Technical Memorandum

Date:	April 24, 2024
Project:	Chehalis River Basin Flood Damage Reduction Project
To:	Chehalis Basin Flood Control Zone District
From:	HDR Engineering, Inc.
Subject:	**2017 Reservoir Operations Plan Sensitivity Analysis**

1.0 Introduction

As a part of recommended measures to reduce damage to communities of the Chehalis River Basin during major flood events, identified as part of the Chehalis River Basin Flood Damage Reduction Project, the Chehalis Basin Flood Control Zone District (District) is proposing a Flood Retention Expandable (FRE) structure located on the Chehalis River, south of the town of Pe Ell, Washington (WA).

This technical memorandum summarizes the findings of the sensitivity analysis completed by HDR on the 2017 Reservoir Operations Plan developed by Anchor QEA, LLE (Anchor QEA).

1.1 Situation

Under the Anchor QEA (2017) Reservoir Operations Plan for the proposed Flood Retention Expandable (FRE) dam, the FRE would retain flows temporarily when streamflow on the Chehalis River at Grand Mound, WA is forecast to exceed 38,800 cubic feet per second (cfs) in the next 48 hours, then release impounded water in a manner that reduces potential for fish stranding, helps maintain downstream geomorphic processes, and maintains slope stability for the dam and inundated hillsides during the recession of the event. The proposed forecast trigger corresponds to the National Oceanographic and Atmospheric Administration National Weather Service major flood category at the Grand Mound gage. This flow corresponds to an annual exceedance probability of p=0.15 (an approximately 1 in 7-year event), estimated using the flow-frequency information developed by WEST Consultants, Inc. in 2014. The proposed drawdown strategy drains the reservoir from full, or almost full, in the span of approximately four weeks.

Changes to the proposed 2017 operations rules might result in greater benefits in terms of water management objectives and/or operational flexibilities. The Chehalis Basin Flood Control Zone District (District) wishes to know how sensitive water management performance is to the proposed operational parameters. Ultimately, the District is interested in understanding if similar, or perhaps better, water management performance could be achieved through optimization of the FRE operations plan.

1.2 Task

HDR was asked to complete a sensitivity analysis in which different maximum release rules, drawdown rates, or forecast information triggers were varied.

1.3 Action

To complete this sensitivity analysis, HDR:

- Modified the existing operations set in the enhanced HEC-ResSim model that represents the 2017 operations plan to create eight new operations sets in three categories as follows:
  - Modified maximum release (when FRE reduces outflow to less than inflow when operations are triggered):
    - Maximum FRE release = 1,000 cfs
    - Maximum FRE release = 2,000 cfs
    - Maximum FRE release = 3,000 cfs
  - Modified forecast triggers
    - 52,500 cfs Grand Mound trigger
    - 38,800 cfs Grand Mound and 25,200 Doty trigger
    - 52,500 cfs Grand Mound and 25,200 Doty trigger
  - Modified drawdown rates
    - Drawdown rates +20%
    - Drawdown rates -20%
- Simulated operations using three historical events patterns (under existing climate conditions):
  - February 1996 – Selected because it is the second largest flood event in the basin above Grand Mound and flows were generally distributed evenly across the basin.
  - December 2007 – Selected because it is the largest flood event in the basin above Grand Mound and there were large contributions from the Willapa Hills (watershed above the FRE facility) compared to those of the Skookumchcuk and Newaukum rivers.
  - January 2022 – Selected because it is the 5th largest flood event in the basin above Grand Mound and there were large contributions from the Skookumchuck and Newaukum rivers compared to that of the Willapa Hills.
- Reviewed results and evaluated performance hydrologically. Specifically:
  - Identified unregulated peak total and local flow to estimate the theoretical a maximum reduction in downstream flow and max water surface elevation (WSE) at Doty, WA and Grand Mound, WA for each event.
  - Compared the reservoir simulation results to these theoretical reduction maxima.

- Compared total reservoir drawdowns times.

2.0 Findings

2.1 Theoretical Maximum WSE Reduction by Event

Theoretical maximum WSE elevation reductions represent a bookend on FRE performance and are useful in contextualizing the reservoir operation simulation results in that they might identify opportunities where operational flexibility may result in increased flood management benefits. HDR estimated theoretical maximum WSE reductions at Doty, WA and Grand Mound, WA by comparing the WSE of the total unregulated flow at a location to the WSE resulting from only the downstream local flows at the same location. (Local flows are defined as the incremental runoff in the system below the FRE facility and the location of interest.) WSEs for a given flow were computed using USGS rating information at the two gage locations. Figure 1 through Figure 3 show the corresponding total and local flow hydrographs by event and Table 1 summarizes the theoretical maximum WSE reduction by event and location.

HDR compared these theoretical maximum reductions to the reductions estimated using the 2017 operations plan. As shown in Table 2, the WSE reductions for the December 2007 event were close to the theoretical maximum as the contribution of flood flows above the FRE facility were significant when compared to the contribution of local flows from other sources downstream of the FRE structure. The same is true for the January 2002 event at Doty. However, the larger reductions in WSE for the February 1996 event may be attainable with a more flexible operation that considers different forecast information and time. The same may be true for the February 1996 event at Doty, WA.

Figure 1. Total and Local Flow at Doty, WA (left) and Grand Mound, WA (right): February 1996 Event

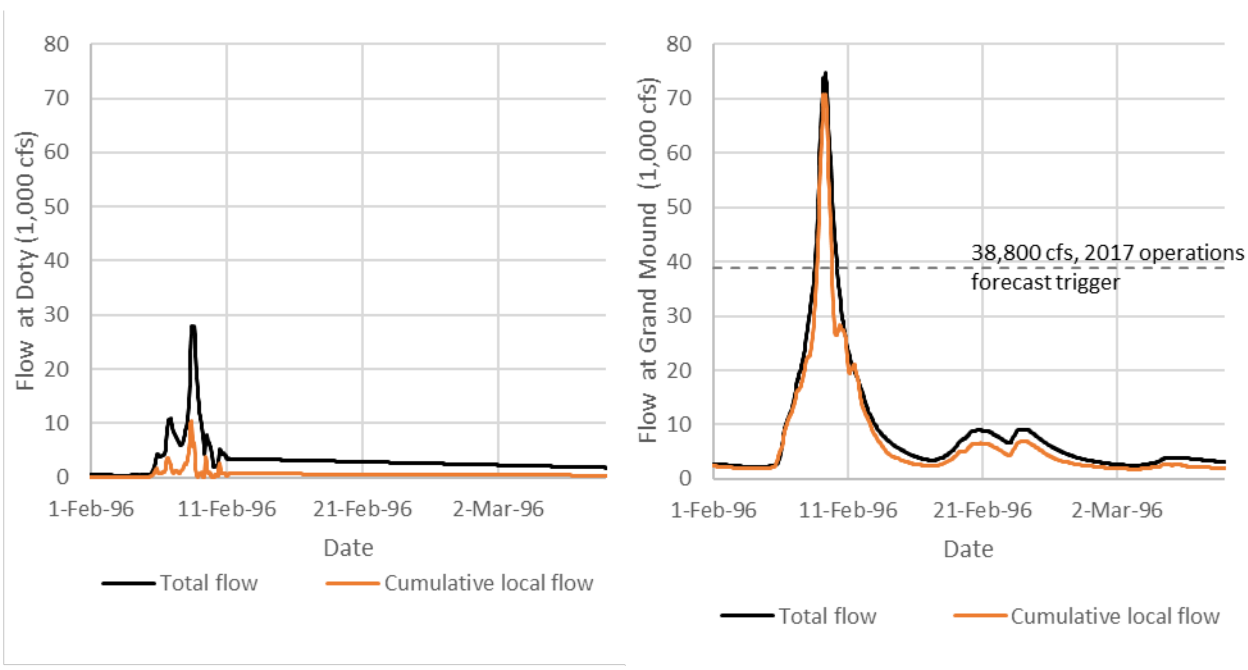


Figure 2. Total and Local Flow at Doty, WA (left) and Grand Mound, WA (right): December 2007 Event

