Modeling of Paonia Reservoir Drawdown Flushing

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Abstract

This work proposes a sediment sluicing/flushing plan at the Paonia Reservoir, in western Colorado, to extend its life span. Two numerical models, SRH-1D and SRH-2D, are employed to predict long-term impacts of sluicing/flushing and the efficiency of drawdown flushing for different reservoir shapes, respectively. The proposed plan is conceptualized to lower the reservoir pool in the early spring and to sluice and flush sediment with high spring run-off flows through the outlet works before closing the gates to refill the pool for the irrigation season.

Introduction

Reservoir sedimentation is impacting all Bureau of Reclamation (and other public and private) facilities as water storage and supply become increasingly threatened with the aging infrastructure. Drawdown flushing can be used to remove reservoir sediment in small gorge-shaped reservoirs and to extend the reservoir life span. Drawdown flushing is achieved by lowering the reservoir pool elevation, so that reservoir sediment deposits can be resuspended and expelled out of the reservoir with released flows. The efficiency of the sediment removal during drawdown flushing depends on many factors, including timing, duration, and reservoir shape, among others.

Drawdown flushing at the Paonia Reservoir is studied in this paper. Paonia Dam and Reservoir are located on Muddy Creek, a tributary of the North Fork Gunnison River in western Colorado. Based on a bathymetric survey of the entire reservoir, conducted in June 2013, the estimated average annual rate of sedimentation has been 101 acre-ft per year. The as-built storage capacity of Paonia Reservoir was 20,950 acre-feet, meaning nearly 25% of the reservoir's original capacity has been lost. In Fall of 2014, the dam became partially blocked with sediment and debris, and emergency action was necessary to maintain water deliveries. To analyze potential solutions to this problem, a proposed sediment sluicing/flushing plan was conceptualized to lower the reservoir pool in the early spring and to sluice and flush sediment with high spring run-off flows through the outlet works before closing the gates to refill the pool for the irrigation season.

. In recent years, numerical models have been used to inform decision makers on reservoir operations for better management strategies (see Teal et al. (2015), Anari et al. (2020), and Lai and Huang (2022), for detailed reviews). Two models are used in this study to examine the timing and efficiency of reservoir drawdown flushing: (a) the one-dimensional (1D) model, SRH-1D, is used to study long-term effects of managing inflow and sediment deposition in Paonia Reservoir under various flushing plans, and (b) the two-dimensional (2D) model, SRH-2D, is used to study short term effects of reservoir drawdown flushing in conditions when the width of the reservoir is wide and to see how the drawdown flushing can be used in other reservoirs

Model Inputs

The required inputs to the Paonia Reservoir sediment models include general model parameters, reservoir bathymetry data, upstream discharges of flow and sediment, downstream water surface elevation or discharge, reservoir sediment gradations, Manning roughness, selection of sediment transport capacity equations, and calibrated/assumed values of associated sediment transport parameters.

Incoming sediment load rating curves are provided herein to show when high sediment concentrations are present and when reservoir drawdown flushing would be preferred. Samples of suspended sediment concentration versus discharge from 2013 through 2015 are plotted in Figure 1. The samples were split into significant time periods of before the annual peak discharge (Pre-Peak), after the annual peak discharge (Post-Peak), and after July 4th. Sediment concentration is significantly higher during the rising stage of the snowmelt. Post-snowmelt peak sediment concentration is usually lower than these of pre-peak and post-July 4. Usually after July 4th, the sediment concentration returns to a higher level. In the spring (Pre-Peak), the sediment concentration is usually high and the reservoir drawdown flushing can be used to flush sediment from the reservoir along with the incoming sediment.

