SEDIMENT MANAGEMENT STRATEGIES ASSOCIATED WITH DAM REMOVAL IN THE STATE OF WASHINGTON

Christopher S. Magirl, Research Hydrologist, U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Tel: 253-552-1617; Fax: 253-552-1581, magirl@usgs.gov; Patrick J. Connolly, Lead Research Fishery Biologist, U.S. Geological Survey, Western Fisheries Research Center, 5501A Cook-Underwood Road, Cook, WA 98605, Patrick_connolly@usgs.gov; Bengt Coffin, Hydrologist, U.S. Forest Service, Mt. Adams Ranger District, 2455 Highway 141, Trout Lake, WA 98650, bcoffin@fs.fed.us; Jeffrey J. Duda, Research Ecologist, U.S. Geological Survey, Western Fisheries Research Center, 6505 N.E. 65th Street, Seattle, WA 98115, jeff_duda@usgs.gov; Christopher A. Curran, Hydrologist, U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; ccurran@usgs.gov; Amy E. Draut, Research Geologist, U.S. Geological Survey, Pacific Sciences Center, 400 Natural Bridges Dr., Santa Cruz, CA 95060, adraut@usgs.gov.

Abstract Different removal strategies are described for dams in three diverse drainage basins (Wind River, White Salmon River, and Elwha River basins) in the State of Washington (USA). The comparisons between the strategies offer the opportunity to track the effects of sediment resulting from dam decommissioning in the Pacific Northwest and to determine possible effects on socio-economically important species of anadromous salmonids. Hemlock Dam, located on Trout Creek and managed by the United States Forest Service, was removed from July to September 2009. To mitigate the effect on fish downstream (specifically, salmonids) and to minimize sediment aggradation downstream in the main-stem Wind River, the Forest Service chose to excavate the approximately 42,000 cubic meters of sediment entrapped behind the dam before removal of the dam. Thus, the reach of Trout Creek downstream of the dam will not be affected by a large, released pulse of accumulated sediment. In contrast, the scheduled removal of Condit Dam, located on the White Salmon River 30 kilometers to the east of Hemlock Dam, involves a different removal strategy. Condit Dam will be breached near its base in order to mobilize the 1.7 million cubic meters of trapped sediment during the reservoir drawdown in an effort to decrease the time needed for the downstream reach to return to normal levels of suspended sediment. Finally, the much-anticipated 2011 removal of two dams on the Elwha River on the Olympic Peninsula in northwestern Washington will take place over 2 years with progressive notches cut into the dams from the top down. Although some portion of reservoir sediment will be carried downstream by the river, the specific timing of notching will be adaptively managed to mitigate the effects of raised sediment concentration on fishes and people living downstream. With improved scientific understanding from these studies, future dam-removal projects can be planned and executed with approaches that mitigate deleterious effectson salmonids.

INTRODUCTION

Because of ample precipitation and topographic relief, many of the rivers in Washington were dammed during the 20th century to provide hydropower, flood control, water supplies, and recreation. As of November 2009, at least 1,125 dams were located in Washington with a storage...
volume 12,000 m$^3$ or greater (Washington State Department of Ecology, 2009). Of these dams, 54% were taller than 5 m and 10% were taller than 15 m.

The precipitation regime and topography that encouraged regional dam construction also promoted historically large runs of anadromous fishes. The most important of these fishes economically and culturally are salmonids including Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), coho (*O. kisutch*), and steelhead (*O. mykiss*). The listing of several salmonids as threatened or endangered under the Endangered Species Act creates economic conditions in which some dam owners consider removal instead of expensive modifications to meet permitting requirements.

