784	$1,701,784	0	1	0
		2001	1	0	0	52,442	$1,350,226	$1,350,226	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		2002	0	0	0				0	0	0
		2003	1	0	1	31,069	$254,075	$254,075	0	0	0
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	2	1965	1	0	0	58,813	$1,455,859	$1,455,859	0	1	0
		1966	0	0	0				0	0	0
		1967	1	0	0	55,682	$1,320,048	$1,320,048	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,908,128	$1,908,128	0	1	0
		1971	1	0	0	61,717	$1,564,579	$1,564,579	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	60,201	$1,367,268	$1,367,268	0	1	0
		1974	1	0	0	116,863	$1,871,168	$1,871,168	0	1	0
		1975	1	0	1	34,238	$836,710	$836,710	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	0	1	31,985	$784,333	$784,333	0	0	0
		1979	1	0	0	54,858	$1,427,435	$1,427,435	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	46,825	$1,048,666	$1,048,666	0	1	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	1	0	0	52,341	$1,336,840	$1,336,840	0	1	0
		1988	0	0	0				0	0	0
		1989	1	0	1	63,447	$1,626,110	$1,626,110	0	1	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	60,308	$1,535,070	$1,535,070	0	1	0
		1993	1	0	1	42,728	$1,097,872	$1,097,872	0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	1	40,188	$933,260	$933,260	1	0	0
		1996	1	0	0	52,961	$1,262,416	$1,262,416	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	1	33,267	$745,765	$745,765	0	0	0
		1999	1	0	0	57,846	$1,434,021	$1,434,021	0	1	0
		2000	2	0	0	69,789	$2,650,900	$2,650,900	0	1	1
		2001	1	0	0	61,776	$1,566,155	$1,566,155	0	1	0
		2002	0	0	0				0	0	0
		2003	2	0	1	80,370	$1,476,322	$1,476,322	0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	3	1965	1	0	0	58,813	$1,548,032	$1,548,032	0	1	0
		1966	0	0	0				0	0	0
		1967	0	0	0				0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,809,684	$1,809,684	0	1	0
		1971	1	0	0	61,717	-$1,524,382		0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	60,201	$427,350	$427,350	0	1	0
		1974	1	1	1	56,148	$1,185,968	$1,185,968	1	0	0
		1975	1	0	1	67,071	$3,385,347	$3,385,347	0	1	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	0	0	45,381	$2,773,567	$2,773,567	0	0	1
		1979	0	0	0				0	0	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	0	0	0				0	0	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	0	0	0				0	0	0
		1989	1	0	1	60,862	$3,078,523	$3,078,523	0	1	1
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	58,284	$1,706,314	$1,706,314	0	1	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	1	1	51,879	$1,625,568	$1,625,568	0	0	0
		1996	1	0	0	52,961	$2,677,273	$2,677,273	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	1	50,612	-$4,453,425		0	0	1
		1999	0	0	0				0	0	0
		2000	1	0	0	65,661	$303,515	$303,515	0	1	0
		2001	1	0	0	52,442	$2,384,979	$2,384,979	0	1	0
		2002	0	0	0				0	0	0
		2003	1	0	1	31,069	$1,072,180	$1,072,180	0	0	0
		2004	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
1 - 4750 (ft^3/s) x 3 day	4	1965	1	0	0	58,813	$1,436,694	$1,436,694	0	1	0
		1966	0	0	0				0	0	0
		1967	1	0	0	55,682	$2,357,065	$2,357,065	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,809,684	$1,809,684	0	1	0
		1971	1	0	0	61,717	-$1,331,256		0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	60,201	-$555,068		0	1	0
		1974	1	0	0	116,863	$3,285,050	$3,285,050	0	1	0
		1975	1	0	1	34,238	$1,383,153	$1,383,153	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	0	1	31,985	$2,200,509	$2,200,509	0	0	0
		1979	1	0	0	54,858	$2,909,283	$2,909,283	0	1	1
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	46,825	-$777,854		0	1	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	1	0	0	45,987	$2,910,466	$2,910,466	0	0	1
		1988	0	0	0				0	0	0
		1989	1	0	0	49,603	$2,860,627	$2,860,627	0	0	1
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	60,308	$2,651,202	$2,651,202	0	1	1
		1993	1	0	1	34,333	$3,423,034	$3,423,034	0	0	1
		1994	0	0	0				0	0	0
		1995	1	0	1	40,188	$1,592,878	$1,592,878	1	0	0
		1996	1	0	0	52,961	$161,172	$161,172	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	1	33,267	$816,332	$816,332	0	0	0
		1999	1	0	0	57,846	-$374,444	-$374,444	0	1	0
		2000	1	0	0	14,378	$3,247,813	$3,247,813	0	0	1
		2001	1	0	0	54,668	$2,583,804	$2,583,804	0	0	1
		2002	0	0	0				0	0	0
		2003	2	0	1	80,370	$2,246,108	$2,246,108	0	0	0
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	5	1965	1	0	1	58,325	$1,490,493	$1,490,493	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1966	0	0	0				0	0	0
		1967	1	0	1	59,457	$1,440,317	$1,440,317	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	0	0	0				0	0	0
		1971	1	0	0	62,443	$1,613,686	$1,613,686	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	59,420	$1,535,686	$1,535,686	0	1	0
		1974	1	0	1	94,406	-$277,469	-$277,469	0	1	0
		1975	0	0	0				0	0	0
		1976	1	0	0	61,422	$1,603,783	$1,603,783	0	1	0
		1977	0	0	0				0	0	0
		1978	1	0	0	56,810	$1,483,231	$1,483,231	0	1	0
		1979	0	0	0				0	0	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	58,607	$1,485,740	$1,485,740	0	1	0
		1983	1	0	1	73,503	$594,670	$594,670	0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	1	0	0	48,006	$1,264,139	$1,264,139	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	0	0	0				0	0	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	0	59,568	$1,718,803	$1,718,803	0	1	0
		1996	0	0	0				0	0	0
		1997	0	0	0				0	0	0
		1998	1	0	0	58,274	-$346,795	-$346,795	0	1	0
		1999	0	0	0				0	0	0
		2000	1	0	0	62,947	$1,607,329	$1,607,329	0	1	0
		2001	0	0	0				0	0	0
		2002	0	0	0				0	0	0
		2003	1	0	0	85,684	$1,553,080	$1,553,080	0	1	0
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	6	1965	2	0	1	73,118	$1,882,040	$1,882,040	0	1	0
		1966	1	0	0	63,778	$1,516,198	$1,516,198	0	1	0
		1967	2	0	1	75,786	$1,907,588	$1,907,588	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1968	0	0	0				0	0	0
		1969	2	0	0	86,014	$2,233,299	$2,233,299	0	1	0
		1970	0	0	0				0	0	0
		1971	2	0	0	84,647	$2,189,578	$2,189,578	0	1	0
		1972	1	0	0	64,375	$1,641,571	$1,641,571	0	1	0
		1973	1	0	0	64,889	$1,668,928	$1,668,928	0	1	0
		1974	2	0	1	109,538	$1,658,933	$1,658,933	0	1	0
		1975	2	0	0	84,030	$2,130,728	$2,130,728	0	1	0
		1976	1	0	0	64,105	$1,673,515	$1,673,515	0	1	0
		1977	0	0	0				0	0	0
		1978	2	0	0	86,364	$2,254,482	$2,254,482	0	1	0
		1979	0	0	0				0	0	0
		1980	1	0	0	64,785	$1,657,243	$1,657,243	0	1	0
		1981	0	0	0				0	0	0
		1982	2	0	0	84,515	$2,173,365	$2,173,365	0	1	0
		1983	2	0	1	88,806	$1,886,602	$1,886,602	0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	1	0	0	48,670	$1,278,570	$1,278,570	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	63,980	$1,657,563	$1,657,563	0	1	0
		1993	2	0	0	86,498	$2,488,126	$2,488,126	0	1	0
		1994	1	0	0	56,899	$1,753,759	$1,753,759	0	1	0
		1995	1	0	0	43,740	$1,319,551	$1,319,551	0	0	0
		1996	0	0	0				0	0	0
		1997	0	0	0				0	0	0
		1998	1	0	1	49,786	$1,535,645	$1,535,645	0	0	0
		1999	2	0	1	79,606	$2,047,893	$2,047,893	0	1	0
		2000	1	0	0	37,917	$974,497	$974,497	0	0	0
		2001	1	0	0	61,622	$1,881,817	$1,881,817	0	1	0
		2002	0	0	0				0	0	0
		2003	2	0	0	89,002	$2,249,182	$2,249,182	0	1	0
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	7	1965	1	0	1	58,132	$2,263,267	$2,263,267	0	1	1
		1966	0	0	0				0	0	0
		1967	1	0	1	59,457	$2,528,812	$2,528,812	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1970	0	0	0				0	0	0
		1971	1	0	0	62,443	-$1,343,138		0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	0	59,420	-$326,500	-$326,500	0	1	0
		1974	1	0	1	94,406	$2,483,352	$2,483,352	0	1	1
		1975	0	0	0				0	0	0
		1976	1	0	0	61,422	$2,686,012	$2,686,012	0	1	1
		1977	0	0	0				0	0	0
		1978	1	0	0	56,810	$2,577,775	$2,577,775	0	1	1
		1979	0	0	0				0	0	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	44,617	$2,397,125	$2,397,125	0	0	1
		1983	1	0	1	73,503	-$2,490,588		0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	1	0	0	48,006	$2,345,263	$2,345,263	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	0	0	0				0	0	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	0	52,580	$2,710,457	$2,710,457	0	0	1
		1996	0	0	0				0	0	0
		1997	0	0	0				0	0	0
		1998	1	0	0	58,274	-$3,734,137		0	1	0
		1999	0	0	0				0	0	0
		2000	1	0	0	62,947	-$370,967	-$370,967	0	1	0
		2001	0	0	0				0	0	0
		2002	0	0	0				0	0	0
		2003	1	0	0	78,991	$2,668,832	$2,668,832	0	1	0
		2004	0	0	0				0	0	0
1 - 4750 (ft^3/s) x 3 day	8	1965	1	0	1	58,524	$2,308,613	$2,308,613	0	0	1
		1966	1	0	0	63,778	-$1,348,553		0	1	0
		1967	1	0	1	61,913	$2,478,826	$2,478,826	0	0	1
		1968	0	0	0				0	0	0
		1969	2	0	0	63,985	$2,760,082	$2,760,082	0	1	1
		1970	0	0	0				0	0	0
		1971	2	0	0	84,647	$2,526,233	$2,526,233	0	1	1

