Quantifying Reservoir Sediment Flushing at the Cowlitz Falls Project

Achilleas Tsakiris, Hydraulic Specialist, Northwest Hydraulic Consultants, Olympia, WA, atsakiris@nhcweb.com
Brad Hall, Principal Hydraulic Engineer, Northwest Hydraulic Consultants, Sacramento, CA, bhall@nhcweb.com
Ali Habibzadeh, Principal Hydraulic Engineer, Northwest Hydraulic Consultants, North Vancouver, BC, Canada, jvasquez@nhcweb.com
Edward Fordham, Junior Geomorphologist, Northwest Hydraulic Consultants, North Bellingham WA, efordham@nhcweb.com

Introduction

The Cowlitz Falls Project is a run-of-the-river hydropower facility located on the Cowlitz River, WA, approximately 1.5 miles downstream of its confluence with the Cispus River (Figure 1). It is the most upstream of three hydropower facilities on Cowlitz River, with the Mossyrock and Mayfield Dams being approximately 17 and 27 miles further downstream.

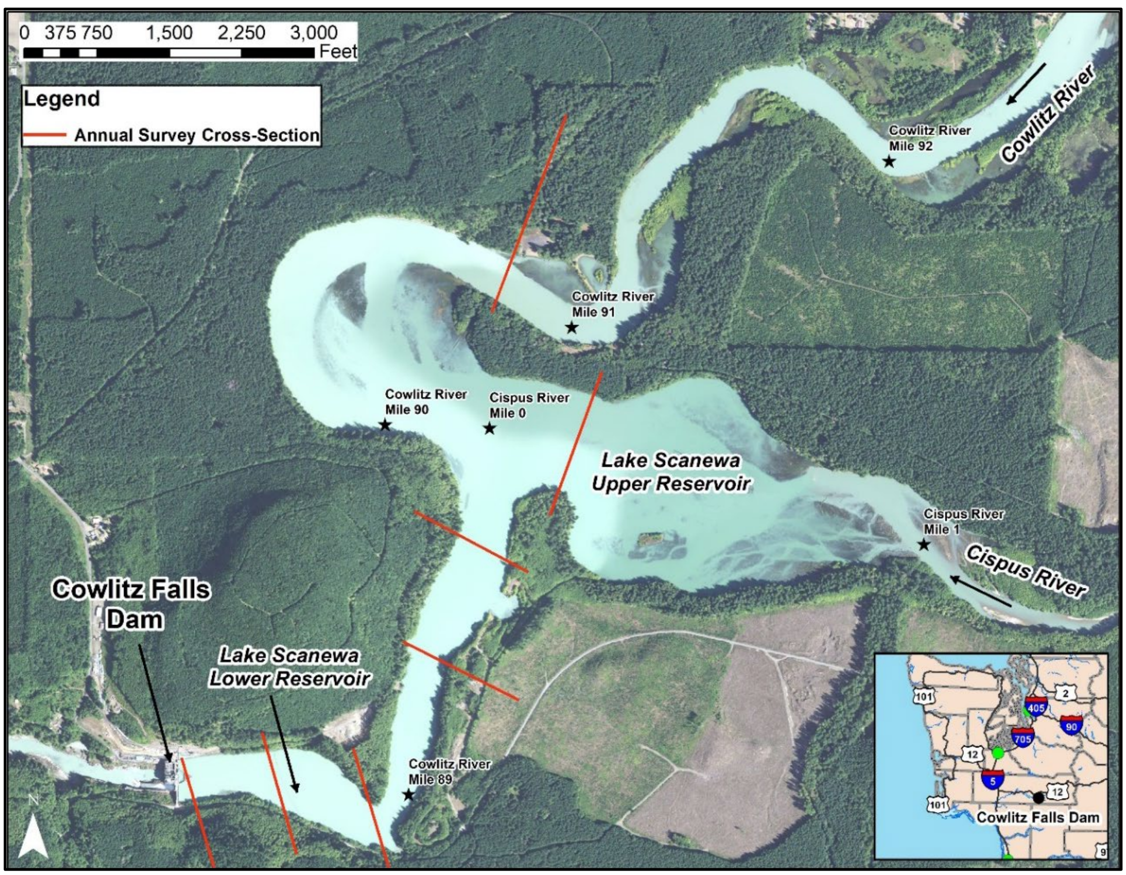

Figure 1. Vicinity map of the Cowlitz Falls Dam

The Cowlitz Falls Dam impounds the Lake Scanewa reservoir, which has a capacity of 11,000 acre-feet and is delineated into the Lower and Upper Reservoir downstream and upstream of the confluence between the Cowlitz and Cispus Rivers, respectively (Figure 1). The Cowlitz and Cispus River headwaters are located at the Cascade Mountains and their hydrologic regime is dominated by rainfall-driven flood events in the fall winter and snowmelt-driven early spring floods, followed by low-flow periods during the summer. Glacial melt from Mt. Rainier also contribute flow to the Cowlitz and Cispus Rivers during the late summer and fall months. During these floods, an estimated 500,000 cubic yards of predominantly sand and silt, with some traces of gravel is conveyed annually to the reservoir. The sediment transported to the dam forebay is flushed by typically late summer reservoir drawdown operations. Additional drawdown operations are implemented during flood periods to limit maximum reservoir pool elevations, and provide sediment flushing. The existing drawdown operations are based on a protocol derived from physical modeling completed prior to dam construction. (CFHP-SOP, 2017).

The primary goal of this is to develop the appropriate tools for evaluating and improving the performance of the current dam operations for flushing sediment through the dam and developing alternatives for reducing long term sediment deposition in the reservoir. In doing so, the present study aims to apply a One-Dimensional (1D) quasi-steady, mobile bed model of the reservoir coupled with a Three-Dimensional (3D) Computational Fluid Dynamics (CFD) hydraulic model of the dam structure and forebay.

