MONITORING & MAINTENANCE REPORT
RAINBOW BEND LEVEE REMOVAL AND FLOODPLAIN RECONNECTION PROJECT

Years 1 and 2 (2014/2015)


Constructed: Summer 2013

Planted: Spring 2011, Fall 2013, Spring 2014

PERMITS: King County #GRDE12-0027, Hydrologic Alteration Permit: #129141-1
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Executive Summary

What is the report about?

This report\(^1\) presents the post-project monitoring results for the final phase of the Rainbow Bend Levee Removal and Floodplain Reconnection Project. The Rainbow Bend project was a multi-partner, multi-objective effort to reduce flood risks and improve salmon habitat in the lower Cedar River. The work was done in two phases spanning more than ten years.

**Phase 1: Reduce flood risk**

In the first phase, King County helped move residents out of harm’s way. Single-family homes and a mobile-home park were threatened with chronic flooding, requiring emergency response and evacuations.

King County purchased the flood-prone properties, helped residents relocate to homes in safer places, and then removed the unoccupied dwellings, creating a 40-acre open space.

**Phase 2: Aid salmon recovery and reduce maintenance costs**

Though the residents had left, the aging levee remained. Like others of its era, the levee contributed to fast, erosive flows, which damaged salmon habitat. In the second phase, the Rainbow Bend Levee Removal and Floodplain Restoration Project was completed. The ecological goal was to improve salmon habitat and floodplain functions.

Fast, erosive flows also created ongoing maintenance needs along the left bank. That bank protects the Cedar River Trail, which contains a major communications line and is flanked by State Route 169, a primary transportation arterial. Removing the old levee helps diminish long-term maintenance costs along the trail.

The restoration project, completed in 2013, removed the levee, built four logjams, created two new channels and backwater habitat, and installed tens of thousands of native plants.

Large-scale, multi-objective projects like Rainbow Bend, where old levees are removed or set back, are central to restoring the viability of threatened Puget Sound fall Chinook salmon. Lessons learned through effectiveness monitoring can help to improve future projects.

A comprehensive, 10-year effectiveness monitoring effort is underway to determine whether project goals and objectives are being met effectively and efficiently.

This report is focused on changes in the river, large wood, fish habitat, and plant performance. Changes in erosive forces against the Cedar River trail are briefly addressed. Generally, public safety topics are addressed in a separate Site Management Plan.

**How has habitat changed?**

**More habitat for salmon**

The project site can support about twice as many juvenile Chinook salmon as before, and that figure is expected to increase as the river continues to change.

A patchwork of new salmon habitat is developing. The number of juvenile Chinook salmon that can reside in the project site during relatively high flow levels increased from a baseline of approximately 600 to nearly 1,600 fish. This gain resulted from increases in habitat within the backwater feature and the side channels.

\(^1\) This is the first of five reports, in total. The final report will be completed in 2024.
Constructed features provided near-term benefits

Deformable, constructed features provided most of the new habitat.

The channel migrated into one of four logjams and large wood began accumulating on the newly-exposed structure. The backwater habitat and cutoff channel provided refuge during high flows. Juvenile salmon habitat was scarce in the floodplain side channel, where flows were unobstructed—by design. As expected, the side channel enlarged and intercepted streamflow. In doing so, the side channel promoted gravel and wood deposition in the mainstem. The side channel also provided access to new habitat in floodplain interior during high flows.

How is the river responding?

Floods reshaped the mainstem

A two-week-long flood in March 2014 caused the river channel to rapidly change.

During a two-week-long flood in March 2014, the mainstem became wider and shallower where the levee had been removed. Relatively little change was observed farther downstream.

As the river adjusted to levee removal, the project site produced sediments from eroding banks and trapped streambed gravels important for spawning.

Nearly six feet of streambed gravel deposited in the mainstem next to the side channel inlet. This sediment trapping probably resulted from channel widening and the routing of stream flows into the new channels, both of which would reduce the ability of the river to transport gravel. Even so, the total volume of material eroded from banks and from the streambed across the entire project site exceeded the rate of instream deposition. Similar responses to flooding were measured at nearby stream reaches.

Side channel is connected all year and is changing quickly

Leaving the floodplain side channel unobstructed—at least initially—probably helped to keep it connected to the mainstem.