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1972	1	0	0	64,375	-$345,472	-$345,472	0	1	0
		1973	1	0	0	64,889	-$144,124	-$144,124	0	1	0
		1974	2	0	1	94,406	$2,483,352	$2,483,352	0	1	1
		1975	2	0	0	84,030	$1,767,824	$1,767,824	0	1	0
		1976	1	0	0	64,105	$2,873,879	$2,873,879	0	1	1
		1977	0	0	0				0	0	0
		1978	1	0	0	56,451	$2,536,201	$2,536,201	0	0	1
		1979	0	0	0				0	0	0
		1980	1	0	0	64,785	$1,234,571	$1,234,571	0	1	0
		1981	0	0	0				0	0	0
		1982	1	0	0	59,776	$3,460,545	$3,460,545	0	0	1
		1983	2	0	1	88,806	$1,522,143	$1,522,143	0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	1	0	0	48,670	$2,421,124	$2,421,124	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	63,980	$2,965,671	$2,965,671	0	1	1
		1993	2	0	0	64,149	$2,821,380	$2,821,380	0	1	1
		1994	1	0	0	56,899	$875,126	$875,126	0	1	0
		1995	1	0	0	43,740	$2,175,737	$2,175,737	0	0	0
		1996	0	0	0				0	0	0
		1997	0	0	0				0	0	0
		1998	1	0	1	49,786	$1,737,396	$1,737,396	0	0	0
		1999	2	0	1	64,996	$2,470,240	$2,470,240	0	1	1
		2000	1	0	0	37,917	$912,926	$912,926	0	0	0
		2001	1	0	0	54,627	$2,656,651	$2,656,651	0	0	1
		2002	0	0	0				0	0	0
		2003	2	0	0	65,400	$2,577,773	$2,577,773	0	1	1
		2004	0	0	0				0	0	0
2 - 4750 (ft^3/s) x 2 day	9	1965	1	0	0	57,179	$1,490,436	$1,490,436	0	1	0
		1966	0	0	0				0	0	0
		1967	1	0	1	53,717	$1,349,612	$1,349,612	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	1	1	52,129	$600,264	$600,264	0	0	0
		1971	1	0	1	70,261	$1,603,568	$1,603,568	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	1	56,729	$1,369,342	$1,369,342	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1974	1	1	1	56,686	$736,462	$736,462	0	0	0
		1975	1	0	1	54,978	$1,364,486	$1,364,486	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	1	1	83,770	$1,826,574	$1,826,574	1	0	0
		1979	1	0	0	45,715	$1,200,418	$1,200,418	0	1	0
		1980	1	0	1	23,365	$596,376	$596,376	0	0	0
		1981	1	0	0	29,516	$771,491	$771,491	0	1	0
		1982	1	0	0	38,605	$895,838	$895,838	0	1	0
		1983	1	1	1	82,330	$1,826,956	$1,826,956	0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	0	0	68,255	$1,696,777	$1,696,777	0	1	0
		1987	0	0	0				0	0	0
		1988	0	0	0				0	0	0
		1989	1	0	1	60,862	$1,580,289	$1,580,289	0	1	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	58,284	$1,491,398	$1,491,398	0	1	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	0	30,604	$488,710	$488,710	1	0	0
		1996	1	0	0	52,961	$1,293,645	$1,293,645	0	1	0
		1997	0	0	0				0	0	0
		1998	1	1	1	44,950	$345,609	$345,609	1	0	0
		1999	1	0	0	48,118	$1,246,639	$1,246,639	0	1	0
		2000	1	1	1	54,420	$1,366,820	$1,366,820	0	0	0
		2001	1	0	1	55,025	$1,426,621	$1,426,621	0	1	0
		2002	0	0	0				0	0	0
		2003	1	0	0	90,251	$1,674,756	$1,674,756	0	1	0
		2004	1	1	1	56,866	$1,556,622	$1,556,622	0	0	0
2 - 4750 (ft^3/s) x 2 day	10	1965	1	0	0	57,179	$841,581	$841,581	0	1	0
		1966	0	0	0				0	0	0
		1967	2	0	1	85,898	$2,126,299	$2,126,299	0	1	0
		1968	0	0	0				0	0	0
		1969	1	0	1	25,783	$540,896	$540,896	0	0	0
		1971	1	0	0	61,717	$1,431,098	$1,431,098	0	1	0
		1972	0	0	0				0	0	0
		1973	1	1	1	38,233	$874,448	$874,448	0	0	0
		1974	1	0	1	128,168	$1,682,206	$1,682,206	0	1	0
		1975	2	0	1	79,965	$1,985,429	$1,985,429	0	0	0
		1976	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1977	0	0	0				0	0	0
		1978	2	0	1	79,932	$1,935,318	$1,935,318	0	1	0
		1979	1	0	0	53,354	$1,377,504	$1,377,504	0	1	0
		1980	1	1	1	30,559	$781,318	$781,318	0	0	0
		1981	1	0	0	52,046	$1,198,153	$1,198,153	0	1	0
		1982	1	0	1	56,742	$1,125,016	$1,125,016	0	1	0
		1983	0	0	0	18,915	-$3,302	-$3,302	0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	0	0	70,052	$1,784,666	$1,784,666	0	1	0
		1987	1	0	1	50,900	$1,284,010	$1,284,010	0	1	0
		1988	0	0	0				0	0	0
		1989	1	0	1	62,448	$1,601,976	$1,601,976	0	1	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	20,541	$527,197	$527,197	0	0	0
		1993	2	0	1	87,563	$2,207,217	$2,207,217	0	1	0
		1994	0	0	0				0	0	0
		1995	1	1	1	25,835	$495,231	$495,231	0	0	0
		1996	1	0	0	59,533	$1,001,791	$1,001,791	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	0	74,485	$1,208,996	$1,208,996	1	0	0
		1999	1	0	1	57,846	$1,384,523	$1,384,523	0	1	0
		2000	1	1	1	67,967	$1,658,011	$1,658,011	0	0	0
		2001	1	1	1	26,124	$652,247	$652,247	0	0	0
		2002	0	0	0	-	-$563	-$563	0	0	0
		2003	2	0	0	87,784	$2,187,637	$2,187,637	0	1	0
		2004	1	1	1	62,183	$1,629,735	$1,629,735	0	0	0
2 - 4750 (ft^3/s) x 2 day	11	1965	1	0	0	57,179	$1,459,980	$1,459,980	0	1	0
		1966	0	0	0				0	0	0
		1967	1	0	1	53,717	$1,878,721	$1,878,721	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	1	1	52,129	$1,164,629	$1,164,629	0	0	0
		1971	1	0	1	70,261	$2,454,079	$2,454,079	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	1	56,729	$2,447,841	$2,447,841	0	1	1
		1974	1	1	1	56,686	$1,370,229	$1,370,229	0	0	0
		1975	1	0	1	54,978	$2,106,099	$2,106,099	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	1	1	83,770	$2,302,552	$2,302,552	1	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1979	1	0	0	45,715	$2,394,869	$2,394,869	0	1	0
		1980	1	0	1	23,365	$1,196,221	$1,196,221	0	0	0
		1981	1	0	0	29,516	$1,348,298	$1,348,298	0	1	0
		1982	1	0	0	38,605	-$621,109		0	1	0
		1983	1	1	1	82,330	$1,982,236	$1,982,236	0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	0	0	68,255	$3,517,145	$3,517,145	0	1	0
		1987	0	0	0				0	0	0
		1988	0	0	0				0	0	0
		1989	1	0	1	60,862	$3,078,523	$3,078,523	0	1	1
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	58,284	$1,706,314	$1,706,314	0	1	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	0	30,604	$683,945	$683,945	1	0	0
		1996	1	0	0	52,961	$2,677,273	$2,677,273	0	1	0
		1997	0	0	0				0	0	0
		1998	1	1	1	44,950	$677,739	$677,739	1	0	0
		1999	1	0	0	48,118	$308,631	$308,631	0	1	0
		2000	1	0	0	54,420	$5,197,430	$5,197,430	0	0	1
		2001	1	0	1	55,025	$2,899,324	$2,899,324	0	1	0
		2002	0	0	0				0	0	0
		2003	1	0	0	74,234	$2,757,627	$2,757,627	0	1	0
		2004	1	1	1	56,866	$2,809,664	$2,809,664	0	0	0
2 - 4750 (ft^3/s) x 2 day	12	1965	1	0	0	57,179	$943,262	$943,262	0	1	0
		1966	0	0	0				0	0	0
		1967	1	0	1	52,748	$2,508,684	$2,508,684	0	0	1
		1968	0	0	0				0	0	0
		1969	1	0	1	25,783	$3,832,470	$3,832,470	0	0	1
		1971	1	0	0	61,717	-$1,357,673		0	1	0
		1972	0	0	0				0	0	0
		1973	1	1	1	38,233	$1,203,443	$1,203,443	0	0	0
		1974	1	0	1	128,168	$3,324,424	$3,324,424	0	1	0
		1975	2	0	0	69,359	$2,930,084	$2,930,084	0	1	1
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	2	0	1	79,932	$2,785,789	$2,785,789	0		1
		1979	1	0	0	53,354	$2,914,037	$2,914,037	0	1	1
		1980	1	1	1	30,559	$3,350,570	$3,350,570	0	0	0
		1981	1	0	0	52,046	$2,769,227	$2,769,227	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1982	1	0	1	56,742	-$2,649,102		0	1	0
		1983	0	0	0	18,915	$47,117	$47,117	0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	0	0	70,052	$3,728,973	$3,728,973	0	1	1
		1987	1	0	1	50,900	$2,707,990	$2,707,990	0	1	0
		1988	0	0	0	-	$118,585	$118,585	0	0	0
		1989	1	0	1	48,588	$2,898,246	$2,898,246	0	0	1
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	20,541	$1,785,413	$1,785,413	0	0	0
		1993	1	0	1	56,878	$2,851,430	$2,851,430	0	1	1
		1994	0	0	0				0	0	0
		1995	1	1	1	25,835	$913,994	$913,994	0	0	0
		1996	1	0	0	59,533	-$258,921	-$258,921	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	0	74,485	$2,692,001	$2,692,001	1	0	0
		1999	1	0	1	57,846	-$609,233			1	0
		2000	1	0	1	55,020	$4,911,388	$4,911,388		0	1
		2001	1	1	1	26,124	$923,308	$923,308		0	0
		2002	0	0	0				0	0	0
		2003	2	0	0	87,784	$1,465,033	$1,465,033		1	0
		2004	1	1	1	12,049	$3,808,112	$3,808,112		0	1
2 - 4750 (ft^3/s) x 2 day	13	1965	1	0	0	57,179	$1,490,436	$1,490,436	0	1	0
		1966	0	0	0				0	0	0
		1967	0	0	0				0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,908,128	$1,908,128	0	1	0
		1971	1	0	0	61,717	$1,602,975	$1,602,975	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	1	31,700	$664,570	$664,570	0	0	0
		1974	1	1	1	56,686	$815,883	$815,883	0	0	0
		1975	1	0	1	54,978	$1,367,200	$1,367,200	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	0	1	59,582	$1,501,597	$1,501,597	0	1	0
		1979	1	0	0	5,714	$1,200,418	$1,200,418	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	38,605	$895,838	$895,838	0	1	0
		1983	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	0	0	0				0	0	0
		1987	0	0	0				0	0	0
		1988	0	0	0				0	0	0
		1989	1	0	1	60,862	$1,580,289	$1,580,289	0	1	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	0	0	58,284	$1,491,398	$1,491,398	0	1	0
		1993	0	0	0				0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	1	51,404	$681,196	$681,196	0	0	0
		1996	1	0	0	52,961	$1,293,645	$1,293,645	0	1	0
		1997	0	0	0				0	0	0
		1998	1	0	1	59,438	$1,998	$1,998	0	1	0
		1999	1	0	0	48,118	$1,246,639	$1,246,639	0	1	0
		2000	1	0	0	65,661	$1,701,784	$1,701,784	0	1	0
		2001	1	0	0	52,442	$1,350,226	$1,350,226	0	1	0
		2002	0	0	0				0	0	0
		2003	1	0	0	90,251	$1,674,756	$1,674,756	0	1	0
		2004	0	0	0				0	0	0
2 - 4750 (ft^3/s) x 2 day	14	1965	1	0	0	57,179	$1,414,601	$1,414,601	0	1	0
		1966	0	0	0				0	0	0
		1967	2	0	1	83,967	$2,114,896	$2,114,896	0	1	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	0	0	85,265	$1,908,128	$1,908,128	0	1	0
		1971	1	0	0	61,717	$1,564,579	$1,564,579	0	1	0
		1972	0	0	0				0	0	0
		1973	1	0	1	31,700	$733,346	$733,346	0	0	0
		1974	1	1	1	77,394	$446,584	$446,584	0	0	0
		1975	1	0	1	28,069	$681,455	$681,455	0	0	0
		1976	0	0	0				0	0	0
		1977	0	0	0				0	0	0
		1978	1	1	1	30,035	$749,604	$749,604	0	0	0
		1979	1	0	0	54,858	$1,427,435	$1,427,435	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	0	46,825	$1,048,666	$1,048,666	0	1	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1986	0	0	0				0	0	0
		1987	1	0	1	52,341	$1,336,840	$1,336,840	0	1	0
		1988	0	0	0	-	-$537	-$537	0	0	0
		1989	1	0	1	63,447	$1,626,110	$1,626,110	0	1	0
		1990	0	0	0	-	-$1,052	-$1,052	0	0	0
		1991	0	0	0	-	-$1,685	-$1,685	0	0	0
		1992	1	0	0	60,308	$1,535,070	$1,535,070	0	1	0
		1993	1	0	1	42,549	$1,090,855	$1,090,855	0	0	0
		1994	0	0	0				0	0	0
		1995	1	0	1	40,188	$933,260	$933,260	1	0	0
		1996	1	0	0	52,961	$1,262,416	$1,262,416	0	1	0
		1997	0	0	0				0	0	0
		1998	1	1	1	28,668	$620,121	$620,121	0	0	0
		1999	1	0	1	57,846	$1,434,021	$1,434,021	0	1	0
		2000	2	0	0	69,789	$2,650,900	$2,650,900	0	1	1
		2001	1	0	1	61,776	$1,566,155	$1,566,155	0	1	0
		2002	0	0	0	-	-$977	-$977	0	0	0
		2003	2	0	0	89,214	$2,268,261	$2,268,261	0	1	0
		2004	0	0	0	-	$73,424	$73,424	0	0	0
3 - 3250 (ft^3/s) x 1 day	15	1965	1	0	1	21,713	$558,260	$558,260	0	1	0
		1966	1	0	0	26,793	$636,899	$636,899	0	1	0
		1967	0	0	0				0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	1	1	18,842	$454,243	$454,243	0	0	0
		1971	1	1	1	14,774	$383,951	$383,951	0	0	0
		1972	1	1	1	8,725	$229,048	$229,048	0	0	0
		1973	1	1	1	6,707	$123,008	$123,008	0	0	0
		1974	1	1	1	41,017	$536,853	$536,853	0	0	0
		1975	1	1	1	14,902	$348,428	$348,428	0	0	0
		1976	1	1	1	6,175	$165,040	$165,040	0	0	0
		1977	1	0	0	27,083	$708,248	$708,248	0	1	0
		1978	1	1	1	12,535	$303,510	$303,510	0	0	0
		1979	1	0	0	15,974	$421,658	$421,658	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	1	13,573	$161,532	$161,532	0	1	0
		1983	0	0	0				0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	1	1	10,020	$259,379	$259,379	0	0	0
		1987	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1988	1	1	1	18,580	$492,217	$492,217	0	0	0
		1989	1	1	1	14,712	$379,478	$379,478	0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	6,324	$150,016	$150,016	0	0	0
		1993	0	0	0				0	0	0
		1994	1	1	1	10,079	$360,458	$360,458	0	0	0
		1995	1	1	1	9,002	$367,279	$367,279	0	0	0
		1996	1	1	1	9,539	$253,329	$253,329	0	0	0
		1997	1	0	1	26,989	$827,404	$827,404	0	1	0
		1998	1	1	1	14,081	$561,285	$561,285	0	0	0
		1999	1	0	1	17,707	$456,485	$456,485	0	1	0
		2000	1	1	1	13,881	$352,270	$352,270	0	0	0
		2001	1	0	1	19,184	$486,610	$486,610	0	1	0
		2002	1	0	1	26,880	$1,392,084	$1,392,084	0	1	0
		2003	1	0	1	51,386	$602,654	$602,654	0	1	0
		2004	0	0	0				0	0	0
3 - 3250 (ft^3/s) x 1 day	16	1965	1	1	1	10,887	$207,160	$207,160	0	0	0
		1966	1	0	0	26,793	$525,512	$525,512	0	1	0
		1967	1	1	1	8,739	$198,687	$198,687	0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	1	1	1	18,842	$454,243	$454,243	0	0	0
		1971	1	1	1	14,774	$345,555	$345,555	0	0	0
		1972	1	1	1	8,724	$218,188	$218,188	0	0	0
		1973	1	1	1	6,707	$123,008	$123,008	0	0	0
		1974	1	1	1	82,328	$319,374	$319,374	0	0	0
		1975	1	1	1	14,041	$326,292	$326,292	0	0	0
		1976	1	1	1	6,175	$138,904	$138,904	0	0	0
		1977	1	0	0	27,083	$680,164	$680,164	0	1	0
		1978	1	1	1	17,531	$396,613	$396,613	0	0	0
		1979	2	1	2	9,894	$820,355	$820,355	0	0	0
		1980	0	0	0						
		1981	0	0	0						
		1982	1	1	2	40,505	$752,564	$752,564	0	0	0
		1983	0	0	0						
		1984	0	0	0						
		1985	0	0	0						
		1986	1	1	1	8,240	$810,698	$810,698	0	0	0
		1987	1	1	1	6,584	$160,801	$160,801	0	0	0
		1988	1	1	1	18,580	$489,774	$489,774	0	0	0
		1989	1	1	1	9,990	$258,207	$258,207	0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	7,711	$183,710	$183,710	0	0	0
		1993	1	1	1	8,303	$204,286	$204,286	0	0	0
		1994	1	1	1	10,079	$342,718	$342,718	0	0	0
		1995	1	1	1	42,047	$410,346	$410,346	1	0	0
		1996	1	1	1	9,894	$253,329	$253,329	0	0	0
		1997	1	0	1	26,989	$810,530	$810,530	0	1	0
		1998	1	1	1	15,172	$126,453	$126,453	0	0	0
		1999	1	1	1	6,213	$107,765	$107,765	0	0	0
		2000	1	1	1	8,305	$663,155	$663,155	0	0	0
		2001	1	1	1	7,450	$181,460	$181,460	0	0	0
		2002	1	0	1	26,880	$1,377,188	$1,377,188	0	1	0
		2003	1	1	1	6,077	$131,838	$131,838	0	0	0
		2004	0	0	0				0	0	0
3 - 3250 (ft^3/s) x 1 day	17	1965	2	0	0	46,445	$1,162,651	$1,162,651	0	1	1
		1966	1	1	1	11,993	$292,618	$292,618	0	0	0
		1967	2	1	2	39,782	$1,007,977	$1,007,977	0	0	0
		1968	2	0	2	49,852	$1,259,812	$1,259,812	0	1	1
		1969	1	1	1	9,356	$237,377	$237,377	0	0	0
		1970	1	1	1	18,842	$454,243	$454,243	0	0	0
		1971	1	1	1	18,711	$447,528	$447,528	0	0	0
		1972	1	1	1	15,928	$390,590	$390,590	0	0	0
		1973	1	1	1	6,707	$123,008	$123,008	0	0	0
		1974	1	1	1	82,328	$319,374	$319,374	0	0	0
		1975	1	1	1	29,850	$760,822	$760,822	0	0	0
		1976	2	0	1	48,904	$1,239,429	$1,239,429	0	1	1
		1977	2	0	0	52,656	$1,327,852	$1,327,852	0	1	1
		1978	1	1	1	24,065	$565,744	$565,744	0	0	0
		1979	2	1	2	37,192	$954,884	$954,884	0	0	0
		1980	1	1	1	11,834	$394,142	$394,142	0	0	0
		1981	1	1	2	38,993	$951,779	$951,779	0	0	0
		1982	2	1	2	27,411	$450,387	$450,387	0	0	0
		1983	0	0	0				0	0	0
		1984	2	1	1	37,034	$973,950	$973,950	0	0	0
		1985	2	0	1	48,665	$1,249,193	$1,249,193	0	1	1
		1986	1	1	1	8,144	$561,522	$561,522	0	0	0
		1987	1	1	1	7,061	$170,167	$170,167	0	0	0
		1988	2	0	0	52,224	$1,355,059	$1,355,059	0	1	1
		1989	1	1	1	11,202	$175,068	$175,068	0	0	0
		1990	1	1	1	18,200	$478,300	$478,300	0	0	0
		1991	1	1	1	18,083	$473,234	$473,234	0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1992	1	1	1	7,075	$182,234	$182,234	0	0	0
		1993	1	1	1	10,382	$264,118	$264,118	0	0	0
		1994	2	0	2	48,854	$1,276,257	$1,276,257	0	1	1
		1995	1	1	1	64,922	$765,332	$765,332	0	0	0
		1996	1	1	1	9,894	$253,329	$253,329	0	0	0
		1997	1	1	1	8,613	$214,265	$214,265	0	0	0
		1998	1	1	1	10,507	$127,218	$127,218	0	0	0
		1999	1	1	1	15,222	$358,599	$358,599	0	0	0
		2000	1	1	1	10,104	$798,276	$798,276	0	0	0
		2001	1	1	1	15,228	$388,312	$388,312	0	0	0
		2002	1	1	1	14,247	$369,104	$369,104	0	0	0
		2003	2	1	2	34,907	$888,143	$888,143	0	0	0
		2004	1	1	1	11,528	$339,198	$339,198	0	0	0
3 - 3250 (ft^3/s) x 1 day	18	1965	1	0	1	21,713	$558,260	$558,260	0	1	0
		1966	1	0	0	26,793	$636,899	$636,899	0	1	0
		1967	1	1	1	7,862	$187,301	$187,301	0	0	0
		1968	1	0	1	20,950	$512,989	$512,989	0	1	0
		1969	0	0	0				0	0	0
		1970	1	1	1	36,670	$272,575	$272,575	0	0	0
		1971	1	1	1	14,353	$258,234	$258,234	0	0	0
		1972	1	1	1	8,724	$229,048	$229,048	0	0	0
		1973	1	1	1	10,029	$216,437	$216,437	0	0	0
		1974	1	1	1	41,016	$536,853	$536,853	0	0	0
		1975	1	1	1	14,902	$348,428	$348,428	0	0	0
		1976	1	1	1	6,175	$165,040	$165,040	0	0	0
		1977	1	0	0	27,083	$708,248	$708,248	0	1	0
		1978	1	1	1	69,076	$574,943	$574,943	0	0	0
		1979	1	0	1	15,974	$421,658	$421,658	0	1	0
		1980	1	1	1	14,142	$359,253	$359,253	0	0	0
		1981	1	0	0	7,254	$193,971	$193,971	0	1	0
		1982	1	0	1	13,573	$161,532	$161,532	0	1	0
		1983	1	1	1	19,254	$374,621	$374,621	0	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	1	1	10,847	$263,091	$263,091	0	0	0
		1987	0	0	0				0	0	0
		1988	1	1	1	18,580	$492,217	$492,217	0	0	0
		1989	1	1	1	14,712	$379,478	$379,478	0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	6,324	$150,016	$150,016	0	0	0
		1993	0	0	0				0	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1994	1	1	1	10,079	$360,458	$360,458	0	0	0
		1995	1	1	1	30,604	$488,710	$488,710	1	0	0
		1996	1	1	1	9,894	$253,329	$253,329	0	0	0
		1997	1	0	1	26,989	$827,404	$827,404	0	1	0
		1998	1	1	1	44,950	$345,609	$345,609	1	0	0
		1999	1	0	1	17,707	$456,485	$456,485	0	1	0
		2000	1	1	1	6,125	$144,035	$144,035	0	0	0
		2001	1	1	1	7,788	$193,580	$193,580	0	0	0
		2002	1	0	1	26,880	$1,392,084	$1,392,084	0	1	0
		2003	1	0	1	51,386	$602,654	$602,654	0	1	0
		2004	1	1	1	10,885	$296,212	$296,212	0	0	0
3 - 3250 (ft^3/s) x 1 day	19	1965	1	1	1	9,362	$242,172	$242,172	0	0	0
		1966	2	0	1	46,739	$1,009,039	$1,009,039	0	1	0
		1967	1	1	1	11,460	$257,053	$257,053	0	0	0
		1968	1	0	1	21,784	$353,321	$353,321	0	1	0
		1969	1	1	1	5,570	$95,414	$95,414	0	0	0
		1970	1	1	1	38,078	$405,910	$405,910	0	0	0
		1971	1	1	1	14,321	$303,679	$303,679	0	0	0
		1972	1	1	1	8,724	$189,969	$189,969	0	0	0
		1973	1	1	1	11,801	$266,681	$266,681	0	0	0
		1974	0	0	0				0	0	0
		1975	1	1	1	13,986	$320,810	$320,810	0	0	0
		1976	1	1	1	6,175	$89,742	$89,742	0	0	0
		1977	1	0	0	27,083	$650,397	$650,397	0	1	0
		1978	1	1	1	63,469	$159,536	$159,536	0	0	0
		1979	1	0	1	20,421	$508,244	$508,244	0	1	0
		1980	1	1	1	16,273	$373,475	$373,475	0	0	0
		1981	1	1	1	10,840	$190,784	$190,784	0	0	0
		1982	1	1	1	22,773	$224,966	$224,966	0	0	0
		1983	1	1	1	37,218	$789,144	$789,144	1	0	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	1	1	10,197	$247,315	$247,315	0	0	0
		1987	1	0	0	19,942	$484,150	$484,150	0	1	0
		1988	1	1	1	18,580	$462,419	$462,419	0	0	0
		1989	1	1	1	9,860	$252,095	$252,095	0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	1	1	1	15,237	$398,317	$398,317	0	0	0
		1993	1	1	1	9,939	$219,782	$219,782	0	0	0
		1994	1	1	1	10,079	$328,334	$328,334	0	0	0
		1995	1	1	1	56,693	$722,150	$722,150	1	0	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1996	1	1	1	6,568	$115,336	$115,336	0	0	0
		1997	1	0	1	26,989	$746,737	$746,737	0	1	0
		1998	1	1	1	15,117	$367,110	$367,110	0	0	0
		1999	1	1	1	6,213	$40,996	$40,996	0	0	0
		2000	1	1	1	14,273	$280,390	$280,390	0	0	0
		2001	1	1	1	12,205	$289,300	$289,300	0	0	0
		2002	1	0	1	26,880	$1,352,808	$1,352,808	0	1	0
		2003	1	1	1	14,039	$332,344	$332,344	0	0	0
		2004	1	1	1	13,736	$328,777	$328,777	0	0	0
3 - 3250 (ft^3/s) x 1 day	20	1965	1	0	1	20,713	$532,186	$532,186	0	1	0
		1966	1	0	0	26,549	$630,545	$630,545	0	1	0
		1967	0	0	0				0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	0	0	0				0	0	0
		1971	1	0	1	25,824	$664,878	$664,878	0	1	0
		1972	1	1	1	14,538	$377,157	$377,157	0	0	0
		1973	1	1	1	20,334	$526,446	$526,446	0	0	0
		1974	1	1	1	46,902	$349,837	$349,837	0	0	0
		1975	1	0	1	21,901	$558,898	$558,898	0	1	0
		1976	1	1	1	6,008	$160,659	$160,659	0	0	0
		1977	1	0	0	27,000	$706,103	$706,103	0	1	0
		1978	1	0	1	21,611	$566,821	$566,821	0	1	0
		1979	1	0	1	26,445	$687,009	$687,009	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	1	0	1	20,419	$523,706	$523,706	0	1	0
		1983	1	0	1	28,441	$816,683	$816,683	0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	1	1	9,907	$256,688	$256,688	0	0	0
		1987	1	0	0	26,020	$685,998	$685,998	0	1	0
		1988	1	0	1	26,429	$696,001	$696,001	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	0	0	0				0	0	0
		1993	1	0	1	23,279	$896,223	$896,223	0	1	0
		1994	1	1	1	10,018	$357,905	$357,905	0	0	0
		1995	1	0	1	23,569	$598,113	$598,113	0	1	0
		1996	1	1	1	17,463	$451,395	$451,395	0	0	0
		1997	1	0	0	26,633	$811,277	$811,277	0	1	0

