6 Sediment Problems and Consequences During Temporary Drawdown of a Large Flood Control Reservoir for Environmental Retrofitting

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Abstract

Retrofitting a large flood control dam on the South Fork McKenzie River, Oregon, USA with a temperature control structure required drawdown of Cougar Reservoir. 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, prompting concern that sediment contained within the turbidity plume might intrude into river gravels, with potentially negative effects for fish and other aquatic biota. We sampled gravels both upstream and downstream of Cougar Dam and on the mainstem McKenzie River both above and below the confluence with the South Fork to compare affected gravels to unaffected gravels. The results suggest that intrusion of very fine clays into gravel substrate can occur even when the clay is carried as wash load.

Keywords

Reservoir drawdown • Freeze cores • Sediment intrusion • Turbidity

6.1 Introduction

As part of an effort to improve river temperatures for aquatic organisms, the intake tower of Cougar Dam on the South Fork McKenzie River, Oregon USA was modified to allow operators to release colder water during the winter and warmer water during the summer, to improve habitat conditions for threatened bull trout and spring Chinook salmon. Cougar Reservoir was lowered below minimum pool elevation exposing deltaic and lake bottom sediments to reworking by the South Fork McKenzie and other reservoir tributaries. This resulted in a prolonged discharge of turbid water visible for hundreds of kilometers downstream. Between April 1st and May 25th, 2002, turbidity levels at the gauging station below the dam averaged 68 Nephelometric Turbidity Units (NTU) with spikes of up to 379 NTU.

The release of highly turbid water from Cougar Reservoir captured public attention and raised concerns over possible downstream impacts to fish and wildlife, including the potential negative impacts to spawning gravels by fine sediment intrusion. Fine sediments, including fine silts and clays that are typically transported as suspended load, can be driven into a coarser river bed by hydraulic forces or be deposited as bedload clay clasts. The accumulation of fine sediment via infiltration depends upon many factors including fine sediment concentration, bed particle grain-size, and the hydraulic gradient (Beschta and Jackson 1979; Carling 1984). Fine sediment intrusion into gravel bars is of interest because it may decrease bed permeability and intergravel flow rates (Koltermann and Gorelick 1995; Wu 2000), and can result in fish egg mortality and/or decreased habitat for macroinvertebrates (Einstein 1968; Richards and

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Bacon 1994). Depending on the depth of penetration, fine sediment can remain trapped in the bed until discharge exceeds the shear stress needed to mobilize the surrounding larger grains (Schalchli 1995).

6.2 Cougar Dam and Reservoir

Cougar Dam and Reservoir, operated by the US Army Corps of Engineers (ACOE), were constructed in 1964 along the South Fork of the McKenzie River. Its headwaters are in the High Cascades, with elevations >1,200 m underlain by glacial deposits and <2 million year (MY) old, porous, volcanic rocks. Most of the basin, however, is located in the Western Cascades, with elevations of 400–1,200 m underlain by 3.5–25 MY old, deeply weathered but relatively impervious, volcanic rocks. Landforms have been sculpted by fluvial, glacial, and mass movement processes; the latter include shallow, rapid movements of soil on hillslopes (debris slides), rapid movements of alluvium, colluvium, and organic matter down stream channels (debris flows), and large, slow-moving landslides (earthflows). Channels in this region are relatively steep with slopes ranging from 1 to 4 %, with beds of mixed alluvium and bedrock, and valleys narrowly confined by steep hillslopes.

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. Turbidity levels remained within normal seasonal levels until April 1st, when the reservoir dropped below "low pool"; the minimum flood-control elevation. Turbidity began to rise in the reservoir and became noticeable downstream of the dam. On May 25th, the ACOE stopped lowering the reservoir and was releasing water with an average turbidity of 106 NTU. Turbidity did not return to pre-drawdown levels ($\sim$1 NTU) until early September 2002.

