Eos, Vol. 93, No. 43, 23 October 2012

River Turbidity and Sediment Loads During Dam Removal

PAGES 425–426

Dam decommissioning has become an important means for removing unsafe or obsolete dams and for restoring natural fluvial processes, including discharge regimes, sediment transport, and ecosystem connectivity [*Doyle et al.*, 2003]. The largest dam-removal project in history began in September 2011 on the Elwha River of Washington State (Figure 1a). The project, which aims to restore the river ecosystem and increase imperiled salmon populations that once thrived there, provides a unique opportunity to better understand the implications of large-scale river restoration.

Two concrete dams are being removed incrementally (the downstream 32-meter-high Elwha Dam impounding Lake Aldwell and the 64-meter-high Glines Canyon Dam impounding Lake Mills) during this approximately 2-year project. More than 19 million cubic meters of sediment stored in both reservoirs is being exposed, with the majority (16 million cubic meters) in the Lake Mills reservoir [*Bountry et al.*, 2010]. Physically removing the sediment stored in the reservoirs was not logistically or financially feasible. Thus the methods and schedule of deconstruction are largely focused on the natural erosion and transport of the stored sediment by the river, and expectations are that approximately 7–8 million cubic meters of the stored reservoir sediment will be transported to river and coastal regions downstream of the dams [*Duda et al.*, 2011]. This short-term pulse in sediment supply, coupled with the long-term reconnection of natural upstream sediment supplies, will help to restore natural processes that, for example, maintain salmon spawning habitat in the channel downstream of the dams and replenish the eroding beach at the river mouth.

During the initial stages of dam decommissioning—i.e., during reservoir drawdown but prior to complete dam removal—sediment was exposed subaerially on the reservoir deltas and eroded downstream into the river and coastal waters. The dam-removal strategy involved controlled drawdowns of the reservoir levels (Figures 1b and 1c) to enhance downstream transport of reservoir sediment in a metered fashion without the deleterious impacts of an instantaneous release [*Randle et al.*, 1996]. Sediment was also eroded from several temporary cofferdams built just upstream from the Elwha Dam site to assist with deconstruction. Planned stoppage of reservoir drawdown occurred during "holding periods" and "fish windows." Holding periods occurred regularly to allow the river to laterally erode into delta sediment, and fish windows occurred to reduce potential negative effects of water turbidity on migrating adult or juvenile salmon in the river.

The new sediment supplies to the river increased turbidity in downstream waters, which may have short-term ecosystem effects—e.g., high turbidity can reduce aquatic light levels and thus reduce rates of photosynthesis in aquatic organisms. Substantial changes to downstream river water turbidity were caused by several intentional cofferdam breaching events that took place between September 2011 and March 2012 at Elwha Dam (Figure 1c; for background and access to real-time and historical river data, see http://www.usgs.gov/elwha). Immediately following cofferdam breaching, which caused reservoir drawdown and increased river erosion of the Lake Aldwell delta, peaks in downstream turbidity were observed for 2–6 hours (Figure 1c). After these initial peaks, river turbidity remained elevated with respect to conditions both upstream of the dams and before the breaching events.

High flow in the river also resulted in increased river turbidity at stations both above and below the dams (Figure 1c). The highest winter flows occurred during late November and late December 2011, when