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		1998	1	1	1	10,176	$157,773	$157,773	0	0	0
		1999	1	1	1	11,476	$306,212	$306,212	0	0	0
		2000	1	1	1	6,349	$161,333	$161,333	0	0	0
		2001	1	0	1	22,986	$706,993	$706,993	0	1	0
		2002	1	0	1	26,650	$1,381,683	$1,381,683	0	1	0
		2003	1	0	0	50,147	$570,333	$570,333	0	1	0
		2004	0	0	0				0	0	0
3 - 3250 (ft^3/s) x 1 day	21	1965	1	1	1	10,887	$264,971	$264,971	0	0	0
		1966	1	0	0	26,549	$579,847	$579,847	0	1	0
		1967	1	1	1	13,904	$326,907	$326,907	0	0	0
		1968	0	0	0				0	0	0
		1969	0	0	0				0	0	0
		1970	0	0	0				0	0	0
		1971	1	0	1	25,824	$664,878	$664,878	0	1	0
		1972	1	1	1	14,538	$377,157	$377,157	0	0	0
		1973	1	1	1	20,334	$524,418	$524,418	0	0	0
		1974	1	1	1	46,902	$349,837	$349,837	0	0	0
		1975	1	0	1	21,901	$557,145	$557,145	0	1	0
		1976	1	1	1	6,008	$160,659	$160,659	0	0	0
		1977	1	0	0	27,000	$706,103	$706,103	0	1	0
		1978	2	0	1	36,967	$964,956	$964,956	0	1	0
		1979	1	0	1	26,445	$687,009	$687,009	0	1	0
		1980	0	0	0				0	0	0
		1981	0	0	0				0	0	0
		1982	2	0	1	37,249	$953,913	$953,913	0	1	0
		1983	1	0	1	3,695	-$816,683		0	1	0
		1984	0	0	0				0	0	0
		1985	0	0	0				0	0	0
		1986	1	1	1	9,907	$244,527	$244,527	0	0	0
		1987	1	0	0	26,020	$686,005	$686,005	0	1	0
		1988	1	0	1	26,429	$696,001	$696,001	0	1	0
		1989	0	0	0				0	0	0
		1990	0	0	0				0	0	0
		1991	0	0	0				0	0	0
		1992	0	0	0				0	0	0
		1993	1	0	1	23,279	$896,223	$896,223	0	1	0
		1994	1	1	1	10,018	$348,747	$348,747	0	0	0
		1995	1	0	1	23,569	$678,257	$678,257	0	1	0
		1996	1	1	1	17,463	$447,069	$447,069	0	0	0
		1997	1	0	0	26,633	$810,051	$810,051	0	1	0
		1998	1	1	1	6,851	$47,884	$47,884	0	0	0
		1999	1	1	1	11,476	$297,203	$297,203	0	0	0

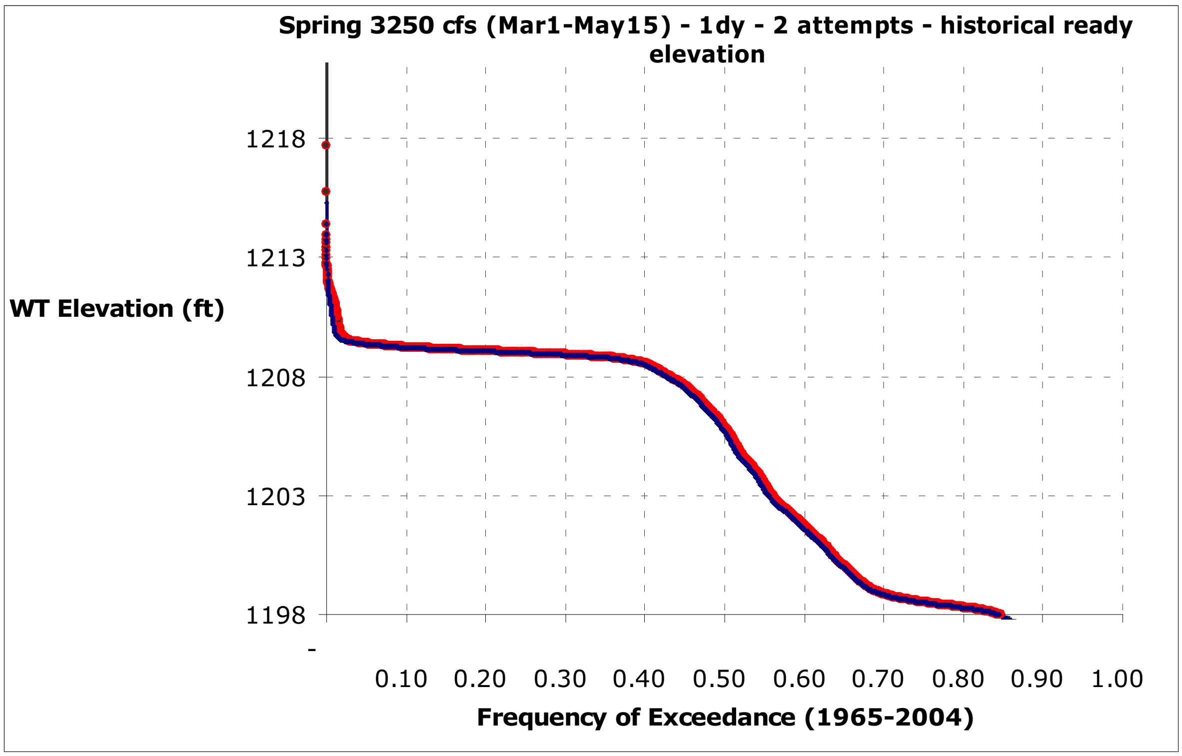
Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		2000	1	1	1	6,349	$135,482	$135,482	0	0	0
		2001	1	0	1	22,986	$705,969	$705,969	0	1	0
		2002	1	0	1	26,650	$1,378,071	$1,378,071	0	1	0
		2003	1	0	0	50,147	$563,453	$563,453	0	1	0
		2004	0	0	0				0	0	0
3 - 3250 (ft^3/s) x 1 day	22	1965	2	1	1	36,012	$908,988	$908,988	0	0	0
		1966	2	0	1	48,280	$1,181,026	$1,181,026	0	1	1
		1967	1	1	1	12,198	$290,747	$290,747	0	0	0
		1968	2	1	1	36,728	$912,551	$912,551	0	0	0
		1969	2	0	1	44,584	$1,150,556	$1,150,556	0	1	1
		1970	2	1	1	45,156	$1,069,240	$1,069,240	0	0	0
		1971	2	0	1	44,275	$1,135,091	$1,135,091	0	1	1
		1972	1	1	1	12,965	$328,953	$328,953	0	0	0
		1973	2	0	1	43,718	$1,120,171	$1,120,171	0	1	1
		1974	1	1	1	46,902	$349,837	$349,837	0	0	0
		1975	2	0	1	48,280	$1,204,163	$1,204,163	0	1	1
		1976	1	1	1	10,408	$275,383	$275,383	0	0	0
		1977	2	1	1	45,351	$1,173,631	$1,173,631	0	0	0
		1978	1	1	1	6,600	$173,290	$173,290	0	0	0
		1979	2	0	1	49,274	$1,285,483	$1,285,483	0	1	1
		1980	1	1	1	6,632	$169,307	$169,307	0	0	0
		1981	2	0	1	49,382	$1,298,320	$1,298,320	0	1	1
		1982	2	1	1	30,118	$759,885	$759,885	0	0	0
		1983	2	0	1	60,098	$807,598	$807,598	0	1	0
		1984	1	1	1	9,997	$255,243	$255,243	0	0	0
		1985	2	0	1	53,423	$1,392,964	$1,392,964	0	1	1
		1986	2	0	1	47,003	$1,191,519	$1,191,519	0	1	1
		1987	1	1	1	18,376	$493,355	$493,355	0	0	0
		1988	2	1	1	36,515	$961,466	$961,466	0	0	0
		1989	2	0	1	49,291	$1,287,188	$1,287,188	0	1	1
		1990	0	0	0				0	0	0
		1991	2	1	1	36,782	$961,161	$961,161	0	0	0
		1992	2	1	1	41,331	$1,078,537	$1,078,537	0	0	0
		1993	2	0	1	42,859	$1,187,281	$1,187,281	0	1	1
		1994	2	0	1	48,820	$1,403,211	$1,403,211	0	1	1
		1995	1	1	1	14,296	$558,571	$558,571	0	0	0
		1996	2	1	1	36,087	$923,021	$923,021	0	0	0
		1997	2	0	1	53,167	$1,377,782	$1,377,782	0	1	1
		1998	1	1	1	22,989	$670,111	$670,111	0	0	0
		1999	1	1	1	15,589	$406,027	$406,027	0	0	0
		2000	2	1	1	53,119	$1,426,934	$1,426,934	0	0	0
		2001	2	0	1	49,422	$1,285,231	$1,285,231	0	1	1

Scenario	Model ID No. (Variant)	Year	# EWP Attempts	No. Successful EWP Releases Reach 1[1]	No. Successful EWP Releases Reach 5[2]	Glory Hole Volume Released (acre-ft) during EWP Period[3]	Foregone Power[4]	Foregone Power with profits over 500K removed[5]	No. stopped due to excessive lower Clear Creek flow	No. stopped due to insufficient water	No. stopped due to cost
		2002	2	1	1	35,617	$924,486	$924,486	0	0	0
		2003	2	0	1	50,440	$1,304,664	$1,304,664	0	1	1
		2004	2	1	1	49,484	$1,217,457	$1,217,457	0	0	0

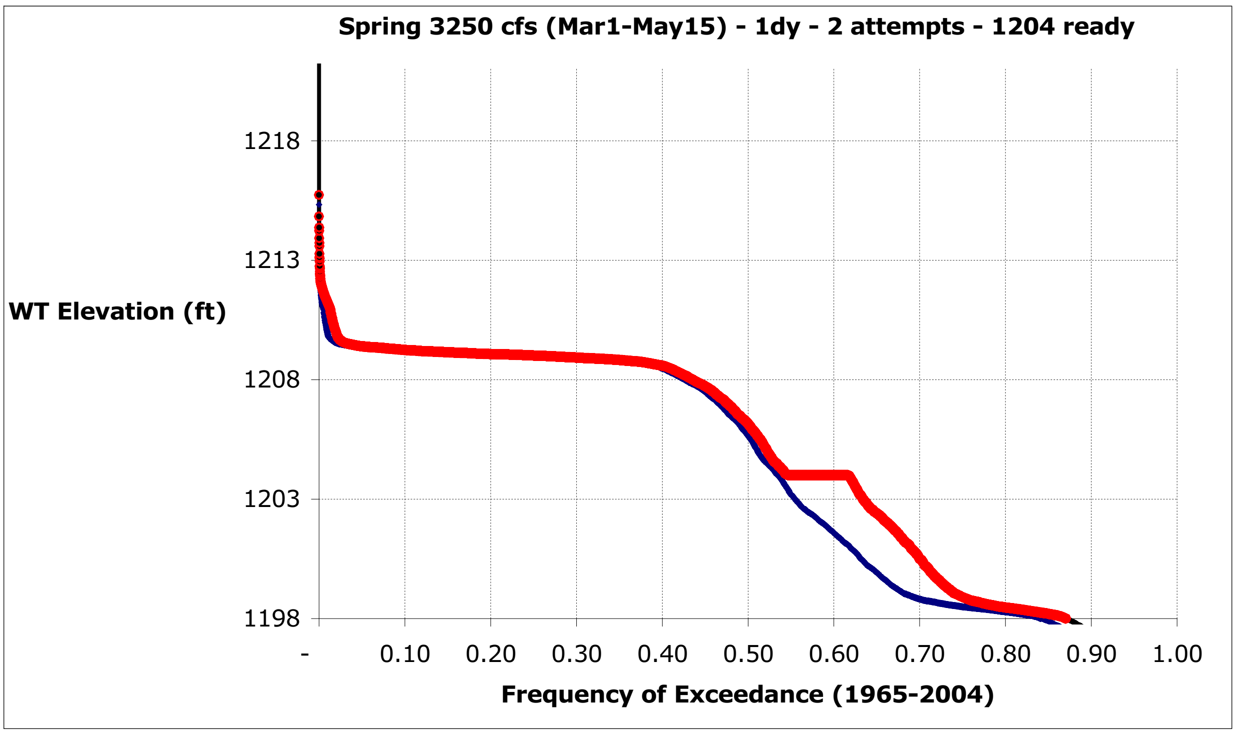
[1] No. of EWP Releases for Reach 1, i.e., X days >= target flow during EWP Attempt window
[2] No. of EWP Releases for Reach 5, i.e., X days >= target flow during EWP Attempt window
[3] Glory Hole spill for entire EWP Period; treat 0 values as null if state is AtHistorical throughout
[4] Cost in foregone power over the entire EWP Period (to InEWP+1 if stopped on success); always report cost when an EWP Attempt is made; for non-historical runs in which no EWP Attempt is made, report costs from the start of the EWP Period through BuildToElevation +1 day
[5] Foregone Power as in Column I, but with negative foregone power values greater than -$500K considered to be artifacts and treated as null