Outcomes thus far have validated the design decision to promote a sustained connection to surface flow in the mainstem by not placing large wood in the floodplain side channel.

The floodplain side channel grew substantially wider and deeper, but the cutoff channel was surprisingly stable.

The streambed elevation in the side channel has cut down three feet and the width has more than doubled, in some places. As this continues, the channel will undercut and topple trees from the riparian forest and instream habitat will increase.

Deposition in the mainstem channel enhanced the connectivity of the side channel.

A localized shift in water levels was observed. Water surface elevations at the upstream end of the project increased during flow levels less than 4,000 cubic feet per second. The increase was particularly high at low flows. This shift in water levels helped to keep both channels connected to flowing water from the mainstem. Additionally, an increase in water levels during the dry season may benefit riparian vegetation.

Contact between the river and the logjams is slower than expected

Two of the four placed logjams are not likely to be encountered by the river in the near-term.

Against expectations, relatively little channel migration has occurred near two of the logjams built in the floodplain. This outcome highlights the difficulty of predicting future channel
positions with certainty and validates the decision to reduce the investment in each logjam, in light of that uncertainty.

How has flood and erosion risk changed?

Risk to residents is reduced

Home buyouts and assisted relocation of residents reduced the risk to public safety. As a consequence of the first phase of the project, localized flooding no longer threatens residences or endangers people. Flood risks have been reduced. Emergency responses and evacuations have been avoided by helping residents to move to safer homes.

Risk to infrastructure is reduced

Removing the levee and constructing new channels reduced the risk to public infrastructure. By diverting a portion of the river flow away from Cedar River trail, which slows down the water along the left bank, the second phase of the project reduced the risk of damage from erosion and the need for future maintenance.

Changes in flood levels

The levee removal and new channels contributed to a small, localized decrease in water surface elevations during high flows. Specifically, when stream flows exceed 4,000 cubic feet per second (at Renton), the water level at the upstream end of the site was an inch or two lower than before the project was completed. Even though lowering the flood water surface elevation was not a project objective, it remains an outcome of interest to many and will be monitored over time.

Summary

The project, in its entirety, has reduced flood risks, protected public infrastructure, and increased habitat for threatened salmonids; it is meeting near-term goals and objectives.

Given that the flood-risk reduction strategy and the restoration design used at Rainbow Bend produced multiple benefits, including near-term gains in salmon habitat, King County should consider replicating these strategies and designs in future projects to achieve flood risk reduction and salmon recovery goals in the Cedar River.

The river is still adjusting. Changes in project performance and river conditions will be documented in future reports.

No corrective actions are needed at this time. Monitoring and maintenance of the site will continue through 2024.
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I. Site Description

Location
The 40-acre project site is located in unincorporated King County (NW 1/4 of Section 32, Township 23 North, Range 6 East (Willamette Meridian) between River Miles (RM) 10.7 and 11.5 of the Cedar River, Washington (Figure 1)\(^2\). The site is north of the intersection of State Route 169 (Renton-Maple Valley Road SE) and Cedar Grove Road east of the City of Renton.

Human Alterations
The Cedar River has been extensively modified (WRIA 8, 2005). The river once drained to the Duwamish River via the Black River, but was re-routed to Lake Washington in 1916. The project site is upstream from the site of these historic channel re-alignments. However, the site is affected by flow regulation, as it is downstream from two dams that have been in place for over a century. The Landsburg diversion

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\(^2\) The project site is located between two previous King County restoration projects. It is 1,700 feet downstream from the Lion’s Club project, where side channels were excavated from the left-bank floodplain. It is approximately three miles upstream from the Cedar Rapids project, where a revetment was removed and a setback levee and engineered logjams were built.
dam (ca. 1901) at RM 22 extracts flow for municipal use. Upstream from the diversion dam, the Masonry dam (ca. 1914) stores floodwaters and restricts peak flows. Flow extraction and flood control may contribute to channel narrowing downstream from the dams. Channel migration has been limited by channelization, but may still average eight meters per year in unconfined reaches (Gendaszek et al. 2012). This indicates the river retains the potential to migrate laterally across its floodplain, at least in some places.

The project site has been primarily altered by channelization and low-density rural development. A levee was constructed on both banks in 1962. The right-bank levee extended from the Cedar Grove Road downstream for approximately 950 feet and (formerly) protected residential homes. The left-bank revetment (Trail Site 6) protects the Cedar River trail, State Route 169, and a communications line.

