Sediment Mass Balance for Cougar Reservoir Sediment Releases

Supplement to "Evaluation of Fine Sediment Intrusion into Salmon Spawning Gravels as Related to Cougar Reservoir Sediment Releases"

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INTRODUCTION

Retrofitting Cougar Dam on the South Fork McKenzie River, Oregon, with a temperature control structure required drawdown of Cougar Reservoir over several months during spring 2002. The drawdown initiated incision of the reservoir delta that had developed in the 40 years since Cougar Dam was constructed. Remobilization of deltaic sediments resulted in a sustained release of turbid water from Cougar Reservoir from April to July 2002, prompting concern that sediment contained within the turbidity plume might intrude into river gravels, with potentially negative effects for fish and other aquatic biota.

Scope of Report

In August 2002, the Corps of Engineers (COE) contracted with Oregon State University and the USDA Pacific Northwest Research Station to conduct an investigation to determine: 1) to what extent and depth have fine sediments associated with the reservoir drawdown intruded into gravels in the South Fork McKenzie below the dam; and 2) to a first approximation, how much of the sediment released from the reservoir has traveled in suspension through the McKenzie River system and how much was still stored in the basin. The first objective was addressed in an October 4, 2002 report to the Corps titled "*Evaluation of Fine Sediment Intrusion into Salmon Spawning Gravels as Related to Cougar Reservoir Sediment Releases*" (Stewart and others, 2002).

In this supplemental report, we address the second objective. Here we make a rough mass balance calculation of the total suspended sediment released from Cougar Reservoir from April 1 to July 1, 2002, and compare it with the total suspended sediment measured 45 miles downstream at the EWEB Hayden Bridge water treatment facility (Figure 1). These results are expressed as a ratio of total downstream sediment mass to upstream sediment mass as a means of estimating the fraction of total sediment released from the reservoir that remains in the system. Because of the assumptions and error in this method, the results provide only an order of magnitude calculation, but are useful for estimating whether some, most, or all of the sediment has been transported downstream, or may have been deposited in the bed.

We first present the timing and details of the Cougar Reservoir drawdown, and describe the nature of the turbidity pulse that traveled downstream. We then explain our methods for the collection and calculation of the discharge, turbidity and suspended sediment concentration data sets needed to estimate sediment flux. Finally, we summarize our findings and discuss them in the larger context of our investigation into the sediment release.

