HEC-RAS Sediment Simulation of a Snake River Dam Removal Alternative

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Abstract

A 2019 Environmental Impact Statement was updated for the Columbia River System management, a system that includes fourteen federal, water-regulation projects in Idaho, Montana, Oregon, and Washington. One multiple-objective alternative included structural measures for breaching of the four Lower Snake River dams (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite). This alternative explored potential impacts of breaching the earthen embankments for these four dams. The analysis included a sediment impact assessment of a two-stage dam removal (USACE, 2019). This paper describes the HEC-RAS, 1D, sediment model constructed to assess these impacts.

The modeling team developed and balanced the sediment budget and then calibrated the model against three evaluation metrics. First, the modeling team calibrated sediment-flux volume by comparing the model to total, observed, reservoir deposition over two time windows. Second, we calibrated the flux gradation, comparing model results to reservoir gradation trends. Third, we evaluated the model performance in an erosion regime by simulating a 1992 partial drawdown that eroded the sediment delta in the upper two reservoirs, comparing the drawdown model results to repeated bathymetries and a few mid-drawdown concentration measurements.

Then the modeling team ran long-term forecast simulations, that included two-phases of mid-simulation dam removals to evaluate the sediment concentrations this alternative would introduce, downstream deposition, as well as temporary and persistent flood risk impacts from downstream deposition. The study also explored the sensitivity of sediment impacts to the post-removal hydrology. This talk will describe the modeling approach, data analysis, calibration effort, and lessons learned.

Sediment Budget

A sediment budget is a helpful pre-modeling step to organize the data, identify the relative importance of sources and sinks, identify data gaps, and evaluate the data quality. Sediment budgets rarely balance, which can provide a preview of data deficiencies and assumptions modelers will need to make to calibrate. The sediment budget domain and the quantitative, average, annual, sediment budget from 1997 to 2010 is included in Figure 1.

Most of the sediment influx comes from the Upper Snake River, but the Clearwater and tributaries contribute non-trivial sediment loads. The downstream gage at Burbank also recorded a substantial flux out of the system (the highest of the tributary inputs other than the Upper Snake) though this flux is mostly fine sediment.