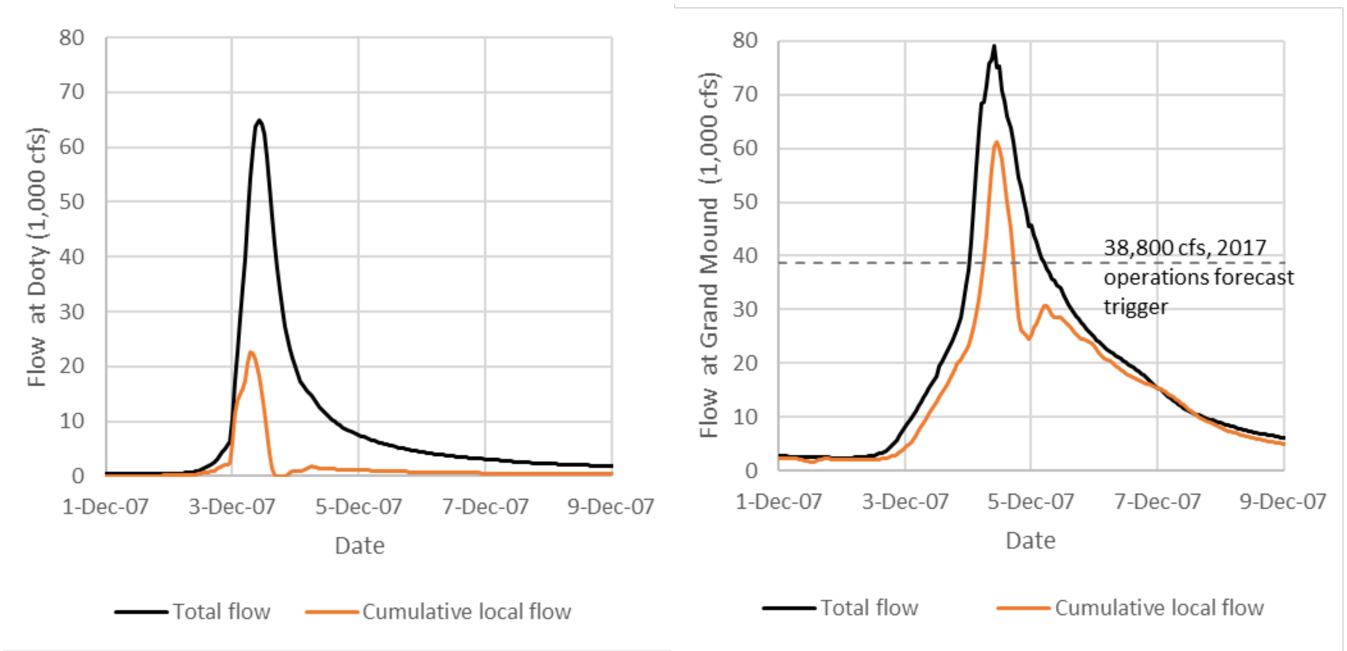


Figure 3. Total and Local Flow at Doty, WA (left) and Grand Mound, WA (right): January 2022 Event

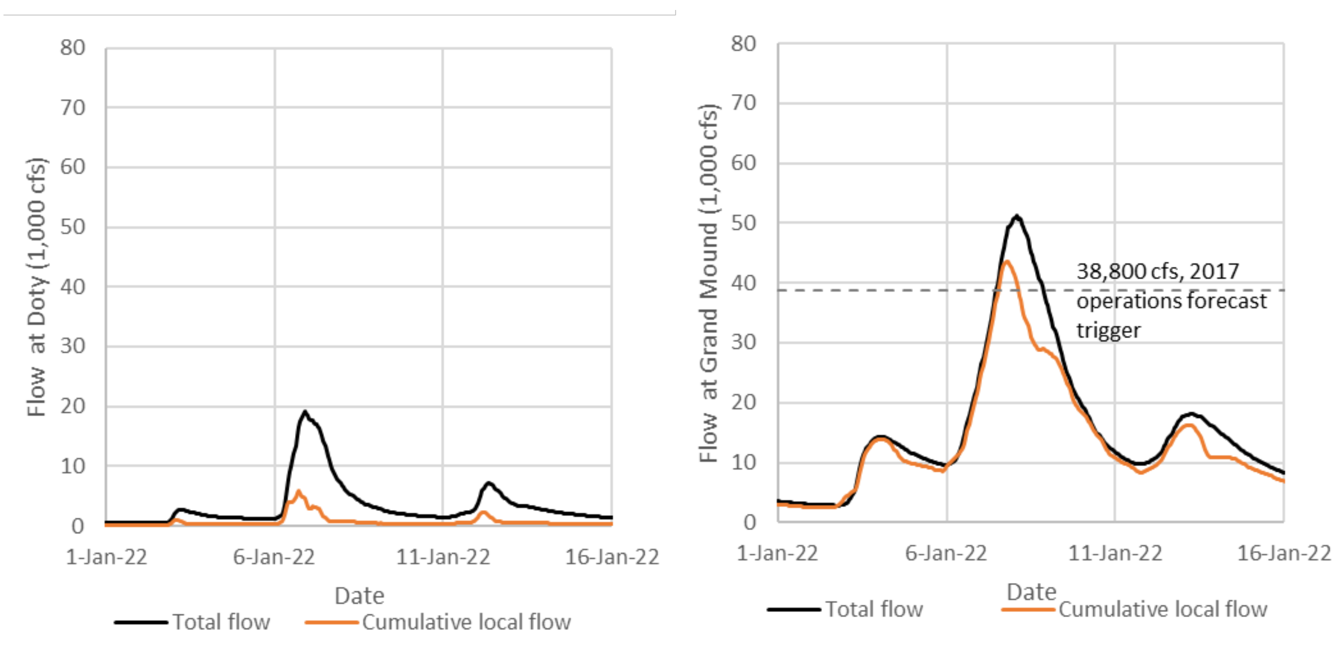


Table 1. Summary of Theoretical Maximum WSE Reductions by Location and Event

Event	Doty, WA						Grand Mound, WA					
	Peak total flow (cfs)	Peak local flow (cfs)	Difference in flow (cfs) [%]	Peak total flow WSE (ft)	Peak local flow WSE (ft)	Difference in WSE (ft)	Peak total flow (cfs)	Peak local flow (cfs)	Difference in flow (cfs) [%]	Peak total flow WSE (ft)	Peak local flow WSE (ft)	Difference in WSE (ft)
February 1996	27,966	10,508	-17,458 [-62%]	324.9	316.9	-8.2	74,800	70,725	-4,075 [-5%]	146.0	146.7	-0 0.3
December 2007	64,882	22,555	-42,327 [-65%]	336.8	322.7	-14.1	79,100	61,267	-17,833 [-23%]	147.2	146.0	-1.2
January 2022	19,071	5,787	-13,284 [-70%]	321.2	313.6	-7.6	51,300	43,536	-7,764 [-15%]	145.2	144.5	-0.7