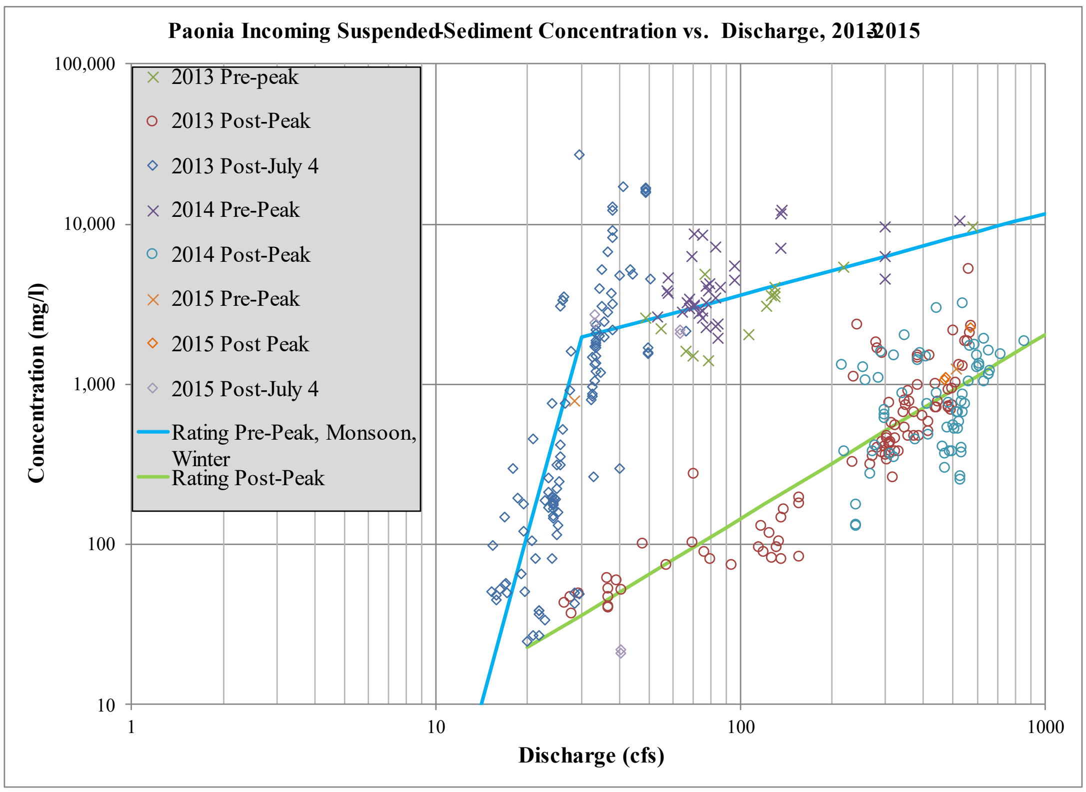

Figure 1. Suspended sediment concentration versus discharge in Paonia Reservoir (2013-2015)

Long Term Simulations with SRH-1D

1D modeling was performed for long-term prediction from 2015 to 2035, after the model was calibrated with field data.

Figure 2 presents the cumulative reservoir sediment deposition volumes. Most reservoir deposition occurs in the 5 wet years (2017, 2018, 2025, 2028, and 2031) when the annual incoming flow reaches more than 150 (thousand-acre-ft) TAF. In some dry years, more sediment is flushed out of the reservoir than comes in. Over the 20-year simulation, the reservoir trap efficiency is about 29%, with 2248 acre-ft incoming sediment and 656 acre-ft deposited in the reservoir.