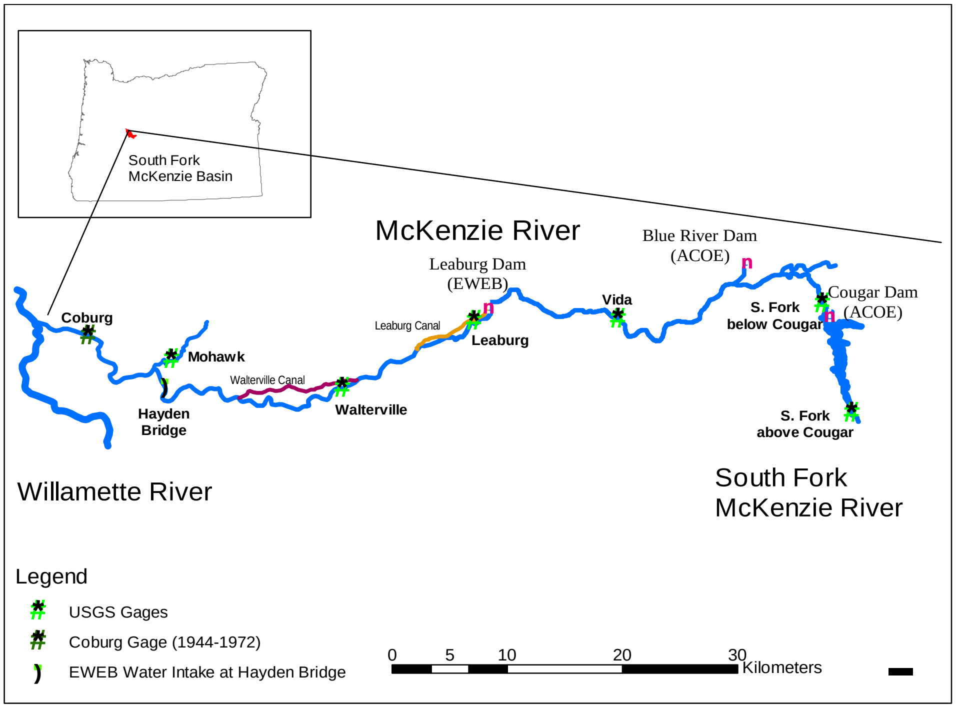

Figure 1. Location Map

Reservoir Drawdown

In order to lower the reservoir below normal operating levels, the diversion tunnels used in construction of Cougar Dam were blasted clear on February 23rd, creating a brief spike in turbidity downstream of the dam (Figure 2). Turbidity levels remained within normal seasonal levels until April 1st, when the reservoir dropped below "low pool"; the minimum flood-control elevation of 1535 ft. Turbidity began to rise in the reservoir and also became noticeable in the South Fork downstream of the dam. On May 25th, the Corps stopped lowering the reservoir (at 1400 ft), and was releasing water with an average turbidity of 106 NTU. Turbidity in Cougar Reservoir did not return to pre-drawdown levels (~1 NTU) until early September.

DATA SETS AND CALCULATIONS

In calculating sediment flux we utilized discharge and turbidity measurements made during the time of reservoir drawdown at two sites: USGS gaging station 14159500 (South Fork McKenzie below Cougar Dam) and the EWEB Hayden Bridge water treatment facility. Both sites record turbidity every half hour using optical measuring devices; the USGS site also records discharge, but only river stage is recorded at Hayden Bridge. Methods used to estimate Hayden Bridge discharge and suspended sediment concentration and to calculate sediment flux are detailed below.

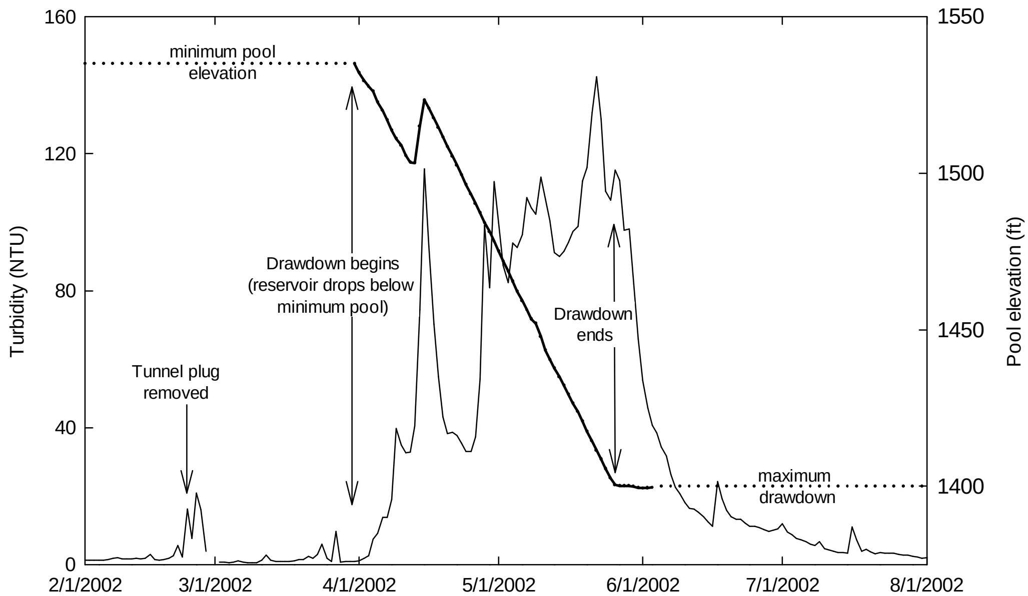

Figure 2. Turbidity during Cougar Reservoir drawdown. Average daily turbidity (solid line) from USGS gage below Cougar Reservoir; Cougar Reservoir pool elevation data (dotted line) provided by COE.