Table 2. Summary of Theoretical Maximum WSE Reductions by Location and Event

Event	Theoretical maximum WSE reduction		2017 Operations Plan WSE reductions	
	At Doty, WA (ft)	At Grand Mound, WA (ft)	At Doty, WA (ft)	At Grand Mound, WA (ft)
February 1996	-8.2	-0.3	-8.0	-0.3
December 2007	-14.1	-1.2	-14.0	-1.2
January 2022	-7.6	-0.7	-5.0	-0.7

2.2 Sensitivity analysis results

2.2.1 Modified maximum release

HDR examined the differences in FRE performance if, when FRE operations are activated, the maximum permissible release is varied. The proposed 2017 operations plan specifies that maximum release through the FRE is limited to 300 cfs when the forecasted flow at Grand Mound, WA exceeds 38,800 cfs in the next 48 hours. HDR investigated three different maximum release rates:

- Maximum FRE release = 1,000 cfs
- Maximum FRE release = 2,000 cfs
- Maximum FRE release = 3,000 cfs

In general, as maximum permissible release increases the potential for reduction in downstream flows and WSE decreases because the FRE releases tend to be coincident with downstream peak flows. In general, the increase in downstream peak flows were less than 5 percent and increases in downstream maximum WSE at Grand Mound, WA were less than 0.5 feet. Table 3 through Table 5 summarize these findings by event and corresponding results are shown in Figure 4 through Figure 6.

2.2.2 Modified forecast triggers

HDR examined the differences in FRE performance if different forecast triggers were used for FRE operation activation. Specifically, we investigated potential impacts of a larger forecast trigger at Grand Mound, WA and the addition of a forecast trigger condition at Doty, WA. In general, HDR found that larger, or additional forecast triggers resulted in shorter durations of operation, reduced maximum FRE reservoir elevations with similar but slightly increased (by as much as 0.7 ft) WSE at Grand Mound, WA. Table 6 through Table 8 summarize these findings and corresponding results are shown in Figure 7 through Figure 9.

2.2.3 Modified drawdown rates

HDR examined the differences in FRE performance if drawdown rates of +/-20 percent were considered. In general, increasing the drawdown rate by 20 percent results in the reservoir draining approximately 5 days faster, and decreasing the rates by 20 percent results in an approximate 5-day increase in drainage time. Downstream peaks are unaffected. Table 9 through Table 11 summarize these findings and corresponding results are shown in Figure 10 through Figure 12.

Table 3. Summary of Maximum Release Sensitivity Analysis Results: February 1996 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	22,365	27,966	324.9	74,800	147.0	N/A	N/A	N/A
2017 operations plan	610.3	7,394	10,808	316.9	71,035	146.8	-67	-8.0	-0.3
Maximum FRE release = 1,000 cfs	605.2	7,394	11,507	317.3	71,714	146.8	-67	-7.6	-0.2
Maximum FRE release = 2,000 cfs	597.4	7,125	12,507	317.9	72,725	146.8	-68	-7.0	-0.2
Maximum FRE release = 3,000 cfs	589.1	6,852	13,508	318.4	73,726	146.9	-69	-6.5	-0.1

Table 4. Summary of Maximum Release Sensitivity Analysis Results: December 2007 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	50,482	64,882	336.8	79,100	147.2	N/A	N/A	N/A
2017 operations plan	631.1	11,091	22,855	322.8	61,567	146.0	-78	-14.0	-1.2
Maximum FRE release = 1,000 cfs	630.7	10,092	23,553	323.1	62,269	146.1	-80	-13.7	-1.1
Maximum FRE release = 2,000 cfs	630.0	9,043	24,546	323.6	63,204	146.2	-82	-13.2	-1.0
Maximum FRE release = 3,000 cfs	629.3	9,103	25,544	324.0	64,340	146.2	-82	-12.8	-1.0

Table 5. Summary of Maximum Release Sensitivity Analysis Results: January 2022 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	15,085	19,071	321.2	51,300	145.2	N/A	N/A	N/A
2017 operations plan	594.8	8,158	9,655	316.2	43,840	144.5	-46	-5.0	-0.7
Maximum FRE release = 1,000 cfs	587.8	7,878	9,378	316.0	44,535	144.6	-48	-5.2	-0.6
Maximum FRE release = 2,000 cfs	578.8	7,325	8,821	315.7	45,896	144.7	-51	-5.5	-0.5
Maximum FRE release = 3,000 cfs	569.8	7,325	8,823	315.7	46,832	144.8	-51	-5.5	-0.4