Appendix C: Select Whiskeytown Reservoir Exceedance Plots

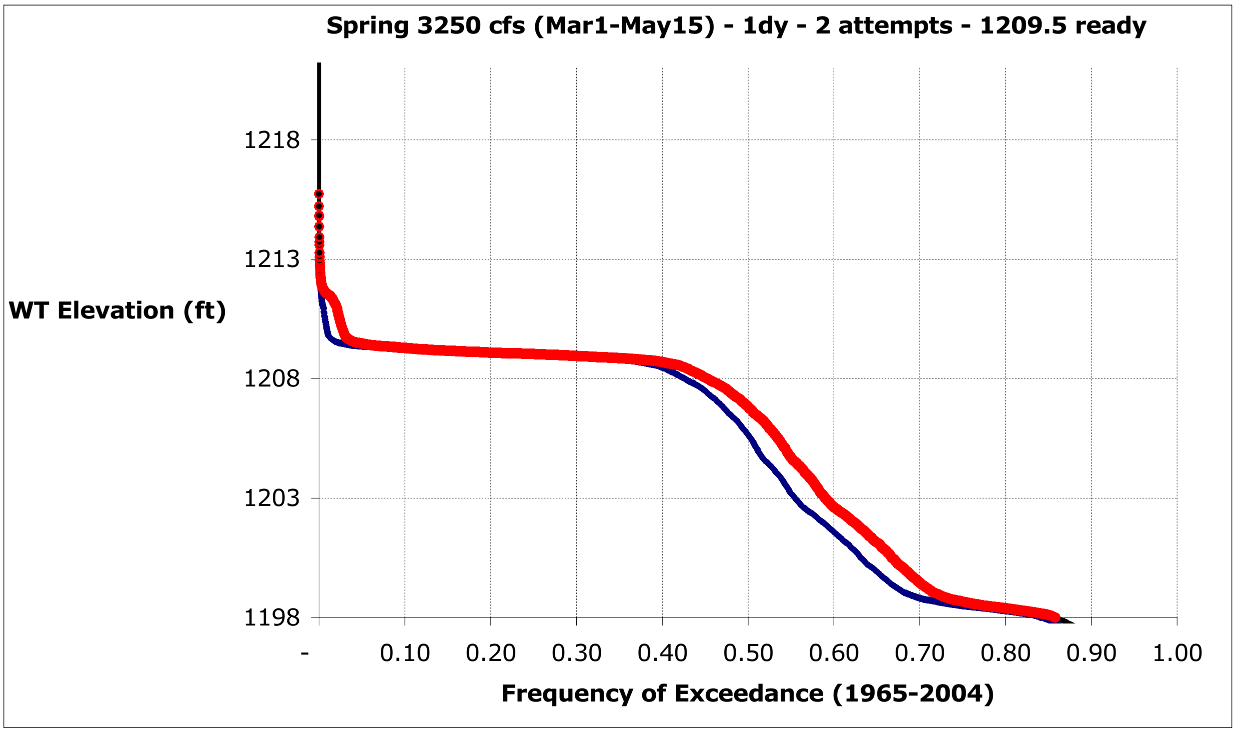
The exceedance plot data below as well as cases not shown are available from the detailed project electronic archive at: ftp://ftp.essa.com/pub/essa/EWP/.



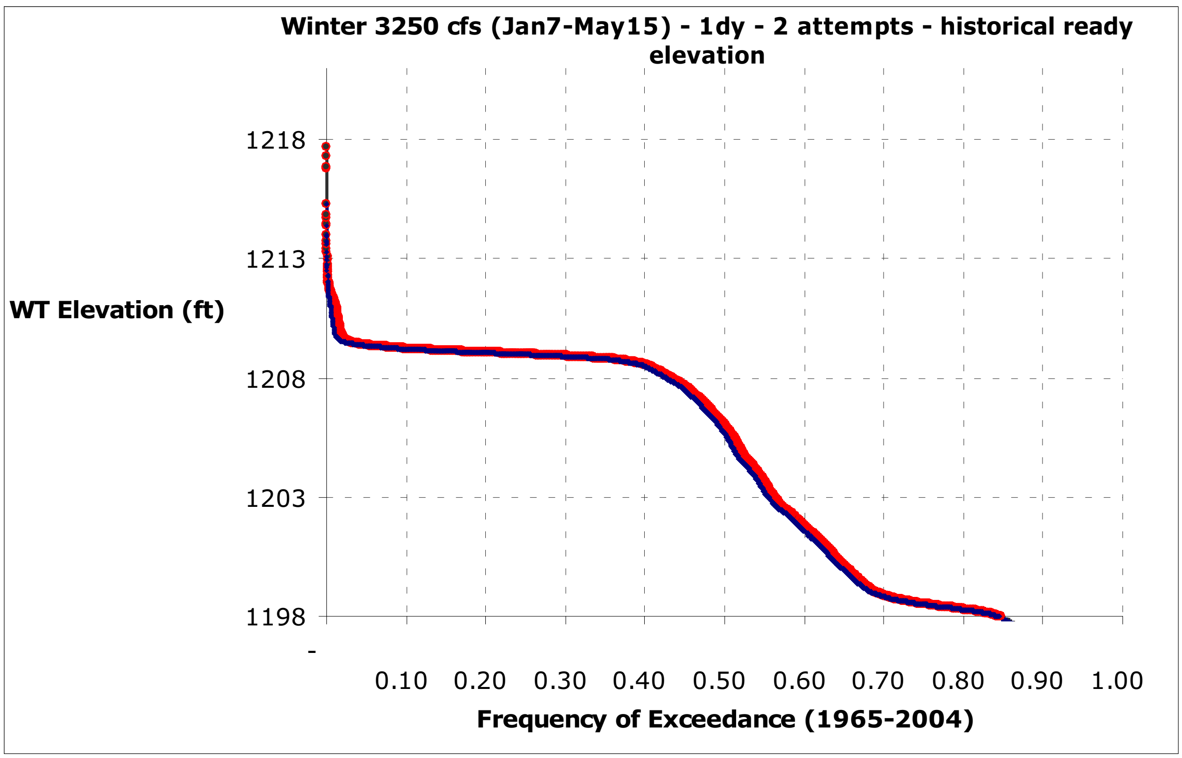
Appendix C1: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-15 – 3250 ft^3/s for 1 day between March 1 and May 15.



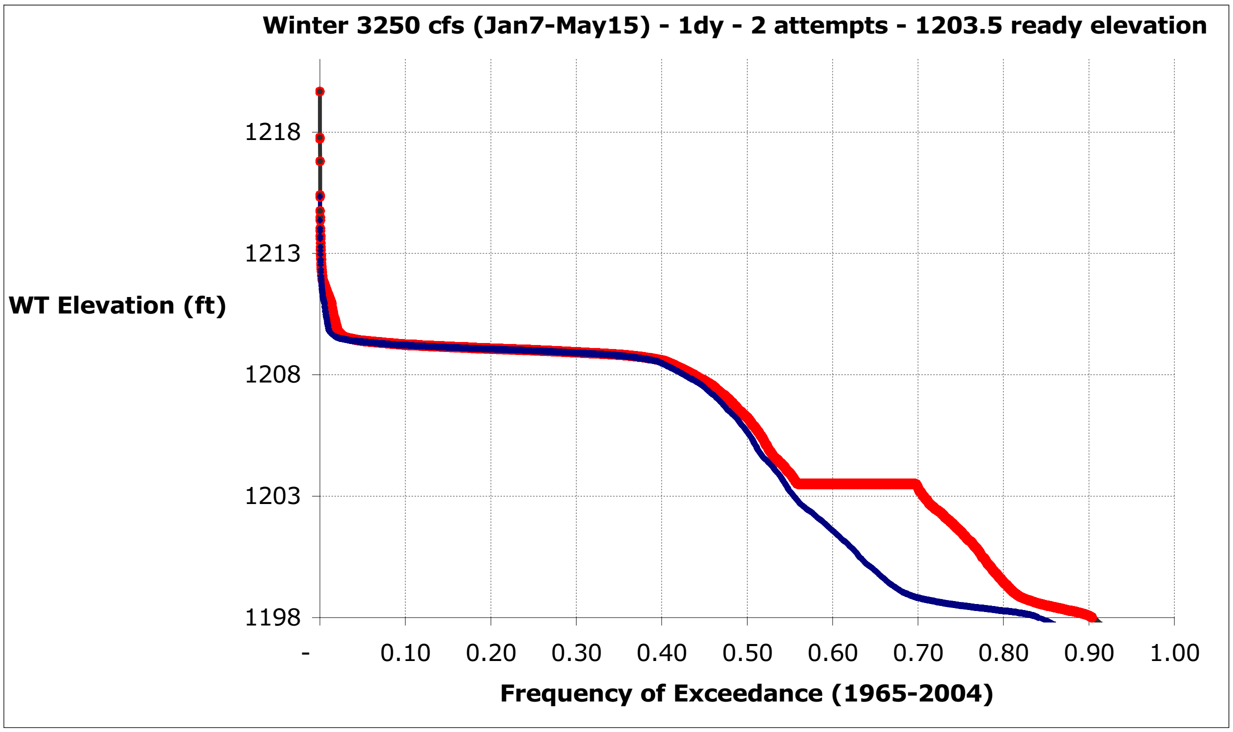
Appendix C2: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-16 – 3250 ft^3/s for 1 day between March 1 and May 15, 1204 ft ready elevation.



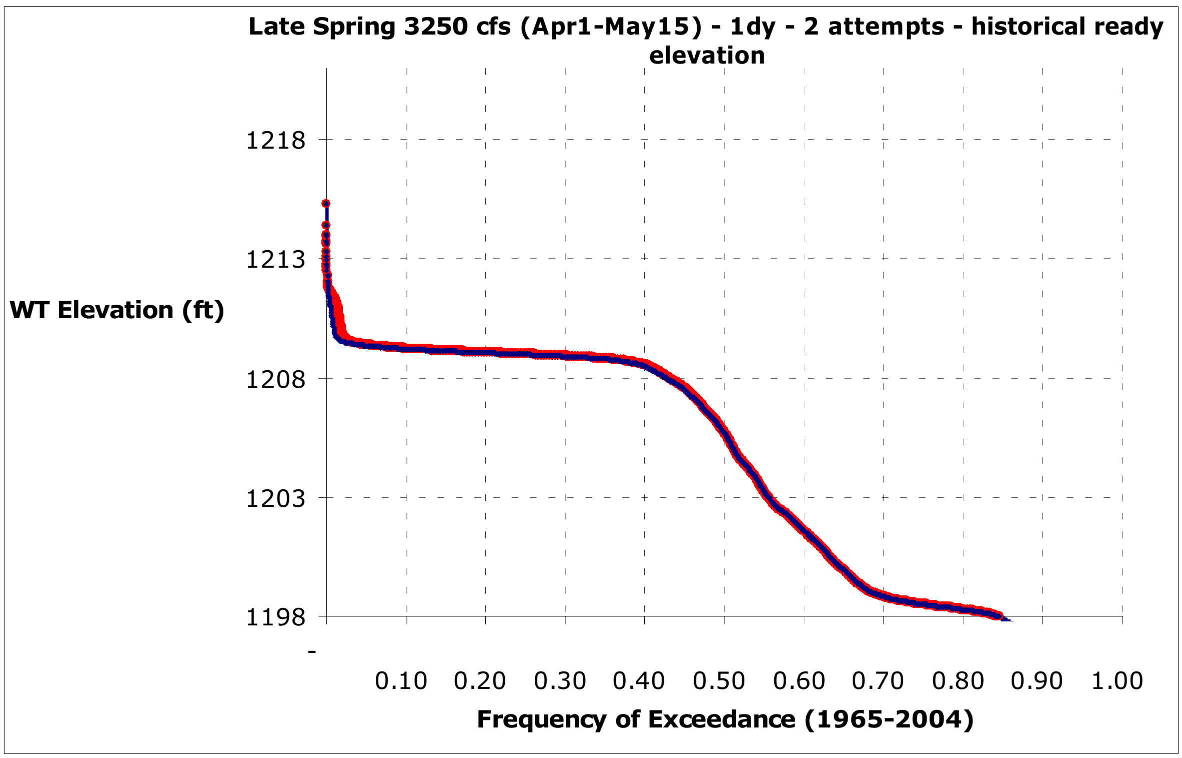
Appendix C3: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-17 – 3250 ft^3/s for 1 day between March 1 and May 15, 1209.5 ft ready elevation.



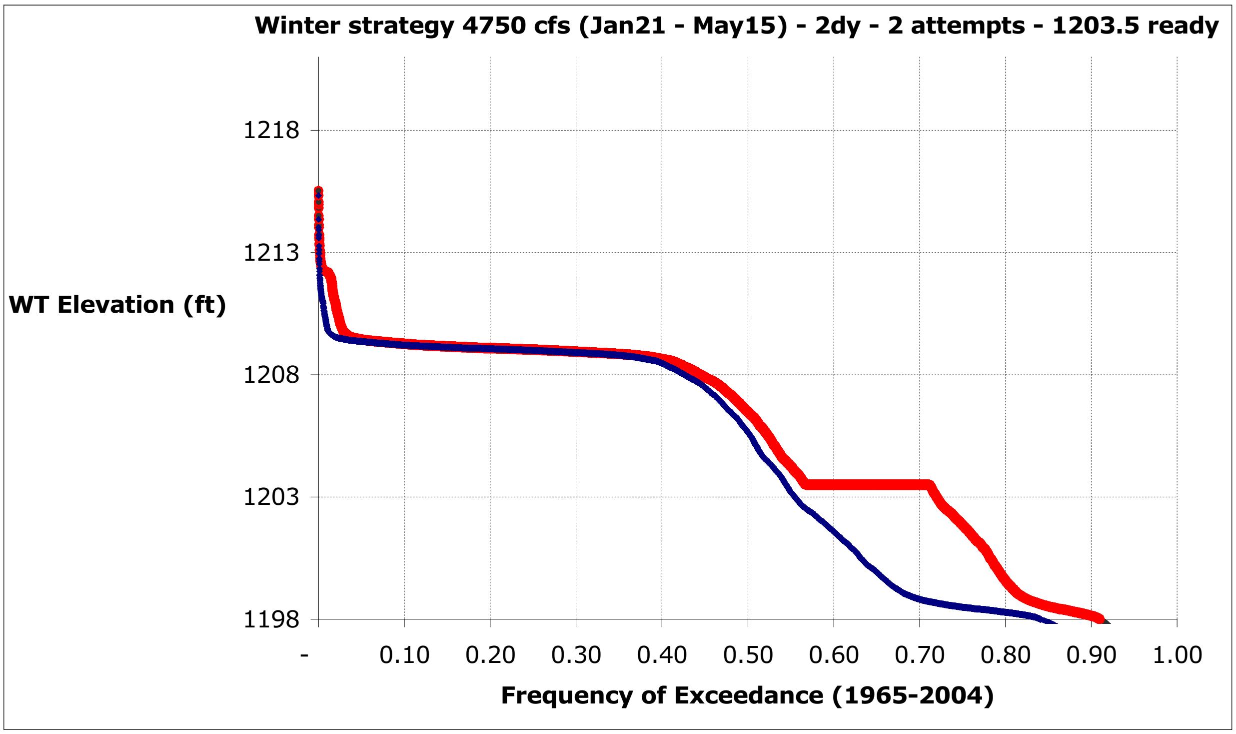
Appendix C4: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-18 – 3250 ft^3/s for 1 day between January 7 and May 15



Appendix C5: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-19 – 3250 ft^3/s for 1 day between January 7 and May 15 with a 1203.5 ready elevation.

