DOWNSTREAM SEDIMENT IMPACTS ON FISH RESTORATION, RIVER DYNAMICS, FLOODPLAIN DEVELOPMENT, AND WATER QUALITY FROM BREACHING THE ELWHA AND GLINES CANYON DAMS, NEAR PORT ANGELES, WASHINGTON

Dr. Frank Reckendorf, Fluvial Geomorphologist, Reckendorf and Associates, Salem, Oregon, frecken@mac.com
Dr. Barry Southerland, Fluvial Geomorphologist, NRCS, WNTSC, Water Quality and Quantity Technology Development Team, Portland, Oregon, barry.southerland@por.usda.gov

INTRODUCTION

The Natural Resources Conservation Service (NRCS) in Washington generated a request for post-project appraisals of Engineered Log Jams (ELJs) in December of 2005. In February of 2006 the Washington NRCS in Spokane, and the West National Technical Support Center of NRCS in Portland, Oregon, assembled an interdisciplinary team including two fluvial geomorphologists, a fisheries biologist, and a stream-mechanics engineer. They were to study the results of the ELJs Implementation since the mid1990s in the State of Washington. One major study site was the ELJs on the Lower Elwha River. During the 2010 evaluation of the Lower Elwha it was decided to extend the study to look at the effects of sedimentation on the Elwha River and the ELJs once a large dam removal project started in 2011. We monitored 49 ELJs on the Lower Elwha River between 2006 and 2013.

Two hydroelectric dams were constructed on the Elwha River by a private company in the early part of the last century. Elwha Dam was constructed in 1910, and the Glines Canyon Dam in 1925. They were constructed without regard to fish passage facilities, although regulations were in effect in Washington at the time. The dam's lack of fish passage decimated native populations of salmon including spring Chinook known to exceed 100 pounds. The dams altered the natural hydrologic regime, caused downstream scour to occur below both dams, and an increased transported particle size passing through the spillway, because the coarser material is trapped. The downstream scour after the dams are built causes there to be an increase insize because the flow contains less load. This condition is called hungry water. In addition, the altered hydrology caused an increase in downstream temperatures, and decreased transport of large woody debris (McHenry et al., 2007).

STUDY AREA

The Elwha River watershed is in the Olympic Peninsula, with its headwaters on the slopes of Mt. Olympus in Olympic National Park. About 80 percent of the Elwha River watershed lies within the Park boundaries. Limited development occurs within Olympic National Park, so the Elwha has largely remained in its natural condition above the dams.

Construction began on the Elwha Dam, located at RM 6, in 1913. The dam was 108 feet high. Construction began on the Glines Canyon Dam, located at RM 13, in 1926. This dam was 220 feet high. The portion of the Elwha River impacted by sediment that is discussed in this study

extends from RM 2.5 to the mouth at the Puget Sound near Port Angeles. The ELJ study site is located between RM 2.25 and RM 1.33, downstream of both dam sites.

SETTING

The watershed has a drainage area of 325 square miles. The period of record, including pre-dam construction and pre-breaching, had a bankfull discharge in the range between 6,500 to 8,250 cfs with a drainage area of 270 square miles to the ELJs. Table 1 shows the recent high flows of significance since ELJ implementation.

Year	Discharge (cfs)	Log Pearson III
2002	25,700	9Q
2003	29,700	17Q
2006	20,900	5Q
2007	35,900	37Q
2010	22,300	6Q
2013	11,100	1.6Q

Table 1 USGS Gage 12045500

The tortuosity, defined as R_c/W_{bkf}, (Rc is Radius of Curvature and W_{bkf} is Width at bankfull Q), in the ELJ evaluation reach varied from 2.5 ft/ft to 2.6 ft/ft. Prior to dam removal the Elwha was migrating laterally towards the left streambank at the study site. Local scallop patterns were present on the left streambank, and excessive streambank loss is still a major concern.

The Elwha River is typical of many Northwestern rivers that have undergone channel modification by straightening, gravel removal, and destruction of the riparian vegetation. Historically, under natural conditions the Elwha River was a pool/riffle, gravel-bed system. The riparian area functioned hydraulically with the river adding a large woody debris component that was functionally important for salmonid habitat. After the dams were constructed, the Elwha River lost legendary fish runs of ten species, destroying the habitat complexity. Before the dams were removed, it provided limited spawning and rearing habitat for remnant populations of native Pacific Salmon (McHenry et al., 2007). Two species, Chinook salmon and bull trout, are listed as threatened under the Endangered Species Act and steelhead is proposed for listing (McHenry et. al, 2007).

The construction of the two dams changed the hydraulics, sedimentation, and meander geometry downstream. The absence of sediment loads below the dams caused scour to occur downstream all the way to the mouth of the Elwha River. The bed load component played a much greater role in determining the medium load size in the river with the dams in place, causing an increase in the bed material load.