Figure 4. Maximum Release Sensitivity Analysis Results: February 1996 Event

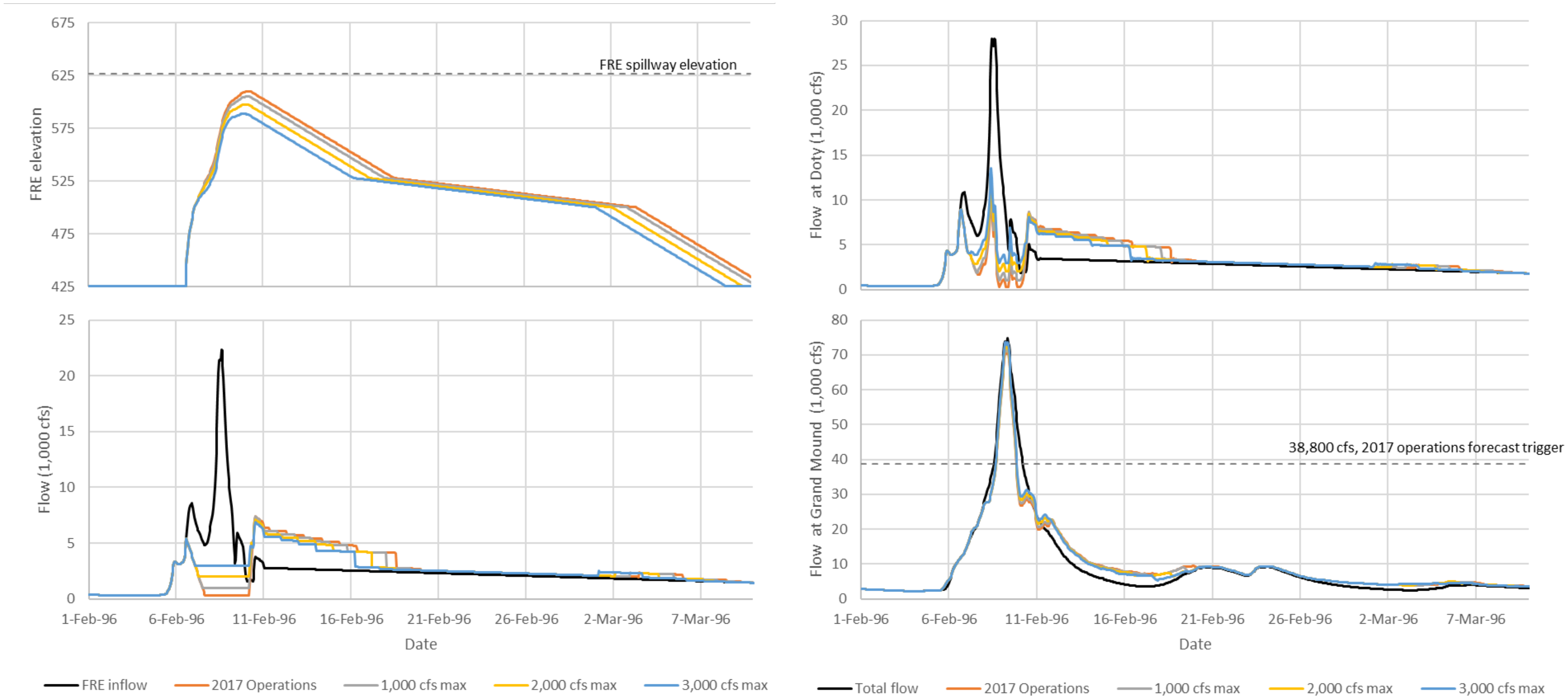


Figure 5. Maximum Release Sensitivity Analysis Results: December 2007 Event

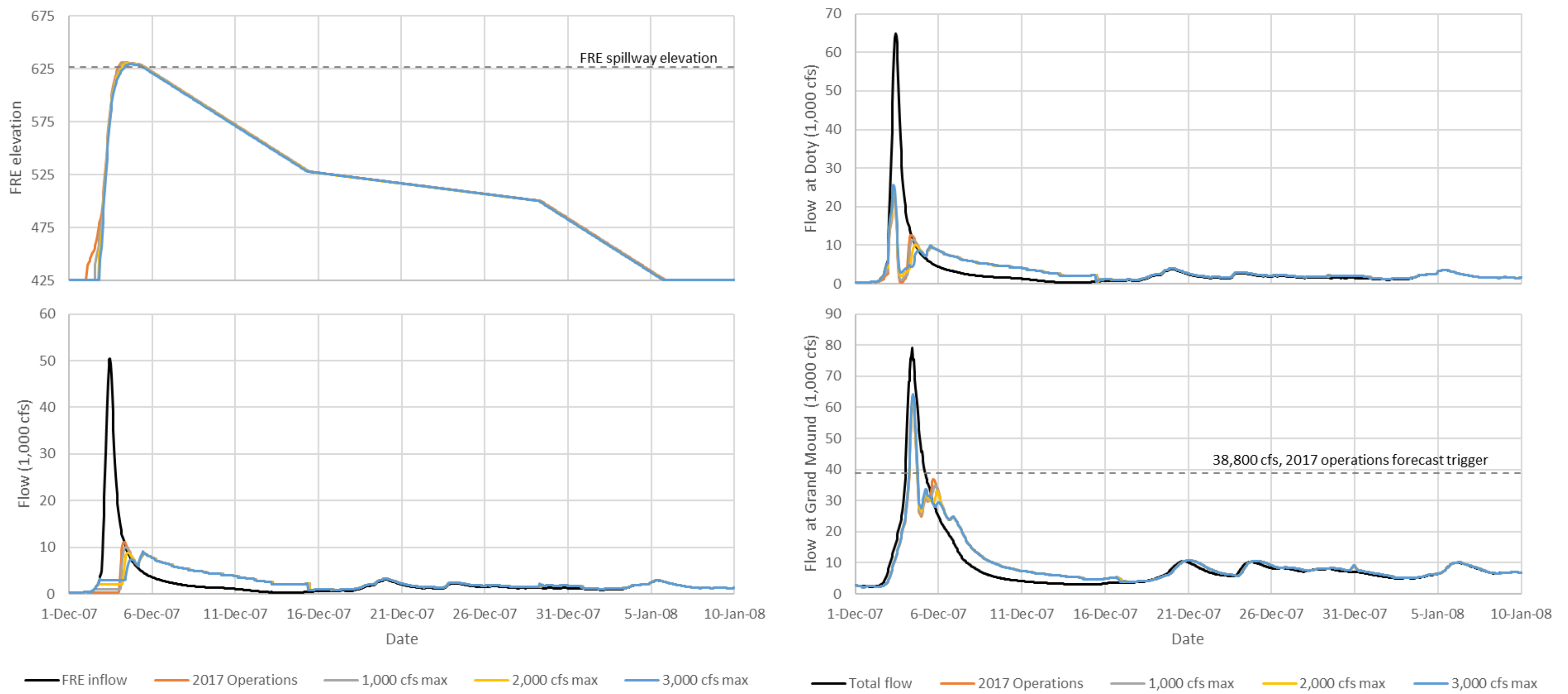


Figure 6. Maximum Release Sensitivity Analysis Results: January 2022 Event

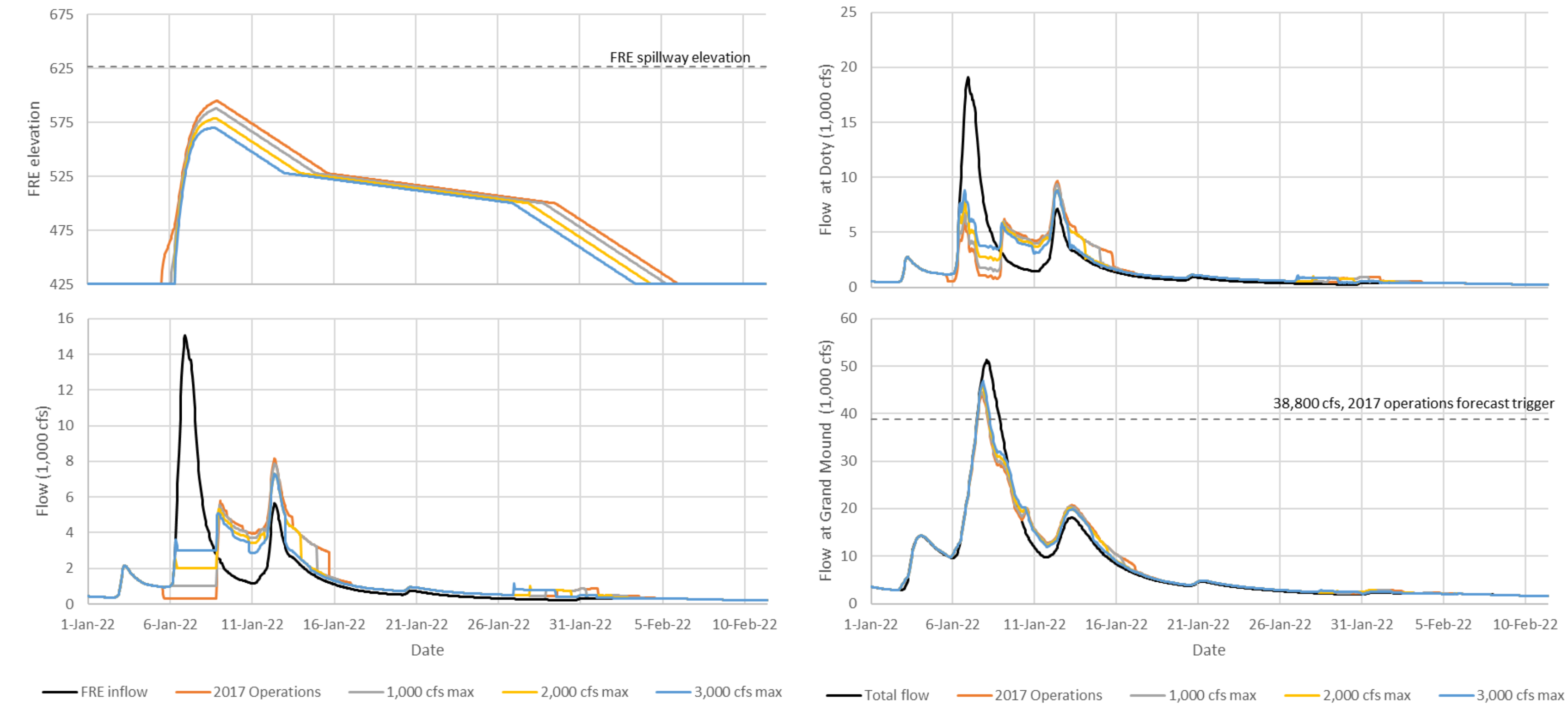


Table 6. Summary of Forecast Trigger Sensitivity Analysis Results: February 1996 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	22,365	27,966	324.9	74,800	147.0	N/A	N/A	N/A
2017 operations plan	610.3	7,394	10,808	316.9	71,035	146.8	-67	-8.0	-0.3
52,500 cfs Grand Mound trigger	592.5	8,443	11,428	317.26	74,304	146.92	-62	-7.67	-0.04
38,800 cfs Grand Mound & 25,200 Doty trigger	589.6	11,856	12,249	317.72	71,035	146.71	-47	-7.21	-0.25
52,500 cfs Grand Mound & 25,200 Doty trigger	570.5	11,444	12,138	317.66	74,304	146.92	-49	-7.27	-0.04