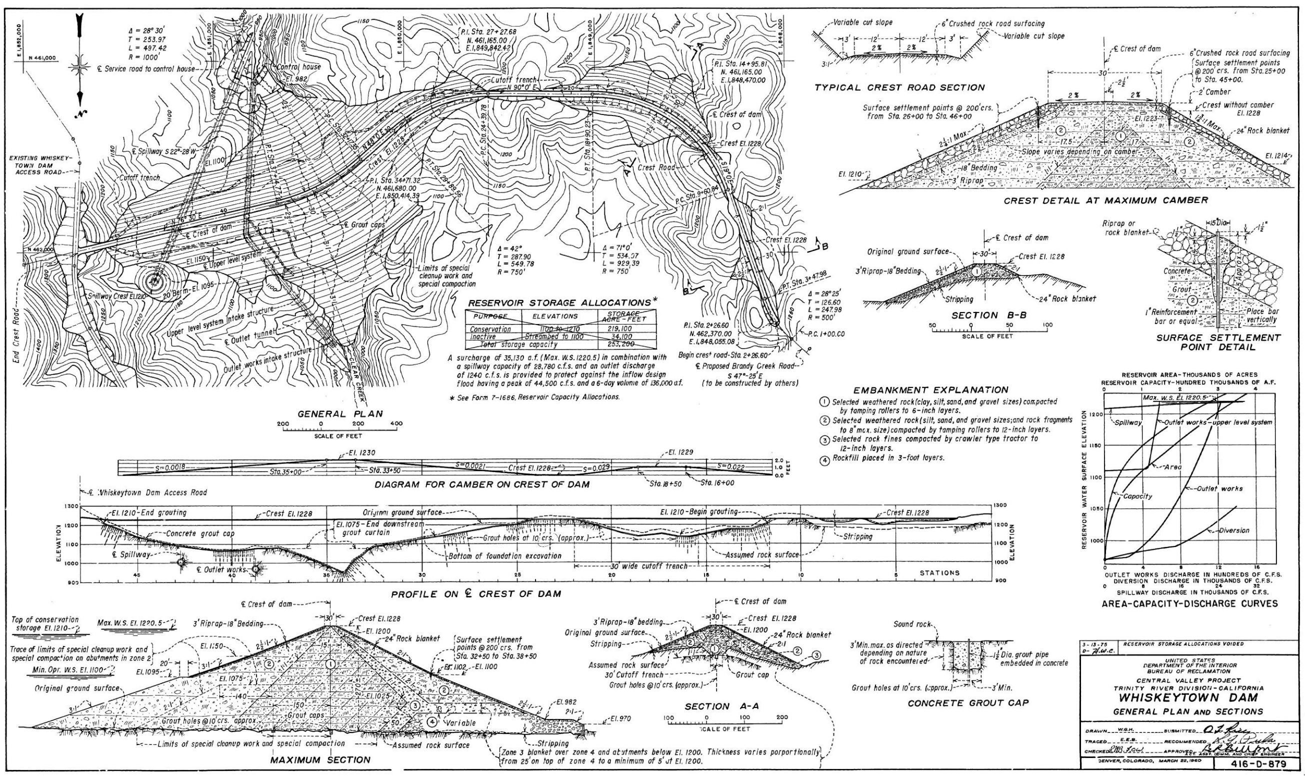


Appendix C6: Plot of Exceedance Curves for Historical and CCDAM results for EWP #3-20 – 3250 ft^3/s for 1 day between April 1 and May 15



Appendix C7: Plot of Exceedance Curves for Historical and CCDAM results for EWP #2-10 – 4750 ft^3/s for 2 days between Jan 21 and May 15, with 1203.5 ready elevation.

Appendix D: Drawings



GENERAL PLAN
DIAGRAM FOR CAMBER ON CREST OF DAM
PROFILE ON ℄ CREST OF DAM
MAXIMUM SECTION
SECTION A-A
SECTION B-B
TYPICAL CREST ROAD SECTION
CREST DETAIL AT MAXIMUM CAMBER
SURFACE SETTLEMENT POINT DETAIL
CONCRETE GROUT CAP
RESERVOIR STORAGE ALLOCATIONS*
PURPOSE | ELEVATIONS | STORAGE ACRE-FEET
Conservation | 1100 to 1210 | 219,100
Inactive | Streambed to 1100 | 34,100
Total storage capacity | 253,200
A surcharge of 35,130 a.f. (Max. W.S. 1220.5) in combination with a spillway capacity of 28,780 c.f.s. and an outlet discharge of 1240 c.f.s. is provided to protect against the inflow design flood having a peak of 44,500 c.f.s. and a 6-day volume of 136,000 a.f.
* See Form 7-1686, Reservoir Capacity Allocations.
EMBANKMENT EXPLANATION
1 Selected weathered rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers.
2 Selected weathered rock (silt, sand, and gravel sizes; and rock fragments to 8" max. size) compacted by tamping rollers to 12-inch layers.
3 Selected rock fines compacted by crawler type tractor to 12-inch layers.
4 Rockfill placed in 3-foot layers.
Zone 3 blanket over zone 4 and abutments below El. 1200. Thickness varies porportionally from 25' on top of zone 4 to a minimum of 5' at El. 1200.
AREA-CAPACITY-DISCHARGE CURVES
OUTLET WORKS DISCHARGE IN HUNDREDS OF C.F.S.
DIVERSION DISCHARGE IN THOUSANDS OF C.F.S.
SPILLWAY DISCHARGE IN THOUSANDS OF C.F.S.
3-13-75 RESERVOIR STORAGE ALLOCATIONS VOIDED
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION-CALIFORNIA
WHISKEYTOWN DAM
GENERAL PLAN AND SECTIONS
DRAWN W.G.H.
TRACED E.E.B.
SUBMITTED
RECOMMENDED
APPROVED
ACT. ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO, MARCH 22, 1960
416-D-879

5. Appendix E: 2007a Risk Analysis

The following table provides a restatement between the model id's and the risk analysis. The risk analysis identified the runs by season and reservoir water surface (RWS) rather than the EWP model run ID number.

Model ID	Season	Beginning Reservoir Water Surface (feet)
3-15	Spring	Historical
3-16	Spring	1204
3-17	Spring	1209.5
3-18	Winter	Historical
3-19	Winter	1203.5

Table 5-1 – Definition of the EWP model IDs

The following table summarizes the historical 2006 IE APF and ALL, the historical APF and ALL computed using the event tree, and the APFs and ALLs for EWP runs # 3-15, 3-16, 3-17, 3-18 and 3-19. This summary shows an increase in the APF and the ALL.

2007a Risk	2006 IE	APF for Historical	EWP ID Expected APF	EWP ID	2006 IE	ALL for Historical	EWP ID Expected ALL	EWP ID
Summary	APF for Historical	using worksheet	Spring	Winter	ALL for Historical	using worksheet	Spring	Winter
RWS			3-15	3-18			3-15	3-18
1198	1.19E-04	1.18E-04	1.21E-04	1.26E-04	8.21E-03	8.14E-03	8.31E-03	8.68E-03
			3-16	3-19			3-16	3-19
1204	1.19E-04		1.25E-04	1.26E-04	8.21E-03		8.59E-03	8.68E-03
			3-17				3-17	
1209	1.19E-04		1.30E-04		8.21E-03		8.94E-03	

Table 5-2- Summary of APF and ALL for Risk Analysis 2007a

The following tables show the derivation of the probabilities of failure for the expected, low, and high estimates of the 2007a risk analysis. This information is presented in graph form in Figure 3-13: Annualized risk plot 2007a for current and EWP re-operation scenarios (#3-15, #3-16, #3-17, and #3-18) using a hydrologic event tree to determine risks. and in tabular form in Table 3-10 – Risk results 2007a using a hydrologic event tree only (details in Appendix E)

Whiskeytown Dam **Historical rws1198**

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING)

Hydrologic Risk

0.95 to 1.68 Percent time above 1210

109 days increase

250 Total days above 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.01E-04	1.18E-04	1.41E-04	69	6.97E-03	8.14E-03	9.71E-03

Spring Expected

Load Rang	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	5	0	0	0.0005000	0.0000040	1.03E-04	69	2.76E-04
3	500	1000	28100	37400	0.001	1217	1198	1	2	0	0.0020000	0.0000020	1.05E-04	69	1.38E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	4	0	0.0040000	0.0000020	1.07E-04	69	1.38E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	1	0.0100000	0.0000030	1.10E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2.5	0.0250000	0.0000025	1.13E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	1.15E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.18E-04	69	2.07E-04
											AFP =	1.18E-04			8.14E-03

LOW ESTIMATE

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	0.9	0	0	0.0000900	0.0000891	8.91E-05	69	6.15E-03
2	100	500	13400	28100	0.008	1213	1198	1	0	0	0.0001000	0.0000008	8.99E-05	69	5.52E-05
3	500	1000	28100	37400	0.001	1217	1198	5	0	0	0.0005000	0.0000005	9.04E-05	69	3.45E-05
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	0	0.0010000	0.0000005	9.09E-05	69	3.45E-05
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	7	0	0.0070000	0.0000021	9.30E-05	69	1.45E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2.5	0.0250000	0.0000025	9.55E-05	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	9.80E-05	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.01E-04	69	2.07E-04
											AFP =	1.01E-04			6.97E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Historical-1198

HIGH ESTIMATE

	Flood - years		Load: Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS (Base response)	Structural Response: Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	1	1	0	0.0010000	0.000008	1.07E-04	69	5.52E-04
3	500	1000	28100	37400	0.001	1217	1198	1	8	0	0.0080000	0.000008	1.15E-04	69	5.52E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	1	0.0100000	0.000005	1.20E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	2.5	0.0250000	0.0000075	1.28E-04	69	5.18E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	5	0.0500000	0.000005	1.33E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	7.5	0.0750000	0.00000375	1.36E-04	69	2.59E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	9	0.0900000	0.0000045	1.41E-04	69	3.11E-04
											AFP =	1.41E-04			9.71E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Historical-1198

Whiskeytown Dam #3-15 Spring, Initial RWS 1198, 3250 cfs for 1 day 0.95 to 1.68 Percent time above 1210

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING) 109 days increase

Hydrologic Risk 250 Total days above 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.01E-04	1.21E-04	1.41E-04	69	6.97E-03	8.31E-03	9.71E-03

Spring Expected

Load Rang	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	5	0	0	0.0005000	0.0000040	1.03E-04	69	2.76E-04
3	500	1000	28100	37400	0.001	1217	1198	1	2	0	0.0020000	0.0000020	1.05E-04	69	1.38E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	9	0	0.0090000	0.0000045	1.10E-04	69	3.11E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	1	0.0100000	0.0000030	1.13E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2.5	0.0250000	0.0000025	1.15E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	1.18E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.21E-04	69	2.07E-04
											AFP =	1.21E-04			8.31E-03

LOW ESTIMATE

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	0.9	0	0	0.0000900	0.0000891	8.91E-05	69	6.15E-03
2	100	500	13400	28100	0.008	1213	1198	1	0	0	0.0001000	0.0000008	8.99E-05	69	5.52E-05
3	500	1000	28100	37400	0.001	1217	1198	5	0	0	0.0005000	0.0000005	9.04E-05	69	3.45E-05
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	0	0.0010000	0.0000005	9.09E-05	69	3.45E-05
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	7	0	0.0070000	0.0000021	9.30E-05	69	1.45E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2.5	0.0250000	0.0000025	9.55E-05	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	9.80E-05	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.01E-04	69	2.07E-04
											AFP =	1.01E-04			6.97E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Spring-1198

HIGH ESTIMATE

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	1	1	0	0.0010000	0.000008	1.07E-04	69	5.52E-04
3	500	1000	28100	37400	0.001	1217	1198	1	8	0	0.0080000	0.000008	1.15E-04	69	5.52E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	1	0.0100000	0.000005	1.20E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	2.5	0.0250000	0.0000075	1.28E-04	69	5.18E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	5	0.0500000	0.000005	1.33E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	7.5	0.0750000	0.00000375	1.36E-04	69	2.59E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	9	0.0900000	0.0000045	1.41E-04	69	3.11E-04
											AFP =	1.41E-04			9.71E-03

Whiskeytown Dam **#3-18 Winter, Initial RWS 1198, 3250 cfs for 1 day** 0.95 to 1.79 Percent time above 1210

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING) **125** days increase

Hydrologic Risk 266 Total daysabove 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.00E-04	1.26E-04	1.41E-04	69	6.91E-03	8.68E-03	9.73E-03

Expected

Load Ra	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS	Base response 1/10,000 Structural Response Historical El. 1215	1/1000 Air vent El. 1221	1/100 TOD El 1228	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	6	0	0	0.0006000	0.0000048	1.04E-04	69	3.31E-04
3	500	1000	28100	37400	0.001	1217	1198	1	3	0	0.0030000	0.0000030	1.07E-04	69	2.07E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	1	0.0100000	0.0000050	1.12E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	2	0.0200000	0.0000060	1.18E-04	69	4.14E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2.5	0.0250000	0.0000025	1.20E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	1.23E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.26E-04	69	2.07E-04
											AFP =	1.26E-04			8.68E-03

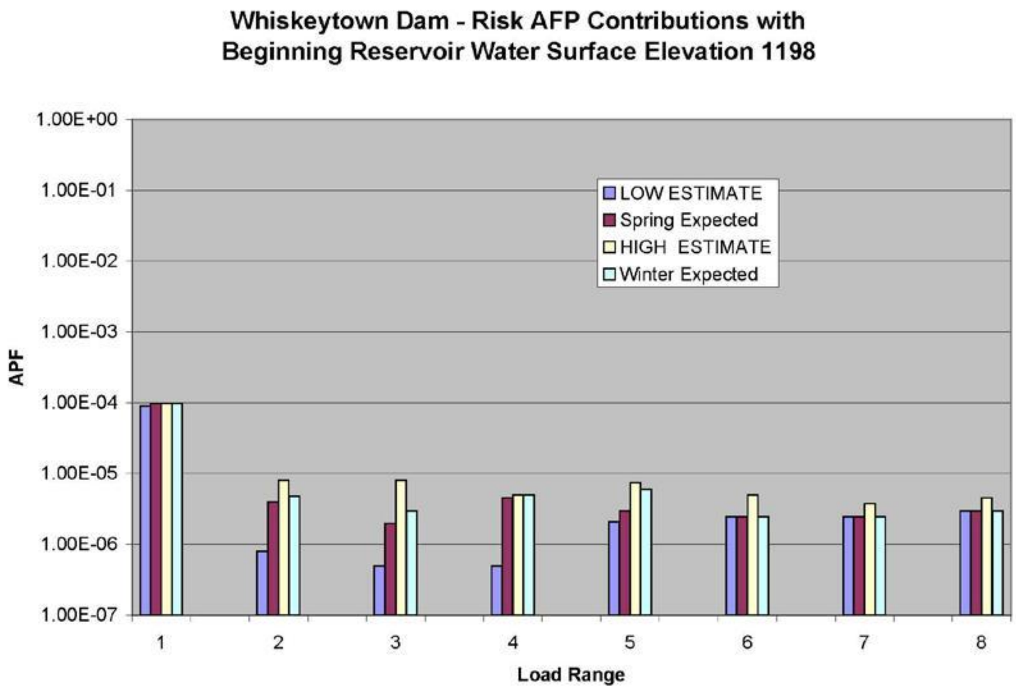
LOW ESTIMATE

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS	Base response 1/10,000 Structural Response Historical El. 1215	1/1000 Air vent El. 1221	1/100 TOD El 1228	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1204	1198	0.9	0	0	0.0000900	0.0000891	8.91E-05	69	6.15E-03
2	100	500	13400	28100	0.008	1213	1198	1	0	0	0.0001000	0.0000008	8.99E-05	69	5.52E-05
3	500	1000	28100	37400	0.001	1217	1198	2	0	0	0.0002000	0.0000002	9.01E-05	69	1.38E-05
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	0	0.0010000	0.0000005	9.06E-05	69	3.45E-05
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	7	0	0.0070000	0.0000021	9.27E-05	69	1.45E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	2	0.0200000	0.0000020	9.47E-05	69	1.38E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	5	0.0500000	0.0000025	9.72E-05	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	6	0.0600000	0.0000030	1.00E-04	69	2.07E-04
											AFP =	1.00E-04			6.91E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Winter1198