Safety concerns and maintenance costs also have been motivating factors in dam removal. For example, Rat Lake Dam, a 10-m high earth-fill embankment dam built on Whitestone Creek in northeastern Washington, was removed in 1989 after the structure was determined to be unsafe (American Rivers et al., 1999). No special precautions were taken for sediment in the dam-removal project due to the urgency of removing the structure and the fact that little sediment had accumulated in the 1.85 million m$^3$ reservoir since dam construction in 1910 (American Rivers et al., 1999). Safety concerns, as well as river restoration goals, also motivated the September 2009 removal of Growden Dam on Sherman Creek in northeastern Washington (U.S. Department of Agriculture, 2006). This structure, managed by the U.S. Forest Service (USFS), was an 8-m high earth-filled dam built by the Civilian Conservation Corps in 1937. It had completely filled with sediment by 1954. The entrapped sediment was excavated before the dam removal and transported from the site.

The removal of four other large dams for the purpose of enhancing long-term health of anadromous salmonids have potential shorter-term habitat issues that deleteriously may affect those very anadromous salmonids. These short-term habitat issues are the focus of this paper. Hemlock Dam, Condit Dam, Elwha Dam, and Glines Canyon Dam are all concrete structures at least 70 years old blocking or affecting aquatic habitat for one or more threatened salmonids (Figure 1; Table 1). The release of impounded sediment potentially could have deleterious effects on fishes downstream, but the dam-removal strategies for each project differ significantly. Balancing effects to habitat and people with the costs of removal projects are primary factors governing specific dam-removal strategy. The decision to completely remove sediment prior to dam removal in order to minimize deleterious effects downstream is largely dependent on the size of the dam and the volume of trapped sediment—a topic we explore in this paper.

**HEMLOCK DAM REMOVAL**

Hemlock Dam was an 8-m high concrete-arch dam constructed by the Civilian Conservation Corps in 1935 and managed by the USFS. Originally used for hydropower (1935–1957) and later to supply irrigation for a USFS tree nursery (1957–1996), the dam was used exclusively for recreation after 1996 (U.S. Department of Agriculture, 2005). The dam was built on Trout Creek 2.5 km upstream from Wind River and 20 km upstream from the confluence of Wind River and the Columbia River (Randle and Greimann, 2004). The creek is relatively steep (0.015–0.022 m/m) and predominantly bedrock controlled. The catchment area upstream of the dam is 79 km$^2$. Sediment transport in Trout Creek completely filled the reservoir by the 1950s resulting in a
large, shallow, sediment-filled reservoir. A sediment sluiceway in the dam was last used in the 1980s. During the summer, this shallow, sediment-filled reservoir warmed Trout Creek to near-lethal levels, which contributed to poor fish-habitat conditions downstream of the dam (U.S. Department of Agriculture, 2005).

In 1996, the lower Columbia River steelhead was listed as threatened under the Endangered Species Act, [http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Steelhead/Index.cfm](http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Steelhead/Index.cfm), accessed January 25, 2010). Owing to high gradient and relative lack of suitably sized gravel, no active steelhead spawning occurred in the reach of Trout Creek downstream of the dam. A fish ladder installed at the dam in 1936 permitted passage of steelhead into the upper drainage basin for spawning. However, the steelhead run declined dramatically in the 1990s (U.S. Department of Agriculture, 2005) prompting the USFS and partner agencies to undertake a significant restoration effort within the Trout Creek drainage basin to improve fish habitat conditions. In spite of the restoration effort, Hemlock Lake and the dam continued to affect steelhead by warming Trout Creek (U.S. Department of Agriculture, 2005).
Table 1 Comparison of four major dam-removal projects in Washington.