Table 7. Summary of Forecast Trigger Sensitivity Analysis Results: December 2007 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	50,482	64,882	336.8	79,100	147.2	N/A	N/A	N/A
2017 operations plan	631.1	11,091	22,855	322.8	61,567	146.0	-78	-14.0	-1.2
52,500 cfs Grand Mound trigger	631.1	11,084	22,855	322.8	61,567	146.0	-78	-14.0	-1.2
38,800 cfs Grand Mound & 25,200 Doty trigger	628.4	14,733	22,855	322.8	61,567	146.0	-71	-14.0	-1.2
52,500 cfs Grand Mound & 25,200 Doty trigger	628.40	14,726	22,855	322.8	61,567	146.0	-71	-14.0	-1.2

Table 8. Summary of Forecast Trigger Sensitivity Analysis Results: January 2022 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	15,085	19,071	321.17	51,300	145.2	N/A	N/A	N/A
2017 operations plan	594.8	8,158	9,655	316.2	43,840	144.5	-46	-5.0	-0.7
52,500 cfs Grand Mound trigger	448.9	14,925	18,899	321.1	51,040	145.2	-1	-0.2	-0.0
38,800 cfs Grand Mound & 25,200 Doty trigger	448.9	14,925	18,899	321.1	51,040	145.2	-1	-0.2	-0.0
52,500 cfs Grand Mound & 25,200 Doty trigger	448.9	14,925	18,899	321.1	51,040	145.2	-1	-0.2	-0.0