Physical Setting
The project site is located in a low-gradient (<0.31% or 0.0031) reach of the lower Cedar River (Mansfield et al. 2013). The channel historically exhibited a meandering or island-braided planform. The project site, similar to much of the river, was historically unconfined and probably contained many logjams (Gendaszek et al. 2012). The site was historically shaped by large floods. The north valley wall contains unstable steep slopes with a documented history of failure in reaches upstream and downstream of the project site (Mansfield et al. 2013). However, slopes within the project site are relatively stable and no failures are evident in the period of photo record (1936 to present). The site contains three wetlands associated with abandoned channels in the floodplain. These features were either floodplain tributaries or former channels of the Cedar River. Soil type at the site is Pilchuck loamy fine sand which is commonly found on nearly level surfaces of <2% slopes and on terraces adjacent to streams. Pilchuck soils are excessively drained (not hydric) soils that formed in alluvium on low stream terraces under a cover of hardwoods and conifers.

Fish Use
The 21-mile segment of the Cedar River downstream from the Landsburg Diversion is used for spawning and rearing by salmonids, including Chinook salmon (WRIA 8, 2005). Beginning in 2003, salmonids other than sockeye salmon have been able to access the river above Landsburg up to the natural barrier at Cedar Falls. Three main tributaries—Lower Rock Creek, Peterson Creek, and Taylor Creek—are also used for spawning and rearing. The following other salmonids use the project site for spawning and rearing by salmonids: coho salmon, sockeye salmon, and steelhead and coastal cutthroat trout. Bull trout have also been documented to use the Cedar River for foraging and migration, but there is no known resident population. Three species—Chinook salmon, steelhead, and bull trout—are all protected as threatened species under the Endangered Species Act.
Riparian Conditions
The lower Cedar River is mostly forested and only small patches of intact riparian vegetation remained at the project site, prior to restoration. Wetlands landward of the levee support forested, shrub3 and emergent4 layers. Upland edges contain black cottonwood (*Populus balsamifera trichocarpa*), red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*), Douglas-fir (*Pseudotsuga menziesii*), Western red cedar (*Thuja plicata*), and various shrubs5. Invasive species are also common, including knotweed (*Polygonum X bohemicum*), English ivy (*Hedera helix*) and Himalayan blackberry (*Rubus armeniacus*). In 2011, approximately 15,000 six-foot-tall cottonwood poles were planted on the eastern portion of the site. In 2012, King County began an Integrated Vegetation Management Program, in which ivy, blackberry, knotweed, tansy ragwort, butterfly bush, and all invasive tree species were controlled.

Recreational Uses
The project site is located across the river from the Cedar River Trail, a regional recreational amenity for walking, jogging, bicycling, and river viewing. The site is also opposite the Cedar Grove Natural Area, a public property which offers an access point for recreational boaters and floaters in tubes and small rafts, as well as walking, fishing, birding and wildlife viewing via informal river trails.

Regulatory Designations
The project site is classified as a floodway and contains a Type S Aquatic Area regulated by the King County Critical Areas Ordinance. The three wetlands found in former river channels are regulated as Category II wetlands (Mansfield et al. 2013).

II. Project Goals and Objectives
The Rainbow Bend project was a multi-objective effort to reduce flood hazards and improve salmon habitat. The Rainbow Bend project was proposed as Project C235/236 in the WRIA 8 Chinook Salmon Conservation Plan (WRIA 8, 2005; see Appendix A for details). In addition to being a top priority for salmon habitat, the project was identified as an important flood hazard reduction project in the 2006 Flood Hazard Management Plan (King County, 2013)6. The work was completed in two phases that spanned more than ten years.

In the first phase, King County eliminated the flood risk by helping to move residents out of harm’s way. The site was once occupied by single-family homes and a mobile-home park. Chronic flooding threatened the residents. King County purchased the flood-prone properties, helped residents relocate to homes in safer places, and then removed the unoccupied dwellings, creating a 40-acre open space.