6.3 Sample Collection

Nine sites were chosen for bed sediment sampling (Fig. 6.1): two sites *above* Cougar Reservoir on the South Fork McKenzie (SFA1 & SFA2); four sites *below* (SFB1, SFB2, SFB3, and SFB4); one site on the *mainstem* McKenzie above the confluence with the South Fork (MS1); and two sites below (MS2 and MS3). Because no pre-drawdown spawning gravels samples were available for comparison, we used a space-for-time replacement where sites above the dam and upstream of the confluence (e.g. not impacted by the release) were used as proxies for pre-drawdown samples and compared with sites downstream of the dam and in the mainstem McKenzie River. SFA1, SFA2 and MS1 are assumed to represent baseline conditions against which other sites can be compared. Sediment sampling was conducted using freeze cores, which involves pumping cold CO_2 into metal rods that have been driven into the bed of the river, and then removing the rods and the associated block of frozen river substrate.

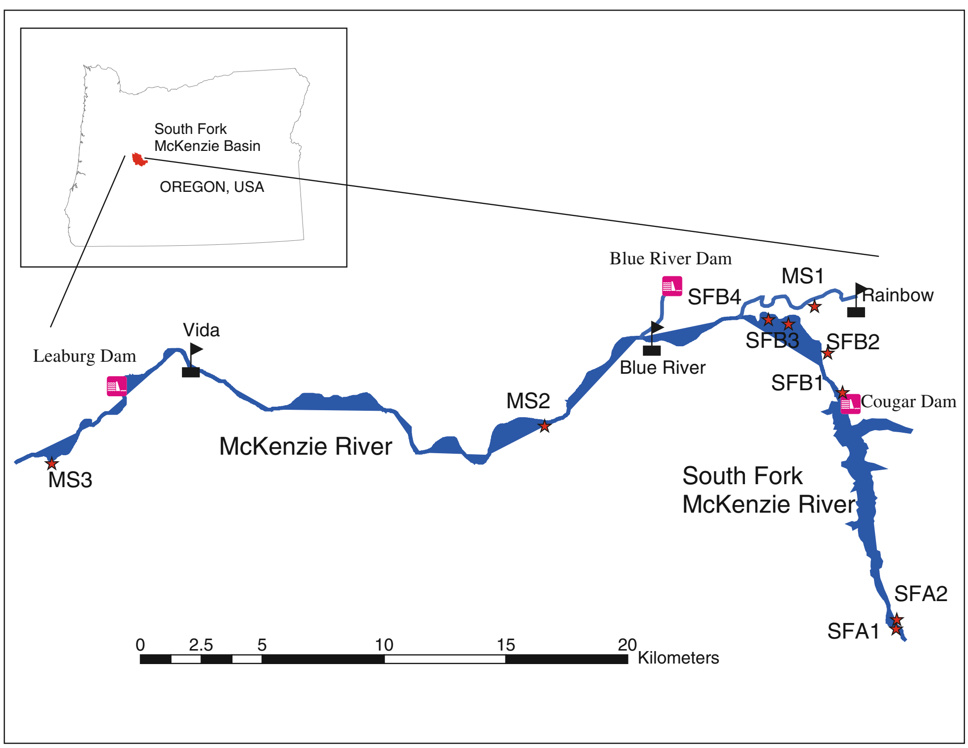


Fig. 6.1 Sampling sites along the mainstem McKenzie and South Fork McKenzie Rivers, Oregon

Each freeze core was subsampled into three or four depth intervals, maintaining bed sediment stratigraphy.