Figure 7. Forecast Trigger Analysis Results: February 1996 Event

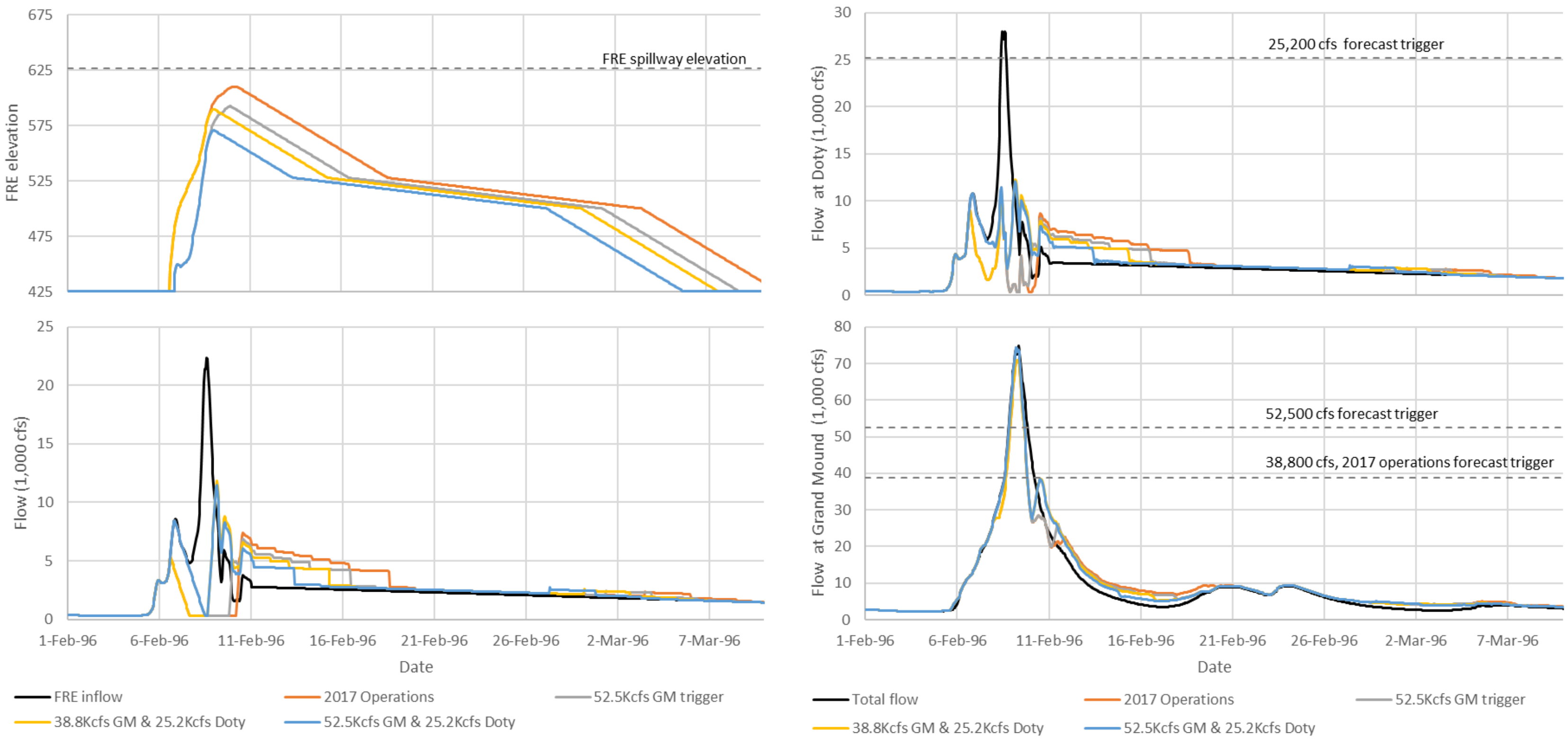


Figure 8. Forecast Trigger Sensitivity Analysis Results: December 2007 Event

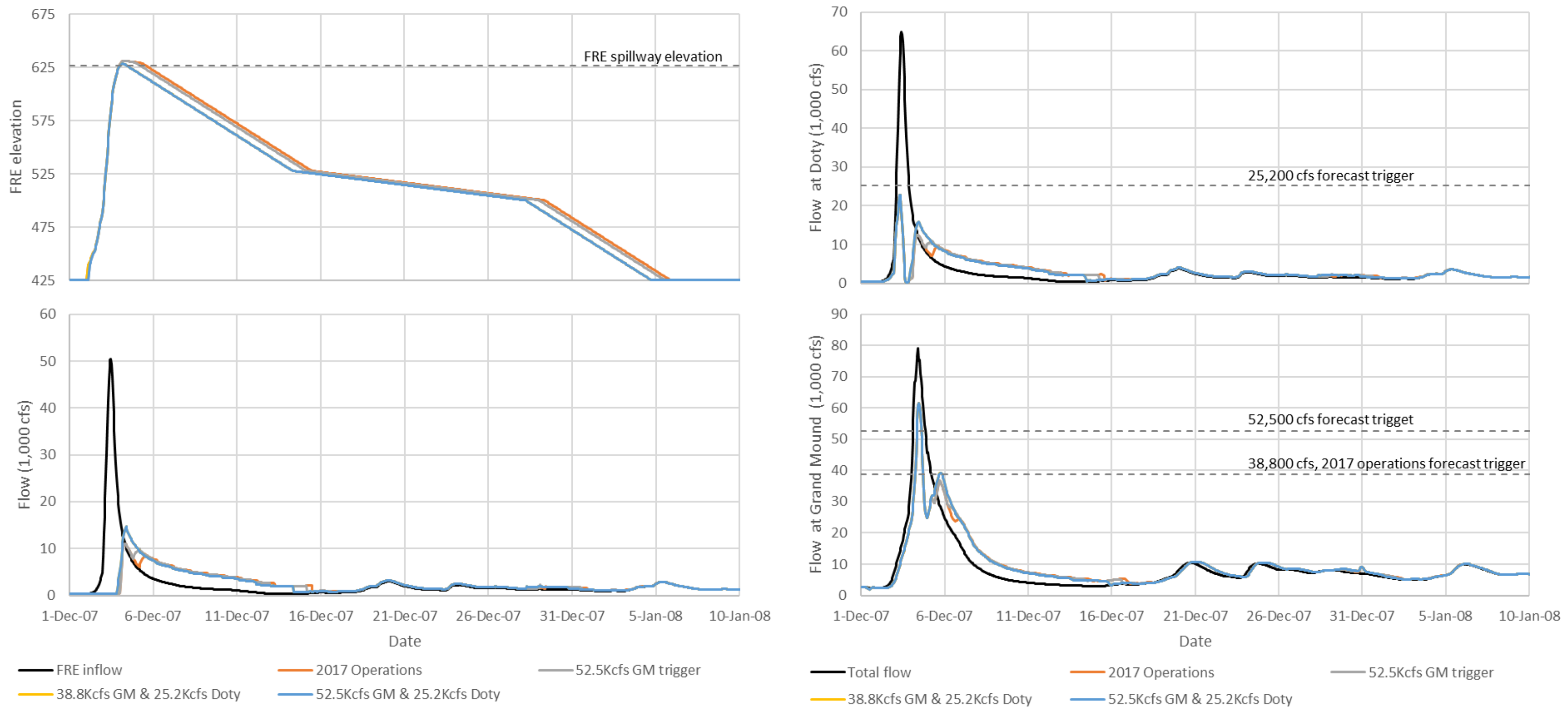


Figure 9. Forecast Trigger Sensitivity Analysis Results: January 2022 Event

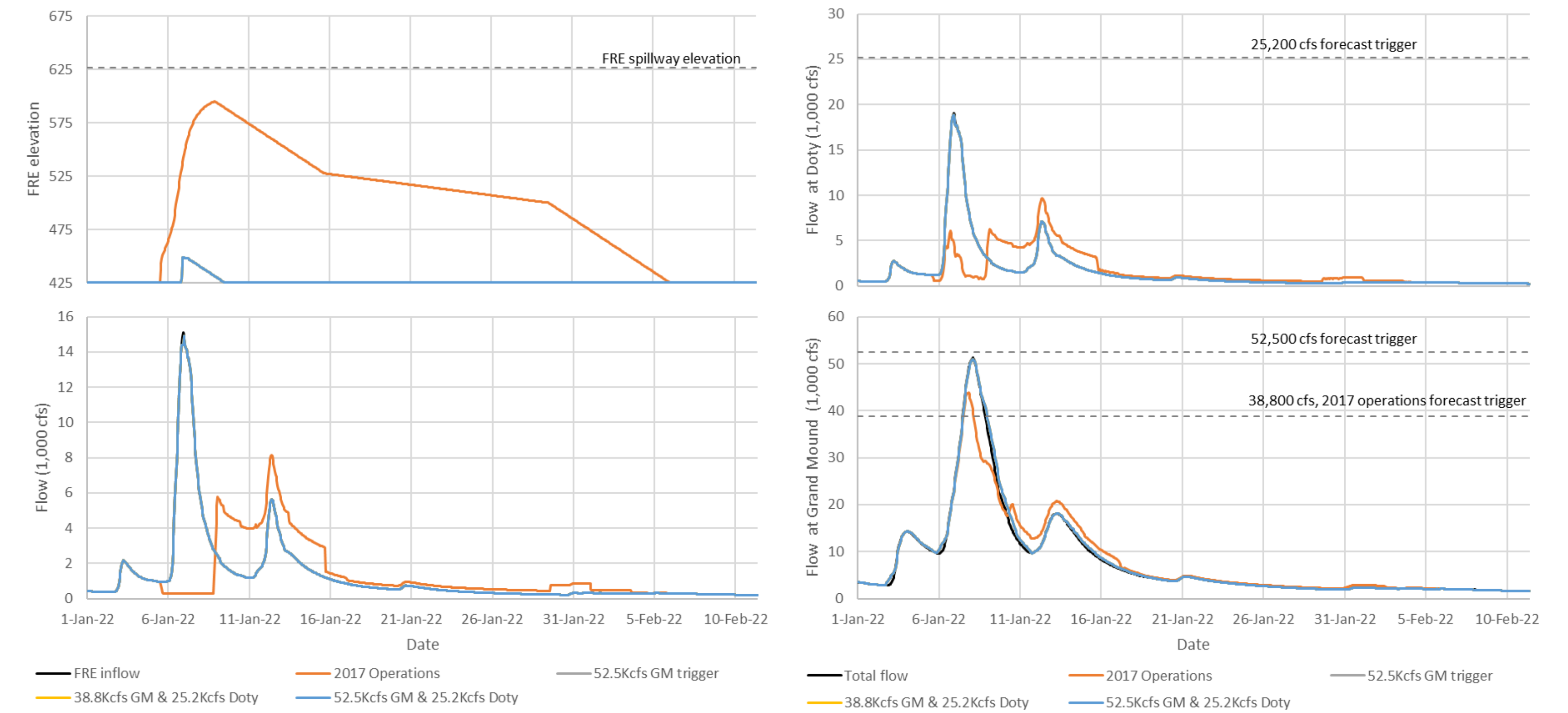


Table 9. Summary of Drawdown Rate Sensitivity Analysis Results: February 1996 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	22,365	27,966	324.9	74,800	147.0	N/A	N/A	N/A
2017 operations plan	610.3	7,394	10,808	316.9	71,035	146.8	-67	-8.0	-0.3
Drawdown rate +20%	610.3	6,676	10,808	316.90	71,035	146.71	-70	-8.03	-0.25
Drawdown rate -20%	610.3	8,113	10,808	316.90	71,035	146.71	-64	-8.03	-0.25