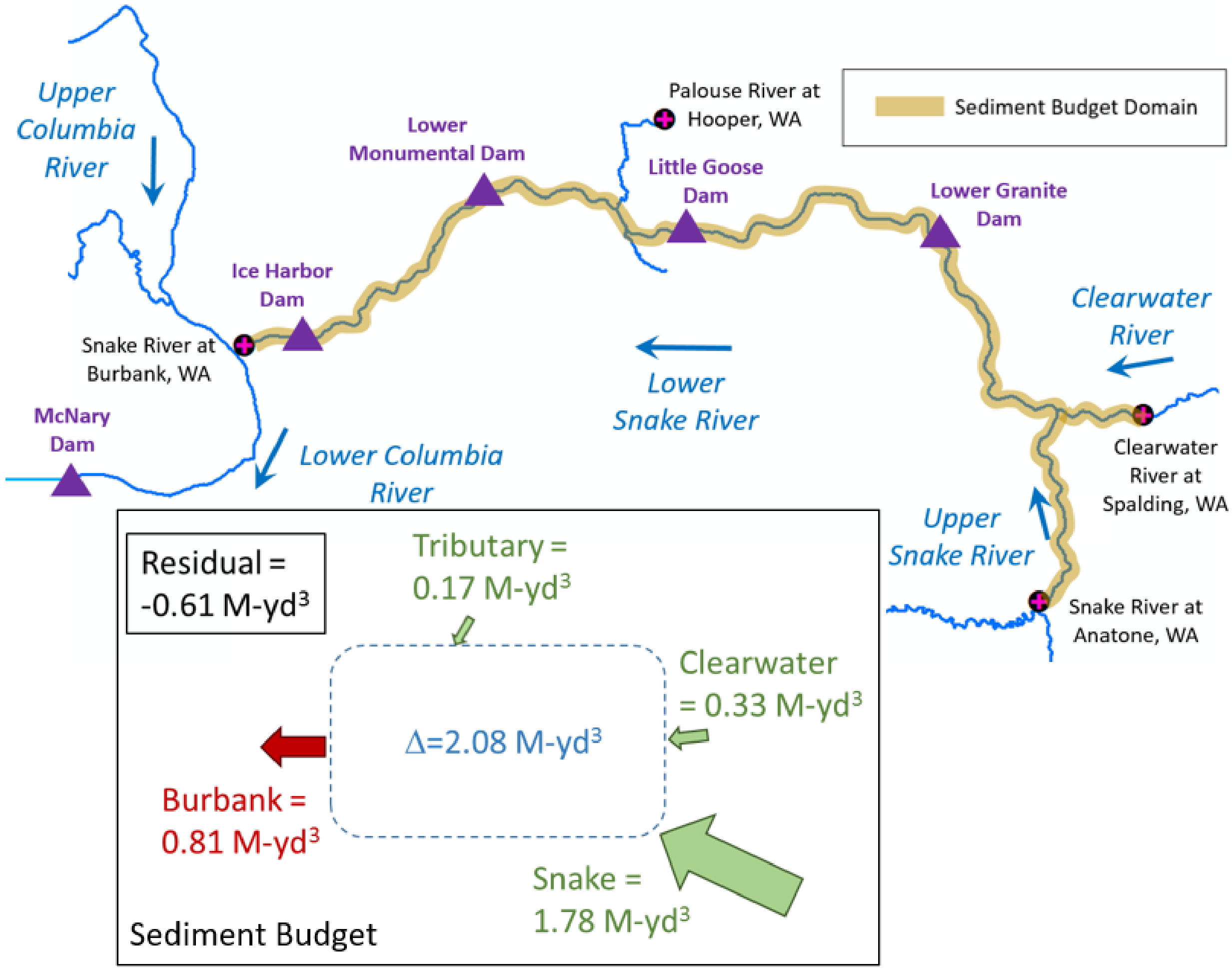

Figure 1. Sediment Budget extents, terms and residuals for the Lower Snake River between 1997 and 2010.

The sediment budget does not balance. The deposition in the reservoir is about 200,000 yd^3/yr less than the three sources, but about 600,000 yd^3/yr more than the net flux (inputs-outlet at Burbank). Therefore, the model must adjust one or more of these inputs just to conserve mass, before detailed calibration.

Model Development

Hydraulic Calibration

A detailed historic hydraulic model of the system was developed and calibrated before the study team added sediment. The model domain included the entire Lower Snake River reach between the Columbia and the junction between the Snake and Clearwater, parts of the Upper Snake River and Clearwater River, and the potentially impacted section of the Columbia River downstream of the Snake (Figure 2). The Columbia River was included from McNary Dam to a gage upstream of the confluence with the Snake. The hydraulic model was calibrated over a 23-year period (WY 1985-2008) which included a large event in 1997 (~4% annual exceedance probability). The hydraulic model was calibrated to the forebay stages in the four Snake River reservoirs (Figure 3).

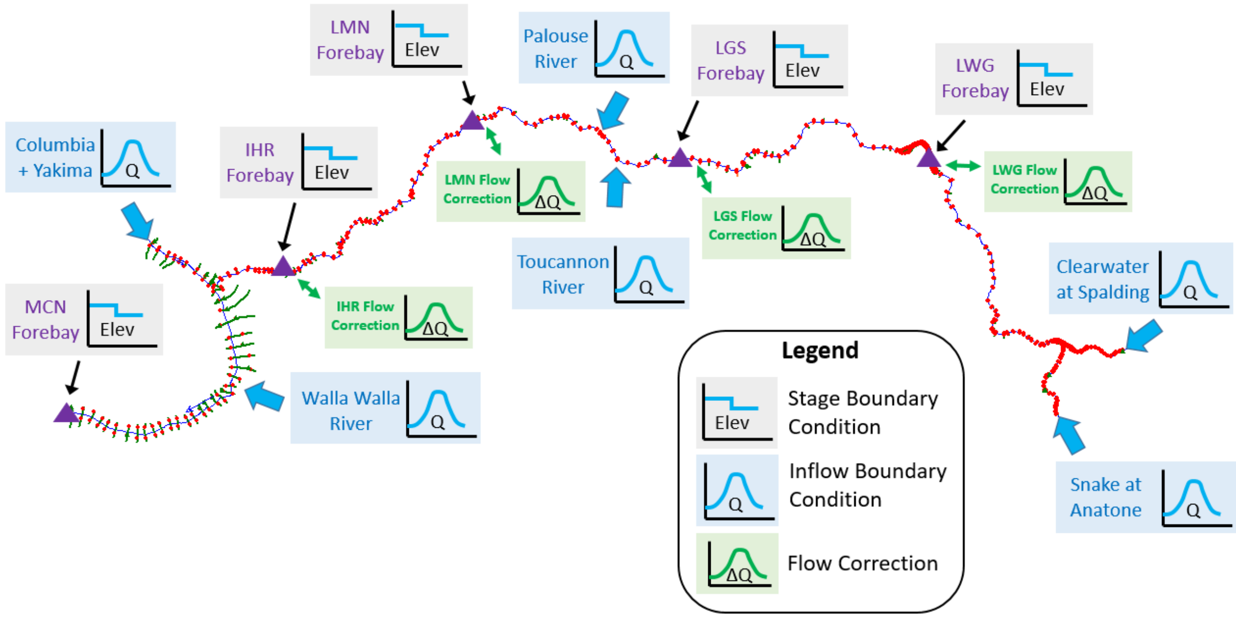

Figure 2. Model domain and boundary conditions for the hydraulic simulation and calibration.

