Potential erosion of an unlined rock spillway at New Melones Dam, CA

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Extended Abstract

The New Melones Reservoir is a 2,400,000 acre-foot (ac-ft) reservoir located on the Stanislaus River approximately 45 miles (mi) northeast of Modesto, California. The main dam is a zoned earthfill and rockfill embankment with a structural height of 637 feet (ft) and a hydraulic height of 578 ft. The emergency spillway is located approximately 1.5 mi north of the right abutment of the dam. The spillway consists of an unlined 5,945 ft long open channel blasted into rock. The channel bottom is 200 ft wide with stepped, variable-sloped side walls and is covered with a thin layer of excavated debris and sediment. Discharge from the spillway exits onto a soil-covered hillslope on the left valley wall of a small stream, Bean Gulch, approximately one mile upstream from its confluence with the Stanislaus River (Feinberg, 2009).

The spillway poses a Low Probability – High Consequence erosion risk, as asbestos-laden sediment eroded from the spillway could impact the Stanislaus River and Tulloch Reservoir, located 4.2 mi downstream. The asbestos is sourced from highly erodible serpentinite rock. Even though New Melones Dam has never utilized the spillway, overland flow from precipitation and groundwater infiltration has eroded gullies into the serpentinite at the downstream end of the spillway, demonstrating the high susceptibility to erosion in a spillway flow event.

This type of study requires a model for an unlined spillway with variable lithology and the ability to model headward knick propagation. After extensive literature review, existing models were not sufficient for our purposes (Bollaert, 2004; Wahl, 2016). We therefore have developed and applied a three-tiered approach to estimating erosion risk in the spillway and subsequent sediment deposition downstream. Our three-tiered approach includes the application of: (1) the Sedimentation and River Hydraulics two-dimensional (SRH-2D) sediment transport model (Lai, 2010); (2) a two-dimensional (2D) probabilistic erosion model using the Annandale Erodibility Index Method (Annandale, 1995); and (3) the Hurst one-dimensional (1D) Erosion model (H1DE), a 1D bedrock incision model (Hurst et al., 2021).

SRH-2D was used to test the assumption that floods would completely remove the sediment cover on the spillway and expose bedrock, and to calculate any potential impacts on Tulloch Reservoir. The Annandale Erodibility Index Method was used to identify zones of potential bedrock erosion on the spillway for a range of flow events by applying geologic field data. The H1DE model was used to constrain vertical incision and potential volume of erosion for a range of flow events by running 50 iterations of randomly generated fracture networks along the right and left spillway. We tested two different initial reservoir water surface elevations for New Melones Lake of 1,049 (NM1049) and 1,088 (NM1088) feet (ft) and a range of flood recurrence intervals that water conveyance calculated.

First, we used SRH-2D to simulate flow and sediment transport from the spillway, through the Stanislaus River, and down to Tulloch Reservoir. Flows as low as 50 cubic feet per second (cfs) are capable of mobilizing silt and sands on the spillway (Table 1). Monitoring point (MP) locations are shown in Figure 1. By 3,000 cfs, sands, fine pea gravel, and pebbles are also mobilized on the spillway (Table 1). For the hypothetical hydrographs we simulated, we found that erosion is dominant in both the spillway and in Bean Gulch. The minimum volume of spillway erosion is 77,490 yd^3 for the 20 thousand year (kyr) recurrence interval (RI) flow (NM1049) using a starting spillway sediment volume of 210,000 yd^3. The maximum amount of erosion on the spillway is 207,703 yd^3 for the 1 million year (Myr) RI flow (NM1088).

Tulloch Reservoir was not impacted by significant deposition associated with the modeled flow events. In contrast, the upstream portions of the Stanislaus River were heavily impacted. The minimum amount of deposition in the Stanislaus River was 84,769 yd^3 for the 20 kyr RI flow (TM1049 with a Tulloch Reservoir elevation of 515 ft); this deposit extended approximately 2,120 ft downstream from the junction of Bean Gulch and the Stanislaus River. The maximum amount of deposition in the Stanislaus River was 296,583 yd^3 for the 1 Myr RI flow (TM1088 with a Tulloch Reservoir elevation of 500 ft); this deposit extended approximately 8,750 ft downstream from the junction of Bean Gulch and the Stanislaus River. If the deposit remains in the upper Stanislaus River, it could be subsequently transported farther downstream. Additional runs using flows from the outlet works at 8,000 cfs or less should likely be conducted to better understand how this deposit will be transported with time. Given enough time, finer grains within the deposit will likely reach Tulloch Reservoir. If deposition within Tulloch needs to be avoided, in-river dredging would likely be the only candidate to remove the large sediment deposits in the upper Stanislaus River.