The Cowlitz and Cispus Rivers watersheds are 588.7 and 434.2 square miles upstream of the project site. Their drainage basins receive on average, 74.6 and 78.0 inches of precipitation annually (PRISM Climate Group, 2015). Flow data on the Cowlitz River was acquired from gaging station No. 14231000, which is approximately 11 miles upstream of the project site. Flow on the Cispus River was retrieved from gaging station No. 14232500 located approximately 15 miles upstream of the project site. The flows from these gaging stations were extrapolated to the project site, using the procedure of Mastin et al. (2016). The water surface elevation upstream of the Cowlitz Falls Dam was acquired from gaging station No. 14233490. Grain size distributions of the Cowlitz and Cispus River bed material were derived from grab samples taken at six representative locations within the project site, which revealed that the bed of these rivers is comprised predominantly of sand and silt, with some traces of gravel. The bathymetry at the project site was mapped on September 8th, 2017, while the annual cross sectional survey of the reservoir and along Cowlitz River (Figure 1) was conducted on January 31st, 2018.

Methods

The mobile bed hydraulic analysis was performed using the HEC-RAS 1D hydrodynamic software (USACE, 2018). The downstream end of the modeling domain was at the Cowlitz Falls Dam and extended approximately 5 miles upstream along the Cowlitz River and 1 mile along the Cispus River upstream of its confluence with the Cowlitz River. Cross-sections for specifying the HEC-RAS model geometry were extracted with a 400-foot average spacing from a bathymetric survey conducted on September 8th, 2017. Following a sensitivity analysis, the Manning's n roughness coefficient for the main channel and floodplain areas of the model was specified to be 0.035 and 0.08, based on site observations. A quasi-unsteady, mobile-bed flow simulation of the period between September 8th, 2017 and January 31st, 2018 was performed, as it included the annual sediment flushing drawdown and three typical drawdowns for flood regulation (Figure 2). The Lake Scanewa water surface elevation time series during this period was specified as the downstream boundary condition with the concurrent the on the Cowlitz and Cispus Rivers specified as the model inflow (Figure 2). The grain size distributions determined from the grab samples on the Cowlitz and Cispus Rivers were utilized for the sediment inputs.