Discharge at Hayden Bridge

Since the EWEB Hayden Bridge water treatment facility does not record discharge, an estimate of discharge must be made using available USGS gage data from upstream and downstream of Hayden Bridge (Figure 1). We used three gages for this calculation: McKenzie River at Vida (14162500), Mohawk River (14165000), and McKenzie River at Coburg (discontinued in 1972). The Walterville and Leaburg gages, although also potentially useful, are each located within a reach of the McKenzie that is partially diverted into the EWEB power canal, and therefore underestimate the discharge of the McKenzie.

Given the data sets available, a good approximation of historic Hayden Bridge (HB) discharge can be made by subtracting the discharge of the Mohawk River (which enters the McKenzie 1.2 miles downstream from HB) from the discharge of the McKenzie River at Coburg (7 miles downstream from HB). The Mohawk River is the only significant inflow to the McKenzie between HB and Coburg. We recognize that this approach slightly overestimates the actual discharge at HB, since it does not account for localized inflows along the 7 miles between HB and Coburg. As the Coburg gage is no longer in service, we developed a regression for our Hayden Bridge proxy (Coburg minus Mohawk) vs. Vida for the period of record (1944 to 1952; 1963 to 1972). This regression is based on mean daily discharges; instantaneous discharges are likely to be somewhat higher during storms. A linear model was fit to the data with an R^2 of 0.92 (Figure 3). We then used this relationship to calculate spring and summer 2002 discharges for Hayden Bridge based on data from the Vida gage.

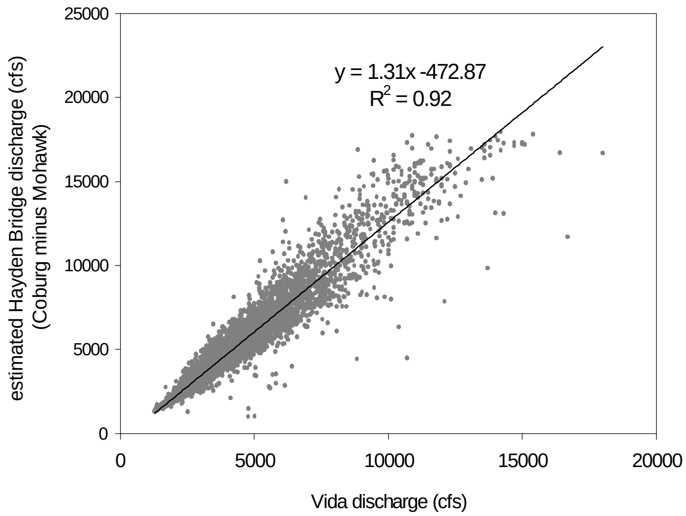

Figure 3. Regression of mean daily discharges of <20,000 cfs for water years 1944 to 1952 and 1963 to 1972. This linear regression was used to estimate discharge at Hayden Bridge for April to June 2002.

Suspended Sediment Concentration and Sediment Flux

At both Cougar Reservoir and Hayden Bridge, we transformed the turbidity measurements into suspended sediment concentrations (SSC), using relationships developed for turbidity and suspended sediment for the North Santiam River (Uhrich and others, in review). We recognize that SSC/turbidity relationships could potentially differ for the Santiam and the McKenzie, but we use the Santiam data set because: 1) it represents the best available data set relating turbidity to SSC over a range of flows for the western Cascades (similar work has not been done for the McKenzie); 2) geology in the Santiam and the McKenzie is quite similar, particularly in the types of clays present that contribute to turbidity (Bates and others, 1998; Hulse and other, 2002); 3) stream-to-stream variability within the Uhrich data set is relatively modest (see Table 1), suggesting that it can provide a first-order approximation of the SSC/turbidity relationship elsewhere, and; 4) using the same relationship for both the Cougar Reservoir and Hayden Bridge sites introduces no systematic bias into the calculations, and can therefore provide a useful relative if not absolute calculation of sediment transport.