							Base response	1/10,000	1/1000	1/100					
HIGH ESTIMATE								Structural Response							
			Load					Historical	Air vent	TOD				loss of life	ALOL
	Flood - years		Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS	El. 1215	El. 1221	El 1228	Structural Response	AFP	Cumulative		
1	1	100	0	13400	0.99	1204	1198	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1213	1198	1	1	0	0.0010000	0.000008	1.07E-04	69	5.52E-04
3	500	1000	28100	37400	0.001	1217	1198	1	8	0	0.0080000	0.000008	1.15E-04	69	5.52E-04
4	1000	2000	37400	48900	0.0005	1226	1198	1	1	1	0.0100000	0.000005	1.20E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1198	1	1	2.5	0.0250000	0.0000075	1.26E-04	69	5.18E-04
6	5000	10000	68400	86900	0.0001	1230.6	1198	1	1	5	0.0500000	0.000005	1.33E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1198	1	1	8	0.0800000	0.000004	1.37E-04	69	2.76E-04
8	20000	50000	109500	118600	0.00005	1231.9	1198	1	1	9	0.0900000	0.0000045	1.41E-04	69	3.11E-04
											AFP =	1.41E-04			9.73E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Winter1198



C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls PltSpring-1198

Whiskeytown Dam **#3-16 Spring, Initial RWS 1204, 3250 cfs, 1 day** 0.95 to 1.98 Percent time above 1210

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING) 153 days increase

Hydrologic Risk 294 total Days above 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.10E-04	1.25E-04	1.43E-04	69	7.59E-03	8.59E-03	9.83E-03

Spring Expected

Load Rang	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Structural Response Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1204	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1204	5	0	0	0.0005000	0.0000040	1.03E-04	69	2.76E-04
3	500	1000	28100	37400	0.001	1221	1204	1	6	0	0.0060000	0.0000060	1.09E-04	69	4.14E-04
4	1000	2000	37400	48900	0.0005	1226	1204	1	9	0	0.0090000	0.0000045	1.14E-04	69	3.11E-04
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	1	0.0100000	0.0000030	1.17E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	2.5	0.0250000	0.0000025	1.19E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	5	0.0500000	0.0000025	1.22E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	6	0.0600000	0.0000030	1.25E-04	69	2.07E-04
					1 Sum of Probabilities						APF =	1.25E-04			8.59E-03

LOW Estimate

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1204	0.99	0	0	0.0000990	0.0000980	9.80E-05	69	6.76E-03
2	100	500	13400	28100	0.008	1215	1204	1	0	0	0.0001000	0.0000008	9.88E-05	69	5.52E-05
3	500	1000	28100	37400	0.001	1221	1204	2	0	0	0.0002000	0.0000002	9.90E-05	69	1.38E-05
4	1000	2000	37400	48900	0.0005	1226	1204	1	1	0	0.0010000	0.0000005	9.95E-05	69	3.45E-05
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	1	0.0100000	0.0000030	1.03E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	2	0.0200000	0.0000020	1.05E-04	69	1.38E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	5	0.0500000	0.0000025	1.07E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	6	0.0600000	0.0000030	1.10E-04	69	2.07E-04
					1 Sum of Probabilities						APF =	1.10E-04			7.59E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Spring 1204

HIGH Estimate

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1204	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1204	1	1	0	0.0010000	0.000008	1.07E-04	69	5.52E-04
3	500	1000	28100	37400	0.001	1221	1204	1	1	1	0.0100000	0.00001	1.17E-04	69	6.90E-04
4	1000	2000	37400	48900	0.0005	1226	1204	1	1	1.2	0.0120000	0.000006	1.23E-04	69	4.14E-04
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	2	0.0200000	0.000006	1.29E-04	69	4.14E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	5	0.0500000	0.000005	1.34E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	8	0.0800000	0.000004	1.38E-04	69	2.76E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	9	0.0900000	0.0000045	1.43E-04	69	3.11E-04
					1 Sum of Probabilities						APF =	1.43E-04			9.83E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Spring 1204

Whiskeytown Dam **#3-19 Winter, Initial RWS 1204, 3250 cfs, 1 day** 0.95 to 1.95 Percent time above 1210

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING) 149 days increase

Hydrologic Risk 290 Days above 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.12E-04	1.26E-04	1.44E-04	69	7.70E-03	8.68E-03	9.94E-03

Winter Expected

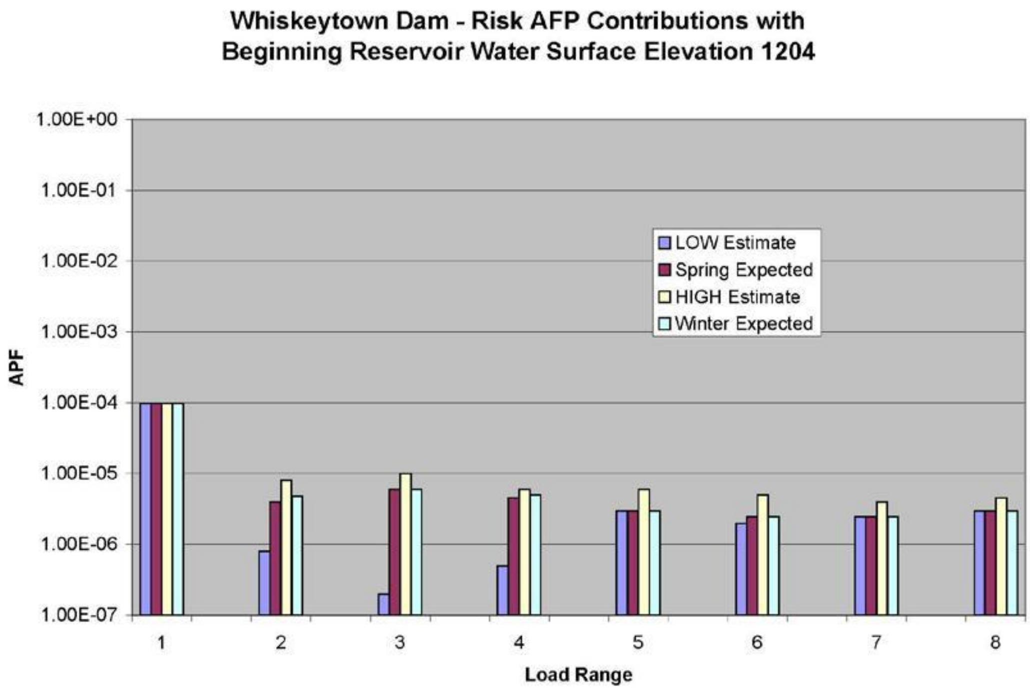
Load Rang	Flood - years		Load Peak inflow (cfs)		Load Probability of load	Est. max rws	Initial RWS	Historical El. 1215	Air vent El. 1221	TOD El 1228	Structural Response	AFP	Cumulative	loss of life	ALOL
							Base response	1/10,000	1/1000	1/100					
1	1	100	0	13400	0.99	1214	1204	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1204	6	0	0	0.0006000	0.0000048	1.04E-04	69	3.31E-04
3	500	1000	28100	37400	0.001	1221	1204	1	6	0	0.0060000	0.0000060	1.10E-04	69	4.14E-04
4	1000	2000	37400	48900	0.0005	1226	1204	1	1	1	0.0100000	0.0000050	1.15E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	1	0.0100000	0.0000030	1.18E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	2.5	0.0250000	0.0000025	1.20E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	5	0.0500000	0.0000025	1.23E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	6	0.0600000	0.0000030	1.26E-04	69	2.07E-04
					1	Sum of Probabilities					APF =	1.26E-04	0		8.68E-03

Winter LOW Estimate

	Flood - years		Load Peak inflow (cfs)		Load Probability of load	Est. max rws	Initial RWS	Historical El. 1215	Air vent El. 1221	TOD El 1228	Structural Response	AFP	Cumulative	loss of life	ALOL
							Base response	1/10,000	1/1000	1/100					
1	1	100	0	13400	0.99	1214	1204	0.9	0	0	0.0000900	0.0000891	8.91E-05	69	6.15E-03
2	100	500	13400	28100	0.008	1215	1204	5	0	0	0.0005000	0.0000040	9.31E-05	69	2.76E-04
3	500	1000	28100	37400	0.001	1221	1204	1	3	0	0.0030000	0.0000030	9.61E-05	69	2.07E-04
4	1000	2000	37400	48900	0.0005	1226	1204	1	9	0	0.0090000	0.0000045	1.01E-04	69	3.11E-04
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	1	0.0100000	0.0000030	1.04E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	2.5	0.0250000	0.0000025	1.06E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	5	0.0500000	0.0000025	1.09E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	6	0.0600000	0.0000030	1.12E-04	69	2.07E-04
					1	Sum of Probabilities					APF =	1.12E-04			7.70E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Winter 1204

	Winter HIGH Estimate		Load		Load												
	Flood - years		Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1204	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1204	1	1	0	0.0010000	0.000008	1.07E-04	69	5.52E-04
3	500	1000	28100	37400	0.001	1221	1204	1	1	1	0.0100000	0.00001	1.17E-04	69	6.90E-04
4	1000	2000	37400	48900	0.0005	1226	1204	1	1	1.2	0.0120000	0.000006	1.23E-04	69	4.14E-04
5	2000	5000	48900	68400	0.0003	1229.4	1204	1	1	2.5	0.0250000	0.0000075	1.31E-04	69	5.18E-04
6	5000	10000	68400	86900	0.0001	1230.6	1204	1	1	5	0.0500000	0.000005	1.36E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1204	1	1	8	0.0800000	0.000004	1.40E-04	69	2.76E-04
8	20000	50000	109500	118600	0.00005	1231.9	1204	1	1	9	0.0900000	0.0000045	1.44E-04	69	3.11E-04
											APF =	0.000144			9.94E-03



C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls PltSpring-1204

Whiskeytown Dam **#3-17 Spring, Initial RWS 1209, 3250 cfs, 1 day** 0.95 to 2.83 Percent time above 1210

Estimate of Risks for EWP and Raised Initial RWS (Includes PIPING) 279 days increase

Hydrologic Risk 0=no 420 Total Days above 1210

Low	Expected	High	LOSS OF LIFE	Low	Expected	High
1.10E-04	1.30E-04	1.51E-04	69	7.59E-03	8.94E-03	1.04E-02

Spring Expected

Load Rang	Flood - years		Load Peak inflow (cfs)		Load Probability of load	Est. max rws	Initial RWS	Historical El. 1215 Base response 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1209	1	0	0	0.0001000	0.0000990	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1209	7.5	0	0	0.0007500	0.0000060	1.05E-04	69	4.14E-04
3	500	1000	28100	37400	0.001	1221	1209	1	8	0	0.0080000	0.0000080	1.13E-04	69	5.52E-04
4	1000	2000	37400	48900	0.0005	1226	1209	1	1	1	0.0100000	0.0000050	1.18E-04	69	3.45E-04
5	2000	5000	48900	68400	0.0003	1229.4	1209	1	1	1.2	0.0120000	0.0000036	1.22E-04	69	2.48E-04
6	5000	10000	68400	86900	0.0001	1230.6	1209	1	1	2.5	0.0250000	0.0000025	1.24E-04	69	1.73E-04
7	10000	20000	86900	109500	0.00005	1231.6	1209	1	1	5	0.0500000	0.0000025	1.27E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1209	1	1	6	0.0600000	0.0000030	1.30E-04	69	2.07E-04
					1	Sum of Probabilities					APF =	1.30E-04			8.94E-03

LOW Estimate

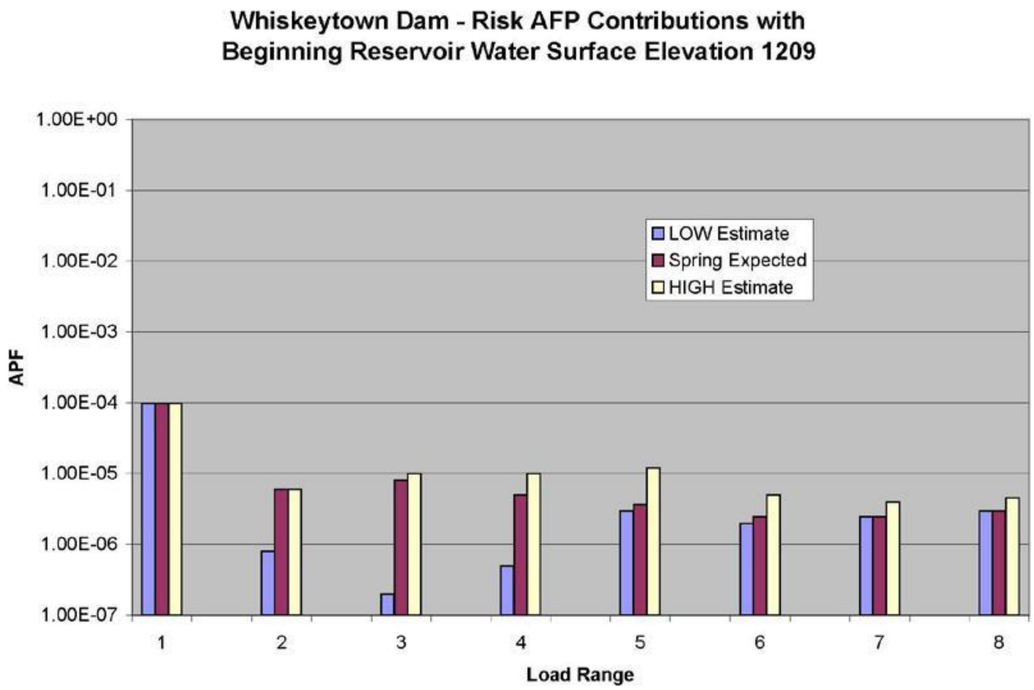
	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS	Historical El. 1215 Base response 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1209	0.99	0	0	0.0000990	0.0000980	9.80E-05	69	6.76E-03
2	100	500	13400	28100	0.008	1215	1209	1	0	0	0.0001000	0.0000008	9.88E-05	69	5.52E-05
3	500	1000	28100	37400	0.001	1221	1209	2	0	0	0.0002000	0.0000002	9.90E-05	69	1.38E-05
4	1000	2000	37400	48900	0.0005	1226	1209	1	1	0	0.0010000	0.0000005	9.95E-05	69	3.45E-05
5	2000	5000	48900	68400	0.0003	1229.4	1209	1	1	1	0.0100000	0.0000030	1.03E-04	69	2.07E-04
6	5000	10000	68400	86900	0.0001	1230.6	1209	1	1	2	0.0200000	0.0000020	1.05E-04	69	1.38E-04
7	10000	20000	86900	109500	0.00005	1231.6	1209	1	1	5	0.0500000	0.0000025	1.07E-04	69	1.73E-04
8	20000	50000	109500	118600	0.00005	1231.9	1209	1	1	6	0.0600000	0.0000030	1.10E-04	69	2.07E-04
					1	Sum of Probabilities					APF =	1.10E-04			7.59E-03

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Spring 1209

HIGH Estimate

	Flood - years		Load Peak inflow (cfs)		Probability of load	Est. max rws	Initial RWS Base response	Historical El. 1215 1/10,000	Air vent El. 1221 1/1000	TOD El 1228 1/100	Structural Response	AFP	Cumulative	loss of life	ALOL
1	1	100	0	13400	0.99	1214	1209	1	0	0	0.0001000	0.000099	9.90E-05	69	6.83E-03
2	100	500	13400	28100	0.008	1215	1209	7.5	0	0	0.0007500	0.000006	1.05E-04	69	4.14E-04
3	500	1000	28100	37400	0.001	1221	1209	1	1	1	0.0100000	0.00001	1.15E-04	69	6.90E-04
4	1000	2000	37400	48900	0.0005	1226	1209	1	1	2	0.0200000	0.00001	1.25E-04	69	6.90E-04
5	2000	5000	48900	68400	0.0003	1229.4	1209	1	1	4	0.0400000	0.000012	1.37E-04	69	8.28E-04
6	5000	10000	68400	86900	0.0001	1230.6	1209	1	1	5	0.0500000	0.000005	1.42E-04	69	3.45E-04
7	10000	20000	86900	109500	0.00005	1231.6	1209	1	1	8	0.0800000	0.000004	1.46E-04	69	2.76E-04
8	20000	50000	109500	118600	0.00005	1231.9	1209	1	1	9	0.0900000	0.0000045	1.51E-04	69	3.11E-04
					1	Sum of Probabilities					APF =	1.51E-04	0		1.04E-02

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls Spring 1209



C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007a RiskEventTree-all fin20080130.xls PltSpring-1209

Appendix F: Risk 2007b Risk Evaluation, Event Trees, Static, Hydrologic and Seismic, and results using the EWP Scenarios

