Geomorphic Framework to Assess Changes to Aquatic Habitat Due to Flow Regulation and Channel and Floodplain Alteration, Cedar River, Washington

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Abstract

Flow regulation, bank armoring, and floodplain alteration since the early 20th century have contributed to significant changes in the hydrologic regime and geomorphic processes of the Cedar River in Washington State. The Cedar River originates in the Cascade Range, provides drinking water to the Seattle metropolitan area, and supports several populations of anadromous salmonids. Flow regulation currently has limited influence on the magnitude, duration, and timing of high-flow events, which affect the incubation of salmonids as well as the production and maintenance of their habitat. Unlike structural changes to the channel and floodplain, flow regulation may be modified in the short-term to improve the viability of salmon populations. An understanding of the effects of flow regulation on those populations must be discerned over a range of scales from individual floods that affect the size of individual year classes to decadal high flow regime that influences the amount and quality of channel and off-channel habitat available for spawning and rearing. We present changes to channel morphology derived from historical orthoimagery and LiDAR (Light Detection and Ranging), current water-surface and streambed longitudinal profiles, specific gage analyses at three streamflow-gaging stations to quantify trends in aggradation, and substrate particle-size distributions. These data suggest a gradient of channel types from unconfined, sediment-rich segments to confined, sediment-poor segments that are likely to have distinct responses to high flows. These historical and current data constitute a preliminary geomorphic framework to help assess different river management scenarios for salmonid habitat and population viability.

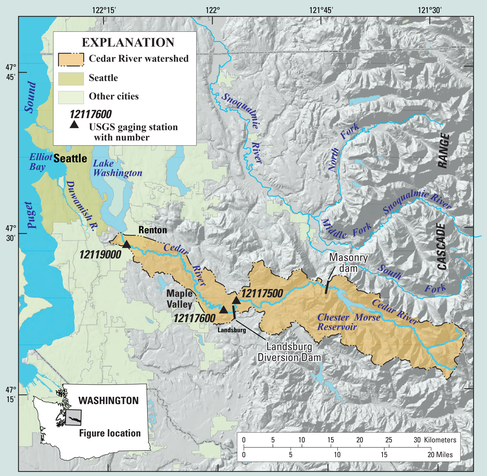

Figure 1. Cedar River watershed and surrounding area, western Washington.

Figure 2. Distribution in channel widths of Cedar River, 1936–2009: The distribution of channel widths averaged over twenty-seven 1-km segments along the Geomorphic Floodplain defined as the area that fluvial processes of the Cedar River have influenced. Each box and whisker plot shows the maximum, minimum, 25th, 50th, and 75th percentiles of channel width measured at 10 time intervals between 1936 and 2009. The maximum interval between measurements is 11 years; the minimum interval is 4 years. White dots show the value of the earliest survey (1936). Note that the channel was at its widest at 14 of the twenty-seven 1-km segments in 1936.