Due to the uncertainty in the sediment cover thickness and distribution and the fact that the majority of the spillway sediment was removed for many of the modeled hydrographs, we chose to model the potential of bedrock erosion assuming no protective sediment cover for both the 2D Annandale model and the H1DE model.

We performed a 2D probabilistic model (Annandale Erodibility Index Method) to identify spatial zones of potential bedrock erosion. Minor erosion can be expected in the gully that connects the spillway to Bean Gulch for flows as low as 50 cfs (NM1049, 20,000 yr RI). However, localized erosion is currently evident in this gully in the absence of spillway flow, so this is not surprising. For higher flows, more erosion is expected within the gully and within Bean Gulch along the contact between the serpentinite and the meta-volcanics (Figure 2). The spillway is not expected to be impacted based on the outcome of the 2D probabilistic model.

We finally performed the H1DE model to quantify potential bedrock incision and volume of eroded material due to block plucking. We ran the model for separate transects along the left and right spillway, which had different block fracture properties. The result is that for lower RI floods and Tulloch Reservoir elevation of 505 ft, the left spillway erodes a similar volume of material as the right spillway. However, for NM1088 100 kyr RI and greater, the right spillway has the potential for more erosion. The worst case scenario is for the NM1088 1 Myr RI flood on the right spillway. In this scenario, the average eroded volume could be 645,000 ft^3 (Figure 3). This erosion can progress all the way upstream to MP10 within the spillway. However, the majority of the erosion in this scenario is concentrated within the gully at MP 5 and only 0.15 ft of incision occurs at MP10, which is not enough for concern of dam breach (Figure 4).

Erosion on the New Melones spillway does not pose a dam safety risk. For the 1Myr RI flow (NM1088) erosion of sediment within the spillway and Bean Gulch could contribute up to 296,583 yd^3 of sediment, assuming an initial spillway sediment cover of 210,000 yd^3. Bedrock erosion within the spillway and gully could contribute an additional 23,889 yd^3 (645,000 ft^3), an order of magnitude less sediment. The SRH-2D model results show that this sediment is largely deposited at the junction between the Stanislaus River and Bean Gulch. Tulloch Reservoir is not likely to be impacted by sediment transport during the initial floods, but later flows could redistribute sediment and transport it to Tulloch Reservoir.

Table 1. Starting bed elevations, starting sediment thickness, and erosion or deposition results at model conclusion, NM Reservoir WSE of 1088 ft.

MP	RI	Bed start (ft)	Sed thick (ft)	Tulloch 500 ft Bed Change (ft)	Tulloch 505 ft Bed Change (ft)	Tulloch 510 ft Bed change (ft)	Tulloch 515 ft Bed end (ft)	Erosion or Deposition >0.5 ft
1	100	397.6	15	0.03	0.02	0.01	0.01	No
1	500	397.6	15	0.03	0.02	0.01	0.01	No
1	5000	397.6	15	0.06	0.03	0.01	0.01	No
1	20000	397.6	15	0.09	0.06	0.03	0.02	No
1	100000	397.6	15	0.11	0.08	0.06	0.04	No
1	1000000	397.6	15	0.13	0.10	0.08	0.06	No
2	100	514.5	1	-0.30	-0.33	0.12	2.40	No/Dep
2	500	514.5	1	-0.07	-0.31	0.08	2.00	No/Dep
2	5000	514.5	1	0.53	0.19	0.62	1.29	No/Dep
2	20000	514.5	1	1.89	2.02	2.51	2.32	Deposition
2	100000	514.5	1	0.34	0.86	0.82	0.76	No/Dep
2	1000000	514.5	1	-0.48	-0.43	-0.26	-0.58	No/Ero
3	100	982.3	5.4	-5.17	-4.95	-5.17	-4.93	Erosion
3	500	982.3	5.4	-4.88	-5.37	-5.38	-5.37	Erosion
3	5000	982.3	5.4	-5.45	-5.45	-5.45	-5.45	Erosion
3	20000	982.3	5.4	-4.77	-4.77	-4.78	-4.77	Erosion
3	100000	982.3	5.4	-5.44	-5.44	-5.44	-5.44	Erosion
3	1000000	982.3	5.4	-5.47	-5.47	-5.47	-5.47	Erosion
4	100	888.7	1	8.51	6.31	8.64	10.11	Deposition
4	500	888.7	1	9.02	6.60	9.10	9.47	Deposition
4	5000	888.7	1	12.14	11.42	11.41	12.47	Deposition
4	20000	888.7	1	12.10	12.22	11.99	13.52	Deposition
4	100000	888.7	1	13.86	12.60	12.83	13.88	Deposition