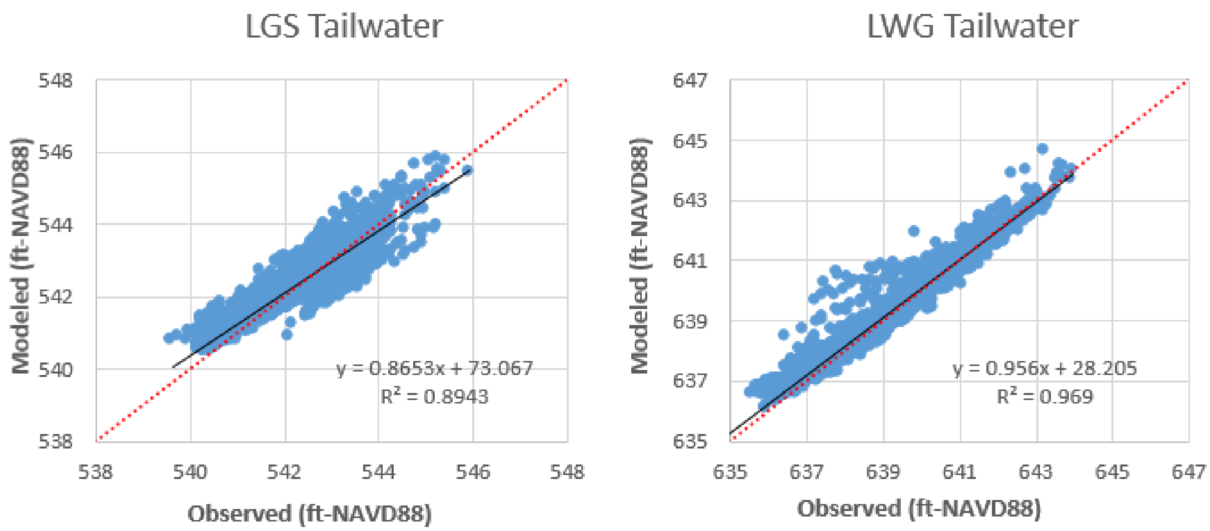

Figure 3. Model domain and boundary conditions for the hydraulic simulation and calibration.

Sediment Data

Sediment boundary conditions included bias corrected sediment rating curves from sediment gages on the Clearwater, Upper Snake, and Palouse. The study team added an additional linear correction factor to the Upper Snake and Clearwater Boundary sediment rating curves to account for the sediment budget residual. Sediment boundary conditions must also be partitioned by grain class. Suspended sediment sample gradations were available for all gages. The Clearwater and Upper Snake loads coarsened with flow (e.g. the sediment loads transported a higher percentage of coarse grain classes at higher flows) while the Palouse, which drains a loess rich sub-basin and is more capacity limited, fined with flow (higher flows had more sediment in the finer grain classes).

The USGS collected bed gradations throughout the system. The Lower Snake River bed gradation data are plotted in Figure 4. Bed gradations in each of the four Lower Snake reservoirs (and McNary on the Columbia) generally fine downstream, but the downstream fining trend is strongest on the two upstream dams (Little Goose and Lower Granite) with the most deposition.

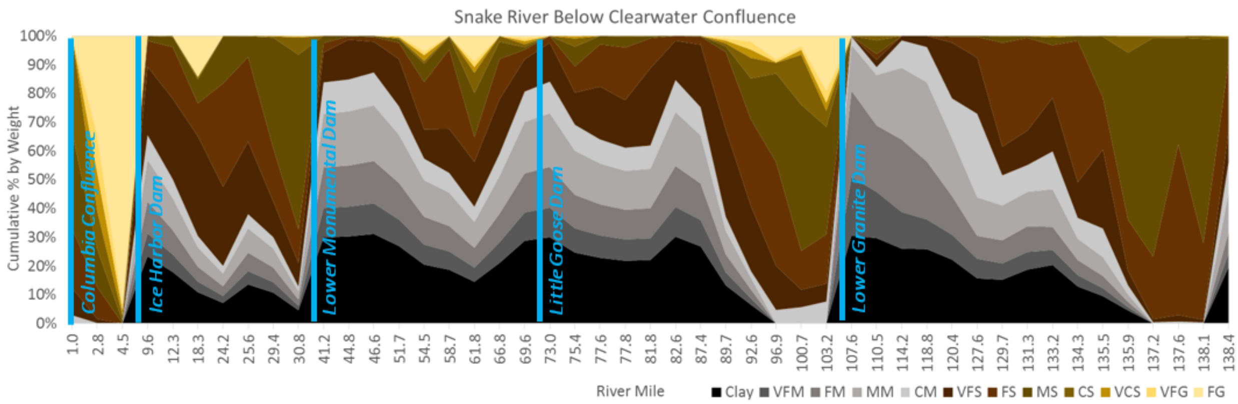

Figure 4. Bed sample gradation by grain class in the Lower Snake River (from Clark et al, 2013). Bed deposits fine downstream in each of the four reservoirs, but the trend is strongest in the upstream reservoirs with the most deposition.