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3 Red-twig dogwood (*Cornus sericea*), salmonberry (*Rubus spectabilis*) and Nootka rose (*Rosa nutkana*).
4 Reed canary grass (*Phalaris arundinacea*), small-fruited bulrush (*Scirpus microcarpus*), buttercup (*Ranunculus sp.*) and skunk cabbage (*Lysichitum americanum*).
5 Snowberry (*Symphoricarpos albus*), vine maple (*Acer circinatum*), Indian plum (*Oemlaria cerasiformis*), beaked hazelnut (*Corylus cornuta*) and Nootka rose (*Rosa nutkana*).
6 Fifty-six homes had been located in this flood prone reach of the river. The homes occupied sixteen parcels, totaling 40 acres. The parcels were acquired, the residents equitably relocated to new homes, and the structures were demolished. These actions eliminated the flood risk to the occupants and prepared the site for restoration.
In the second phase, the Rainbow Bend Levee Removal and Floodplain Restoration Project was completed in 2013 to improve salmon habitat and floodplain functions. The levee—like others of its era—damaged salmon habitat. Removing the levee was intended to benefit salmon. The restoration project removed most of the existing levee, built four logjams, graded the floodplain to reconnect historic side channels, created a backwater habitat and a cutoff channel, and installed tens of thousands of native plants (Figs. 2 and 3).

The main purpose of this report is to document progress toward the ecological goal of the second phase of project (Mansfield et al. 2013):

1. **Restore floodplain functions and processes that provide for natural development of riverine habitat and aid salmon recovery.**

This general goal can be reduced into interrelated, detailed objectives (Table 1).

<table>
<thead>
<tr>
<th>Objective</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase and improve rearing habitat for salmonids</td>
<td>Restore floodplain functions and processes that create and maintain riverine habitat.</td>
</tr>
<tr>
<td>Allow the river to expand and migrate toward the right bank at moderate rates</td>
<td>Remove approximately 1500 feet of toe rock and 900 feet of levee (3,400 cubic yards of angular rock).</td>
</tr>
<tr>
<td>Reconnect historic side channels and expand and enhance existing habitat in wetlands</td>
<td>Create floodplain side channel; excavate 10,000 cubic yards of alluvium.</td>
</tr>
<tr>
<td>Allow flows to divert across the floodplain</td>
<td>Excavate 900-foot long cutoff channel on diagonal across right bank floodplain</td>
</tr>
<tr>
<td>Increase roughness in the channel and floodplain</td>
<td>Build 2 large and 3 small logjams in the floodplain, and install plantings</td>
</tr>
<tr>
<td>Re-establish riparian forests, increase soil cohesion</td>
<td>Plant 15,000 cottonwood livestakes in 2010, additional plantings in 2013-2015</td>
</tr>
</tbody>
</table>

Three other goals focused on public safety and risks to infrastructure (Mansfield et al. 2013).

2. **Reduce flood risks to people and infrastructure:** This goal was primarily accomplished by the first phase of the project, in which flood-prone homes were purchased and residents were given assistance to relocate to safer places.

3. **Address the impacts of the project on recreational safety:** Goal 3 is being addressed with annual and post-flood safety inspections.

4. **Reduce the need for future facility maintenance and emergency response:** The need for emergency response was eliminated in the first phase of the project. The contributed to fast and erosive flows that posed a maintenance risk to the Cedar River Trail on the left bank (Trail Site 6). The trail contains a major communications line and is beside State Route 169, a primary transportation arterial for the Renton to Maple Valley corridor. Removing the levee is likely to reduce the erosive forces on the trail, and diminish long-term maintenance costs.
FIGURE 2. MAJOR GRADING AND WOOD PLACEMENT DESIGN ELEMENTS OF THE RAINBOW BEND LEVEE REMOVAL AND FLOODPLAIN RECONNECTION PROJECT (SHEET 12 OF 22 SHOWN; SEE FINAL PLAN SET FOR FURTHER DETAIL).
FIGURE 3. PROJECT SITE BEFORE (LEFT) AND AFTER (RIGHT) ACQUISITION, RELOCATION, AND CONSTRUCTION.
III. Permit Requirements

King County’s Department of Permitting and Environmental Review (DPER) and Washington Department of Fish and Wildlife (WDFW) required post-construction monitoring (Table 2).

