Monitoring the Effect of Deep Drawdowns of a Flood Control Reservoir on Sediment Transport and Dissolved Oxygen, Fall Creek Lake, Oregon

Liam Schenk, Hydrologist, U.S. Geological Survey, Klamath Falls, Oregon, lschenk@usgs.gov
Heather Bragg, Hydrographer, U.S. Geological Survey, Portland, Oregon, hmbragg@gmail.com

Introduction

Annual reservoir drawdowns at Fall Creek Lake, Oregon, have occurred for eight consecutive years from December 2012 to November 2019. The annual drawdowns are the result of the 2008 Biological Opinion of the US Army Corps of Engineers (USACE) Willamette Valley Project operations, which directed the USACE to carry out interim operational measures that would provide volitional downstream passage for endangered species act (ESA)-listed Chinook salmon. At Fall Creek Lake, the USACE modifies its operations by lowering the reservoir elevation to 690-ft, approximately 40 feet below the normal winter low-pool elevation. This action results in a run-of-river scenario through the dam allowing juvenile Chinook salmon to safely pass through the regulating outlets. Monitoring of juvenile Chinook salmon in screw traps at the outlet of the dam has shown variable timing in out-migration associated with reservoir elevation, and that most of the juvenile fish exited the reservoir when the pool elevation passed 700-ft (Taylor and others, 2015). The annual drawdown has therefore been effective in providing safe downstream fish passage and has also had the collateral effect of transporting large quantities of suspended sediment to the downstream reaches of Fall Creek and the Middle Fork Willamette River. The US Geological Survey (USGS) has calculated time-series of suspended sediment concentrations (SSC) and suspended sediment loads (SSL) before, during, and after the drawdowns for six of the last nine drawdown years (water years [WY] 2013-2018), which have lasted between 5-14 days. The transport and deposition of sediment from the drawdowns has affected side-channel habitat below the dam by depositing large quantities of sand-size material resulting in streambed aggradation in several locations. The results from the USGS monitoring effort have provided important information to USACE on how the modification of their operations has affected sediment transport in the river reaches below the dam.