Sediment Calibration

Dam removal models are notoriously difficult to calibrate because a dam removal is a novel process, unprecedented in the system, that represents a dramatic discontinuity from historic sediment processes. Therefore, even when dam removal studies do have historic concentration or deposition data, a reservoir deposition calibration does not reduce much of the uncertainty associated with the rapid, post-removal, erosion and transport processes.

This study did calibrate the historic deposition regime to evaluate the boundary conditions for long term simulations. But then it calibrated to a historic drawdown to evaluate and parameterize the model for post-removal erosion and transport. These are described as the "deposition calibration" and "erosion calibration" below. The study team identified the most sensitive and uncertain model inputs for each process (erosion and deposition) and adjusted those data during the calibrations. More certain and less sensitive model inputs were fixed to avoid equifinality issues (Table 1).

Table 1. Summary of model input data stratified by uncertainty and sensitivity. The less sensitive and lower uncertainty data and parameters were fixed and the high uncertainty, very sensitive data were adjusted during the calibration process.

	Lower Uncertainty	High Uncertainty
Less Sensitive	Temperature Fall Velocity: Report 12	Tributary Flow Operations Transport Equation: Larsen Copeland
Very Sensitive	Dredging Roughness/Ineffective Flow Bed gradation Flow: Snake and Clearwater Erodible Depth: Snake Mixing Algorithm: Copeland	**Deposition Calibration:** **Load Gradation: Fine Distribution** **Erosion Calibration:** **Erodible Depth: Clearwater** **Krone-Partheniades Parameters**

Deposition Calibration

The deposition calibration reproduced the volume and longitudinal distribution of the reservoir deposits and the sediment bed gradation trends (Figure 4). The model reproduced the total deposited volume in the model over two time series (1997-2003) and (1997-2010). The longitudinal volume curves for these calibrations are included in the top pane of Figure 5. This system deposits most of the sediment in the delta of the first reservoir. The modeled deposition was low compared to the prototype for the early time series and high for the later time series, so the modeling team chose a calibration parameterization that distributed the error relatively evenly.

