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Geomorphic and Hydrologic Study of Peak-Flow Management of the Cedar River, Washington

By Christopher S. Magirl, Andrew S. Gendaszek, Christiana R. Czuba, Christopher P. Konrad, and Mathieu D. Marineau

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Abstract

Assessing the linkages between high-flow events, geomorphic response, and effects on stream ecology is critical to river management. High flows on the gravel-bedded Cedar River in Washington are important to the geomorphic function of the river; however, high flows can deleteriously affect salmon embryos incubating in streambed gravels. A geomorphic analysis of the Cedar River showed evidence of historical changes in river form over time and quantified the effects of anthropogenic alterations to the river corridor. Field measurements with accelerometer scour monitors buried in the streambed provided insight into the depth and timing of streambed scour during high-flow events. Combined with a two-dimensional hydrodynamic model, the recorded accelerometer disturbances allowed the prediction of streambed disturbance at the burial depth of Chinook and sockeye salmon egg pockets for different peak discharges. Insight gained from these analyses led to the development of suggested monitoring metrics for an ongoing geomorphic monitoring program on the Cedar River.

Introduction

Changes to the hydrologic regime from flow regulation and construction of revetments and levees have affected the riparian and aquatic habitat along the Cedar River, Washington. Because the river remains a regionally important resource that supports anadromous salmonids, water-resource managers require information on how to best manage peak-flow releases during periods of heavy precipitation to minimize flooding while mitigating the negative effects on fish populations and river habitat. For example, a critical management goal is to avoid deleteriously affecting the spawning and incubation cycles of the various salmonids during the rainy winter season. These fishes depend on an array of habitat types (passable reaches for migration, pools for holding and rearing, gravel bars for spawning and incubation) that are essential to their survival. These fishes also depend on hydrologic processes that establish suitable physical conditions.

In anticipation of potential listings of a number of salmonids and other species under the federal Endangered Species Act, the City of Seattle, working with State and Federal agencies and the Muckleshoot Indian Tribe, initiated the development of a habitat-conservation plan in 1994. An Agreement in Principle was approved by State and Federal agencies in 1997 and the full Cedar River Watershed Habitat Conservation Plan (HCP) was formally accepted by State and Federal agencies in April 2000 (City of Seattle, 2000). Implementation of the 50-year plan began immediately under the guidance of the interagency Cedar River Instream Flow Commission (IFC) established by the HCP to oversee implementation of the instream-flow management provisions as defined in the companion Instream Flow Agreement (IFA) for the Cedar River. Subsequent objections to aspects of the HCP by the Muckleshoot Indian Tribe were resolved in 2006 with a settlement agreement between the Tribe and the City of Seattle. This settlement agreement restricted the maximum amount of water Seattle could withdraw from the basin in any year, emphasized the importance of natural hydrologic patterns, and incorporated all other provisions of the IFA.

The HCP, its associated IFA, and the Muckleshoot Indian Tribe/City of Seattle settlement agreement identify natural flow patterns as a topic for possible further investigation in support of potential instream-flow-management protocols. The IFC identified the effects of peak flows on the Cedar River, its habitat features, and associated biota as a key area of uncertainty requiring additional investigation. To inform the decision process for peak-flow management, Seattle Public Utilities (SPU), at the direction of the IFC, asked the U.S. Geological Survey (USGS) to conduct a study of the geomorphology of the Cedar River and to assess how geomorphic processes may influence aquatic habitat.

Populations of anadromous salmonids return to the Cedar River each year to spawn, including Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). During spawning, salmon eggs are deposited and buried in depressions in the streambed called redds, and the development and survival of salmonid embryos may be affected by gravel movement and scour during the winter high-flow season (DeVries, 1997). The IFC recognized the need to better quantify these potentially detrimental effects while also improving understanding of the beneficial effects provided by peak flows in shaping and maintaining a healthy river and associated biotic communities.

Purpose and Scope

This report contains a file of a slide presentation given to the Cedar River IFC on May 2, 2012, in Seattle, Washington. The material summarizes the major findings from the study of the geomorphic and hydrologic effects of peak-flow management on the Cedar River. The overall objectives of this study were to define the geomorphic framework and riverine habitat of the Cedar River and to better understand river response and habitat health for different peak-flow management practices. Components of the entire study were prepared and presented as three separate journal article manuscripts addressing the following topics: geomorphology of the Cedar River, field measurements of streambed scour, and numerical modeling of channel hydraulics. This slide presentation gives reference information for these articles and summarizes the key conclusions from each study component.