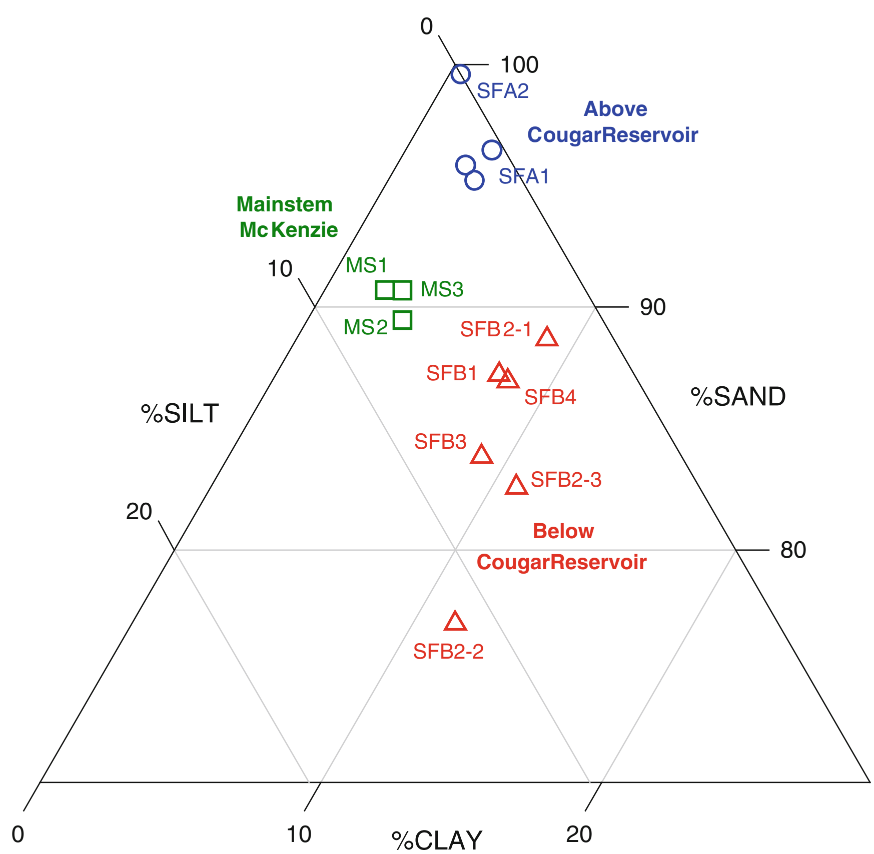
In the lab, grain-size analysis was performed on each of the freeze core bin to determine the quantity of fine sediment in the riverbed at different depths. Sediment from each bin was oven dried, and dry sieved. The fine fraction sediment was analyzed using a hydrometer tube, which calculated grainsize based on setting rates and measured water density. We also subjected at least one sample per core to X-ray powder diffraction (XRD) to fingerprint clay composition.

6.4 Results

Pebble counts and freeze core analyses reveal that all the sites are composed of moderately to poorly sorted, coarse to very coarse gravel. The subsurface grain-size generally mimics the surface grain-size with an average surface d_{50}/subsurface d_{50} ratio of 1.0, suggesting that little or no armoring has occurred in locations where salmon spawn. Sites SFA2 and SFB1 have the coarsest gravel and a ratio of 0.95, while, SFA1, SFB4, and MS3 have the finest gravel and a ration of 1.2. SFB2, SFB3, MS1 and MS2 are also composed of coarse gravel, yet the ratio is either significantly greater or less than one (0.5–1.3).

Grain-size above Cougar Reservoir (SFA1 and SFA2) is relatively uniform, both between and within sites. SFA1 and SFA2 are gravel dominated with minor amounts of sand and very little clay or silt. Grain-size below Cougar Reservoir (SFB1, SFB2, SFB3 and SFB4) is dominated by gravel with moderate amounts of sand and silt and relatively high clay abundance. All South Fork below dam samples are significantly enriched in all fractions of sediment less than 2 mm compared with upstream samples though silt and sand abundances are similar to the mainstem McKenzie sites, including the site above the South Fork confluence (MS1). Replicate cores at sites SFA1 and SFB2 show that downstream sites have much higher spatial variability in fine sediment when compared with upstream samples, but not enough variability to account for the differences in clay abundance. Clay abundance on the South Fork appears to peak at the upstream end of the South Fork alluvial reaches (SFB2) and decrease downstream. The mainstem McKenzie sites are dominated by gravel with moderate amounts of sand, silt and clay. While silt abundance on the mainstem McKenzie is higher than above the dam, they are similar to the South Fork sites and show no difference between sites located above or below the South Fork confluence. Mainstem samples below the confluence with the South Fork have significantly less clay than the South Fork samples,