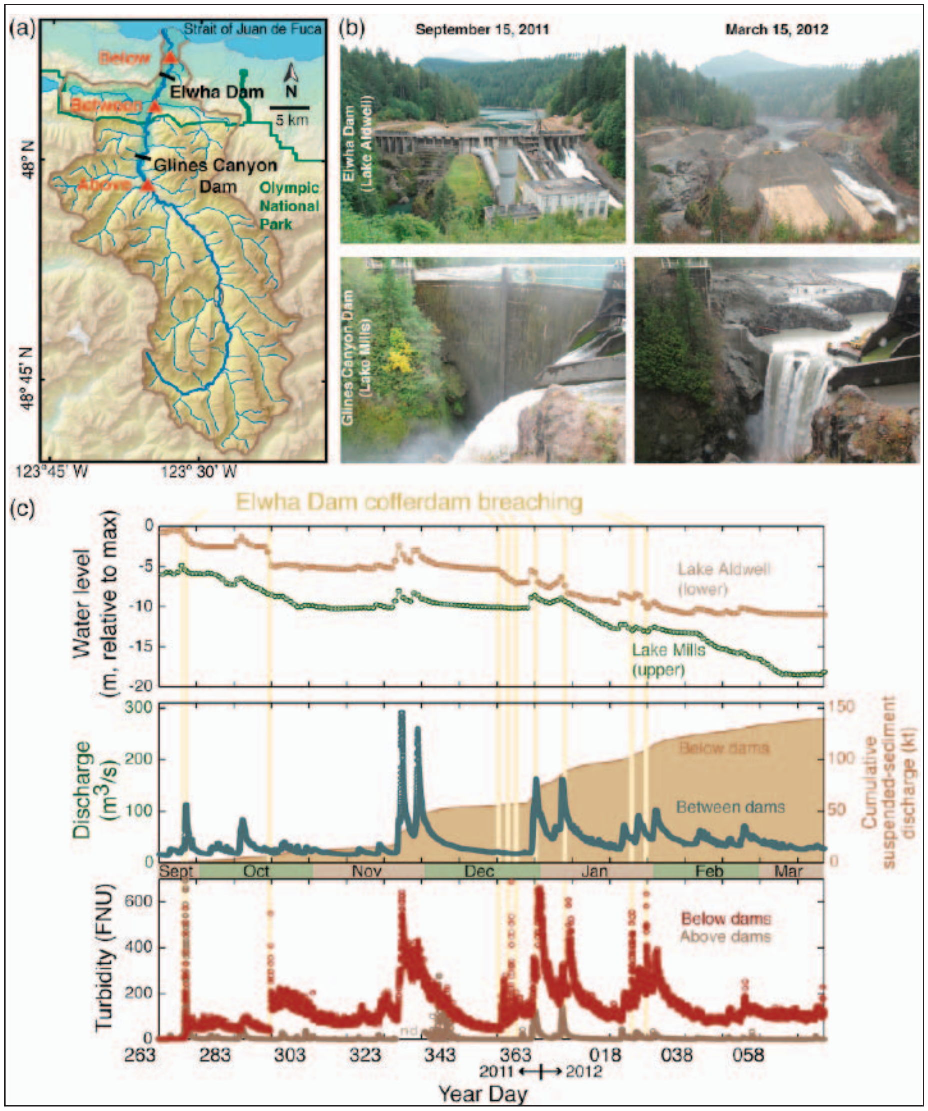

Fig. 1. (a) Location map of the Elwha River watershed and turbidity monitoring sites. (b) Photographs of the Elwha and Glines Canyon Dams before and during dam removal. Images provided by collaborative webcams from Erdman Video Systems, Inc., and the National Park Service. (c) Elwha River conditions during the initial stages of dam removal, including water levels in the two reservoirs at Bureau of Reclamation stations, river discharge at the U.S. Geological Survey (USGS) station between the dams and cumulative sediment load at the USGS station below the dams, and river water turbidity at USGS stations above and below the dam sites. The cofferdam breaching events are highlighted with yellow bars. Turbidity results shown as formazin nephelometric units (FNU) according to Anderson *[2005].*

river turbidities downstream of the dams were sustained at several 100s of formazin nephelometric units (FNU) for weeks, which were many times higher than natural conditions measured upstream of Lake Mills. The station above the dams was inoperable during the highest November flow event (Figure 1c), but the available turbidity observations at this station rose during high flows and then consistently returned to values less than 10 FNU within days of peak flows (Figure 1c).