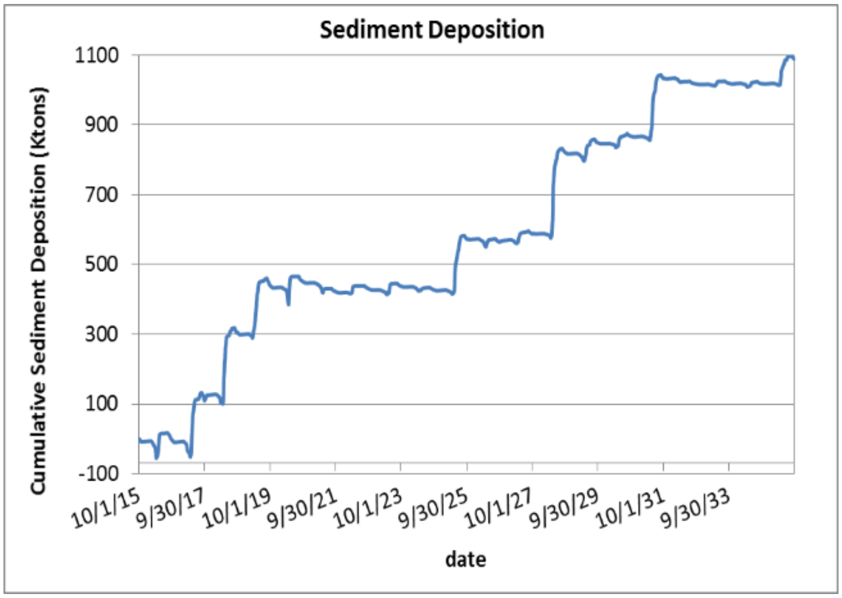

Figure 2. Cumulative reservoir sediment deposition of long-term simulation

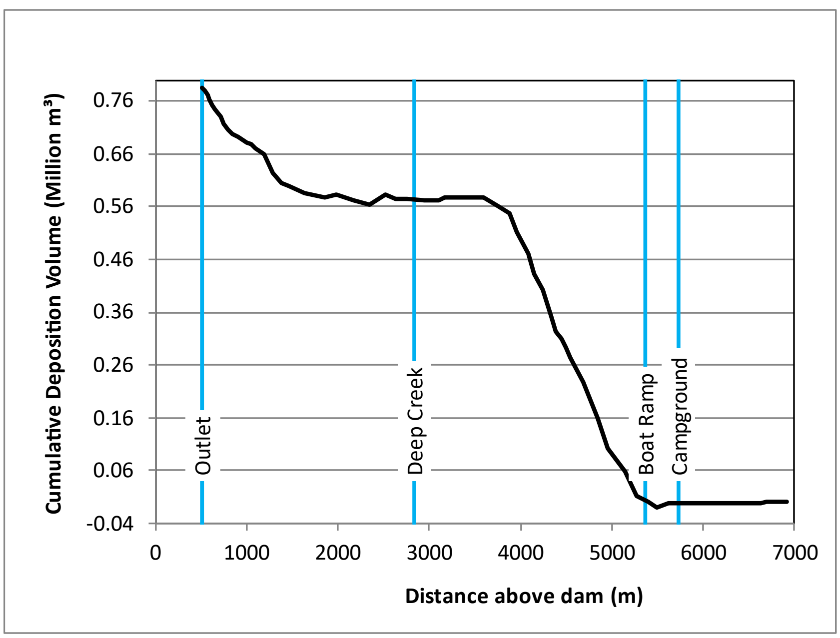

Figure 3. Cumulative reservoir sediment of long-term simulation as a function of distance from dam outlet.

Cumulative sediment deposition volume by station at the end of the simulation is displayed in Figure 3. Most sediment is deposited in the first 1.6 km of the reservoir entry downstream of the boat ramp. The boat ramp is located about 5.4 km from the reservoir outlet. Additional sediment is deposited near the reservoir outlet.

Figure 4 shows the simulated outflow sediment concentration from reservoir release in year 1. The simulated water surface elevation is also presented in this figure. The sediment release concentration remains small during both winter operations, at a water surface elevation (WSE) of 1943.8m (6377 ft), and the spring water storage period at a WSE of 1965.2 m (6447.5 ft). Peak concentration occurs at the end of the water year when the reservoir empties. During winter operation or spring storage, sediment is deposited near the reservoir outlet. When the reservoir empties and the WSE reaches its minimum stage, the sediment built near the outlet is eroded abruptly, resulting in a surge in sediment concentration.