MP	RI	Bed start (ft)	Sed thick (ft)	Tulloch 500 ft Bed Change (ft)	Tulloch 505 ft Bed Change (ft)	Tulloch 510 ft Bed change (ft)	Tulloch 515 ft Bed end (ft)	Erosion or Deposition >0.5 ft
4	1000000	888.7	1	11.14	13.28	14.44	14.19	Deposition
5	100	932.3	4	-1.74	-1.75	-1.70	-1.75	Erosion
5	500	932.3	4	-3.27	-3.27	-3.49	-3.48	Erosion
5	5000	932.3	4	-4.01	-3.97	-3.98	-4.01	Erosion
5	20000	932.3	4	-3.99	-3.99	-4.01	-3.97	Erosion
5	100000	932.3	4	-3.97	-3.97	-3.97	-3.97	Erosion
5	1000000	932.3	4	-3.96	-3.96	-3.97	-3.96	Erosion
6	100	489.8	8	14.82	16.04	17.93	20.80	Deposition
6	500	489.8	8	15.24	16.64	18.04	21.14	Deposition
6	5000	489.8	8	17.04	16.73	17.77	19.97	Deposition
6	20000	489.8	8	18.28	17.81	18.00	20.67	Deposition
6	100000	489.8	8	18.09	17.93	17.75	21.57	Deposition
6	1000000	489.8	8	17.50	16.21	17.55	18.71	Deposition
7	100	485.9	8	1.74	1.10	0.75	0.43	Deposition
7	500	485.9	8	3.02	1.90	1.22	0.77	Deposition
7	5000	485.9	8	3.72	4.09	2.59	1.54	Deposition
7	20000	485.9	8	4.70	4.81	3.77	2.06	Deposition
7	100000	485.9	8	5.80	5.72	4.70	3.25	Deposition
7	1000000	485.9	8	5.66	7.10	6.60	5.02	Deposition
8	100	459.0	8	0.01	0.00	0.00	0.00	No
8	500	459.0	8	0.04	0.01	0.01	0.00	No
8	5000	459.0	8	0.08	0.06	0.04	0.03	No
8	20000	459.0	8	0.09	0.08	0.06	0.04	No
8	100000	459.0	8	0.11	0.08	0.07	0.06	No
8	1000000	459.0	8	0.13	0.10	0.08	0.07	No
9	100	1072.2	5.4	-4.88	-4.88	-4.88	-4.88	Erosion
9	500	1072.2	5.4	-4.96	-4.96	-4.96	-4.96	Erosion
9	5000	1072.2	5.4	-5.18	-5.18	-5.18	-5.18	Erosion
9	20000	1072.2	5.4	-5.21	-5.21	-5.21	-5.21	Erosion
9	100000	1072.2	5.4	-5.02	-5.02	-5.02	-5.02	Erosion
9	1000000	1072.2	5.4	-5.10	-5.10	-5.10	-5.10	Erosion
10	100	1021.8	5.4	-4.83	-4.83	-4.83	-4.83	Erosion
10	500	1021.8	5.4	-5.23	-5.22	-5.23	-5.23	Erosion
10	5000	1021.8	5.4	-5.26	-5.27	-5.26	-5.27	Erosion
10	20000	1021.8	5.4	-5.25	-5.25	-5.25	-5.25	Erosion
10	100000	1021.8	5.4	-5.31	-5.31	-5.31	-5.31	Erosion

MP	RI	Bed start (ft)	Sed thick (ft)	Tulloch 500 ft Bed Change (ft)	Tulloch 505 ft Bed Change (ft)	Tulloch 510 ft Bed change (ft)	Tulloch 515 ft Bed end (ft)	Erosion or Deposition >0.5 ft
10	1000000	1021.8	5.4	-5.25	-5.25	-5.25	-5.25	Erosion