Hydrology

Table 4 – Hydrologic Hazards for Whiskeytown Dam, California						
Return Period (yr)	Peak Discharge (ft^3/s)	1-Day Volume (ac ft)	3-Day Volume (ac ft)	5-Day Volume (ac ft)	7-Day Volume (ac ft)	15-Day Volume (ac ft)
1	1,000					
2	3,700					
5	6,000					
10	7,500					
20	9,000					
30	10,000					
50	11,000					
70	12,000					
90	12,750					
100	13,400	17,000	38,700	56,200	70,300	115,800
200	18,700	24,700	54,500	75,100	89,600	135,100
500	28,100	38,900	82,800	108,000	123,000	168,400
1,000	37,400	53,500	111,200	140,200	155,500	201,000
2,000	48,900	72,200	147,000	180,200	195,900	241,400
5,000	68,400	105,100	208,500	247,900	264,000	309,500
10,000	86,900	137,500	268,100	312,600	329,100	374,600
20,000	109,500	178,000	341,400	391,600	408,400	453,900
50,000	118,600	194,700	371,300	423,700	440,600	486,200

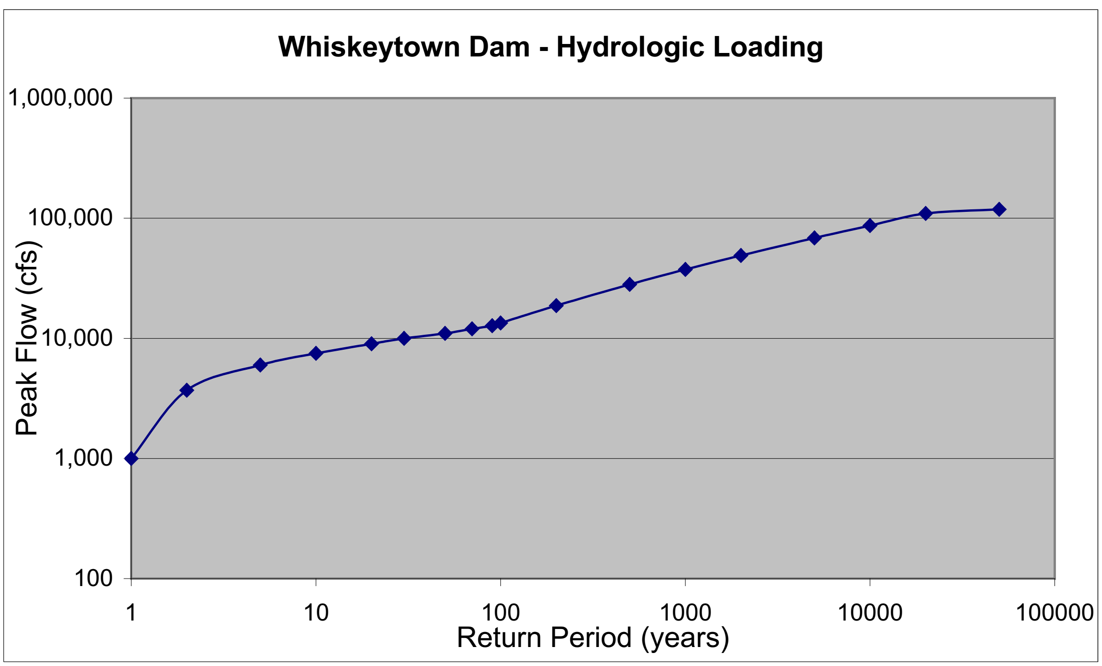
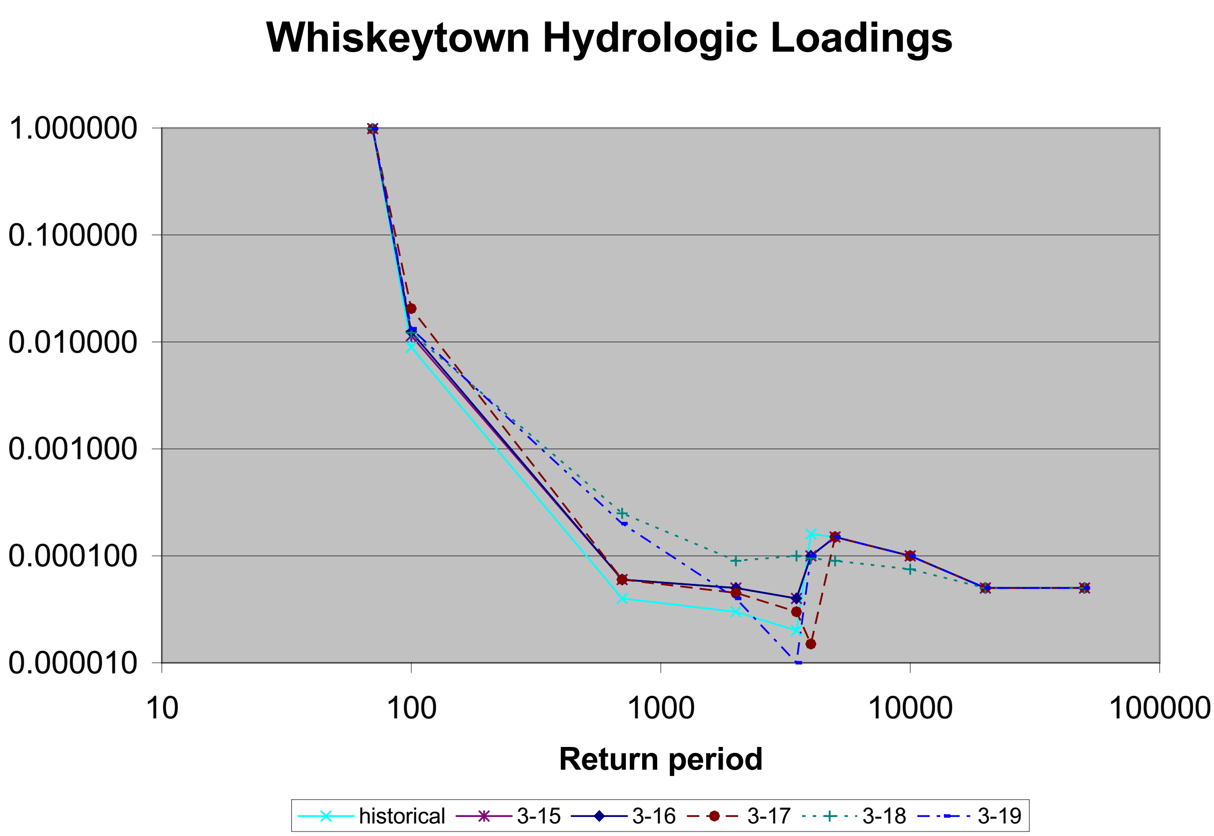


Figure 5-1: Hydrologic loadings for 2007b risk analysis

Water Surface Elevation							
Current operation is historical versus EWP Scenarios							
	Return period	Probability at or below elevation (Range is from the elevation to the elevation in row above)					
Elevation	(yrs)	Historical	3-15	3-16	3-17	3-18	3-19
1211	70	0.990500	0.988000	0.987000	0.979000	0.987000	0.986000
1214	100	0.008900	0.011400	0.012400	0.020500	0.012200	0.013300
1215	700	0.000040	0.000060	0.000060	0.000060	0.000250	0.000200
1218.5	2000	0.000030	0.000050	0.000050	0.000045	0.000090	0.000040
1221	3500	0.000020	0.000040	0.000040	0.000030	0.000100	0.000010
1226	4000	0.000160	0.000100	0.000100	0.000015	0.000095	0.000100
1229.4	5000	0.000150	0.000150	0.000150	0.000150	0.000090	0.000150
1230.6	10000	0.000100	0.000100	0.000100	0.000100	0.000075	0.000100
1231.6	20000	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050
1231.9	50000	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050
	Sum of Probabilities	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000



	C	D	E
2	*Table 3 0- Static Loading - Piping and Erosion during Normal reservoir water surface elevations (Elevations at or below*		
3	Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
4	Reservoir rises to Elevation 1211	Likely:	3-18
5		o The reservoir is regularly at El. 1210 but doesn't experience the loads to 1214 regularly	
6		Unlikely:	
7		o This is within experienced operating conditions and the embankment has experienced these reservoir water surface elevations and loads.	
8		o Maximum historical reservoir water surface elevation 1215.33 (1983)	0.9870
9	Initiation – Concentrated leak due to cracks, settlement of embankment, up to elevation 1214	Likely:	
10		o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock.	
11		o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers).	
12		o Top of cores is at elevation 1223.	
13		o less confining pressures, higher Reservoir Water Surface means cracks don't have to be as deep	
14		o First filling above el. 1214 (never wetted)	
15		Unlikely:	
16		o 25 years of operation	
17		o Little settlement of dam based on survey	
18		o Reservoir regularly at 1211 & no cracking or seepage observed	0.0012
19	Continuation – Filtered exit is deficient by criteria, unfiltered exit - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely:	
20		o Zone 1 material though compacted is highly erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers	
21		o Zone 2 material is also likely to be erodible	
22		o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1	
23		o Higher reservoir durations with greater heads	
24		Unlikely:	
25		o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug off	
26		o	0.1
27	Progression – Roof supported.	Likely:	
28		o Pavement acts as a roof in initial stages	
29		o Zone 1 material is capable of sustaining a roof or pipe	
30		Unlikely:	
31		o	0.5
32	Progression – Flows are not limited	Likely:	
33		o Seepage has occurred at Dike No. 2 and likely similar at main dam	
34		o **Dam construction is simliar so if flow start, little to stop them**	
35		Unlikely:	
36		o	
37		o	
38		o	0.1
39	Progression – core erodible	Likely:	
40		o Zone 1 (core) is erodible and likely zone 2 material is also erodible	
41		o Higher heads mean higher pressures and hence greater erodibility	
42		Unlikely:	
43		o	0.5
44	Intervention Fails	Likely:	
45		o Remote location in park system, no equipment nearby	
46		o Reservoir does not have complete observation full time for this loading	
47		o	
48		Unlikely:	
49		o Crest is 30 feet wide at top	
50		o	0.5
51	Dam Breaches - Uncontrolled release of the reservoir	Likely:	
52		o	
53		Unlikely:	
54		o	0.5
55	Unsuccessful Heroic Intervention	Likely:	
56	(Uncontrolled Release of the Reservoir)	o High dam, hard to control	
57		Unlikely:	
58		o	0.9
59		Total	6.66E-07

	G	H	I
2	***Table 3 A- Static Loading - Piping and Erosion during elevated reservoir water surface elevations***		
3	Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
4	Reservoir rises to Elevation 1211-1214	Likely:	3-18
5		o The reservoir is regularly at El. 1210 but doesn't experience the loads to 1214 regularly	
6		Unlikely:	
7		o This is within experienced operating conditions and the embankment has experienced these reservoir water surface elevations and loads.	
8		o Maximum historical reservoir water surface elevation 1215.33 (1983)	0.0122
9	Initiation – Concentrated leak due to cracks, settlement of embankment, up to elevation 1214	Likely:	
10		o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock.	
11		o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers).	
12		o Top of cores is at elevation 1223.	
13		o less confining pressures, higher Reservoir Water Surface means cracks don't have to be as deep	
14		o	
15		Unlikely:	
16		o 25 years of operation	
17		o Little settlement of dam based on survey	
18		o Dam has experience full loads at this level	0.01
19	Continuation – Filtered exit is deficient by criteria, unfiltered exit - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely:	
20		o Zone 1 material though compacted is highly erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layer:	
21		o Zone 2 material is also likely to be erodible	
22		o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1	
23		o Higher reservoir durations with greater heads	
24		Unlikely:	
25		o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug off	
26		o	0.1
27	Progression – Roof supported.	Likely:	
28		o Pavement acts as a roof in initial stages	
29		o Zone 1 material is capable of sustaining a roof or pipe	
30		Unlikely:	
31		o	0.5
32	Progression – Flows are not limited	Likely:	
33		o Seepage has occurred at Dike No. 2 and likely similar at main dam	
34		o	
35		Unlikely:	
36		o	
37		o	
38		o	0.1
39	Progression – core erodible	Likely:	
40		o Zone 1 (core) is erodible and likely zone 2 material is also erodible	
41		o Higher heads mean higher pressures and hence greater erodibility	
42		Unlikely:	
43		o	0.5
44	Intervention Fails	Likely:	
45		o Remote location in park system, no equipment nearby	
46		o Reservoir does not have complete observation full time for this loading	
47		o	
48		Unlikely:	
49		o Crest is 30 feet wide at top	
50		o	0.5
51	Dam Breaches - Uncontrolled release of the reservoir	Likely:	
52		o	
53		Unlikely:	
54		o	0.5
55	Unsuccessful Heroic Intervention	Likely:	
56	(Uncontrolled Release of the Reservoir)	o High dam, hard to control	
57		Unlikely:	
58		o	0.9
59		Total	6.86E-08

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007b 1206d detailedevent trees with reoperation.xls Static ET

	K	L	M
2	***Table 3B - Static Loading - Piping and Erosion during elevated reservoir water surface elevations***		
3	Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
4	Reservoir rises to Elevation 1214-1215	Likely:	3-18
5		o Reservoir reached this elevation 1 time in 37 years	
6		Unlikely:	
7		o Maximum historical reservoir water surface elevation 1215.33 (1983)	0.00025
8	Initiation – Concentrated leak due to cracks, settlement of embankment, up to elevation 1215	Likely:	
9		o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock.	
10		o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers).	
11		o Top of cores is at elevation 1223.	
12		o less confining pressures, higher Reservoir Water Surface means cracks don't have to be as deep	
13		**o First Filling**	
14		Unlikely:	
15		o 25 years of operation	
16		o Little settlement of dam based on survey	
17		o	0.1
18	Continuation – Filtered exit is deficient by criteria, unfiltered exit zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely:	
19		o Zone 1 material though compacted is highly erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers	
20		o Zone 2 material is also likely to be erodible	
21		o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1	
22		o Higher reservoir durations with greater heads	
23		Unlikely:	
24		o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug c	
25		o	0.1
26	Progression – Roof supported.	Likely:	
27		o Pavement acts as a roof in initial stages	
28		o Zone 1 material is capable of sustaining a roof or pipe	
29		Unlikely:	
30		o	0.5
31	Progression – Flows are not limited	Likely:	
32		o Seepage at Dike No. 2 and likely similar at main dam	
33		o	
34		Unlikely:	
35		o	
36		o	
37		o	0.1
38	Progression – core erodible	Likely:	
39		o Zone 1 (core) is erodible and likely zone 2 material is also erodible	
40		o Higher heads mean higher pressures and hence greater erodibility	
41		Unlikely:	
42		o	0.5
43	Intervention Fails	Likely:	
44		o Remote location in park system, no equipment nearby	
45		o Reservoir does not have complete observation full time for this loading	
46		o	
47		Unlikely:	
48		o Crest is 30 feet wide at top	
49		o	0.5
50	Dam Breaches - Uncontrolled release of the reservoir	Likely:	
51		o	
52		Unlikely:	
53		o	0.5
54	Unsuccessful Heroic Intervention	Likely:	
55	(Uncontrolled Release of the Reservoir)	o High dam, hard to control	
56		Unlikely:	
57		o	0.9
58		Total	1.41E-08

	O	P	Q
2	*Table 3C - Static Loading - Piping and Erosion during elevated reservoir water surface elevations*		
3	Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
4	Reservoir rises to Elevation 1221	Likely:	3-18
5		Reservoir should see this load during operation, Estimated to occur 1 in 162 years	
6		Unlikely:	
7		o This is within the designed maximum reservoir water surface elevations	0.00019
8	Initiation – Concentrated leak due to cracks, settlement of embankment, to elevation 1221	Likely:	
9		o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock	
10		o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacte by tamping rollers to 12-inch layers)	
11		o Top of cores is at elevation 1223.	
12		o less confining pressures, higher Reservoir Water Surface means cracks don't have to be as deep	
13		**o First filling - Never loaded or wetted above el. 1215.3**	
14		Unlikely:	
15		o 25 years of operation	
16		o Little settlement of dam based on survey	
17		o Still has core at this elevation	0.5
18	Continuation – Filtered exit is deficient by criteria, unfiltered ex - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely:	
19		o Zone 1 material though compacted is highly erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers	
20		o Zone 2 material is also likely to be erodible	
21		o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1	
22		o Higher reservoir durations with greater heads	
23		Unlikely:	
24		o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug c	
25		o	0.1
26	Progression – Roof supported.	Likely:	
27		o Pavement acts as a roof in initial stages	
28		o Zone 1 material is capable of sustaining a roof or pipe	
29		Unlikely:	
30		o	0.5
31	Progression – Flows are not limited	Likely:	
32		o Seepage at Dike No. 2 and likely similar at main dam	
33		o	
34		Unlikely:	
35		o	
36		o	
37		o	0.5
38	Progression – core erodible	Likely:	
39		o Zone 1 (core) is erodible and likely zone 2 material is also erodible	
40		o Higher heads mean higher pressures and hence greater erodibility	
41		Unlikely:	
42		o	0.5
43	Intervention Fails	Likely:	
44		o Remote location in park system, no equipment nearby	
45		o Reservoir may not have complete observation full time for this loading due to long length of crest	
46		o	
47		Unlikely:	
48		o Crest is 30 feet wide at top	
49		o	0.5
50	Dam Breaches - Uncontrolled release of the reservoir	Likely:	
51		o	
52		Unlikely:	
53		o	0.5
54	Unsuccessful Heroic Intervention	Likely:	
55	(Uncontrolled Release of the Reservoir)	o High dam, hard to control	
56		Unlikely:	
57		o	0.9
58		Total	2.67E-07