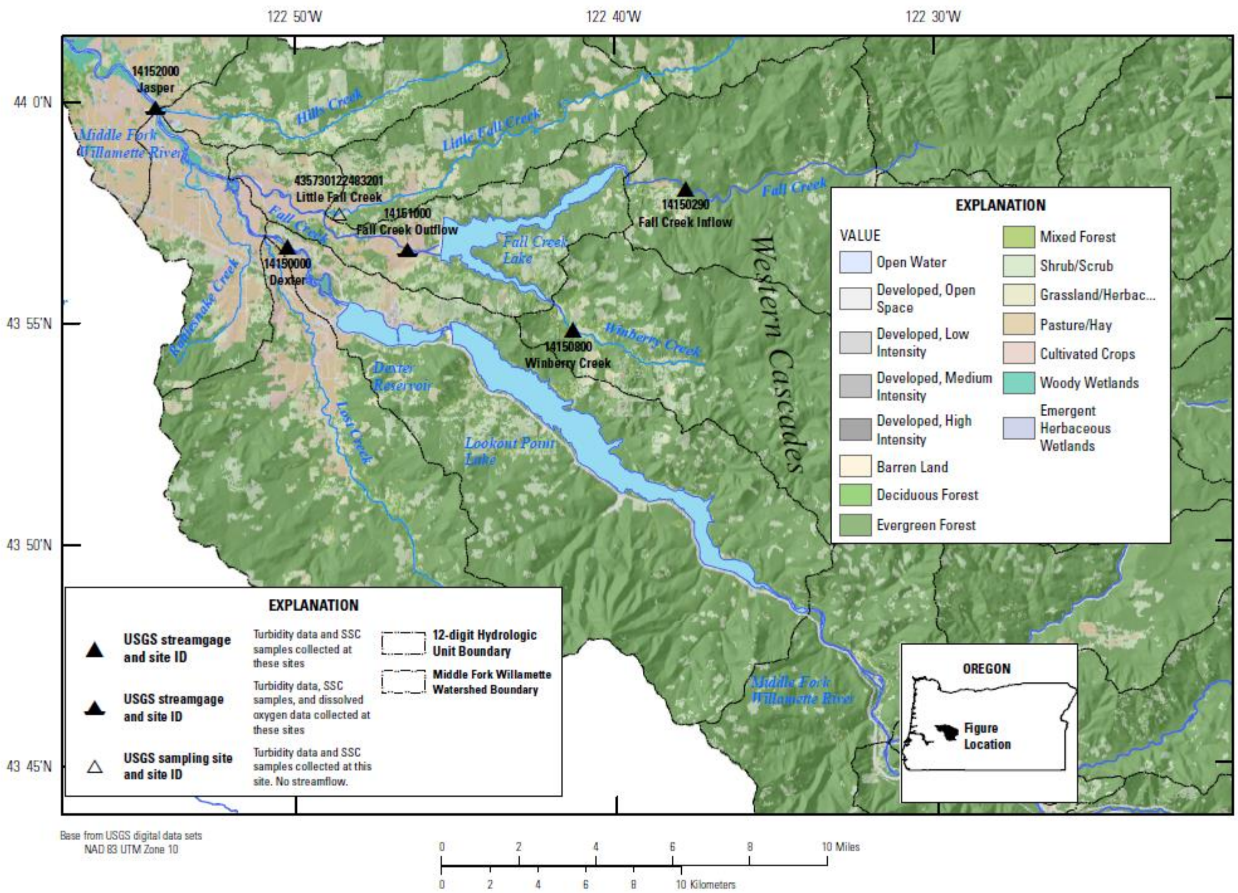

Figure 1. Project Area Map

Data Collection and Analysis Methods

The USGS monitored turbidity, dissolved oxygen, and suspended sediment over a range of hydrologic conditions and sediment transport during the drawdown operations at Fall Creek Lake (Figure 1). Monitoring in all years typically began in November and ended in February or March. USACE conducted a drawdown operation in water year (WY) 2012, during which no sediment samples or turbidity data were collected. USGS began monitoring in WY 2013, when six monitoring stations were established for the lake and at strategic locations downstream, including the two main inflows to Fall Creek Lake, Fall Creek below Fall Creek Dam (Fall Creek Outflow in Figure 1), Little Fall Creek (a tributary to Fall Creek), and two sites on the Middle Fork Willamette River (Dexter and Jasper). Results from the WY 2013 monitoring, including a short-term sediment budget are presented in Schenk and Bragg (2014). During WY 2014-2018, only the stations at Fall Creek Outflow and Jasper were monitored. Turbidity sensors measuring in Formazin Nephelometric Units (FNUs) and dissolved oxygen sensors were deployed on Hydrolab multi-parameter instruments (sondes), and Equal-Width-Increment (EWI) suspended-sediment concentration (SSC) samples were collected at all sites. Automatic pump samplers were installed at several sites to provide additional SSC data. Correction coefficients (box coefficients) were calculated to adjust the pump sample concentrations to cross section EWI samples. All samples were analyzed for SSC (in milligrams per liter [mg/L]) and percent finer than 63 microns (% fines) at the USGS Cascades Volcano Observatory sediment lab. Each discrete SSC sample was assigned an associated turbidity and streamflow (in cubic feet per second [cfs]) value from the continuously monitored instream data.

Site-specific regression models were developed from discrete turbidity, streamflow, and SSC data. Sample data for sites downstream of the dam were divided into pre-drawdown, drawdown, and post-drawdown analysis periods. Log10-transformed and untransformed turbidity and streamflow data were used to create both simple and multiple linear regression models which were based on residual plots and summary statistics. Model development followed USGS guidelines outlined in Rassmussen et al. (2009). The preferred models were used to compute continuous SSC records for each of the sites. Continuous suspended-sediment loads were computed from the SSC and streamflow records. For WY 2013, suspended-sediment loads were computed for all six stations. For WY 2014-2018, suspended-sediment loads were only computed for Fall Creek outflow, during and after the drawdown, for comparison to SSL calculated in WY 2013. SSC samples, turbidity data, and dissolved oxygen data were collected at the Jasper site in WY 2014-2018, but poor mixing of suspended sediment in the channel made turbidity-SSC relations difficult since the turbidity sensor was deployed on the right edge of water, where SSC concentrations were higher than the left edge of water during storm events and the drawdown periods. As a result, this poster will focus on data at Fall Creek outflow (USGS site 14151000), where SSC, turbidity, and dissolved oxygen data were consistently collected for six consecutive drawdown operations.