<table>
<thead>
<tr>
<th>Type</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>King County DPER Clearing and grading permit #GRDE12-0027</td>
<td>The project’s habitat benefit for riparian cover and invasive cover shall be monitored by the applicant for three years following acceptance of installation. Riparian cover and invasive cover shall meet the performance standards in Section 1.6 of the Monitoring Plan prepared by King County Department of Natural Resources and Parks, dated March 7, 2013. A monitoring report shall be provided to DPER after December 31 of each year. Performance standards include the following: 1. Year 3 survival &gt;50% and native woody cover &gt;50% in planted areas; 2. By Year 5, stem density higher than as-built in planted areas owing to natural recruitment; 3. Bohemian knotweed cover is lower than baseline conditions (2010) and is decreasing over time.</td>
</tr>
<tr>
<td>WDFW Hydraulic Project Approval #129141-1</td>
<td>Vegetative cuttings shall be planted at a maximum interval of three feet (on center). Plantings shall be maintained as necessary for three years to ensure 80% or greater survival of each species or a contingency species approved by AHB.</td>
</tr>
</tbody>
</table>

IV. Ecological Performance Standards

This section outlines performance standards associated with project objectives established by King County. Each objective supports Goal 1 which is concerned with the ecological benefits of the project.

Objective 1: Increase and improve rearing habitat for juvenile salmonids by restoring floodplain functions and processes that create and maintain riverine habitat.

Fish habitat benefits were evaluated on the basis of changes in edge habitat area. Habitat preferences were validated by comparisons of juvenile fish density among edge habitat types. Changes in habitat capacity were estimated as the product of average fish density and the increase in edge habitat.

Edge habitats (i.e., bars, banks, backwaters, and side channels) are readily identifiable in mainstem rivers and their boundaries can be mapped objectively. These features are indicators of complexity in that they integrate the combined influences of many physical changes. These habitat types “effectively stratify microhabitat characteristics and seasonal abundances of juvenile salmonids”, and are both “(1) sensitive to anthropogenic change and (2) reasonable predictors of juvenile salmonid abundances” (p. 727, Beechie et al. 2005).
**Indicator** | **Performance Standard** | **Timing**
--- | --- | ---
1a: Edge habitat area | The summed area of ‘edge habitat’ (i.e., bar, bank, backwater and side channel units) increases by at least 50%, relative to either pre-project conditions or the control reach. Alternatively, the summed area is at least 50% of reference levels, measured at approximately 760 cfs at Landsburg. | By Year 5 (2018) or after three 2-year recurrence interval (RI) floods.

1b: Fish use | No standard specified. |  

**Objective 2:** Allow the river to expand and migrate toward the right bank at moderate rates.

Changes in channel movement, planform, width, and depth were used to evaluate the second objective.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A: Lateral channel migration rate</td>
<td>Rates of bank retreat are similar to reference conditions (e.g., rates are within the middle 50%—the interquartile range—of observed rates at reference sites).</td>
<td>By Year 5 (2018) or after three two-year recurrence interval floods</td>
</tr>
<tr>
<td>2B: Mainstem planform, channel width and depth</td>
<td>The channel planform is transitioning from single-thread to island-braided with stable forested islands. Mainstem gets wider, shallower, and more uneven in profile, relative to baseline and control.</td>
<td>By Year 10 (2023) or after three two-year recurrence interval (RI) floods</td>
</tr>
<tr>
<td>2C: Stability of large wood structures 1 and 2</td>
<td>Key members of the jams are initially stable upon contact with channel, and become more stable as they trap additional wood.</td>
<td>Until at least Year 5 (2018)</td>
</tr>
<tr>
<td>2D: Stability of large wood structures 3 and 4</td>
<td>Upon contact with the channel, jams remain stable long enough to reduce lateral channel migration rate.</td>
<td>Until at least Year 5 (2018)</td>
</tr>
</tbody>
</table>

Measurements of bank retreat indicate the rate at which the river is either migrating or widening in response to levee removal, which is assumed to be important for new habitat formation. Moderate rates of migration are assumed to help create and maintain complex morphology, and to promote hydraulic diversity.

Channel planform represents the channel as viewed from above, historically divided into straight, meandering, or braided types (Leopold and Wolman 1964), though at least 14 patterns may exist (Knighton 1998).

The cross-sectional form refers to the size and shape of a channel expressed at a given point or reach average (Knighton 1998). Changes in cross-sectional form help explain how the channel is adjusting.