The post-dam hydraulics caused roughly three feet of downcutting to a coarse cobble material with a d_{50} of roughly 190 mm.

Figure 1 Downcutting shown in the left portion exposed an old channel, which is, now, a floodplain. The right portion of the image shows this old channels remnant floodplain as it was 50 years ago.

Figure 2 Close up of the streambank of the remnant floodplain shown in the right part of Figure 1. This figure shows a cantilever overhang that is sloughing as described by Reckendorf (2009 and 2010).

There was still sediment contributed to the Elwha River from the uncontrolled drainage area below the dams, including streambank erosion such as shown in Figures 1 and 2, and from sediment that was passed through the spillways of both dams. Prior to dam removal, the Lower Elwha study area had a bimodal sediment distribution, with some of the gravel bed with a d_{50} of roughly 50 mm associated with the current flow regime. In addition, part of the bed and bar had a d_{50} of roughly 130 mm, associated with coarse (cobble) bed material exposed through the downcutting process. The maximum d_{50} was roughly 200 to 225 mm (coarse cobbles). The velocity that could transport a 225 mm particle with a flow depth of 10 feet is estimated to be 15 ft/second (Simon and Senturk, 1977).

The post-dam downcutting resulted in the exposure of coarse streambanks (Figure 3) and in cobble beds and bars throughout the Lower Elwha, as shown in Figure 4.

Figure 3 The coarse cobble bed materials on a bar and in the lower bank prior to breaching the dams.

Figure 4 Coarse bed material next to an ELJ prior to dam breach.

There was an estimated 18 million cubic yards of gravel, sand, and silt accumulated in the two reservoirs (NPS, 2015). There was a projected potential release of 13 million cubic yards after the dams were breached (Glines, 2014). Sediment from the dams was expected to move downstream in pulses associated high flows. The largest sediment pulse, or flux, would be expected to occur after the major draw-down of the Elwha Dam and partial draw-down of Glines Canyon Dam in 2011. For the 2011-2012 winter runoff, the maximum post-breach Q was 10,300 cfs.

Observations at the upper end of Glines Canyon Dam in October of 2013 indicated new deposition of coarse gravel with an average size of 25 mm. There were also some small gravel bars with an estimated d_{50} of 10 mm. However, most of the post reservoir deposition was sand.

Extensive sedimentation after the two dam breaches likely caused sediment intrusion into spawning gravels of the type pointed out by Reckendorf and Van Liew (1988), and Everett, Lotspeich, and Meeham (1982). These studies showed that even a small sediment supply in winter runoff of sand and silt particles caused sufficient packing of sediment intruded into the gravel above spawned eggs to reduce dissolved oxygen to lethal levels for salmonid egg survival. Streamflow under normal circumstances would have kept new redds saturated with dissolved oxygen as water is pushed through the open gravel.

DAM REMOVAL EFFECTS

The Elwha Ecosystem and Fisheries Restoration Act of 1992 authorized the Department of Interior to remove the dams beginning in 2009. Dam removal started in September of 2011. The Elwha Dam was fully removed by March of 2012. The Glines Canyon Dam was partially cut down from 220 to 60 feet by then, and was fully removed by the spring of 2014.

According to the Peninsula Daily News (Rice, 2011) the storm events on December 9 through 11, 2011, caused the flushing of 1.5 to 2.0 million cubic yards of sediment from Lake Mills above Glines Canyon Dam and Lake Aldwell above Elwha Dam. The newspaper reported that a three-storm event raised the peak flow on the Elwha River to 17,000 cfs. This caused extensive streambank erosion resulting in the loss of riparian trees along the river.

Sedimentation started large, new lateral and center bars, which appeared when the flow receded after the 2011-2012 runoff. During the 2012 event, a new first flat depositional surface developed at RM 2.5, at the upstream end of the evaluation reach. The top of the first flat depositional surface formed about 2.5 feet above the adjacent new lateral bars, which is shown in Figure 5, as observed in 2013. This new first flat depositional surface has been observed upstream as far as RM 12.8, at the Elwha River Bridge near Glines Canyon Dam. Figure 6 is an example of the consistent first flat depositional feature in the study area, and it occurs all the way downstream to the mouth of the river.

Figure 5 The top of the first flat depositional surface formed about 2.5 feet above the adjacent new lateral bars, as observed in 2013.

Figure 6 An example of the consistent first flat depositional feature in the study area. It occurs all the way to the mouth of the river at the Puget Sound.

A new flat depositional surface is apparent around ELJs such as shown in Figures 7. This new first flat depositional surface varies in height from 2.5 feet to 3.0 feet above the adjacent lateral bars. The first flat depositional surface is still growing from deposition that occurred during recent winter runoff.

The first flat sedimentation after the first dam flush (pulse) and the new bar deposition have essentially covered most of the coarse cobble channel and bars. The new first flat depositional surface extends right into ELJs such as shown in Figures 7 and 8, and has filled pools created by the ELJs.