<table>
<thead>
<tr>
<th></th>
<th>Hemlock Dam</th>
<th>Condit Dam</th>
<th>Elwha Dam</th>
<th>Glines Canyon Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River</strong></td>
<td>Trout Creek (tributary to the Wind River)</td>
<td>White Salmon River</td>
<td>Elwha River</td>
<td>Elwha River</td>
</tr>
<tr>
<td><strong>Impounded lake</strong></td>
<td>Hemlock Lake</td>
<td>Northwestern Lake</td>
<td>Lake Aldwell</td>
<td>Lake Mills</td>
</tr>
<tr>
<td><strong>Dam administrator</strong></td>
<td>U.S. Forest Service</td>
<td>PacifiCorp</td>
<td>National Park Service</td>
<td>National Park Service</td>
</tr>
<tr>
<td><strong>Dam height (m)</strong></td>
<td>8</td>
<td>38</td>
<td>33</td>
<td>64</td>
</tr>
<tr>
<td><strong>Reservoir storage volume (m³)</strong></td>
<td>48,000</td>
<td>2.5 × 10⁶</td>
<td>10 × 10⁶</td>
<td>49 × 10⁶</td>
</tr>
<tr>
<td><strong>Volume of sediment trapped in reservoir (m³)</strong></td>
<td>42,000</td>
<td>1.7 × 10⁶</td>
<td>3.0 × 10⁶</td>
<td>13 × 10⁶</td>
</tr>
<tr>
<td><strong>Estimate of reservoir sediment released after dam removal</strong></td>
<td>0%</td>
<td>70 - 95%</td>
<td>~65%</td>
<td>~40%</td>
</tr>
<tr>
<td><strong>Drainage basin upstream of dam (km³)</strong></td>
<td>79</td>
<td>1000</td>
<td>816</td>
<td>635</td>
</tr>
<tr>
<td><strong>Construction date</strong></td>
<td>1935</td>
<td>1913</td>
<td>1913</td>
<td>1927</td>
</tr>
<tr>
<td><strong>Dam removal date</strong></td>
<td>2009</td>
<td>2011</td>
<td>2011-2014</td>
<td>2011-2014</td>
</tr>
<tr>
<td><strong>Removal strategy</strong></td>
<td>Excavate all sediment with heavy equipment</td>
<td>Rapid draining from drilled tunnel</td>
<td>Controlled increments with adaptive management</td>
<td>Controlled increments with adaptive management</td>
</tr>
<tr>
<td><strong>Salmonids benefitting from the removal</strong></td>
<td>steelhead</td>
<td>Chinook, coho, steelhead, chum</td>
<td>bull trout, Chinook, chum, coho, pink, sockeye, steelhead</td>
<td>bull trout, Chinook, chum, coho, pink, sockeye, steelhead</td>
</tr>
</tbody>
</table>

The final environmental impact statement analyzed five alternatives for improving aquatic habitat for threatened steelhead: (A) no action, (B) remove the dam and let the river erode sediments, (C) remove the dam after removing all entrapped sediment, (D) retain the dam while replacing the fish ladder and improving deficiencies, and (E) retain the dam while improving deficiencies and retaining the existing fish ladder (U.S. Department of Agriculture, 2005). Ultimately, the USFS chose Alternative C as the best way to address the habitat conditions affecting the threatened steelhead (U.S. Department of Agriculture, 2005). From the sediment management standpoint, Alternative B would have been less expensive but was not chosen because the short-term impacts to steelhead were deemed unacceptable. Compared to larger dam-removal projects, the relatively small volume of entrapped sediment was cost-effectively excavated before dam removal. Such a sediment-removal strategy on a larger project can become cost prohibitive.

The Hemlock Dam removal started in July 2009. A cofferdam and pumps were installed upstream of the reservoir to divert the summer low-flow in Trout Creek around the work site. The reservoir sediment was then dredged and trucked to a USFS property about 2 km away. A
splash dam located within the reservoir, predating Hemlock Dam, was also removed. After all reservoir sediment and the splash dam were removed, the concrete dam structure was removed and disposed (Figures 2 and 3). The pre-dam channel elevation of Trout Creek was unknown, so sediment was excavated down to underlying bedrock. Finally, an engineered channel was constructed through the reservoir site matching the extant hydraulic geometry of the creek upstream and located in a best-guess approximation of the pre-1935 stream location. The disturbed ground also was revegetated to accelerate the restoration of the site to undammed conditions (Figure 4). Monitoring data were collected before and after the removal including long profiles, channel cross sections, sediment-size distribution, water temperature, large woody debris, shade, turbidity, pool depth, and some macroinvertebrate characterization. These data will be reported in future publications.