We used the composite SSC/turbidity relationship developed from USGS measurements at Breitenbush River (14179000; drainage area 108 mi^2), Blowout Creek (14180300; drainage area 26 mi^2) and the North Santiam River (14178000; drainage area 216 mi^2) for water years 1999 to 2001 (Table 1). The resulting power law relationship ($SSC = 1.91T^{1.03}$) was used to convert daily mean turbidity measurements for Cougar and Hayden Bridge to SSC. By compositing the SSC/turbidity data from all three streams measured by the USGS, we incorporated data from two basins whose drainage areas are of the same order of magnitude as the South Fork below Cougar Reservoir (208 mi^2), and a smaller basin, but one with a high concentration of clay-rich earthflows, similar to that observed on the South Fork. We chose this approach rather than using the SSC/turbidity relation for any

Table 1. Estimated sediment mass flux on the McKenzie from April 1 to July 1, 2002 for different SSC/turbidity relationships for the North Santiam. Data from all three sites was used in final analysis.

	Regression	r^2	Cougar (kg)	Hayden Bridge (kg)	Difference (kg)	Sediment transported	Sediment stored
ALL DATA							
4/1 to 5/23			35,714,078	22,118,401	13,595,677	62%	38%
5/24 to 7/1			6,748,138	4,426,844	2,321,294	66%	34%
total	$\mathbf{y = 1.91x^{1.03}}$	**0.92**	**42,462,216**	**26,545,245**	**15,916,971**	**63%**	**37%**
Other Totals							
N. Santiam & Breitenbush	$y = 2.03x^{1.01}$	0.92	41,379,084	26,843,151	14,535,932	65%	35%
N. Santiam	$y = 1.88x^{1.04}$	0.91	43,650,488	26,788,283	16,862,205	61%	39%
Breitenbush	$y = 2.12x^{0.99}$	0.93	39,626,870	26,676,362	12,950,508	67%	33%
Blowout	$y = 1.63x^{1.08}$	0.92	39,513,337	22,523,034	16,990,303	57%	43%

one particular stream because we felt that using all three best captured the effects of both stream size and geology. Even though the drainage areas are similar, we decided not to use the North Santiam River relation alone because the North Santiam above the measurement site drains mostly High Cascade geology, which is likely to have a substantially different clay signature from waters released from Cougar. In fact, the results we obtained are relatively insensitive to choice of SSC/turbidity relation, as we calculated fluxes using relations obtained from different combinations of the three gages without significantly affecting the results (Table 1).

RESULTS

Sediment Mass Balance

Daily suspended sediment concentrations were multiplied by the corresponding mean daily discharge to give total suspended sediment flux per day (Figure 4). For each site, we integrated over the entire discharge record for the period of increased turbidity (April 1 to July 1) to come up with a total sediment mass flux during that period (Table 1). Note that sediment flux through the outflow is heavily dependent on discharge, which is controlled by the dam at Cougar Reservoir. Further settle-out of sediment at Leaburg Reservoir and tributary contribution downstream also influence turbidity levels measured at Hayden Bridge.

Between April 1 and May 25, 2002, the period of the actual drawdown, we estimate that approximately 35 million kilograms of sediment passed through the outflow of Cougar Reservoir. Over that same time period, we estimate that 62% (approximately 22 million