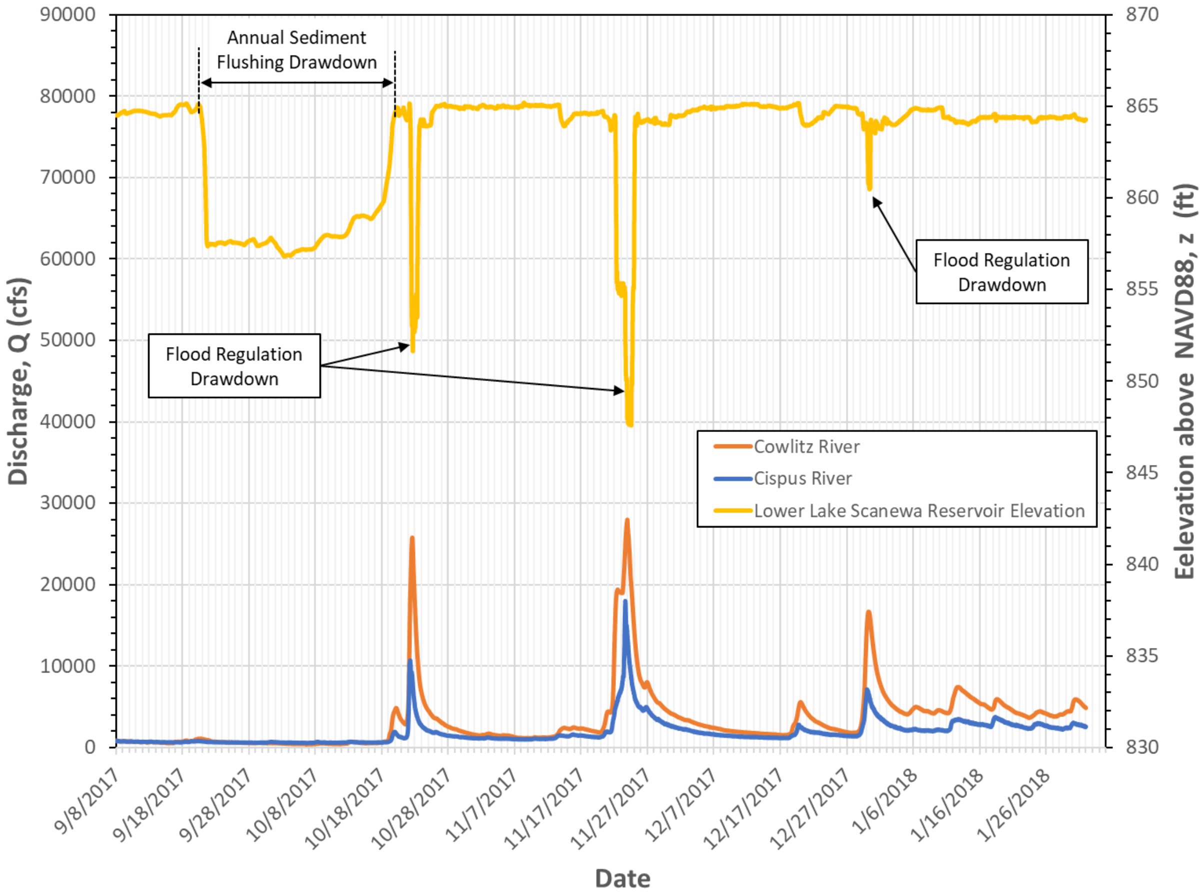

Figure 2. Cowlitz and Cispus River hydrograph and Lake Scanewa water surface elevation between September 8th, 2017 and January 31st, 2018

The 3D CFD model was constructed using Flow3D and its domain extended from downstream of the dam to roughly 4,000 feet upstream utilizing the same bathymetry with the 1D mobile bed model. It incorporated the 3D dam geometry including the sluice gates, generating units and spillways, which was provided in electronic format. Steady state analyses were performed simulating key operating procedures employed currently (Table 1).

Table 1. Simulation scenarios

Test No.	Flow Condition	Flow (cfs)	Reservoir Level (Feet, NAVD88)	Description
1	Maximum normal operations	23,000	865.4	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 60% (9.6 ft) open - all spillway gates closed
2	1st stage drawdown	27,000	846.5	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 60% (12.8 ft) open - spillway gate #1 open 103 degrees
3		25,000	855.3	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 80% (12.8 ft) open - all spillway gates closed
4		25,000	858.2	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 70% (11.2 ft) open - all spillway gates closed
5	2nd stage drawdown	50,000	847.0	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 80% (12.8 ft) open - spillway gate #1 and #4 open 100 degrees
6		50,000	843.7	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 80% (12.8 ft) open - spillway gate #1 and #4 open 96 degrees
7		55,600	845.5	- power units 1 & 2 at maximum generation - sluice gates 1 & 2 80% (12.8 ft) open - spillway gate #1 and #4 open 93 degrees
8	Large Flood	70,000	852.7	- power units 1 & 2 off - sluice gates 1 & 2 fully open - spillway gate #1 and #4 fully open
9		84,000	853.2	- power units 1 & 2 off - sluice gates 1 & 2 fully open - spillway gate #1 and #4 fully open