Suspended Sediment Loads

SSL computed for the drawdowns in WY 2013-2018 do not represent all the sediment removed from behind Fall Creek dam since the dam was constructed in 1966. Operational drawdowns at Fall Creek Lake have occurred on multiple occasions from 1974 to 1988, and in WY 2012 prior to USGS monitoring efforts. Therefore, sediment loads presented here should be viewed within the context of other drawdowns that have occurred without any knowledge of sediment transport in those years.

SSL below Fall Creek dam were highest in WY 2013, the first year of USGS monitoring and the second consecutive drawdown since 1988. During the 6-day drawdown in December 2012, approximately 50,000 tons of sediment were measured downstream of the dam (Figure 2). That year's drawdown also resulted in approximately 16,300 tons of sediment deposited in the reaches between Fall Creek Lake and the Middle Fork Willamette at Jasper, which is 10 miles downstream of the lake (Schenk and Bragg, 2014). Due to unusually cold weather that froze the surface layer of sediment within the reservoir, SSL during the WY 2014 drawdown was particularly low. The area received 8–10 inches of snow followed by air temperatures consistently below freezing for most of the drawdown period concurrent with low streamflow, resulting in a total sediment load of approximately 5,220 tons during the 10-day drawdown period (Figure 2). SSL from WY2015-2018 were approximately 10,000 tons each year and show an overall decrease regardless of average streamflow during the drawdown period or the duration of the drawdown in those years, suggesting that streamflow has not been greatly influencing the SSL since WY 2015.