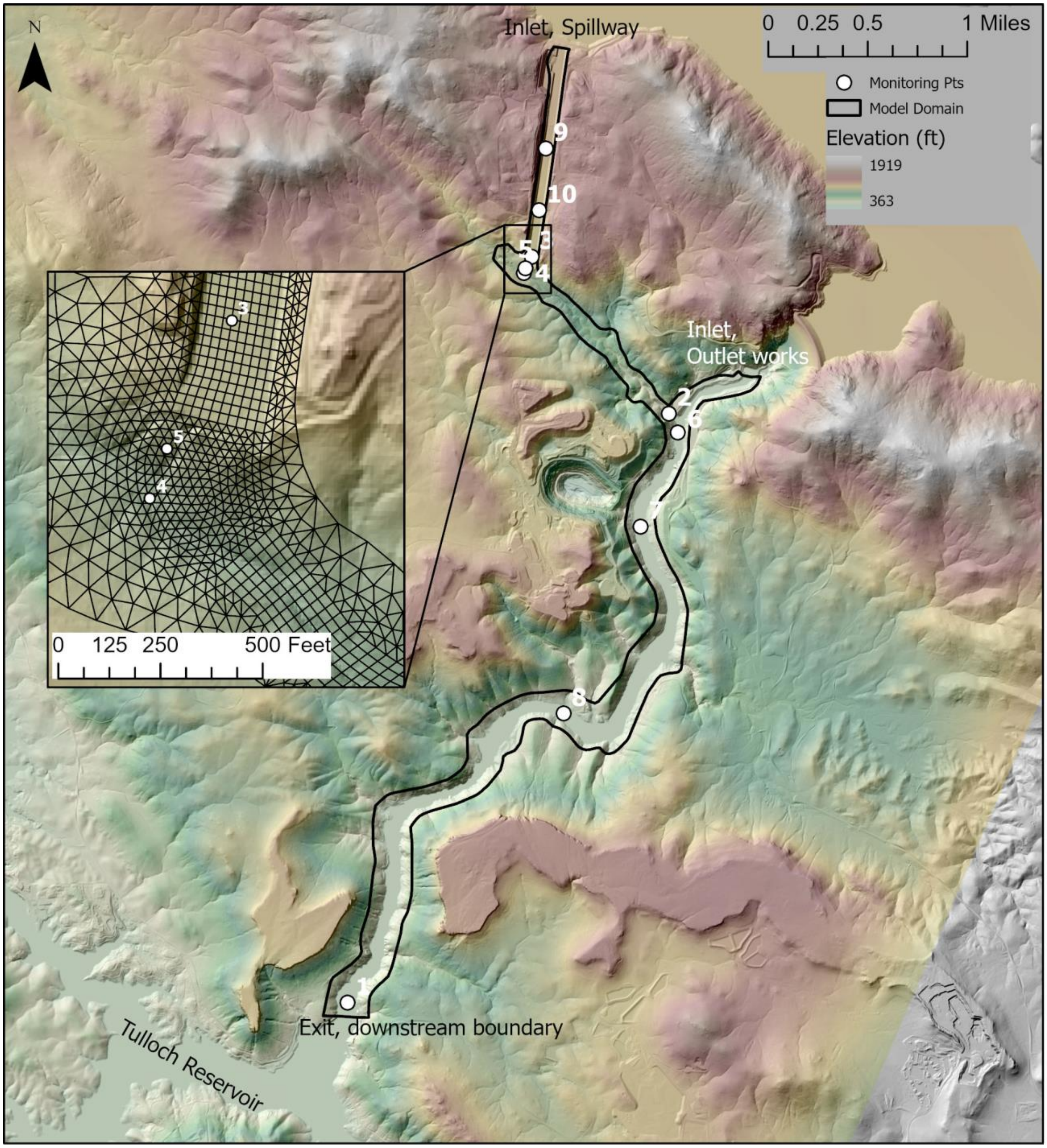

Figure 1. SRH-2D model domain, showing model inlets (upstream boundaries) and model exit (downstream boundary). The inset figure shows the model mesh detail at the junction between the spillway and Bean Gulch. Monitoring points (MPs), which contain detailed model output, are also shown. Flow is from inlet to exit, generally north to south.