Results

The 1D mobile bed model was calibrated by adjusting the sediment influx load as a percentage of the equilibrium load predicted by the Laursen formula (Figure 3). The calibrated 1D mobile bed model predicted an overall tendency of the Cowlitz River bed to erode upstream of station 8,000 feet. A depositional trend was observed in the upper reservoir approximately 2,000 and 8,000 feet upstream of the dam. This deposition in the upper reservoir potentially reduces the sediment supply in the lower reservoir near the dam forebay, likely causing the absence of notable deposition nearest the dam at this most downstream segment of the reservoir.

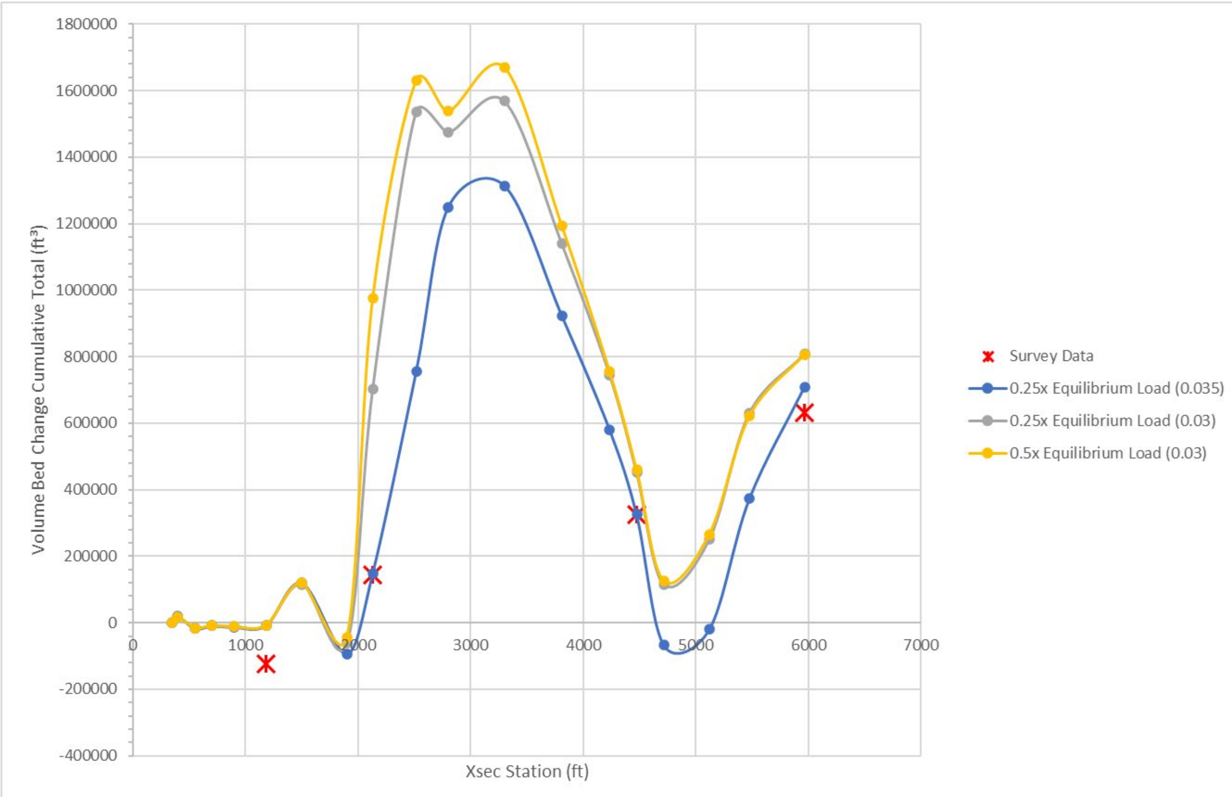

Figure 3. Model calibration

Figure 4 and Figure 5 depict the velocity and wall shear stress calculated by the 3D (CFD) model in the lower reservoir for Tests #2 and #3 of Table 1. These tests have comparable inflows, yet a different combination of operations, which results into a roughly 9-foot difference in the pool water surface elevation. The results clearly show the effects that these operations have on the hydraulics near the dam and that the developed 3D (CFD) model is a reliable tool for understanding these near dam flow hydraulics.