Figure 2 Photographs of Trout Creek before (left) and after (right) the removal of Hemlock Dam. The photographs were taken from about 200 m downstream of the dam site.

Figure 3 Photographs of Trout Creek before (left) and after (right) the removal of Hemlock Dam. The photographs were taken from the right abutment of the dam.
Figure 4 Photographs of the site of Hemlock Lake taken from the Hemlock Road bridge showing (left) the pre-dam-removal condition of the lake and (right) the restored stream channel in September 2009 after dam removal.

**CONDIT DAM**

Condit dam is a 38-m high concrete gravity structure on the White Salmon River in southern Washington (Figure 5). The dam is about 5 km upstream of the river’s confluence with the Columbia River, impounding Northwest Lake, a popular recreation resource ringed by a number of homes. Draining the glaciated, 3,700-m high Mount Adams Volcano, the White Salmon River is a high-gradient river with historical runs of steelhead, coho, Chinook, and chum salmon (NOAA, 2006). Dam removal is expected to restore as much as 22 km of salmon spawning habitat and as much as 53 km of steelhead spawning habitat (NOAA, 2006).

Figure 5 Photograph of Condit Dam from downstream.

Built in 1913 by Northwest Electric Company for power production, PacifiCorp acquired the dam and power plant in 1947. In 1991, the Federal Energy Regulatory Commission (FERC) rejected PacifiCorp’s relicensing application and required the installation of a fish ladder for
continued operation. The estimated cost of the new fish ladder was greater than anticipated revenue from ongoing power production and so PacifiCorp began the process of petitioning for dam decommissioning and removal. Excavation and removal of the estimated 1.76 million m$^3$ of trapped sediment was cost prohibitive. To minimize the effects of mobilized sediment downstream on fishes during dam removal, PacifiCorp proposed a rapid draining approach to the removal (PacifiCorp, 2009). The plan involves drilling a $3.7 \times 5.4$ m$^2$ tunnel 30 m through the base of the dam. After dredging large woody debris and sediment from the upstream face of the dam, the final 4.6 m of the dam would be removed with explosives (PacifiCorp, 2009). The rapidly draining lake would sluice lakebed sediment from the reservoir and reestablish the river channel through the reservoir sediment. The total time to drain the reservoir would be about 6 hours. After the lake is drained, the remaining dam and power plant structure would be removed and the remaining reservoir sediment stabilized. High sediment loads in the river are expected to continue for about 6 months. Independent biological opinions concluded that the long-term benefits to fishes and fish habitat from dam removal outweigh the short-term effects on fishes from increased sediment (NOAA, 2006). The Condit Dam removal is scheduled for 2011.

**ELWHA RIVER DAMS**

Elwha Dam is a 33-m high concrete dam on the Elwha River of northwestern Washington about 8 km upstream from the mouth of the river at the Strait of Juan de Fuca (Figure 1). The dam was constructed between 1910 and 1913 and impounds Lake Aldwell (Figure 6). Glines Canyon Dam is a 64-m high concrete arch structure on the Elwha River located 21 km upstream of the river mouth. Glines Canyon Dam was constructed in 1927 and impounds Lake Mills. Both dams are now managed by the National Park Service (NPS).

![Figure 6 Photographs of (left) Glines Canyon Dam and (right) Elwha Dam on the Elwha River (both images courtesy of the National Park Service).](image)

The Elwha River historically was one of the most productive salmon rivers for its size in the Pacific Northwest (Wunderlich et al., 1994), but construction of Elwha Dam without fish passage restricted access of anadromous fishes from all but the lower 8 km of river. In 1992, Congress enacted the Elwha River Ecosystem and Fisheries Restoration Act (PL 102-495) directing the
Secretary of the Interior to fully restore the river system for anadromous fishes. After years of study, the NPS determined that only dam removal would result in full restoration of the river (U.S. Department of the Interior, 1995). Because 83% of the 833 km² Elwha River drainage basin lies undisturbed within the boundary of Olympic National Park, the dam removal project presents a unique opportunity for ecosystem restoration (Duda et al., 2008). Because 16 million m³ of trapped sediment will not be excavated prior to dam removal, the project also represents the unique opportunity to predict and study the geomorphic response of a large river to a large sediment impulse.