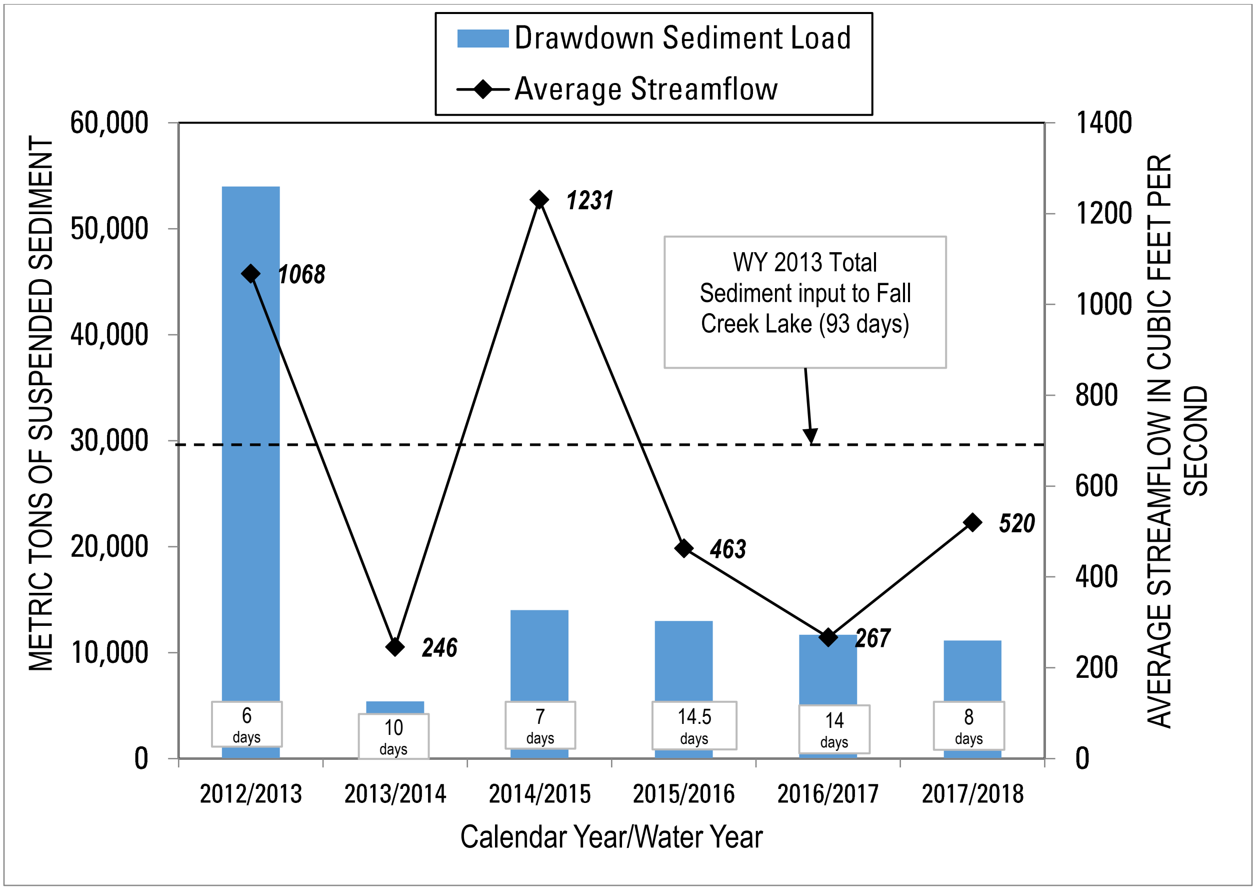

Figure 2. Sediment loads WY 2013-2018

The WY 2013 drawdown resulted in a change in sediment trap efficiency of the lake, from 74% pre-drawdown to 67% post-drawdown (Schenk and Bragg, 2014). Total inflow SSL for the monitoring period in WY 2013 (93 days) was approximately 30,000 tons compared to an average of approximately 10,000 tons from each drawdown in WY 2015-2018. Assuming the annual inflow SSL to Fall Creek Lake is greater than 30,000 tons, this suggests that the drawdown operations have reached a point where a small percentage of the SSL entering the lake over a given water year are being transported out of the lake during the drawdown. One explanation of the reduced sediment loads is the channel morphology within the reservoir during the drawdown. Geomorphic studies have shown that the stream channel within the reservoir during the drawdown is highly constrained, does not erode much of the channel banks during the drawdown periods, and therefore does not access much of the sediment deposited on the areas that are topographically higher than the streambed (Keith and others, 2018), where much of the sediment from the basin is likely deposited throughout the year.

Changes in Sediment Characteristics

Turbidity monitoring and percent fines data from SSC samples have given insight into how sediment characteristics change during the operational drawdowns. In every year of USGS monitoring, the slope and intercept terms of the turbidity-SSC regressions shifted considerably from pre-drawdown to drawdown time frames, resulting from changes in turbidity response to grain size distribution in the SSC samples. Turbidity sensors will have different responses to fine grained versus coarse grained (sand-size) material in suspension, with fine grained samples having more light scattering and higher turbidity values versus less light scattering and lower turbidity values for sand-sized material (Merten and others, 2014). Turbidity-SSC relations from this study follow this theory up to turbidities in the 200 FNU range as shown in Figure 3, which shows how the slopes of the regressions change with the percentage of sand-sized material in the SSC samples. At turbidities above 200 FNU, the regression lines shift from the theoretical turbidity sensor response, which may be the result of the presence of both fines and sand-size material in the samples. The lab studies conducted by Merten and others (2014) evaluated samples with an equal distribution of grain sizes, which may lead to inconsistencies with the theoretical turbidity response from our environmental samples. Because of the grain-size shift during the drawdowns, multiple regression equations were used each year in short durations to reflect the changes in sediment characteristics. Regression equations also changed year-to-year during the drawdowns, so new evaluations of turbidity-SSC relations were required for each individual monitoring period.