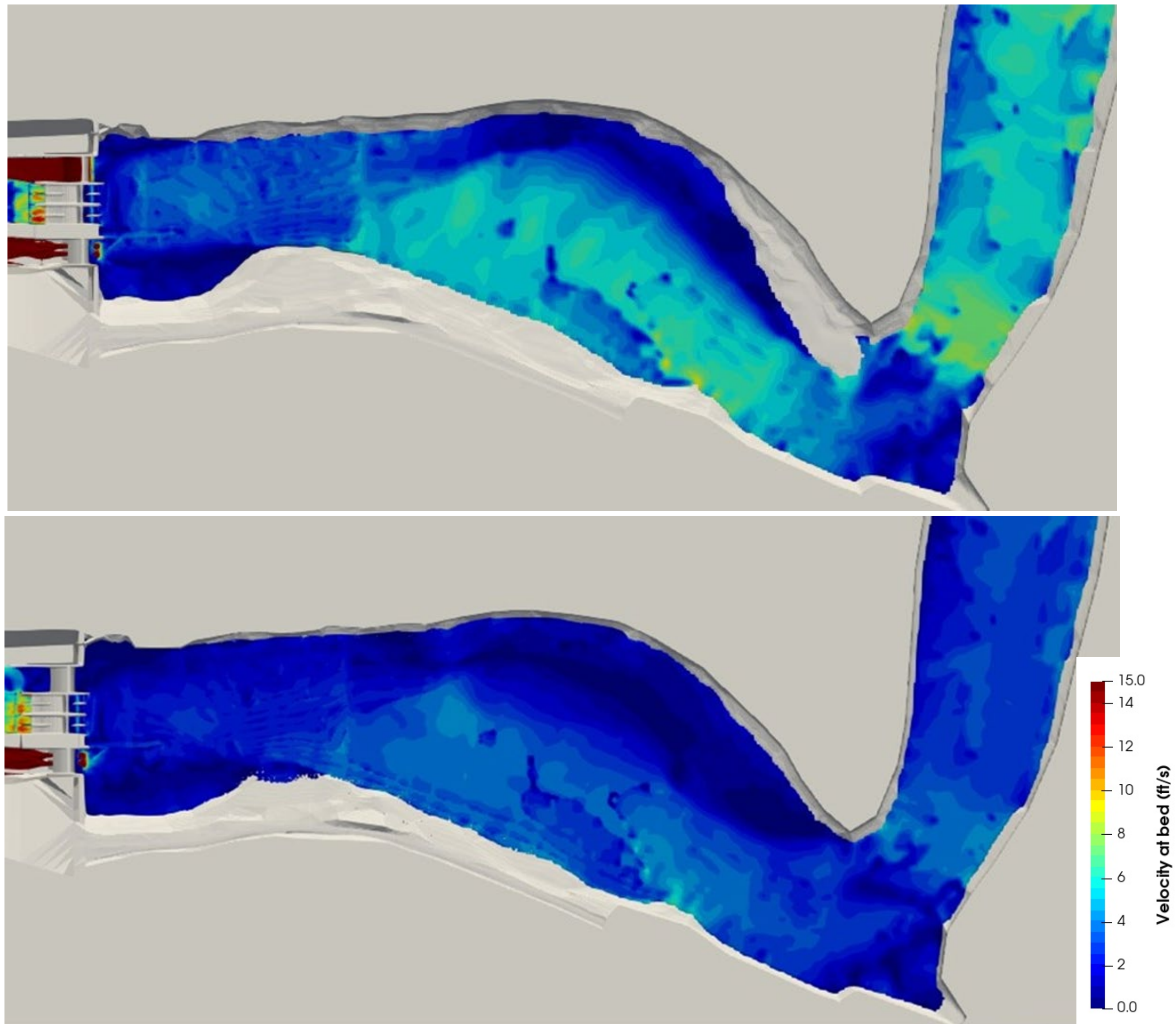

Figure 4. Velocity predicted by the 3D (CFD) model for Test No. 2 (top) and No. 3 (bottom)

