Sediment Loads in the Elwha River, Washington, Prior to Dam Removal

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Introduction

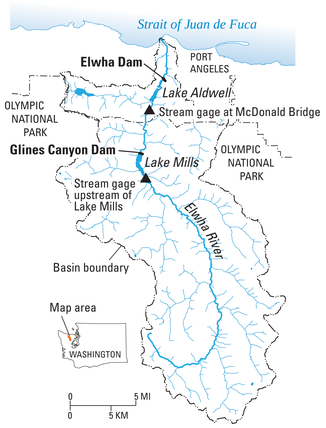
Two dams on the Elwha River in Clallam County, Washington, are scheduled for removal in the near future: the Elwha Dam located at river kilometer (RK) 7.9, which forms Lake Aldwell, and the Glines Canyon Dam at RK 21.6, which forms Lake Mills. Both dams were constructed early in the 20th century without provision for fish passage and are largely responsible for the loss of anadromous fish runs that historically occurred throughout the year. Since their construction, both dams have accumulated sediment that would have been otherwise transported downstream. The volume of retained sediment has been estimated at about 10.6 million cubic meters in Lake Mills and 3.1 million cubic meters in Lake Aldwell (Childers and others, 1999).

When it occurs, the removal of both dams on the Elwha River will be the largest dam-removal project ever attempted in the United States and the release of stored sediment by the free-flowing river will result in significant changes in the channel morphology and habitat of the lower river. The National Park Service and U.S. Geological Survey (USGS) have cooperated to document these changes.

To estimate the suspended-sediment load prior to removal of the dams, the USGS collected suspended-sediment samples during water years 2006–07 at two streamflow-gaging stations on the Elwha River: upstream of Lake Mills and downstream of Glines Canyon Dam at McDonald Bridge. This information was combined with bedload data collected during water years 1995-98 to estimate the total sediment load of the Elwha River. Pre-dam-removal estimates of suspended-sediment load and sediment-discharge relations will be useful to planners in monitoring geomorphic and habitat changes in the river as it reaches a dynamic equilibrium following removal of the dams.

Elwha Dam

Glines Canyon Dam



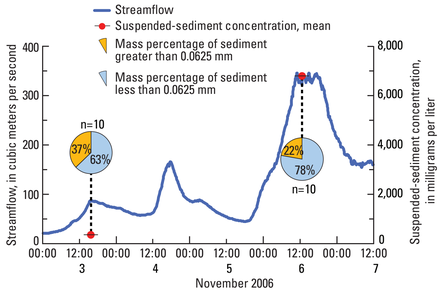
The River Upstream of Lake Mills

The River is Free-Flowing Upstream of Lake Mills

Measurements in the river upstream of Lake Mills are important for understanding the natural flow regime and transport capacity of the river unhindered by the presence of dams. At the USGS gaging station 'Elwha River above Lake Mills' (discontinued in 2008), streamflow measurements and sediment samples were collected from a motorized cableway system over a range of flows during water years 2006–07.

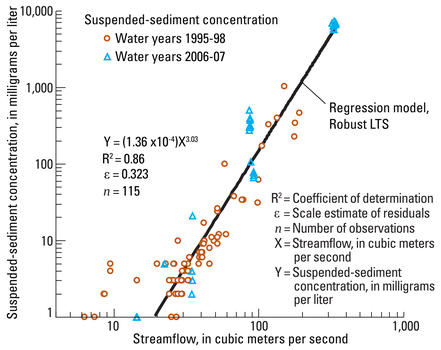
Samples Collected Before and During a Flood Peak

The highest suspended-sediment concentrations were measured during the peak of a precipitation-driven flood event on November 6, 2006 when flows reached 346 m^3/s (12,200 ft^3/s). Sediment concentrations ranged from 5,703 to 7,325 mg/L and were some of the highest ever recorded on the river. Suspended-sediment samples also were collected 3 days prior to the flood peak, when streamflow was about 85 m^3/s. A limited size analysis of samples collected before and during this flood peak indicated that the percentage of fine sediment (<0.0625 mm) increased as the flood progressed, likely due to the magnitude and seasonal timing of the event which was both exceptionally large and the "first flush" of the river basin following a dry summer.