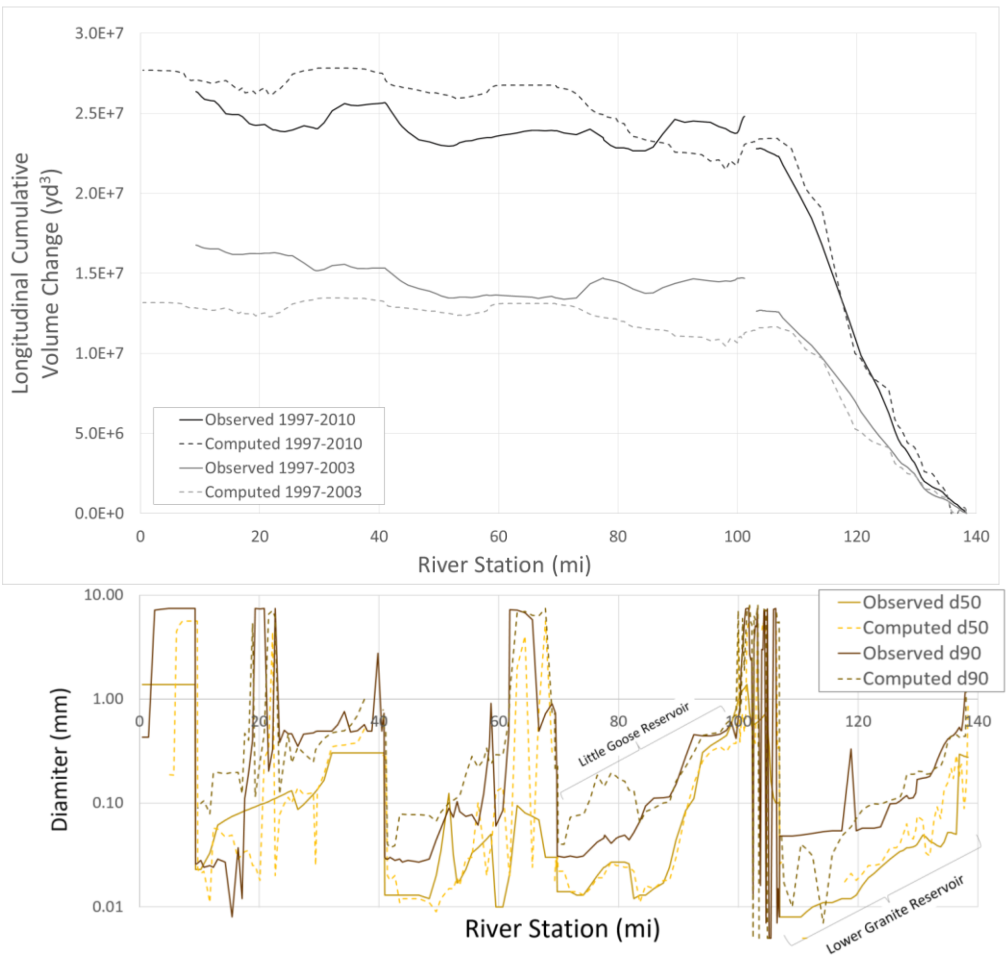

Figure 5. The deposition calibration had multiple components. The longitudinal cumulative volume curves (top) for two separate time series calibrated illustrate the total volume calibration and the longitudinal distribution. Then the modeling team checked the final bed model gradations against prototype data to make sure the model gradations were reasonable.

The model required more sediment flux than the data specified just to balance the sediment budget, even after a bias correction and a generous bed load correction. Therefore, the calibration runs added the sediment budget residual to the boundary condition to calibrate the total deposition volume. But to calibrate the longitudinal distribution of the deposits (i.e. make sure the model deposits in the right place) the study team adjusted the gradational distribution of the sediment boundary conditions. Coarser sediment deposits upstream and finer sediment transports farther into the reservoirs. Adjusting these data can help the model reproduce the location of the deposits.

The study team averaged the load-gradation data available at each boundary condition for low, medium, and high flow conditions. The original load-gradation curves and the averages for three flow ranges at the Clearwater gage are included in Figure 5. These data have a lot of variability, and the location of the deposits was very sensitive to them. So, the modeling team adjusted them to the dashed lines in Figure 6 to generate the results in Figure 5.

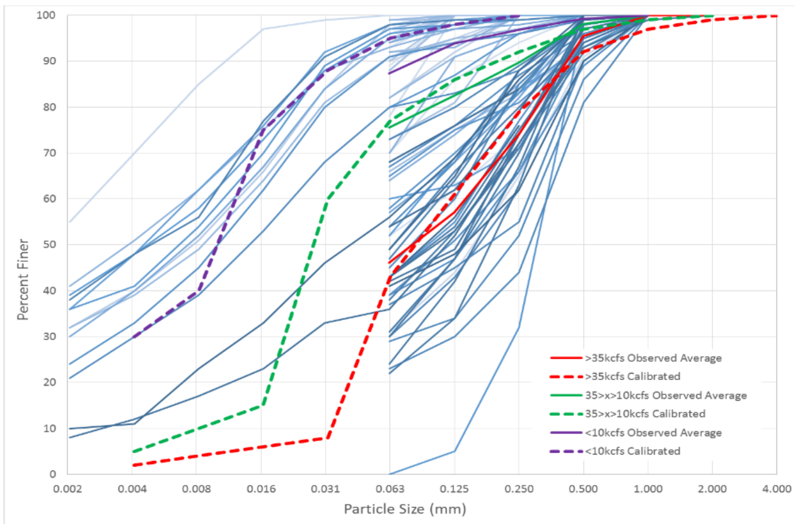

Figure 6. Load-gradation curves collected at the Clearwater gage (blue). The solid colored lines are the average curves for different flow ranges (high, medium, low). The dashed lines are the calibrated gradation curves that reproduced the observations in the previous figure.

When adjusting the flux gradation to reproduce the location of the deposits, it is useful to make sure that the calibrated flux gradations reproduce credible bed gradations. Therefore, the study team compared the median (d_{50}) and 90th percentile (d_{90}) particle size from the final calibration model to the bed gradation data (bottom pane of Figure 4) as another check of the model performance.

Erosion Calibration

A deposition calibration can be useful to establish the context of a dam removal model, and to tune the boundary conditions for long-term, post-removal, simulations. But depositional calibrations do not evaluate the uncertain data inputs or model processes that drive the modeling objectives of most dam removal models.

A reservoir drawdown presented a relatively rare opportunity to calibrate this model to an erosion event. In 1992 reservoir managers dropped the pool of Lower Granite (the upstream reservoir) 34 ft (just over 10 m) and Little Goose (the next reservoir downstream) 12.5 ft (3.8 m). The drawdown exposed the deltas of the upper reservoirs simulating the initial days of a dam removal.

The USGS quantified the erosion from the event with repeated cross sections (Figure 7) (Harper and Lipscomb, 1994).