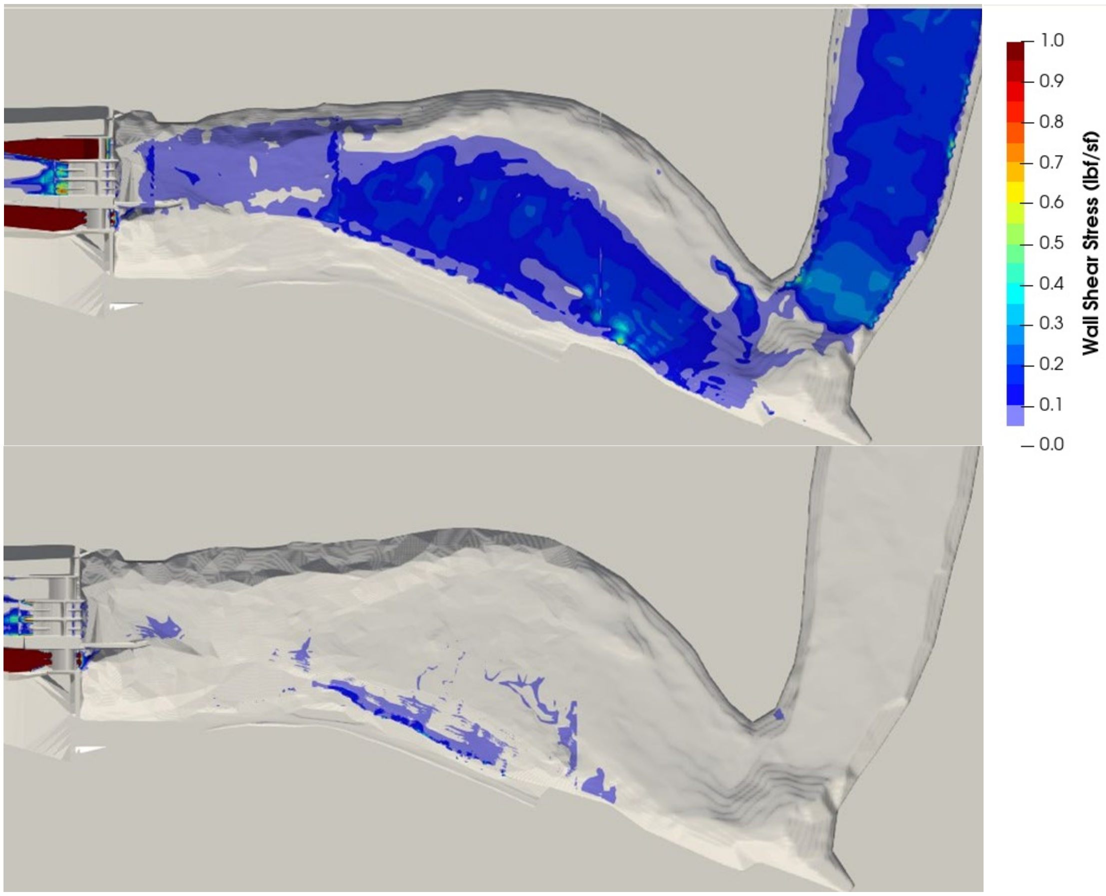

Figure 5. Wall shear stress predicted by the 3D (CFD) model for Test No. 2 (top) and No. 3 (bottom)

Conclusions and Future Directions

Future simulations with the developed and calibrated 1D mobile-bed model will aim to simulate alternative operating procedure of varying, timing, and duration of future sediment flushing drawdowns that maximize the amount of flushed sediment conveyed into the lower reservoir. The 3D (CFD) model will thereafter be enhanced with sediment transport calculations to assess the mobility of the incoming sediment through the lower reservoir and dam. These two tools will be utilized for refining the characteristics of these operations in order to maximize sediment flushing with minimal hydropower losses. These simulations will be verified with on-site, real-time flow, sediment transport and bed topography data that have been deployed at the facility. This combined modeling and field monitoring effort will ultimately provide the dam managers with an improved operational protocol for better sediment management and more efficient facility operation.

References

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