Figure 7 A new flat depositional surface is apparent around an ELJ.

Figure 8 Another new flat depositional surface apparent around an ELJ.

The gravel that had previously been deposited above Glines Canyon Dam now has the opportunity to pass through the sites where the Glines Canyon and Elwha Dams once stood, and can now again provide gravel substrate to the lower reach of the ELJ study site. The size of the gravel that now reaches the channel area developed through the old Lake Mills has a d_{50} with a typical range between 10 to 25 mm.

Side channels along the Elwha River received extensive sedimentation essentially filling side channels. The falling stage of the post-breach hydrograph, with subsequent flood events, partially opened up new side channels. The side channels evaluated in 2013 had extensive new first flat depositional surfaces.

Deposition on the ELJs was observed to be as high as three feet above the first flat depositional surface on ELJ logs. This depositional surface is not continuous and reflects scour during subsequent breach flood flows. This likely occurred during the falling stage of post-breach events but could also have occurred in subsequent events. However, the post-scour effects have not transported the sediment out of the pools under the ELJs.

On the Lower Elwha, most of the pools, including pools under ELJs constructed between 1999 - 2011, filled with sediment during the 2011–2012 winter runoff. This occurred again during the 2012 – 2013 winter runoff, which filled the pools constructed in 2012. There are 49ELJs in the 2013 evaluation; whereas, there were 37 in the original study. From the thirty seven observed in 2007, three ELJs had washed out. Six ELJs were added in 2013 after the winter runoff of 2012 - 2013. Therefore, 37 ELJs could have been impacted by the sediment releases in 2011, 2012, and 2013.

Observations in October 2013 found that 35 of the 37 observed in 2007 were very shallow or non-existent such as those shown in Figure 7. There was essentially no summer refuge or adult holding pools for salmon under the 35 ELJs as the pools filled with sediment. Where the Elwha has been narrowed by opposing ELJs, identified as 10-1 and 10-2, scour has kept the pools under the two ELJs open for summer refugia.

As reported by the Peninsula Daily News (Rice, 2011) the large December 2011 runoff greatly impacted the water supply for the water intake for the Elwha Tribe Hatchery. The water intake for the City of Port Angeles was also significantly impacted by the sediment flux from the two dams.

CONCLUSIONS

After the two dams on the Elwha River had been constructed, there was extensive downcutting in the downstream reaches of the Lower Elwha River. Roughly three feet of river bed downcut to a coarse cobble surface with a rough d_{50} of 190 mm. There is post-dam sedimentation of small gravel with a rough d_{50} of 10 to 25 mm. Before the dam breaches, most locations on the Lower Elwha had a bi-modal distribution of average particle sizes. There was gravel with an average d_{50} of 50 mm associated with coarse cobbles with a d_{50} of 190 mm, and a maximum d_{50} of 225 mm.

The average flow velocity that could transport an average size of 225 mm is 15 feet per second (fps).

Such a flow velocity of 15 fps has probably not occurred in post-dam time, so the coarse cobbles likely represent a paleo-channel formed in Holocene or Late Pleistocene time. By comparison the average flow that would transport a d_{50} with an average size of 50 mm (pre-breach flow regime) would have a velocity of 8 fps. The post-dam flow sized particles could easily be transported by flood runoff in historic time.

The Elwha Rivers hydrologic regime has substantially changed because of the removal of the two dams. Extensive sedimentation created a new first flat depositional surface along many of the lateral bars that covered the coarse-cobble substrate. The sediment flux also created new lateral bars and greatly expanded center bars. The sediment pulses in the 2011-2012 and 2012-2013 events extensively filled the side channels, and they are gradually opening again.

ELJs that were installed along the Elwha starting in 1999 had their foundations in coarse cobbles, for the most part. This coarse-grained foundation adds to their stability. The post-dam sedimentation filled most of the pools under the ELJs constructed between 1999 – 2011, such that there is little summer refugia for salmon, especially adults. Two of the ELJs still have good pools that can be used for summer refugia. These two are opposite one another and have constricted the channel width such that there is increased shear stress on the channel bed and bank (which is the ELJ) so scour keeps the pools open. This would appear to be one solution to maintain pools under the ELJs in the future. The difficulty will be to keep the Elwha channel, which is presently wide, confined between ELJs.

Sedimentation is still occurring in the Lower Elwha, and sediment is being added to the first flat depositional surface, and to existing ELJS> Sedimentation is likely intruding into spawning gravel. It will likely constrain new spawning as long as large sediment loads get reworked down the channel with winter pulses of sediment.

The reworking of sand and fines sediment from the reservoir as well as that now deposioted on bars, will likely constrain being able to have clean flushing flows that sour out the polls under ELJs in the foreseeable future. This along with the sediment intrusion into spawning gravels ,from the excess sediment supply, will also constrain recovery of salmon populations for some time.

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