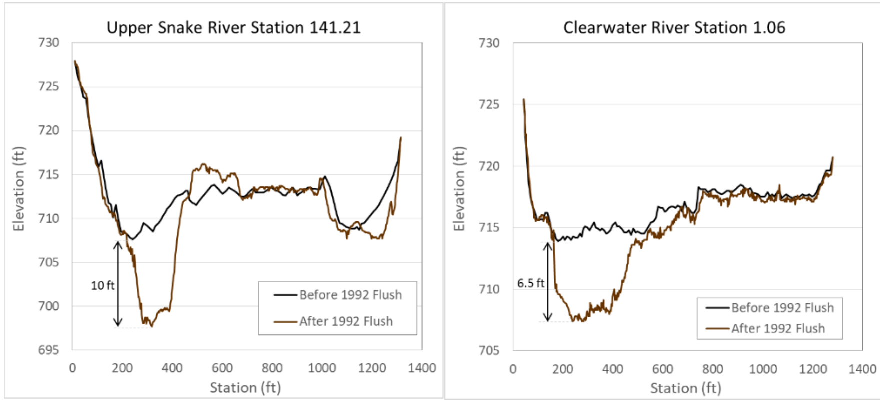

Figure 7. Repeated Cross Sections from the delta of the Lower Granite reservoir on the Snake River.

The study team applied the model to this event, evaluating the model in an erosional regime and calibrated the cohesive parameters (e.g. critical shear and erodibility). Longitudinal volume change curves for the erosion calibration are included in Figure 8. The calibration under-predicted erosion of the deepest deposits, but reproduced the erosional trends through the upper delta, increasing the overall confidence in the model for dam removal analysis.

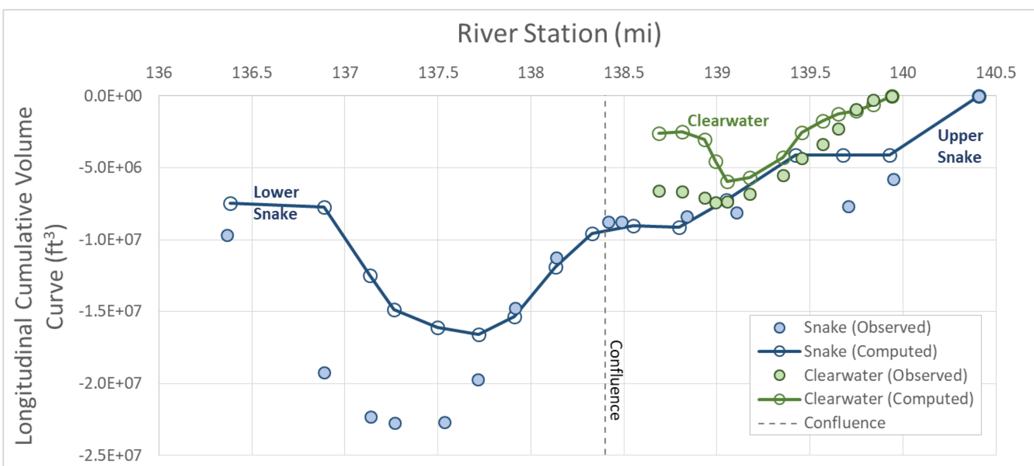

Figure 8. Observed and computed longitudinal cumulative volume curves for the erosion calibration simulation of the 1992 drawdown of the Lower Granite reservoir on the Snake River.

Simulation

The study team used large, "overflow gates" in HEC-RAS to simulate the embankment breaches. These overflow-gates behave like weirs when they are "closed." But users can open these gates mid-simulation, which drops the weir crest without a residual high cord. This is standard practice for mid-simulation dam removal modeling (Figure 9). The gates were sized to the planned geometry of the embankment removal, and then opened during the simulation at the time of the planned removal.

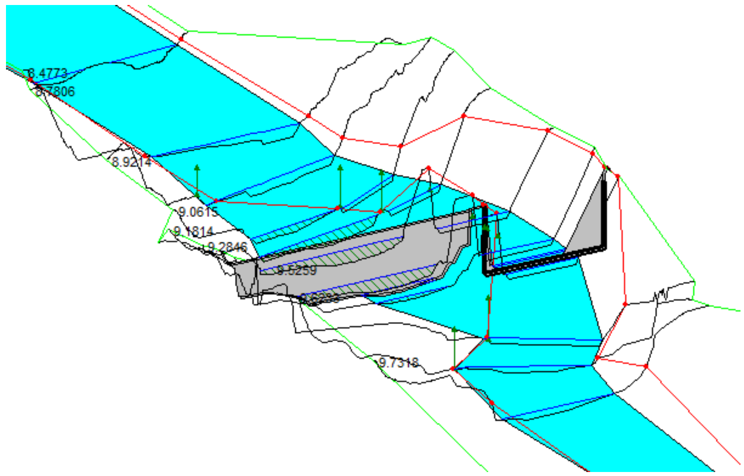

Figure 9. Overflow gates are the standard approach to model mid-simulation dam removals in HEC-RAS.