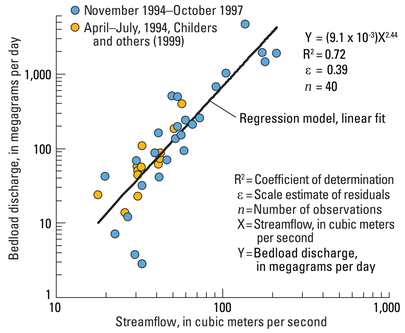
Regression Model for Suspended-Sediment Concentration

Suspended-sediment measurements made during this study were combined with previously published measurements made during water years 1995-98 to develop a regression equation for estimating suspended-sediment concentration as a function of streamflow.



A Regression Model for Bedload Transport

Bedload is the portion of fluvial sediment that moves by sliding, rolling, or bouncing along the streambed (Edwards and Glysson, 1999). Following the Lake Mills drawdown study conducted in 1994 by Childers and others (1999), bedload measurements were collected in anticipation of the imminent removal of the Glines Canyon and Elwha Dams. A total of 1,518 bedload samples, representing 112 cross-sections, were collected from the Elwha River at the gaging station upstream of Lake Mills during water years 1995–98. A regression equation was developed to describe a bedload transport curve relating bedload as a function of streamflow.



Estimates of Total Sediment Load

The regression models developed for suspended-sediment and bedload transport as a function of streamflow were used to estimate the total sediment load into Lake Mills. In estimating the total load, a flow-duration/sediment-rating curve approach as outlined by Julien (1998) was used. A flow-duration curve based on 8 years of daily streamflow data (1995–98, and 2005–08 water years) obtained from the gaging station upstream of Lake Mills was combined with the sediment transport equations for suspended sediment and bedload to determine an estimate of total annual sediment load. The total load at the gaging station upstream of Lake Mills was estimated at 512,000 Mg/yr, of which 82 percent was suspended load, and 18 percent was bedload.

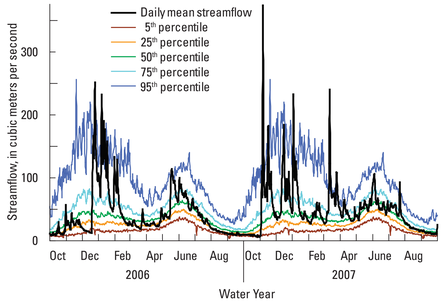
The River Downstream of Glines Canyon Dam

The River is Deprived of Sediment Downstream of Lake Mills

Measurements made downstream of Lake Mills are important for understanding the effects of large dams on altering the natural flow regime and sediment supply of the river. At the McDonald Bridge gaging station, downstream of Lake Mills, daily suspended-sediment samples were obtained using an automated pump sampler. More than 450 samples were collected from the Elwha River over a range of streamflows. The highest recorded suspended-sediment concentration was 946 mg/L, which occurred during the pineapple-express event of November 6, 2006 when the peak streamflow reached 592 m^3/s (20,900 ft^3/s).

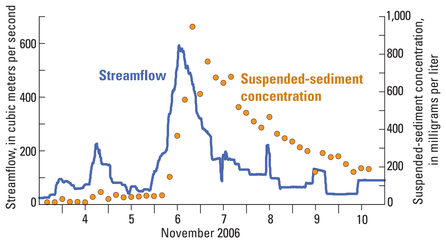
Long-Term Hydrograph at the McDonald Bridge Gaging Station

The variability in the magnitude, timing, and frequency of streamflow can greatly influence the amount of sediment transport that occurs from year to year. A hydrograph from the Elwha River McDonald Bridge gaging station illustrates the magnitude and timing of streamflow during the study period relative to the daily mean streamflow for the 93-year period of record (1897–1900, 1918–2008). Like most mountain-fed rivers in the Pacific Northwest, most of the annual streamflow in the Elwha River occurs during two seasons: in the fall/winter as a result of direct runoff from precipitation and in the spring/summer as a result of melting snowpack. Compared to the long-term mean streamflow at the Elwha River McDonald Bridge gaging station (42.8 m^3/s, based on the 92-year period of record), streamflow for water year 2006 was average (42.4 m^3/s; 1,500 ft^3/s), and for water year 2007 was 15 percent above average (48.7 m^3/s; 1,720 ft^3/s) (U.S. Geological Survey, 2008).