The Elwha River flows 72 km from 2,000-m highlands in the Olympic Mountains to sea level at the Strait of Juan de Fuca. High precipitation and runoff, combined with stream gradient, result in a river with the hydraulic capacity to transport substantial loads of sediment. Curran et al. (2009) estimated that the total annual sediment load in the Elwha River upstream of Lake Mills was between $2.2 \times 10^8$ and $5.1 \times 10^8$ kg/yr; 77% of this load was suspended load and 23% was bedload. Curran et al. (2009) also calculated the trap efficiency of Lake Mills as 0.86. Despite the fact that most Elwha River bedload now is contained behind both reservoirs, the river downstream of Elwha Dam remains active, dynamically migrating 2 to 10 m/yr within its floodplain (Draut et al., 2008). The high rate of channel migration suggests the river entrains ample coarse-grained sediment from the floodplain and from contributing Pleistocene bluffs bounding the floodplain. After removal of both dams, the sediment supply to the lower river will increase dramatically. Sediment-transport modeling suggests that the lower Elwha River will aggrade about 1 m with the input of new coarse-grained sediment following dam removal (U.S. Department of the Interior, 1996; Konrad, 2009). The existing flood-control levees will be raised by 1 m to accommodate this coarse-grained sediment aggradation (U.S. Department of the Interior, 2005).

The removal of both dams on the Elwha River will occur concurrently. The strategy of the timing and mechanics of the removal was formulated to minimize the effect of high sediment load on fishes and three downstream water-treatment facilities (U.S. Department of the Interior, 2005). The dams will be removed from the top down in controlled increments within an adaptive-management framework over a 2- to 3-year period. Progressive lowering of the dam will erode and redistribute the alluvial sediment contained in both deltas throughout each reservoir. The timing of increments can be adjusted to minimize high suspended-sediment concentrations that would otherwise affect fishes downstream and the water-treatment plants. During the removal 25–33% of the sand- and gravel-sized sediment and 50–66% of the silt- and clay-sized sediment is expected to mobilize and move downstream toward the ocean (Randle and Bountry, 2008). The remaining sediment will be stabilized with vegetation in an effort to contain as much sediment as possible in the location of the original reservoirs.

CONCLUSIONS

Some of the factors determining dam-removal strategy include the volume and nature of entrapped sediment (Downs et al., 2009). In the rivers of the Pacific Northwest, consideration of the effects on salmonids downstream that may be listed as endangered or threatened further complicates the options available to resource managers when addressing removal of aging dams. In the State of Washington, the removal of relatively small USFS dams, Hemlock and Growden
Dams, proceeded after mechanically excavating all the entrapped sediment. Although more costly in the short-term, complete sediment excavation minimized effects on fishes downstream and accelerated the projects toward a faster restoration of the river. The complete excavation strategy, however, quickly becomes cost prohibitive as the size of the dam and the volume of impounded sediment increases. For example, the planned Condit Dam removal project involves breaching the dam near the elevation of the extant river channel to sluice as much sediment from the reservoir as possible during the drawdown. The study suggests that this approach will affect fishes downstream for no more than 6 months, and that the overall benefit of improved habitat will outweigh the short-term deleterious effects on the aquatic biology. Finally, the much anticipated removal of Elwha and Glines Canyon Dams on the Elwha River will involve a carefully staged removal governed by adaptive management that could require as many as 3 years to complete. In the case of the Elwha and Glines Canyon Dam removals, exceptional effort will be made to isolate as much sediment in place as possible. Not only is the scale of dam removal in the Elwha River drainage basin much larger than other removal projects, but also the presence of fishes downstream and people require a careful approach.

REFERENCES