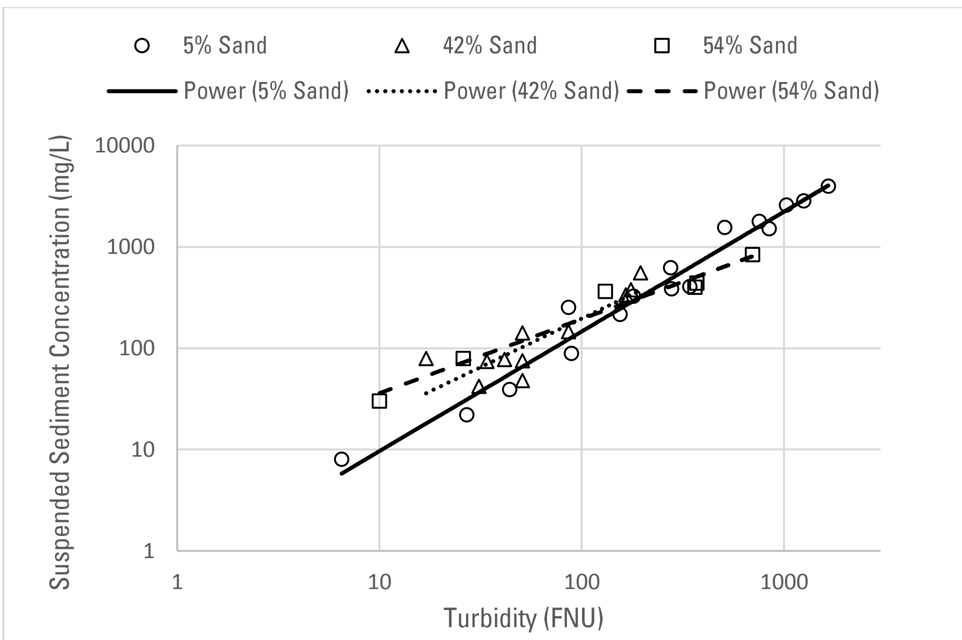

Figure 3. Regression lines for Turbidity-SSC models based on grain size

The shift in grain-size distribution in SSC samples as measured by the percent of fine-grained material less than 0.063mm (percent fines) occurred toward the end of the drawdown and after the reservoir began refilling in all the monitoring years. In the first few days of every drawdown, percent fines in the SSC samples was typically between 90-100%. Toward the end of every drawdown, and after the drawdown had ended, the percent fines in the samples decreased, reflecting an increase in sand-sized material in the samples. The sand-sized material was more readily deposited in side channel habitat downstream of the dam, and in areas of low velocity within the stream channels. The cause of the increase in grain size is unclear, and our monitoring efforts have found that the increase in sand-sized material in SSC samples occurs regardless of streamflow or of the regulating outlet gate positions during the drawdowns, suggesting that stream energy and gate management is not affecting the transport of sands in suspension. Particle settling velocity as described by Stokes Law dictates that coarse-grained material will fall out of suspension first as stream velocity decreases, followed by fine-grained particles (Guy, 1970). When Fall Creek Lake is drawn down to streambed, the fine-grained sediment is likely accessed first, followed by the coarser sediment. However, the shift in particle size in the SSC samples occurs toward the end of the drawdowns regardless of the drawdown length. It is possible that a combination of fines and sands are transported through the dam at the start of the drawdown, and that much of the sands are deposited in the channel just downstream of the dam outlet. Those sands could then be transported when the regulating outlets are closed at the end of the drawdown and much of the fines have already moved downstream.

Drawdown Influence on Dissolved Oxygen

Another collateral effect of the drawdowns is short-term decreases in dissolved oxygen concentrations concurrent with the first pulse of fine-grained sediment at the start of the drawdown. Dissolved oxygen data were collected using Hydrolab sondes in all years of USGS monitoring except WY 2014 when no dissolved oxygen data were collected. In most years, excessive sensor fouling resulted in data loss when the first pulse of sediment was released from behind the dam. After modifications to the deployment structure for the sondes was implemented in WY 2016, data integrity improved, and a minimum dissolved oxygen concentration of 0.7 mg/L was recorded coincident with the peak in turbidity at the start of the drawdown. The dissolved oxygen minimum value was verified by independent sensors deployed by the field crew (Schenk and Bragg, 2017, Figure 4). The low dissolved oxygen event was short, with concentrations remaining below 5 mg/L for approximately one hour. This quick expression of oxygen demand suggests that the demand is chemical in nature and is likely the result of rapid oxygenation of reduced sediments trapped behind the dam. Concurrent studies of the drawdowns by Oregon State University confirm this hypothesis, having shown spikes in reduced nitrogen represented by ammonia concentrations at the onset of the drawdowns, and have also suggested that the oxygen demand of the sediments is “modest” (Johnson and others, 2017).