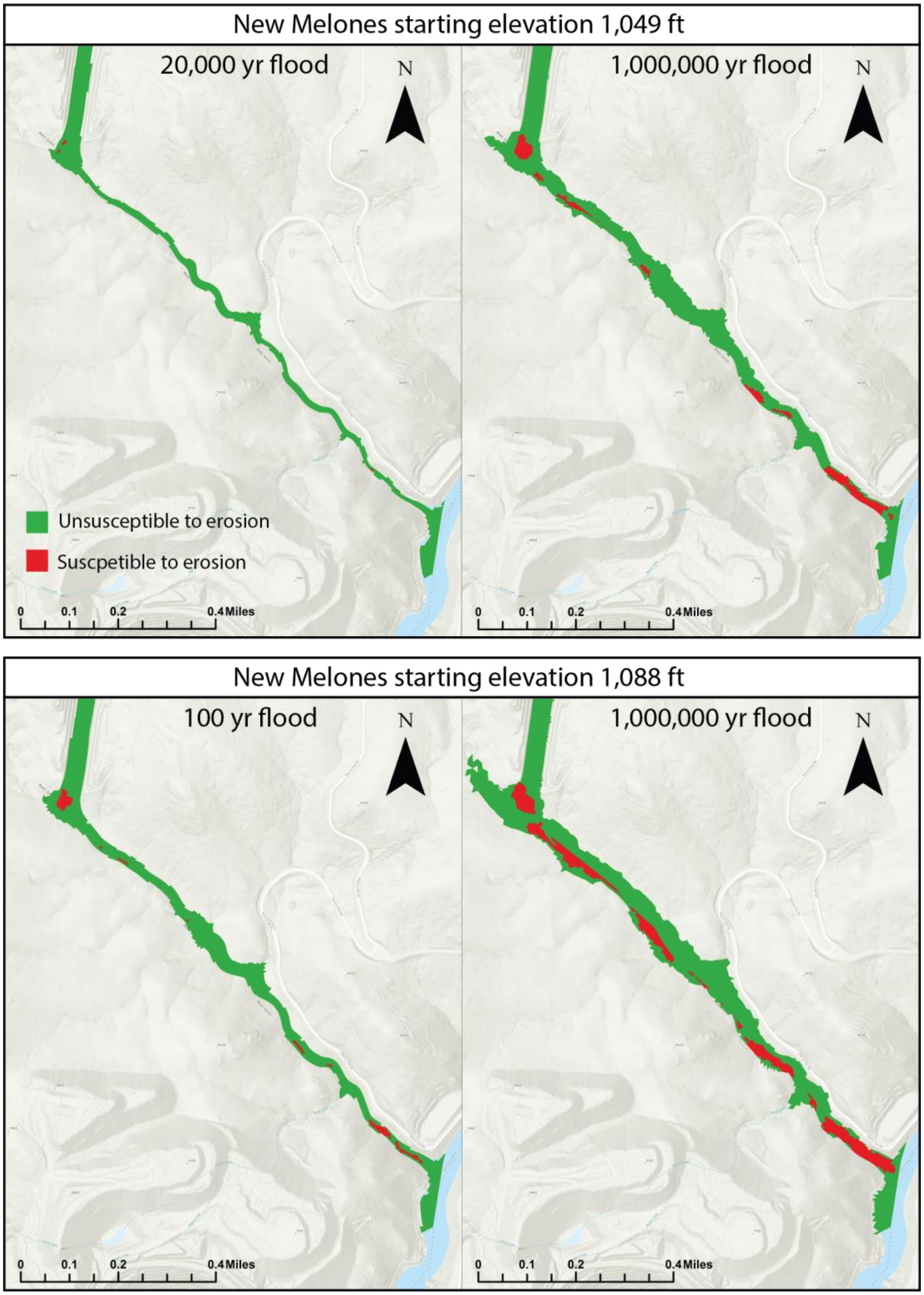

Figure 2. Results from the Annandale erodibility assessment for a downstream Tulloch Reservoir elevation of 505 ft show that erosion is limited to the downstream end of the spillway into Bean Gulch for all flows that we tested. Here we plot the lowest and highest flow recurrence intervals for a starting reservoir elevation at New Melones of 1,049 ft (top) and 1,088 ft (bottom). The results are zoomed into the downstream end of the spillway and Bean Gulch. Everything above the mapped portion is green. Red areas are susceptible to erosion for that flow event, and green areas are unlikely to erode.