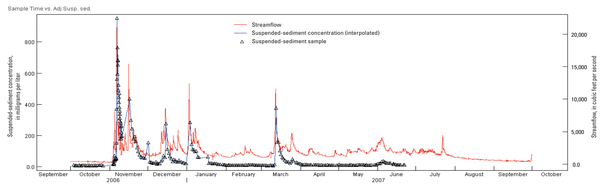
Sampling Over the Course of a Flood Event

The flood event of November 6, 2006, was anticipated and the sampling frequency of the pump sampler at McDonald Bridge was increased to 4-hour intervals. Samples were collected throughout the flood peak and during the recession. During the flood, the peak in suspended-sediment concentration lagged the streamflow peak by about 8 hours. A limited particle-size analysis was performed on 16 pumped samples obtained from December 2005 to January 2006, which had suspended-sediment concentrations ranging from 69 to 454 mg/L. Of these, 14 samples were predominantly fine sediment (< 0.0625 mm) averaging 91 percent by mass. The percentage of fine sediment in samples at this site generally was higher than samples collected from the site upstream of Lake Mills, suggesting that sand-sized particle settling occurs in Lake Mills.



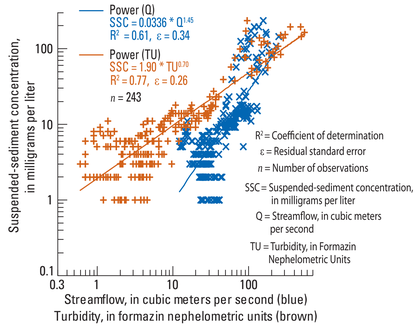
Graphical Constituent Loading and Analysis System (GCLAS)

The software program GCLAS (Koltun and others, 2006), was used to combine discrete sample concentrations with the continuous 15-minute record of streamflow from the gaging station. The interpolation algorithm in GCLAS was used to calculate the daily, monthly, and annual suspended-sediment loads.



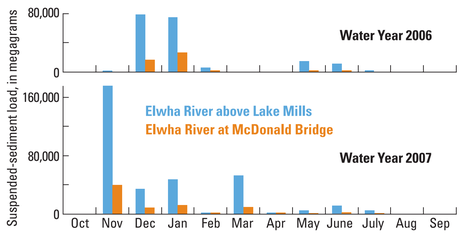
Turbidity as a Surrogate for Suspended Sediment Concentrations

Regression models using streamflow and turbidity to explain the variability in suspended-sediment concentration were developed using the published daily mean streamflow and daily median values of turbidity during water year 2006 (U.S. Geological Survey, 2006). An analysis of these models based on R^2 and the standard error suggests that turbidity provides a better surrogate measurement at this site for suspended-sediment concentration than streamflow. This likely is due to the time lag that occurs between streamflow peaks and sediment concentration peaks downstream of the reservoir, resulting in a weaker correlation. Instream turbidity meters can sample more frequently than automated pump samplers and measurements of turbidity as a surrogate for suspended-sediment concentration may be a cost-effective method for estimating future sediment load at the McDonald Bridge gaging station following dam removal.



Comparison of Sediment Loads Upstream and Downstream of Lake Mills

A comparison between the annual suspended-sediment loads at both gaging stations found loads of 213,000 Mg and 397,000 Mg upstream of Lake Mills in water years 2006–07, respectively, and 50,000 Mg and 74,200 Mg at McDonald Bridge, respectively. Significantly larger sediment loads measured upstream versus downstream of Lake Mills indicated the extent to which the reservoir traps and accumulates sediment. On the basis of suspended-sediment loads determined upstream and downstream of Lake Mills, a trap efficiency of 0.93 was determined for the reservoir. These pre-dam-removal estimates of suspended-sediment loads and sediment-discharge relations provide a baseline of data that should be useful to planners and scientists monitoring geomorphic and habitat changes in the Elwha River as it reaches a dynamic equilibrium following removal of the dams.



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