The simulated removal sequence breached the upper two embankments (Lower Granite and Little Goose – the reservoirs with most of the sediment) in one year, and two downstream embankments in the second year. In both years, removal followed a slow, several-month drawdown.

The serigraphs (concentration time series) at river stations 69.9 (just downstream of Little Goose) for the first year are plotted with the drawdown time series in the top pane of Figure 10. The second year sedigraphs and drawdown time series for the lower two dams are included in the lower pane of Figure 10 (at river station 7.5 which is downstream of all the dams, but upstream of most of the Columbia backwater effects).

The simulations indicate that both events generate two-peak concentration time series. The drawdown phase flushes sediment, generating an early peak (larger in the first event, smaller in the second). Then the breach releases a second concentration peak. The maximum instantaneous concentration at these two locations is the initial drawdown peak from the first phase. But both phases of the removal generate instantaneous concentrations between 15,000 and 25,000 mg/L, nearly more than a month 5,000 mg/L and several months over 2,000 mg/L. However, after these pulses, sediment concentrations return close to a pre-dam baseline relatively quickly. Figure 11 plots the sediment time series (at the downstream end of the lower snake) for each grain class with the flow series used for the simulation. Fine sediment is elevated during the wet season a year after the removals, and coarse sediment loads are elevated several years after the removals. But the peak concentrations of fine sediment are limited to the removal events.

The post-removal baseline concentrations are substantially higher than the pre-removal fluxes because the removal reestablished sediment continuity and the lower Snake can carry the fluxes from the Clearwater, Upper Snake, and tributaries (e.g. Palouse and Walla Walla).

Results were sensitive to the hydrology during the 2-year removal. The study team simulated wet, medium, and dry hydrologic conditions to capture this uncertainty (results above are for the "medium" case).