Fig. 6.2 Relative abundances of sand, silt and clay for sampling sites *above* (*circles*) and *below* (*triangles*) Cougar Dam on the South Fork, and on the mainstem (*squares*) McKenzie River



approaching the low levels found above the dam and above the South Fork confluence.

When fine sediment data are plotted on a ternary diagram, the sites break out into three general groups: South Fork above the dam, South Fork below the dam, and mainstem McKenzie (Fig. 6.2). Taken with the other data, this plot suggests that only the South Fork samples were significantly affected by the sediment release and only in terms of their clay content.

6.5 Discussion

Grain-size analysis of the South Fork and mainstem McKenzie river sediments suggests a relative enrichment in fines in the alluvial reaches below Cougar Reservoir as compared with the reaches above the reservoir. Upstream reaches and mainstem McKenzie sites have clay fractions representing 2.5 % of the <2 mm sample by weight as opposed to 9.5 % in the South Fork below the dam. An increase in fines is not detectable below the confluence of the South Fork on the mainstem McKenzie River. Because no in situ sampling of gravels was conducted prior to the reservoir release in the spring of 2002, we are unable to discern whether this fines enrichment pre-dated the release. In general, however, it is unusual to see significant quantities of fine sediment stored in channel beds below dams, as reservoirs typically act as large-scale sedimentation tanks where fine sediment deposition occurs.

Enrichment of the gravels with reservoir-derived fines is supported by the presence of distinct mineral assemblages, notably pedogenic quartz and mixed-layer clays, as indicated by the XRD measurements. In particular, the presence of elevated quartz in the below dam South Fork samples argues for pool erosion during drawdown as the source of the elevated clays. This is because under "normal pool" conditions, the higher settling velocity of quartz would result in its settling out and fractionation from the water column. In other words, water released under normal operating procedures would not tend to be enriched in quartz. The most likely source for the quartz that was observed below the dam is re-entrainment of previously deposited reservoir sediments, as occurred during the drawdown.

Although an interpretation of enrichment of gravels below Cougar Dam due to reservoir drawdown is supported by increased clay abundance in the gravels and the mineralogic signature of the clays, we are constrained from interpreting the higher clay levels found below the dam as *exclusively* due to the drawdown. There is a difference in depositional environments between sampled reaches above (average gradient 1.2 %) and below the dam (0.7 %) on the South Fork; suggesting a higher energy environment for the upstream reaches. The upstream channel is generally bedrock-floored, narrow, and boulder-filled, in contrast to the wider, alluvium and outwash-dominated fan environment with multiple channel threads. These geomorphic differences will inevitably result in greater deposition of finer-grained facies below the dam, and could result in some of the upstream/downstream differences observed. Furthermore, there is no systematic trend of decreasing clay abundance with distance downstream from the dam; in fact, the site closest to the dam (SFB1) has the lowest clay percentages. The replicate analyses at site SFB2 also show wide scatter in proportion of sand, silt and clay (Fig. 6.2). So although the evidence points in the direction of a dam- and drawdown-driven effect, these results are not unequivocal.

Although measurable, we did not consider whether the increased volumes of fines stored in the gravel below Cougar Dam are "big" or "little" numbers from the standpoint of river function or ecological impacts. Additionally, persistence of this fine-sediment enrichment will depend on the frequence and depth of scour of subsequent gravel transport events, and whether the reservoir again experiences high and sustained turbidity.

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