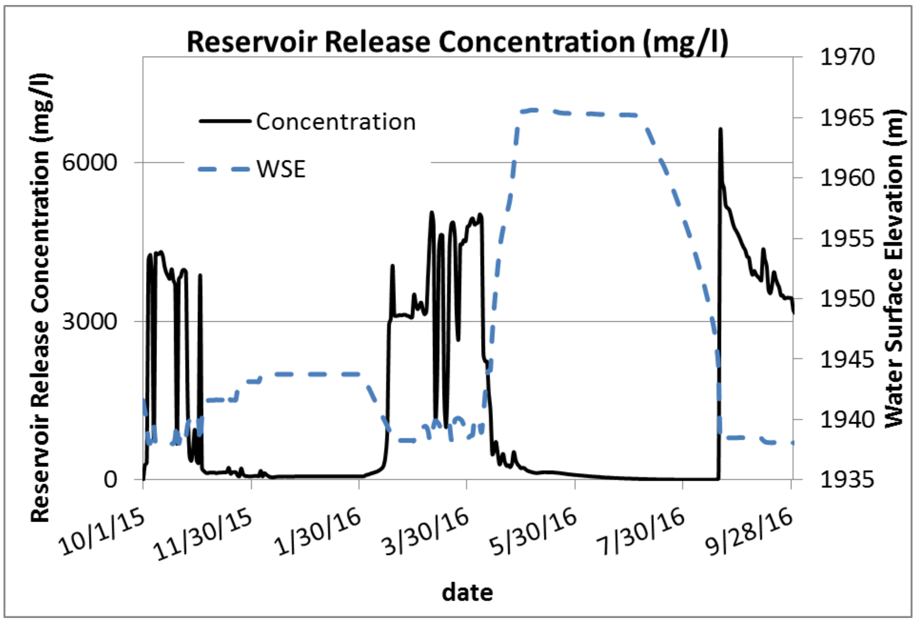

Figure 4. Simulated reservoir release sediment concentration within year 1.

Short Term Simulations with SRH-2D

The short-term simulations with SRH-2D are still in its initial stage and there are many challenges involved in calibrated the sediment concentration and load exiting the reservoir. Currently the model over-predicts the sediment loads during the model starting period and over-predicts the sediment concentration during low reservoir flow release times.

The 2D sediment transport model was calibrated with sediment load and sediment concentration in 2013. The model was calibrated mainly by adjusting fine sediment parameters including fall velocities, sediment angles of repose, and erosion critical shear stress.

In Figure 5, a comparison between the measured and simulated sediment load exiting the reservoir is given. Sediment load exiting the reservoir presents the efficient of the reservoir flushing. The comparison starts on April 10 when the reservoir incoming flows starts to increase in the spring. The model simulated the total sediment load exiting the reservoir in 2013 fairly well after that period.

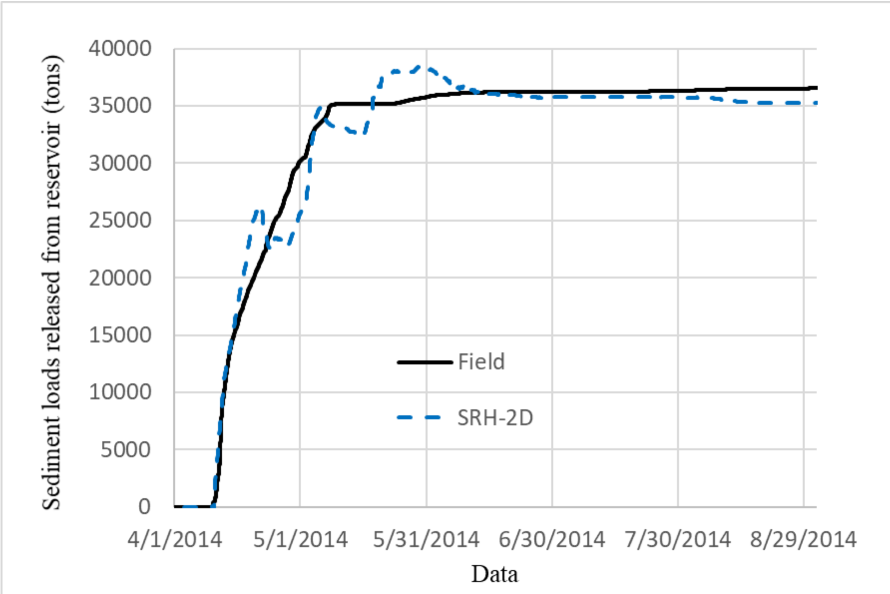

Figure 5. Calibrated 2D model total sediment loads compared to measured total sediment load exiting Paonia

The predicted outgoing suspended sediment concentration (Figure 6) reasonably fits the observations during high concentration measurements greater than 100 mg/l. The model fit is poorer during sediment concentrations less than 100 mg/l. Higher priority was made to matching the higher concentrations when most of the sediment flux in and out of the reservoir is occurring. For comparison, the reservoir incoming sediment concentration is also displayed in the figure.