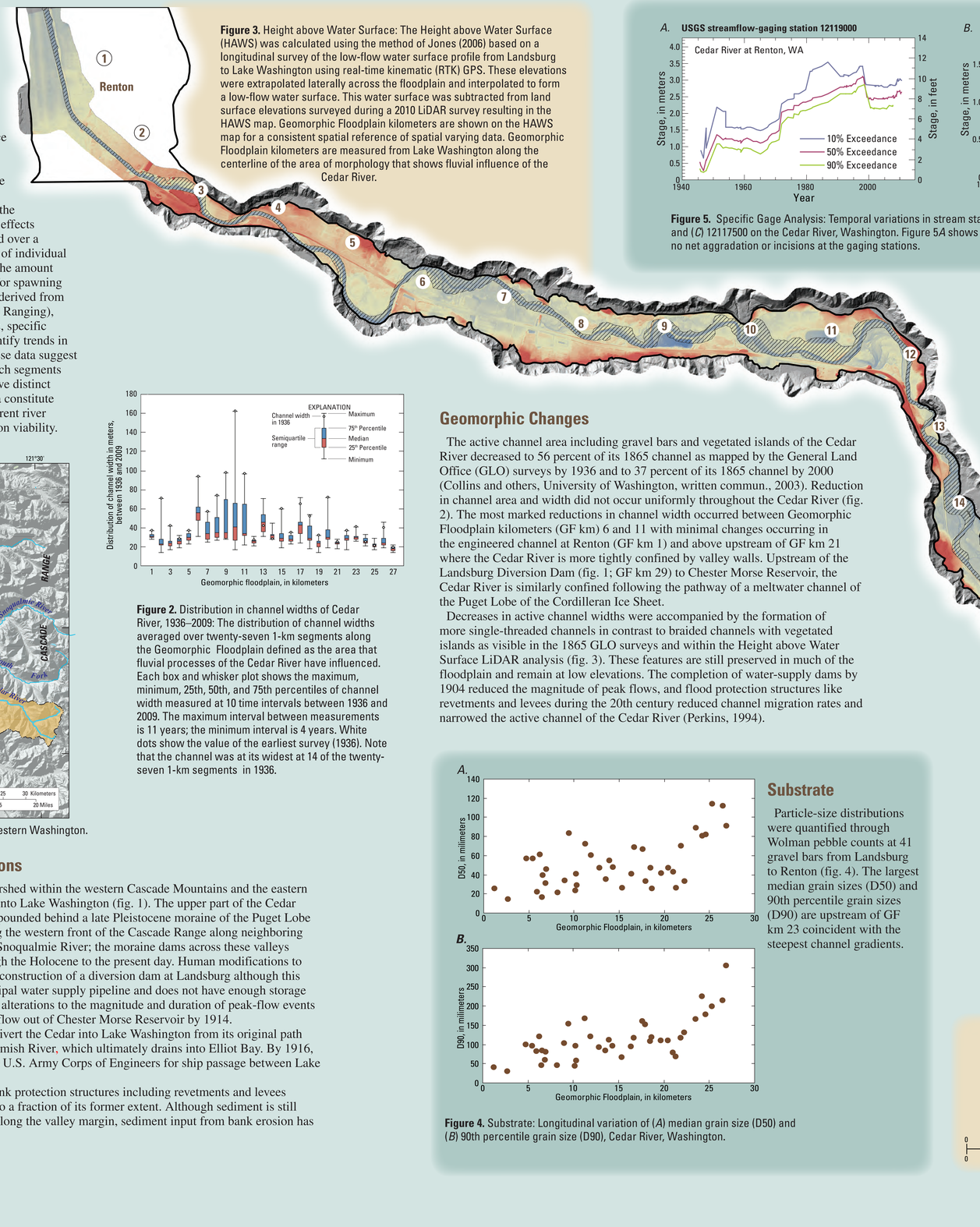

Figure 3. Height above Water Surface: The Height above Water Surface (HAWS) was calculated using the method of Jones (2006) based on a longitudinal survey of the low-flow water surface profile from Landsburg to Lake Washington using real-time kinematic (RTK) GPS. These elevations were extrapolated laterally across the floodplain and interpolated to form a low-flow water surface. This water surface was subtracted from land surface elevations surveyed during a 2010 LiDAR survey resulting in the HAWS map. Geomorphic Floodplain kilometers are shown on the HAWS map for a consistent spatial reference of spatial varying data. Geomorphic Floodplain kilometers are measured from Lake Washington along the centerline of the area of morphology that shows fluvial influence of the Cedar River.

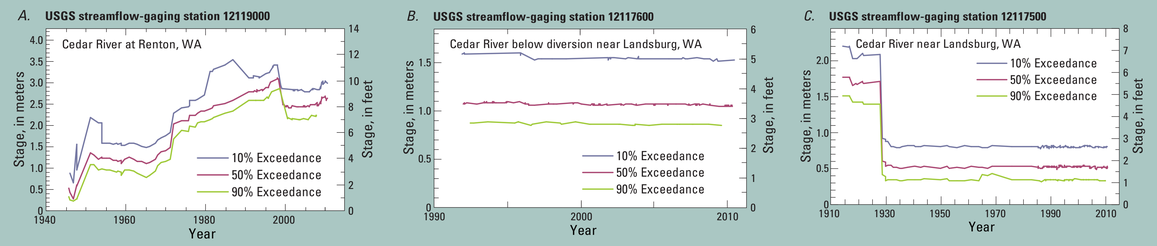

Figure 5. Specific Gage Analysis: Temporal variations in stream stage for 10- 50- and 90-percent exceedance discharges at USGS streamflow-gaging stations (*A*) 12119000, (*B*) 12117600, and (*C*) 12117500 on the Cedar River, Washington. Figure 5*A* shows about 8 feet of aggradation between 1950 and the current data from gaging station 12119000. Figures 5*B* and 5*C* show no net aggradation or incisions at the gaging stations.