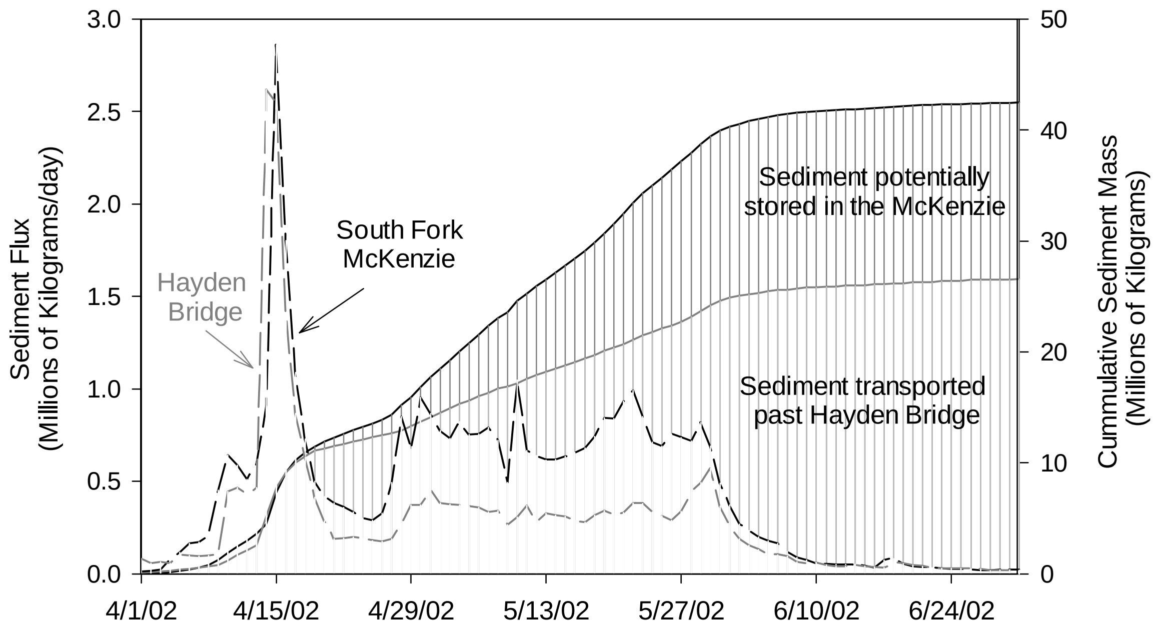

Figure 4. Suspended sediment flux (dashed lines) and cumulative sediment mass (solid lines) for South Fork McKenzie below Cougar Reservoir (black) and Hayden Bridge (gray) from 4/1 to 7/1/02. Difference between the two cumulative curves represents an estimate of total sediment stored (15.9 million kg) between the two sites.

kg) was transported past the water intake at Hayden Bridge. As shown in Figure 4, the shape of the turbidity pulses detected at Cougar Reservoir and HB were similar, suggesting that Cougar Reservoir is the source for the turbidity detected at HB. Both sediment flux curves exhibit an initial peak due to a sustained rainfall event, and a relatively sustained release over the following month. The initial peak of sediment at HB prior to the peak at Cougar is an artifact of the data that at high turbidity levels, discharge dictates total flux, and discharge at Hayden Bridge was greater than discharge at Cougar during this period.

Turbidity was actually rising in the reservoir during the drawdown (Figure 2), but the corresponding discharge was decreasing, resulting in a relatively constant mass of sediment being released. When the drawdown ended, and the turbidity in the reservoir decreased due to diminished input, settle out, and dilution, the sediment flux curves rapidly and exponentially declined, and the proportion of released sediment detected at Hayden Bridge increased slightly to 66%, which represented approximately 4.4 million kg of sediment transported.