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007b 1206d detailedevent trees with reoperation.xls Static ET

Whiskeytown Dam

Table 3D - Hydrologic Loading - Piping during elevated reservoir water surface elevations

Node description	Likely/Unlikely Factors(Factors in **BOLD** are considered key)	Estimated Probability
Reservoir rises to Elevation 1226 (1223)	Likely: o Air vent is at El. 1222, so plugs off during flood Unlikely: o Top of dam is at elevation 1231.0	3-18 9.500E-05
Initiation – Concentrated leak due to cracks, settlement of embankment,	Likely: o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock. o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers). o Top of cores is at elevation 1223. o o **First filling - Never loaded or wetted above el. 1215.3** Unlikely: o o o	0.9
Continuation – Filtered exit is deficient by criteria, unfiltered exit - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely: o Zone 1 material though compacted is likely to be erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers. o Zone 2 material is also likely to be erodible o No Zone 3 in this area. Zone 3does not strictly meet Reclamation "no erosion" filter criteria for zone 1 Unlikely: o	0.1
Progression – Roof supported.	Likely: o Pavement acts as a roof in initial stages o Zone 1 material is likely to form a pipe Unlikely: o	0.5
Progression – Flows are not limited	Likely: o Full Reservoir behind leaks o Unlikely: o o ○	0.9
Progression – core erodible	Likely: o Core is erodible and likely zone 2 material is also erodible Unlikely: ○	0.9
Intervention Fails	Likely: o o ○ Unlikely: o ○	0.5
Dam Breaches - Uncontrolled release of the reservoir	Likely: ○ Unlikely: ○	0.5
Unsuccessful Heroic Intervention (Uncontrolled Release of the Reservoir)	Likely: ○ Unlikely: ○	0.9
	Total	7.79E-07

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007b 1206d detailedevent trees with reoperation.xls Hydrologic ET

Table 3E - Hydrologic Loading - Piping during elevated reservoir water surface elevations		
Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
Reservoir rises to Elevation 1229.4 (1226.4)	Likely: o Air vent is at El. 1222, so plugs off during flood Unlikely: o Top of dam is at elevation 1231.0	3-18 9.000E-05
Initiation – Concentrated leak due to cracks, settlement of embankment,	Likely: o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock. o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers). o Top of cores is at elevation 1223. o o **First filling - Never loaded or wetted above el. 1215.3** Unlikely: o o o	0.9
Continuation – Filtered exit is deficient by criteria, unfiltered exit - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely: o Zone 1 material though compacted is likely to be erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers. o Zone 2 material is also likely to be erodible o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1 Unlikely: o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug off o	0.1
Progression – Roof supported.	Likely: o Pavement acts as a roof in initial stages o Zone 1 material is likely to form a pipe Unlikely: o	0.5
Progression – Flows are not limited	Likely: o Full Reservoir behind leaks o Unlikely: o o o	0.9
Progression – core erodible	Likely: o Core is erodible and likely zone 2 material is also erodible Unlikely: o	0.9
Intervention Fails	Likely: o o o Unlikely: o o	0.5
Dam Breaches - Uncontrolled release of the reservoir	Likely: o Unlikely: o	0.5
Unsuccessful Heroic Intervention (Uncontrolled Release of the Reservoir)	Likely: o Unlikely: o	0.9
	Total	7.38E-07

Table 3F - Hydrologic Loading - Overtopping during elevated reservoir water surface elevations		
Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
Reservoir rises to Elevation 1230.6 (1227.6)	Likely: o Air vent is at El. 1222, so plugs off during flood Unlikely: o Top of dam is at elevation 1231.0	3-18 7.500E-05
Initiation – Concentrated leak due to cracks, settlement of embankment,	Likely: o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock. o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers). o Top of cores is at elevation 1223. o o **First filling - Never loaded or wetted above el. 1215.3** Unlikely: o o o	0.1
Continuation – Filtered exit is deficient by criteria, unfiltered exit - zone 2 wraps around core on both upstream and downstream face, on downstream side extends to elevation 1200,	Likely: o Zone 1 material though compacted is likely to be erodible due to the low plasticity and fine-grained nature of the soil. Core composed of selected rock (clay, silt, sand, and gravel sizes) compacted by tamping rollers to 6-inch layers. o Zone 2 material is also likely to be erodible o Zone 3 does not strictly meet Reclamation "no erosion" filter criteria for zone 1 Unlikely: o University of New South Wales (UNSW) suggest that the zone 3 generally meets criteria for the continuing erosion boundary. Zone 3 will more than likely plug if soil particles begin to move, so it is likely zone 2 will also plug off o	1
Progression – Roof supported.	Likely: o Pavement acts as a roof in initial stages o Zone 1 material is likely to form a pipe Unlikely: o	1
Progression – Flows are not limited	Likely: o Full Reservoir behind leaks o Unlikely: o o o	1
Progression – core erodible	Likely: o Core is erodible and likely zone 2 material is also erodible Unlikely: o	1
Intervention Fails	Likely: o o o Unlikely: o o	1
Dam Breaches - Uncontrolled release of the reservoir	Likely: o Unlikely: o	1
Unsuccessful Heroic Intervention (Uncontrolled Release of the Reservoir)	Likely: o Unlikely: o	1
	Total	7.50E-06

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007b 1206d detailedevent trees with reoperation.xls Hydrologic ET

Table 3G - Hydrologic Loading - Overtopping during elevated reservoir water surface elevations		
Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
Reservoir rises to Elevation 1231.6 (1228.6)	Likely: o This is 1/2 foot above top of dam based on current survey Unlikely: o	3-18 5.000E-05
Overtopping	Likely: o Survey shows top of dam at elevation 1231.1 (in both dikes and dam at low spots) o Can't inspect full dam length due to overtopping, so likely other low spots o o o **First filling - Never loaded or wetted above el. 1215.3** Unlikely: o o o	0.5
Intervention Fails	Likely: o Full length of dam crest is over 4000 feet long o May not have equipment handy o Unlikely: o o	1
Dam Breaches - Uncontrolled release of the reservoir	Likely: o Unlikely: o	1
Unsuccessful Heroic Intervention (Uncontrolled Release of the Reservoir)	Likely: o Unlikely: o	1
	Total	2.50E-05

Table 3H - Hydrologic Loading - Overtopping during elevated reservoir water surface elevations		
Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
Reservoir rises to Elevation 1231.9 (1228.9)	Likely: o This is nearly 1 foot above top of dam based on current survey Unlikely: o	3-18 5.000E-05
Overtopping	Likely: o No designed filter on upstream face (3' riprap, 18" bedding over selected weathered rock. o Zone 2 material is composed of silt, sand, and gravel sizes, and rock fragments to 8" maximum size. Zone was compacted by tamping rollers to 12-inch layers). o Top of cores is at elevation 1223. o o Unlikely: o o o	1
Intervention Fails	Likely: o Full length of dam crest is over 4000 feet long o May not have equipment handy o Unlikely: o o	1
Dam Breaches - Uncontrolled release of the reservoir	Likely: o Unlikely: o	1
Unsuccessful Heroic Intervention (Uncontrolled Release of the Reservoir)	Likely: o Unlikely: o	1
	Total	5.00E-05

Whiskeytown Table 4 - Seismic loading – Liquefaction and Erosion		
Node description	Likely/Unlikely Factors (Factors in **BOLD** are considered key)	Estimated Probability
Reservoir	Likely: o Reservoir fills every year Unlikely: o	1
Initiation – Seismic loading occurs	Likely: o failure occurs with 0.5 g for 2E-05 Unlikely: o	0.00002
Initiation – Crack runs upstream to downstream that intersects the reservoir	Likely: o Has had time to settle and form cracks Unlikely: o No observed cracks to date	0.1
Continuation – Is the crack continuous from upstream to downstream	Likely: o Earthquate shaking will cause cracks to extend full lengths o Unlikely: o	0.1
Progression – Is the water velocity great enough to erode foundation	Likely: o Velocity doesn't need to be very high as zone 1 material is erodible Unlikely: o	1
Progression – There is no self healing ability of the foundation	Likely: o Dam construction is similar throughout entire height o Full reservoir present Unlikely: o	1
Intervention Fails	Likely: o Large earthquake may divert resources elsewhere o o Unlikely: o Inpsection after an earthquake	1
Dam Breaches	Likely: o Unlikely: o	1
	Total	2.00E-07

C:\Documents and Settings\bcohen\My Documents\Projects\Whiskeytown\2007b 1206d detailedevent trees with reoperation.xls Seismic ET

Comparison of Annual Probability of Failure (APF) and Annualized Loss of Life (ALOL)												
	Historical Loading		3-15		3-16		3-17		3-18		2003 CFR	2003 CFR
Static	APF	ALOL	APF	ALOL	APF	ALOL	APF	ALOL	APF	ALOL	APF	ALOL
Piping through the Foundation	1.27E-06	2.53E-04	1.27E-06	2.53E-04	1.27E-06	2.53E-04	1.27E-06	2.53E-04	1.27E-06	2.53E-04	1.27E-06	2.53E-04
Piping through the Embankment	6.69E-07	1.33E-04	6.67E-07	1.33E-04	6.66E-07	1.33E-04	6.61E-07	1.32E-04	6.66E-07	1.33E-04	6.32E-07	1.26E-04
Hydrologic												
Piping through the Foundation below the dam-foundation contact	1.27E-06	8.76E-05	1.27E-06	8.76E-05	1.27E-06	8.76E-05	1.27E-06	8.76E-05	1.27E-06	8.76E-05	1.27E-06	8.76E-05
Piping through the Embankment	2.67E-06	1.84E-04	2.24E-06	1.55E-04	2.25E-06	1.55E-04	1.58E-06	1.09E-04	1.87E-06	1.29E-04	1.90E-06	1.31E-04
Overtopping	8.50E-05	5.87E-03	8.50E-05	5.87E-03	8.50E-05	5.87E-03	8.50E-05	5.87E-03	8.25E-05	5.69E-03	2.86E-04	1.97E-02
Seismic												
Liquefaction	2.00E-07	3.98E-05	2.00E-07	3.98E-05	2.00E-07	3.98E-05	2.00E-07	3.98E-05	2.00E-07	3.98E-05	2.00E-07	3.98E-05
Total Static	**1.94E-06**	**3.86E-04**	**1.94E-06**	**3.85E-04**	**1.94E-06**	**3.85E-04**	**1.93E-06**	**3.84E-04**	**1.94E-06**	**3.85E-04**	**1.90E-06**	**3.78E-04**
Total Hydrologic	**8.89E-05**	**6.14E-03**	**8.85E-05**	**6.11E-03**	**8.85E-05**	**6.11E-03**	**8.78E-05**	**6.08E-03**	**8.56E-05**	**5.90E-03**	**2.89E-04**	**2.00E-02**
Total Seismic	**2.00E-07**	**3.98E-05**	**2.00E-07**	**3.98E-05**	**2.00E-07**	**3.98E-05**	**2.00E-07**	**3.98E-05**	**2.00E-07**	**3.98E-05**	**2.00E-07**	**3.98E-05**

	Historical Loading		3-15		3-16		3-17		3-18		2003 CFR	
	APF	Failure Mode APF Sum	APF	Failure Mode APF Sum	APF	Failure Mode APF Sum	APF	Failure Mode APF Sum	APF	Failure Mode APF Sum	APF	Failure Mode APF Sum
Static Foundation	1.27E-06		1.27E-06		1.27E-06		1.27E-06		1.27E-06		1.27E-06	
Static - Embankment	6.69E-07	1.94E-06	6.67E-07	1.94E-06	6.66E-07	1.94E-06	6.61E-07	1.93E-06	6.66E-07	1.94E-06	6.32E-07	1.90E-06
Hydrologic through foundation	1.27E-06	8.89E-05	1.27E-06	8.85E-05	1.27E-06	8.85E-05	1.27E-06	8.78E-05	1.27E-06	8.56E-05	1.27E-06	2.89E-04
Hydrologic embankment	1.23E-07		1.94E-07		2.00E-07		2.24E-07		3.50E-07		6.32E-07	
Hydrologic freeboard	2.54E-06		2.05E-06		2.05E-06		1.35E-06		1.52E-06		1.90E-06	
Hydrologic overtopping	8.50E-05		8.50E-05		8.50E-05		8.50E-05		8.25E-05		2.86E-04	
Seismic	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07

	2003 CFR			2006 IE RA			2007a		
	Uses historical data			Uses historical data				Risk using historical 1198 event tree	
Static	APF	loss of life	ALOL	APF	loss of life	ALOL	AFP	LOSS OF	ALOL
Piping through the Embankmen	6.32E-07	199	1.26E-04	7.00E-07	199	1.39E-04	7.00E-07	199	2.19E-04
Piping through the Foundation	1.27E-06	199	2.53E-04	1.10E-06	199	2.19E-04	1.10E-06	199	2.19E-04
Overtopping	2.86E-04	18	5.15E-03	1.17E-04	69	8.07E-03	1.10E-05	69	7.59E-04
Piping through the Embankmen	1.90E-06	70	1.33E-04	2.00E-06	69	1.38E-04	1.07E-04	69	7.38E-03
Piping through the Foundation below the dam-foundation contact	1.27E-06	70	n/a	1.27E-06	69	n/a	n/a		
Liquefaction	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05
Total Static	1.90E-06		3.78E-04	1.80E-06		3.58E-04	1.80E-06		3.58E-04
Total Hydrologic	2.89E-04		5.28E-03	1.20E-04		8.21E-03	1.18E-04		8.14E-03
Total Seismic	2.00E-07		3.98E-05	2.00E-07		3.98E-05	2.00E-07		3.98E-05

	2007b			3-15			3-16		
		Risk using internal erosion event trees and hydro event tree			Risk using internal erosion event trees and hydro event tree			Risk using internal erosion event trees and hydro event tree	
Static				AFP		ALOL	AFP	LOSS OF	ALOL
Piping through the Embankmen	6.69E-07	199	1.33E-04	6.67E-07	199	1.33E-04	6.66E-07	199	1.33E-04
Piping through the Foundation	1.27E-06	199	2.53E-04	1.27E-06	199	2.53E-04	1.27E-06	199	2.53E-04
Overtopping	8.50E-05	69	5.87E-03	8.50E-05	69	5.87E-03	8.50E-05	69	5.87E-03
Piping through the Embankmen	2.67E-06	69	1.84E-04	2.24E-06	69	1.55E-04	2.25E-06	69	1.55E-04
Piping through the Foundation below the dam-foundation contact	1.27E-06	69	8.76E-05	1.27E-06	69	8.76E-05	1.27E-06	69	8.76E-05
Liquefaction	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05
Total Static	1.94E-06		3.86E-04	1.94E-06		3.85E-04	1.94E-06		3.85E-04
Total Hydrologic	8.89E-05		6.14E-03	8.85E-05		6.11E-03	8.85E-05		6.11E-03
Total Seismic	2.00E-07		3.98E-05	2.00E-07		3.98E-05	2.00E-07		3.98E-05

	3-17			3-18			3-19		
		Risk using internal erosion event trees and hydro event tree			Risk using internal erosion event trees and hydro event tree			Risk using internal erosion event trees and hydro event tree	
Static	AFP	Loss of Lif	ALOL	AFP	Loss of Lif	ALOL	AFP	Loss of Lif	ALOL
Piping through the Embankmen	6.61E-07	199	1.32E-04	6.66E-07	199	1.33E-04	6.66E-07	199	1.32E-04
Piping through the Foundation	1.27E-06	199	2.53E-04	1.27E-06	199	2.53E-04	1.27E-06	199	2.53E-04
Overtopping	8.50E-05	69	5.87E-03	8.25E-05	69	5.69E-03	8.50E-05	69	5.87E-03
Piping through the Embankmen	1.58E-06	69	1.09E-04	1.87E-06	69	1.29E-04	2.21E-06	69	1.52E-04
Piping through the Foundation below the dam-foundation contact	1.27E-06	69	8.76E-05	1.27E-06	69	8.76E-05	1.27E-06	69	8.76E-05
Liquefaction	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05	2.00E-07	199	3.98E-05
Total Static	1.93E-06		3.84E-04	1.94E-06		3.85E-04	1.94E-06		3.85E-04
Total Hydrologic	8.78E-05		6.06E-03	8.56E-05		5.91E-03	8.85E-05		6.10E-03
Total Seismic	2.00E-07		3.98E-05	2.00E-07		3.98E-05	2.00E-07		3.98E-05