Description of Study Area

The Cedar River drains 477 km^2 of the western slopes of the Cascade Range and the Puget Lowland of Washington State before emptying into Lake Washington at Renton, Washington (Locke and others, 2008). Streamflows are regulated at the Masonry Dam at the outlet of Chester Morse Lake, and water is diverted at the Landsburg Diversion Dam, downstream of Chester Morse Lake, for the City of Seattle’s municipal water supply (City of Seattle, 2000). The largest flows during the year typically occur from November to March when heavy winter precipitation leads to large runoff. The largest peak flow on record occurred at the Cedar River near the Landsburg gage on November 19, 1911 (402 m^3/s; 14,200 ft^3/s), before regulation. The largest peak flow recorded after regulation at the near-Landsburg gage was on November 24, 1999 (306 m^3/s; 10,800 ft^3/s). The current 2-year recurrence-interval peak flow is 68.9 m^3/s (2,430 ft^3/s) (Gendaszek and others, in press). Resource managers have numerous objectives in regulating flow in the Cedar River, including flood control, public water supply, habitat maintenance, and protection of aquatic species.

The entire Cedar River downstream of Masonry Dam, which is affected by peak-flow management, was the focus of the study. In addition, two representative reaches were also selected where intensive studies of scour mechanics and hydraulics during high flows were performed. Reach 1, located about 17 km upstream of Lake Washington, was about 1.0 km in length and represented a section of river relatively unconfined by revetments. Reach 2, located about 12 km upstream of Lake Washington, was 0.5-km long and fully confined by revetments on both sides of the river. One key goal of the study was to determine if the degree of confinement created appreciably different responses in scour of the gravel bed.

Summary and Conclusions

The geomorphic history of the Cedar River, its present geomorphic condition, and the role of high flows in creating and maintaining geomorphic features were assessed from previous investigations (for example, Cascades Environmental Services, 1991), analyses of topographic data and historical aerial imagery, channel surveys, substrate surveys, and the observed geomorphic effects of recent floods in 2009 and 2011. The geomorphic form of the Cedar River has been substantially altered by changes to the flow regime by upstream regulation, development in the flood plain, and the construction of revetments and levees. The formerly wide, anastomosing (although not meandering) channel narrowed by more than 50 percent from an average of 47 meters in 1936 to 23 meters in 1989 and became progressively single-threaded. Subsequent high flows and revetment removal contributed to an increase in mean channel width to about 34 meters by 2011. Channel migration rates between 1936 and 2011 were less than 1 meter per year throughout most of the Cedar River's length, but up to 8 meters per year in reaches not confined by revetments or valley walls. Although high flows are important for maintaining channel dynamics in the Cedar River, their effectiveness is limited by revetments, reduced sediment supply, and the lack of large wood available for recruitment to the channel. Channel-forming flows (10- to 20-year events), which provide benefit to other river systems, appear to result in a net decrease of ecological function for the Cedar River because of the presence of bank armoring.

The timing and depth of scour and fill of the gravel bed was measured during winter 2010–11 with data-logging accelerometers placed within the streambed of two study reaches. At 26 locations in areas of varying channel confinement, 48 accelerometers were installed. Changes to the orientation of accelerometers during the flood season were used to infer when the surrounding gravel matrix was disturbed and re-stabilized. Scour into the gravel bed occurred predominantly during the rising limb of the hydrograph, and maximum scour to a given depth at most locations occurred in a matter of hours. However, a limited number of locations did scour days after the flood peak in response to morphologic evolution of the river channel. Hydrophones deployed in the moving water indicated that bedload was extensive for discharge values greater than the scour threshold. In terms of managing peak flows for differences in magnitude and duration, scour response occurred faster than the ability of resource managers to change flows. Maintaining high flow just after a peak did not cause additional widespread scour.

A two-dimensional hydrodynamic model was constructed to simulate hydraulic conditions and bed shear stress in the two study reaches. Primary model outputs included water depth, water velocity, and bed-shear stress for the simulated flows. Accelerometer scour measurements were combined with simulated bed-shear stresses to estimate the probability of redd disturbance as a function of discharge. Confined reaches generally had greater water depth, water velocity, and shear stress. However, scour to the depth of egg pockets was similar between confined and unconfined reaches, presumably because the river had adjusted to its localized hydraulic conditions. Unconfined reaches provided benefits to river function by providing habitat refugia during high flows as determined with published fish preferences for flow conditions. Not all areas of the bed were disturbed at the largest flows. As discharge increased from 56.6 m^3/s (2,000 ft^3/s) to 142 m^3/s (5,000 ft^3/s), the disturbance probability to the depth of the top of salmonid egg pockets increased linearly from about 5 to about 60 percent, and from about 2 to about 40 percent for sockeye and Chinook salmon, respectively.

A conceptual model describing the interactions between geomorphic processes and ecological responses in the river was developed to aid communication between stakeholders and to guide ongoing scientific studies in the river corridor under an adaptive-management framework. Insight gained from the geomorphic analysis, scour measurements, and hydrodynamic modeling of this study contributed to the development of suggested monitoring metrics of key geomorphic parameters. High-priority monitoring metrics are those most influenced by peak flows and have the greatest beneficial effects on fish. The high-priority monitoring metrics included monitoring seasonal redd scour, measuring and tracking large woody debris, mapping areas of spawnable gravels, and mapping off-channel habitat and quality.

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