Implications of Findings

We estimate that of the 42 million kilograms that was released from Cougar Reservoir from April 1 to July 1, 2002, 63% (26.5 million kg) was flushed through the system, and 37% (15.9 million kg) may have been stored between Cougar Reservoir and Hayden

Table 2. Estimated bed thickness of 15.9 million kilograms of sediment spread uniformly over different reach lengths

	Estimated Distance (m)	Estimated average river width (m)	River bed area (m2)	Mass (g) or Volume (cm3)*	Thickness of deposit
S.Fork (Cougar to confluence)	6450	24	162500	1.59E+10	9.9 cm
McKenzie River (confluence to Hayden Bridge)	65900	61	3954000	1.59E+10	4.0mm
Cougar Reservoir to Hayden Bridge	72400	~	4116500	1.59E+10	**3.9 mm**

Bridge. Although these appear to be large numbers, the likely impact at any given location along the river is expected to be relatively modest. We can estimate the thickness of sediment represented by this stored sediment from rough estimates of river length, width and sediment density (Table 2). From these calculations we estimate that if the released but unaccounted for sediment was spread out to a uniform thickness along the river beds of the South Fork and mainstem McKenzie, it would create a blanket of fines only 3.9 mm thick. If the sediment were concentrated and deposited just in the South Fork alone, before it reached the McKenzie, it would have been 9.9 cm thick.

A thin blanket of fine sediment on the river bed is consistent with our visual observations of muddy substrate, as clouds of sediment were stirred up while wading in the South Fork below Cougar Dam, but were not present above the dam, and were less present in the mainstem McKenzie. As noted by Stewart and others (2002), our cores did not reliably capture the top layers of surface sediment, because the coarse surface substrate tended not to freeze completely and would shear off during collection. But a rough test of whether our mass balance estimates are reasonable can be obtained by taking the amount of fine sediment (silt and clay) measured during grain size analysis in the five cores (SFB-2,-3,-4) below the reservoir on the South Fork, and the two cores on the lower McKenzie (MS-2, -3). These five cores produced an average of 60g of fine sediment (clay and silt) per core. Spreading the hypothesized 9.9cm thick fines layer for the South Fork alone over the approximately 200cm^2 surface area of an individual core should produce 1980 grams of fines. If, however, we use the estimate of fines deposited for the entire McKenzie length (0.39 cm) and spread it over a the same core surface area, the resulting mass of fines would weigh 78 grams, which is of the same order of magnitude of the our estimate for the 5 freeze cores (60 g).

DISCUSSION AND CONCLUSIONS

These order-of-magnitude calculations suggest several conclusions. First, the pattern of sediment release from Cougar Reservoir through time persisted for many miles and was clearly detectable at Hayden Bridge 45 miles downstream. The overall pattern in timing and relative magnitude of peaks and troughs of sediment transport is quite consistent between the two sites (Figure 4). The absolute volume of sediment detected in the flow, which is calculated as the product of the concentration of sediment in the flow and the flow discharge, clearly diminished downstream. The concentration of sediment in the flow could diminish either by dilution from additional water without sediment, or by settle-out of sediment from suspension.

Taking changes in discharge into account, our calculations suggest that as much as one-third of the sediment released from Cougar may have been deposited within the South Fork and Main McKenzie rivers. Flow in the McKenzie is fully turbulent and the finest clays in suspension were likely transported through the McKenzie. The larger clays and silt fraction, however, may have been deposited on the surface of the bed and within the interstices of the gravels. Very approximate calculations suggest that the volume of sediment estimated to have been released from Cougar but not transported by Hayden Bridge – the residual sediment – could be accounted for by storage in the bed along the entire length of the McKenzie in a uniform thickness of approximately 4 mm. This conclusion is consistent with visual observations along the South Fork McKenzie but less so along the mainstem McKenzie. It is also somewhat at odds with our finding discussed in Stewart and others (2002) that a clear reservoir sediment signal in the clay mineralogy was not detectable below the South Fork confluence.

Although based on the best data available, these conclusions are influenced by a number of assumptions and interpretations, notably the methods used for relating measured turbidity levels to suspended sediment concentrations. Although these conclusions appear to be fairly robust in the face of different relationships for the Santiam watershed to the north, absence of an established relationship between suspended sediment and turbidity levels for the McKenzie hampers our ability to estimate sediment flux with a high level of confidence. A sediment monitoring effort similar to that underway in the Santiam watershed (see http://oregon.usgs.gov/projs_dir/or00311/) would permit better tracking of future sediment releases.

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