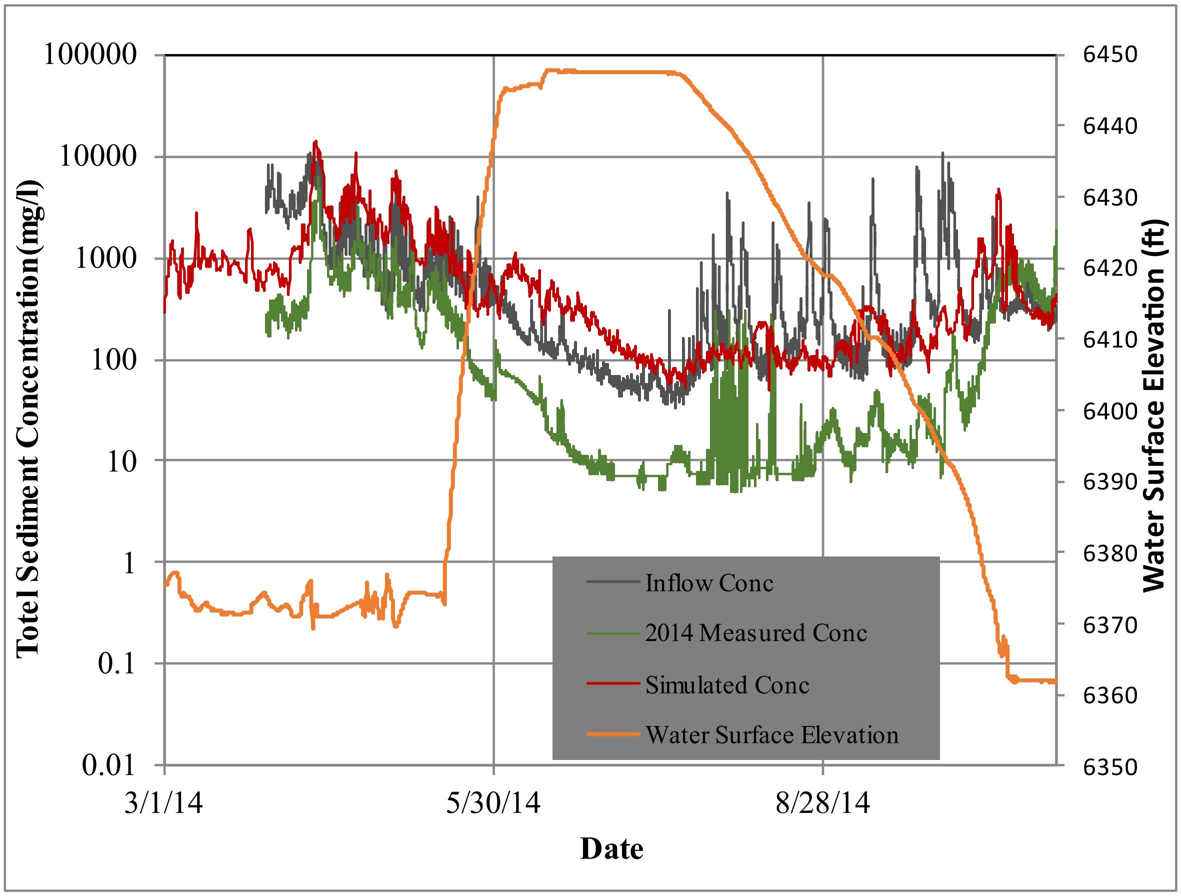

Figure 6. Simulated and observed suspended sediment concentration (mg/l).

Summary

1D and 2D models were calibrated and used to simulate the Paonia Reservoir drawdown flushing. The numerical models were calibrated using reservoir survey and sediment measurements from 2013 to 2014 by adjusting fine sediment parameters. The cumulative sediment load exiting the reservoir and sediment release concentration were used to compare the results.

The numerical models show that a spring sediment flush is a useful method to pass and remove sediment from Paonia Reservoir. Most of the sediment erosion occurs during the spring flush when the reservoir water surface elevation is low.

1D model can be used for long-term simulations when the reservoir width is low. 2D model are time consuming and can be used for short-term simulations.

Currently, the spring drawdown flush is used to manage the reservoir sediment at Paonia Reservoir to better extend its life span. This method could be used to other reclamation reservoirs. However, researches are desired to study the strategies for rewards and consequences of reservoir drawdown flushing. In the next step, 2D model will be used to study reservoir drawdown efficiencies when different shapes ranging from very narrow river-type reservoirs to lake-type reservoirs with large width.

Acknowlegement

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