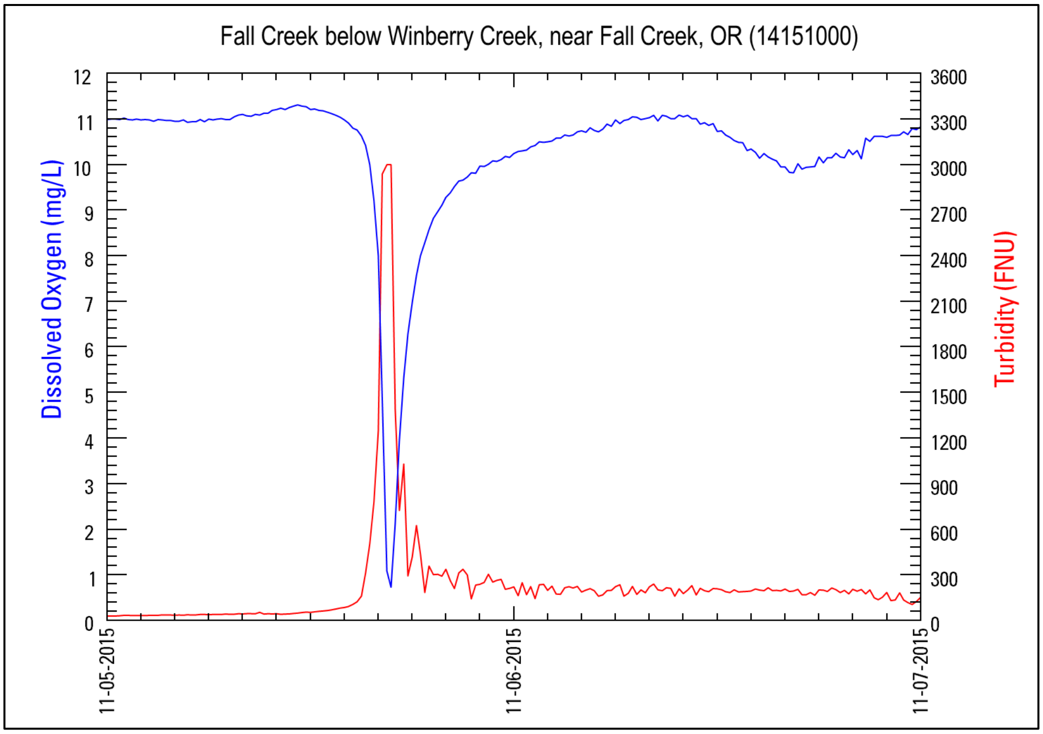

Figure 4. Dissolved oxygen concentrations during the WY 2016 drawdown

Summary

The streambed drawdown of this flood control reservoir has successfully met the goal of providing volitional passage of ESA-listed juvenile chinook salmon through the regulating outlets of Fall Creek dam. The collateral effect of large sediment transport events and short-term low dissolved oxygen events has been well documented through six years of data collection efforts by USGS. Sediment loads were highest in the first year of drawdown monitoring, which was also the second consecutive year of the drawdowns and have been steadily decreasing from 2015-2018 through various hydrologic regimes, suggesting that sediment supply is now the controlling factor in sediment loads compared to the effect that streamflow appeared to have on sediment transport in the first two years of monitoring (WY 2013-2014). The transport of sand-sized material that occurs toward the end of the drawdowns and when the reservoir is refilling has caused sediment deposition and aggradation in off-channel habitats, backwaters, and low-velocity zones within the channel margins downstream of the dam. In some locations, emergent vegetation has inhibited the sediments from being mobilized at the highest flows allowed in the channel. Short term periods of anoxia have resulted from the first release of reduced sediments from behind the dam at the start of the drawdowns. The oxygen demand is typically expressed over short time frames (approximately 1 hour when measured at a fixed location) and occurred after most of the juvenile chinook salmon had passed through the dam. The effect of the drawdowns on sediment transport and dissolved oxygen are specific to this flood control reservoir, but the results of this effort can help inform drawdown operations that may be considered at other reservoirs. Some application of these results could be used to evaluate such operations, but site-specific investigations would best inform implementation of those actions.

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