Hydrologically, the first half of water-year 2012 (1 October 2011 to 31 March 2012) was relatively quiet. Compared to gauging records dating back to 1918, the total water discharge was only 90% of normal. In addition, the peak flows during the period were modest, with the largest event, a flow of 290 cubic meters per second in November (Figure 1c), only 73% of the 2-year recurrence-interval flood [cf. *Duda et al.,* 2011].

Using a relation between river suspended-sediment concentration and measured turbidity, the authors of this brief report estimated that the cumulative sediment load transported past the lower station from 15 September 2011 to 15 March 2012 was 140,000 tonnes (Figure 1c). Assuming a bulk density of 1.65 tonnes per cubic meter, this load is equivalent to approximately 0.4% of the 19 million cubic meters of sediment stored in the reservoirs and approximately 1% of the 7–8 million cubic meters of sediment expected to erode from these deltas [cf. *Duda et al.,* 2011]. Suspended-sediment concentrations were overwhelmingly fine-grained (less than 0.0625 millimeters) as shown by wet sieving of suspended-sediment samples, which averaged 87% fine-grained by mass (standard deviation = 7.2%).

Thus, although the effects of dam removal activities have already been measurable and significant, there will likely be much larger and sustained turbidity and sediment-transport effects during the pending completion of dam removal during 2012–2013. For example, as of September 2012, Glines Canyon Dam had been lowered to approximately half of its original height, and most of the sediment in the Lake Mills reservoir remained trapped. Future erosion of reservoir sediments is likely to result in elevated river, estuarine, and coastal water turbidity and morphologic changes in the downstream fluvial and coastal landforms and habitats. Continued tracking of these systems will be important to assess the habitat evolution and to help explain recolonization patterns and dynamics of salmon recovery in what was historically one of the most productive and diverse salmon-producing rivers in the region.

Acknowledgments

Funding for this research was provided by the U.S. Environmental Protection Agency through the Puget Sound Partnership, the U.S. Geological Survey (USGS) Coastal Habitats in Puget Sound Program, and the USGS Coastal and Marine Geology Program. Additional support and assistance have been provided by Tim Randle, Jennifer Bountry, Andy Ritchie, and the Lower Elwha Klallam Tribe.

References

Anderson, C. W. (2005), *National Field Manual for the Collection of Water-Quality Data, U.S. Geol. Surv. Tech. Water-Resour. Invest.,* book 9, U.S. Geol. Surv., Boulder, Colo. [Available at http://pubs.water.usgs.gov/twri9A.]

Bountry, J., R. Ferrari, K. Wille, and T. J. Randle (2010), 2010 survey report and area-capacity tables for Lake Mills and Lake Aldwell on the Elwha River, Washington, *Rep. SRH-2010-23,* Bur. of Reclam., Denver, Colo.

Doyle, M. W., E. H. Stanley, J. M. Harbor, and G. S. Grant (2003), Dam removal in the United States: Emerging needs for science and policy, *Eos Trans. AGU, 84,* 29, doi:10.1029/2003EO040001.

Duda, J. J., J. A. Warrick, and C. S. Magirl (2011), Coastal habitats of the Elwha River, Washington—Biological and physical patterns and processes prior to dam removal, *U.S. Geol. Surv. Sci. Invest. Rep., 2011-5120,* 264 pp.

Randle, T. J., C. A. Young, J. T. Melena, and E. M. Ouellette (1996), Sediment analysis and modeling of the river erosion alternative, *Elwha Tech. Ser. PN-95-9,* 136 pp., Bur. of Reclam., Denver, Colo.

—Jonathan A. Warrick, Pacific Coastal and Marine Science Center, U.S. Geological Survey, Santa Cruz, California; E-mail: jwarrick@usgs.gov; Jeffrey J. Duda, Western Fisheries Research Center, U.S. Geological Survey, Seattle, Washington, and Christopher S. Magirl and Chris A. Curran, Washington Water Science Center, U.S. Geological Survey, Tacoma, Washington