Location and History of Human Modifications

The Cedar River drains an approximately 460 km^2 watershed within the western Cascade Mountains and the eastern Puget Lowland of Washington State and currently flows into Lake Washington (fig. 1). The upper part of the Cedar River flows into Chester Morse Reservoir, which was impounded behind a late Pleistocene moraine of the Puget Lobe of the Cordilleran Ice Sheet. Similar lakes persisted along the western front of the Cascade Range along neighboring valleys of rivers like Middle Fork and South Fork of the Snoqualmie River; the moraine dams across these valleys were breached much earlier and no lakes persisted through the Holocene to the present day. Human modifications to the hydrology of the Cedar River began in 1901 with the construction of a diversion dam at Landsburg although this dam only functions as a dam to divert water into a municipal water supply pipeline and does not have enough storage capacity to alter the Cedar River's hydrology. Significant alterations to the magnitude and duration of peak-flow events began with the completion of additional dams to control flow out of Chester Morse Reservoir by 1914.

In 1912, a channel was constructed through Renton to divert the Cedar into Lake Washington from its original path into the Black River, an abandoned tributary of the Duwamish River, which ultimately drains into Elliot Bay. By 1916, this diversion supplied water to run locks operated by the U.S. Army Corps of Engineers for ship passage between Lake Washington and Puget Sound.

As the floodplain developed during the 20th century, bank protection structures including revetments and levees limited channel migration and confined the Cedar River to a fraction of its former extent. Although sediment is still supplied to the Cedar River from glacial outwash bluffs along the valley margin, sediment input from bank erosion has been severely limited by revetments and levees.

Geomorphic Changes

The active channel area including gravel bars and vegetated islands of the Cedar River decreased to 56 percent of its 1865 channel as mapped by the General Land Office (GLO) surveys by 1936 and to 37 percent of its 1865 channel by 2000 (Collins and others, University of Washington, written commun., 2003). Reduction in channel area and width did not occur uniformly throughout the Cedar River (fig. 2). The most marked reductions in channel width occurred between Geomorphic Floodplain kilometers (GF km) 6 and 11 with minimal changes occurring in the engineered channel at Renton (GF km 1) and above upstream of GF km 21 where the Cedar River is more tightly confined by valley walls. Upstream of the Landsburg Diversion Dam (fig. 1; GF km 29) to Chester Morse Reservoir, the Cedar River is similarly confined following the pathway of a meltwater channel of the Puget Lobe of the Cordilleran Ice Sheet.

Decreases in active channel widths were accompanied by the formation of more single-threaded channels in contrast to braided channels with vegetated islands as visible in the 1865 GLO surveys and within the Height above Water Surface LiDAR analysis (fig. 3). These features are still preserved in much of the floodplain and remain at low elevations. The completion of water-supply dams by 1904 reduced the magnitude of peak flows, and flood protection structures like revetments and levees during the 20th century reduced channel migration rates and narrowed the active channel of the Cedar River (Perkins, 1994).

Figure 4. Substrate: Longitudinal variation of (*A*) median grain size (D50) and (*B*) 90th percentile grain size (D90), Cedar River, Washington.

Substrate

Particle-size distributions were quantified through Wolman pebble counts at 41 gravel bars from Landsburg to Renton (fig. 4). The largest median grain sizes (D50) and 90th percentile grain sizes (D90) are upstream of GF km 23 coincident with the steepest channel gradients.

Decadal Trends in Aggradation and Incision

Specific gage analyses (fig. 5) show the temporal variation in the stage-discharge relation for the 10-, 50-, and 90-percent exceedance discharges. Changes in the level of the hydraulic control raise or lower the stage at a particular discharge in response to aggradation or incision, respectively. The streamflow-gaging station record of the Cedar River at Renton (12119000, fig. 5*A*) shows net aggradation of approximately 8 ft from 1950 to current. Conversely streamflow-gaging stations on the Cedar River near Landsburg (12117600, fig. 5*B* and 12117500, fig. 5*C*) show no net aggradation or incision. Gaging station 12117500 was releveled in 1929 resulting in an instantaneous change in the stage-discharge relation not related to aggradation or incision. Aggradation near Renton occurs in response to decreasing streamflow gradients (fig. 6).

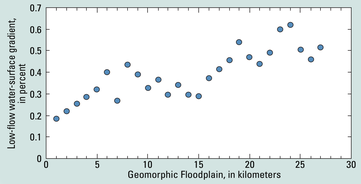

Figure 6. Low-Flow Water-Surface Gradient: Channel low-flow water-surface gradient averaged over 1-km segments of the Geomorphic Floodplain. Overall water-surface gradients decrease downstream of Landsburg (Geomorphic Floodplain kilometer 29), but increase between Geomorphic Floodplain kilometers 15 and 8.

Acknowledgments

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References Cited

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