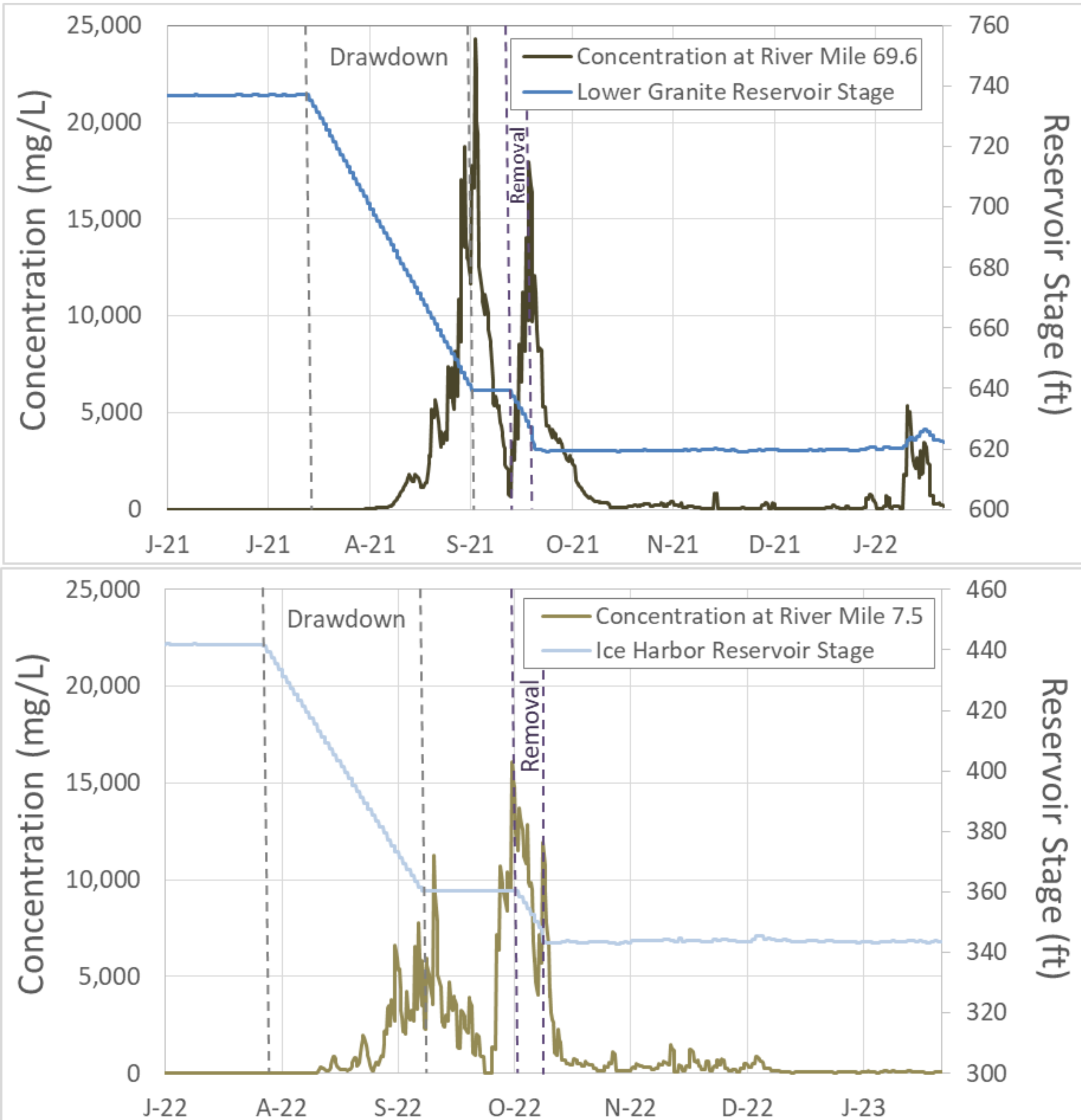

Figure 10. Simulated concentration time series and reservoir drawdowns and embankment breaches. Results in the top pane are just downstream of the upper two dams and reflect the drawdown and breach of those two structures in the first year. The lower pane reflects results near the downstream end of the lower Snake and includes the drawdown of the lower two reservoirs in year 2 and the simulated concentration time series from those drawdowns and breaches (which includes impounded sediment from the upstream reservoirs, breached in the previous year).

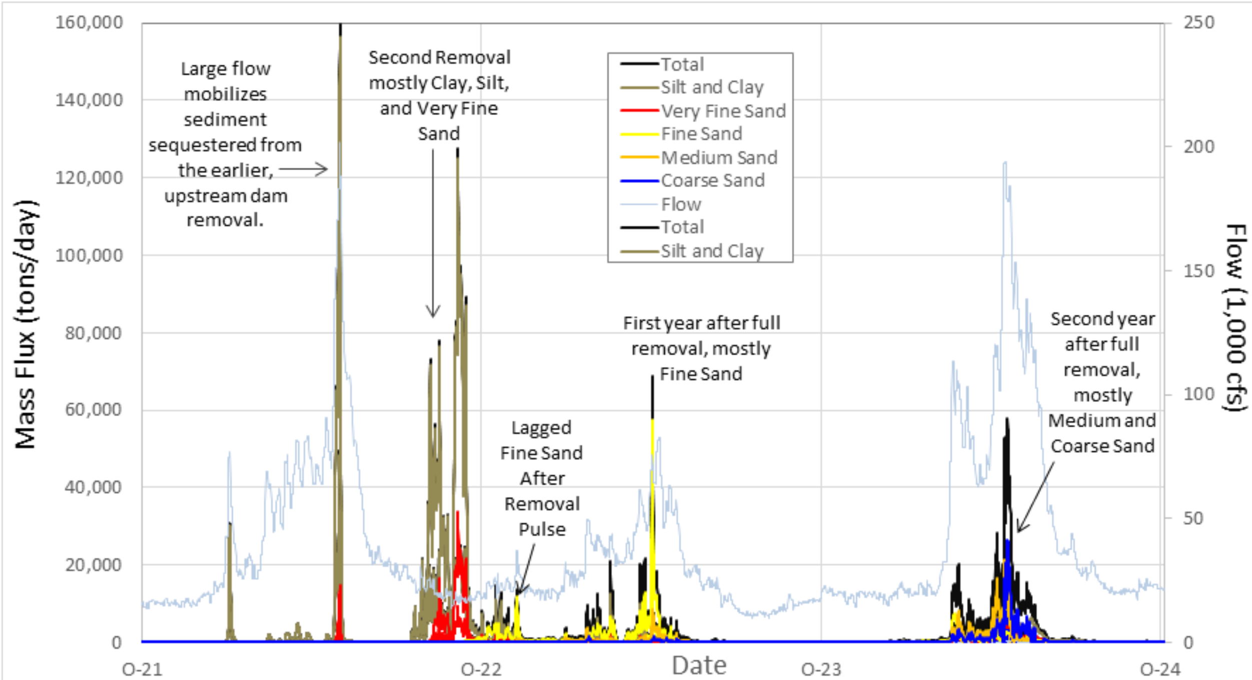

Figure 11. Simulated concentration time series, stratified by grain class, plotted with the hydrology from this "medium flow" simulation. Coarse sediment lags the fine sediment which is mostly transported in the first two years after removal.

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Supplemental EIS Appendix B: Lower Granite and Little Goose 1992. Reservoir Drawdown Test, 32p.

USACE 2019. Technical Memorandum – Lower Snake River HEC-RAS Mobile Bed Modeling for Colombia River System Operation Dam Removal Alternative.