Table 10. Summary of Drawdown Rate Sensitivity Analysis Results: December 2007 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	50,482	64,882	336.8	79,100	147.2	N/A	N/A	N/A
2017 operations plan	631.1	11,091	22,855	322.8	61,567	146.0	-78	-14.0	-1.2
Drawdown rate +20%	631.11	11,091	22,855	322.8	61,567	146.0	-78	-14.0	-1.2
Drawdown rate -20%	631.11	11,091	22,855	322.8	61,567	146.0	-78	-14.0	-1.2

Table 11. Summary of Drawdown Rate Sensitivity Analysis Results: January 2022 Event

Scenario	Maximum by Locations						Difference from Unregulated		
	FRE		Doty, WA		Grand Mound, WA				
	Reservoir Elevation (ft)	Reservoir Release (cfs)	Flow (cfs)	WSE (ft)	Flow (cfs)	WSE (ft)	FRE Flow (%)	Doty WSE (ft)	Grand Mound WSE (ft)
Unregulated conditions	N/A	15,085	19,071	321.2	51,300	145.2	N/A	N/A	N/A
2017 operations plan	594.8	8,158	9,655	316.0	43,840	144.5	-46	-5.0	-0.7
Drawdown rate +20%	594.84	7,652	9,148	315.9	43,840	144.5	-49	-5.3	-0.7
Drawdown rate -20%	594.8	8,327	9,825	316.3	43,840	144.5	-45	-4.9	-0.7