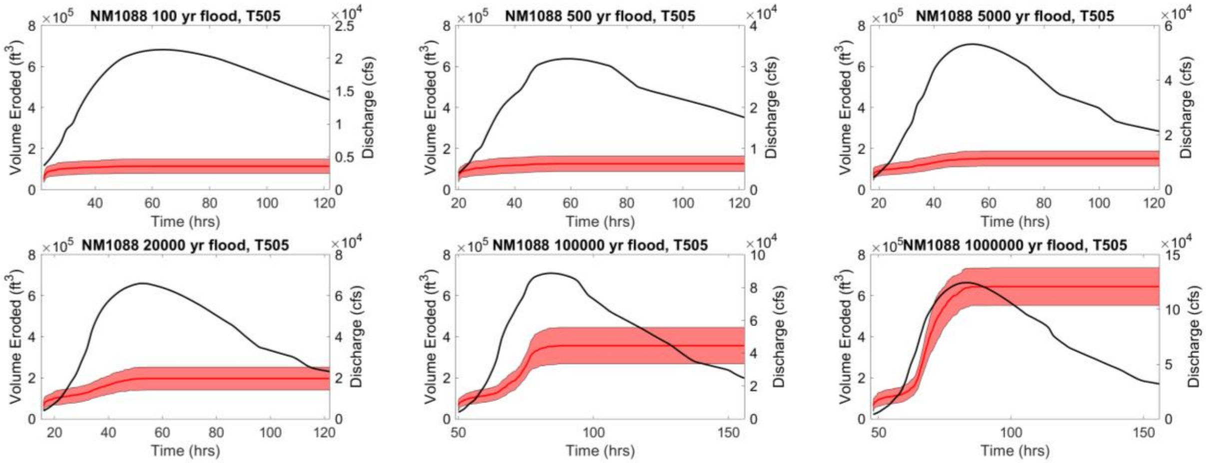

Figure 3. Magnitude of erosion for the right spillway transect and New Melones rws elevation of 1,088 ft. The eroded volume is calculated assuming that erosion occurs across the entire width of the spillway. The black line is the discharge hydrograph. The solid red line is the mean volume eroded for 50 model iterations and the shaded red area encompasses two standard deviations of those runs.

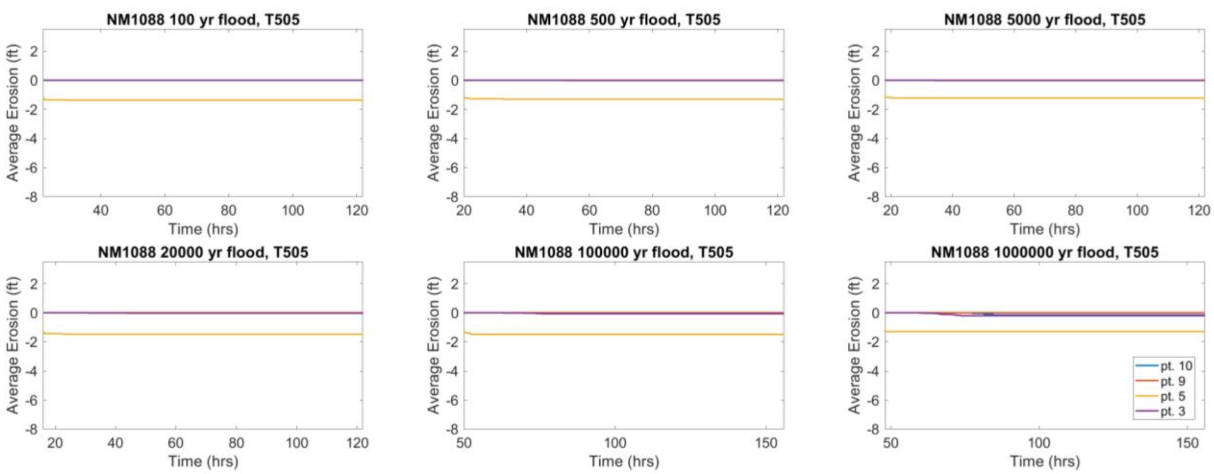

Figure 4. Erosion at four points along the left spillway transect. Erosion at point 5 is in the gully downstream of the spillway and maxes out for all six floods at ~1.5 ft of incision. Minor incision occurs at the downstream end of the spillway (point 3) for the 5,000 yr flood and greater, and incision occurs at point 10 for the 1,000,000 yr flood.

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