Figure 10. Drawdown Rate Sensitivity Analysis Results: February 1996 Event

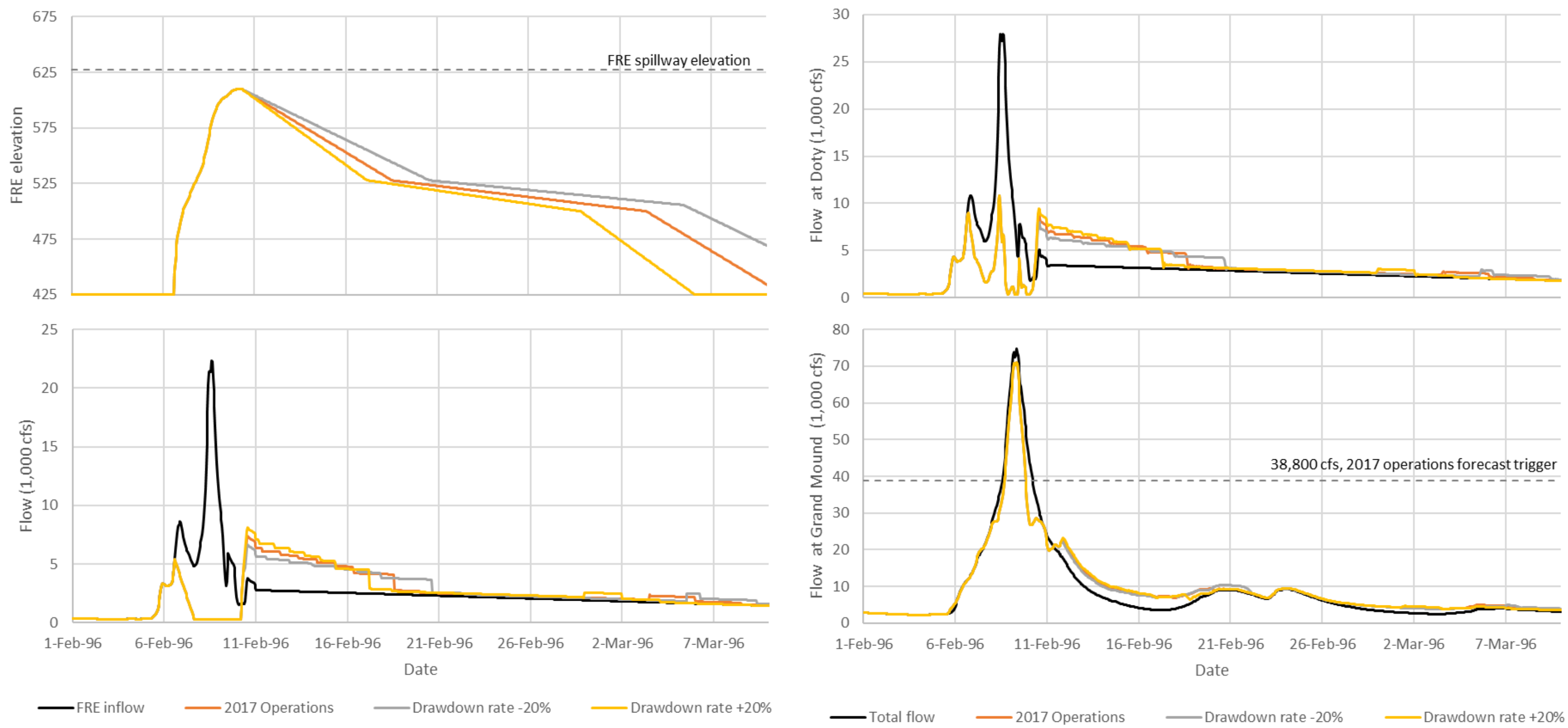


Figure 11. Drawdown Rate Sensitivity Analysis Results: December 2007 Event

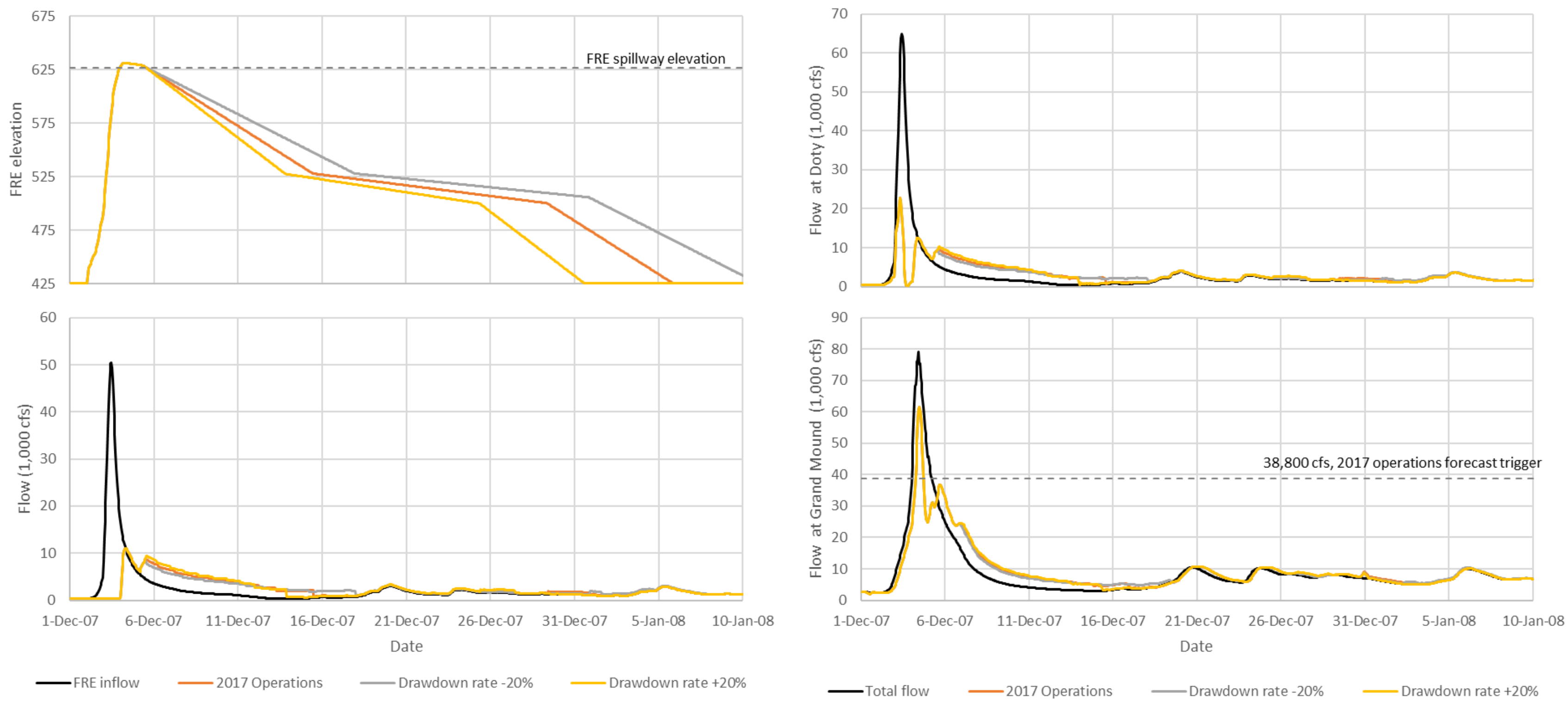
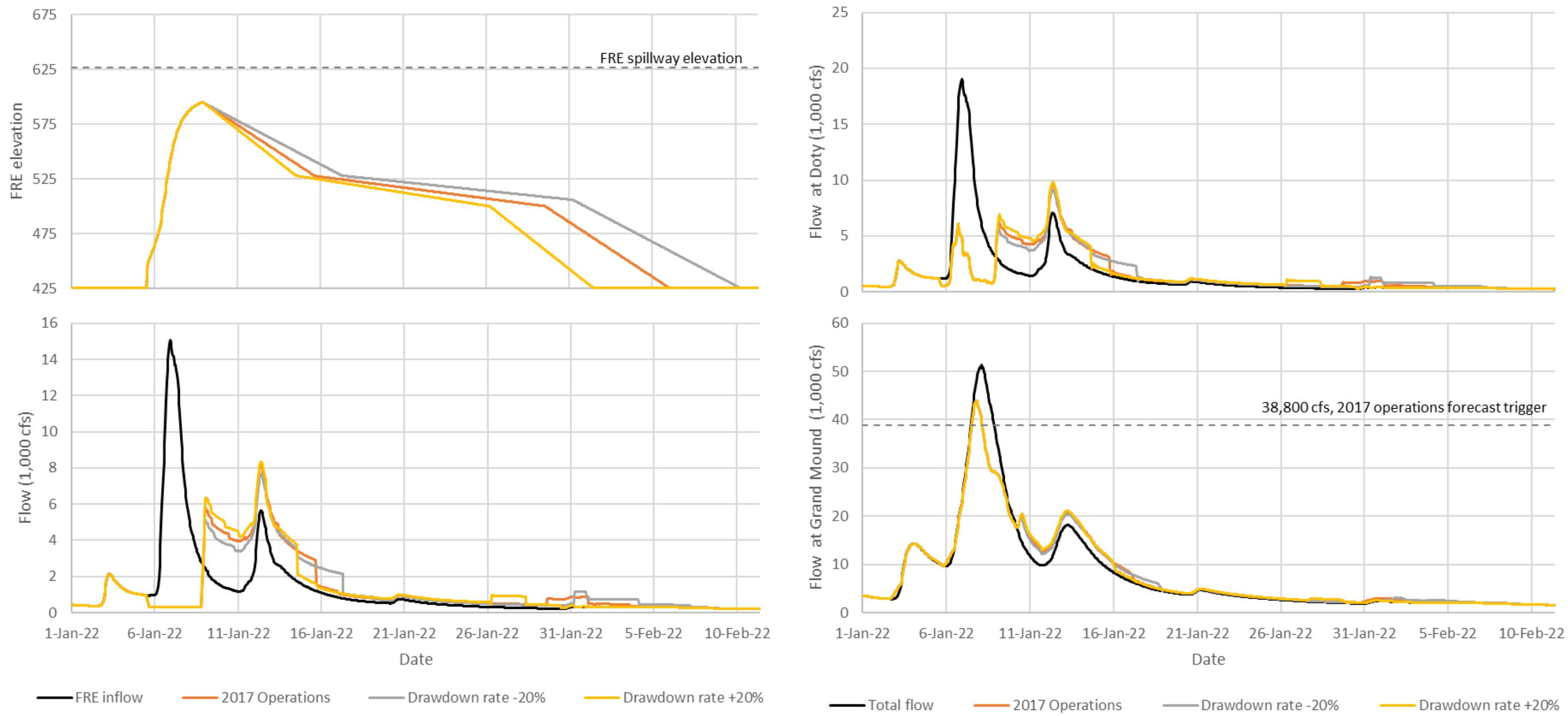


Figure 12. Drawdown Rate Sensitivity Analysis Results: January 2022 Event



3.0 Conclusions

Potential opportunities exist for better optimization of the reservoir operational rules in terms of maximum FRE releases, forecast triggers, and drawdown operations to achieve FRE performance objectives and water management goals given the sensitivity analysis results. Explicitly defining the goals, objectives, constraints, and performance metrics of system should be the next step in studying the flexibility and potential optimization of FRE operations.

4.0 References

Anchor QEA, LLC (Anchor QEA)

2017 Chehalis Basin Strategy, Reservoir Operations Plan for Flood Retention Facilities. June 2017.

WEST Consultants, Inc.

2014 Chehalis Basin Ecosystem Restoration General Investigation Study Baseline Hydrology and Hydraulics Modeling. Prepare for the U.S. Army Corps of Engineers Seattle District. January 2014.

5.0 Acronyms/Abbreviations

Anchor QEA	Anchor QEA, LLC
cfs	cubic feet per second
District	Chehalis Basin Flood Control Zone District
HDR	HDR Engineering, Inc.
FRE	Flood Retention Expandable
RPDR	Revised Project Description Report
USGS	U.S. Geological Survey
WA	Washington
WSE	water surface elevation