Logjam stability was also monitored because logjams were intended to moderate channel migration and expansion (Figure 4). Determining whether the logjams remain stable indicate whether roughness in the channel and floodplain has been increased.
FIGURE 4. PARTIAL VIEW OF LARGE WOOD PLACEMENT PLANS ILLUSTRATING LARGE WOOD STRUCTURES 1-4.
Objective 3: Divert flows across the floodplain and reconnect historic side channels and wetland B
Side channel inlet elevations help describe the connectivity of constructed side channel and wetland. The assumption is that habitat benefits from the channel generally increase with connectivity.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3: Inlet elevations</td>
<td>Inlets to side channel and Wetlands B &amp; D do not fill in from deposition.</td>
<td>By Year 5 (2018) or after three 2-yr RI floods.</td>
</tr>
</tbody>
</table>

Objective 4: Increase roughness in the channel and floodplain
Large wood plays an important role in providing floodplain roughness, as well as cover and hydraulic refuge for juvenile salmon. Wood abundance is a good indicator of channel complexity, as it performs many critical functions⁷ that create habitat and diversify the river (Naiman et al. 2002). The benefits conferred by wood should be positively related to the amount of wood in the project site.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a: Natural wood abundance</td>
<td>Wood abundance increases relative to the baseline, exceeds the control reach, and is similar to previously surveyed reference reaches</td>
<td>By Year 5 (2018)</td>
</tr>
<tr>
<td>4b: Function of two large jams</td>
<td>Placed jams create sites for vegetation establishment, direct overbank flows into floodplain channels, reduce sheet flow in the floodplain, retain transported wood to increase jam size, and force flow divergence to create an island-braided channel.</td>
<td>For at least 10 years (2023)</td>
</tr>
</tbody>
</table>

Objective 5: Re-establish riparian forests
Measurements of riparian cover will indicate the degree of success in re-establishing riparian forests of native trees and shrubs. Changes in invasive cover will indicate whether treatment efforts are effective.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>5a: Riparian survival and cover</td>
<td>Survival of plantings is at least 50% and native cover is at least 50%. Stem density is higher than as-built in planted areas, owing to natural recruitment⁸: • Cottonwood and willow staking areas: 3 feet o.c. • Alder and cottonwood areas: 5 feet o.c. • Shrub areas: 5 feet o.c. • Other tree areas: 8 feet o.c.</td>
<td>By Year 3 (2018) By Year 5 (2018)</td>
</tr>
<tr>
<td>5b: Invasive cover</td>
<td>Knotweed cover is lower than baseline conditions (15 acres of mixed blackberry and knotweed) and is decreasing over time.</td>
<td>For at least 10 years</td>
</tr>
</tbody>
</table>

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⁷ Accumulations of wood may split flow, tighten meander geometry, scour pools, stabilize banks, cause or prevent avulsions, regulate side channel inflows, form bars and sediment wedges, and contribute to forested islands.

⁸ Initially proposed as an expected outcome, this standard does not establish a benchmark to determine success. It should have stipulated that success could be achieved with sufficient densities to meet cover targets by Year 5. Even if natural recruitment was occurring, competitive thinning would be expected by Year 5 in a healthy forest stand.
Ecological Risks
Ecological risks were evaluated to address two stakeholder concerns: juvenile fish stranding in closed depressions and adult passage during low flow. Stranding happens in both natural and modified reaches of the Cedar River, but there is of more concern when it happens in a constructed setting. Fish must constantly balance risks (e.g., stranding) and benefits (e.g., reduced flood injury and displacement). Some habitats may be risky but beneficial; others may act as ‘ecological traps’ as a consequence of artificial habitat characteristics or altered environmental cues⁹.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>6a: Juvenile stranding in closed depressions</td>
<td>By late spring (early June), closed depressions in the impact reach are inhabited by salmonids at similar frequencies, and contain similar species (including redds) as closed depressions in the reference reach (Dorre Don).</td>
<td>2013-2016</td>
</tr>
<tr>
<td>6b: Adult passage in the mainstem</td>
<td>No geomorphic changes will cause a barrier to upstream passage by adult Chinook salmon</td>
<td>2013-2023</td>
</tr>
</tbody>
</table>

Flood Hazard Reduction
The first phase of the project eliminated flood risk to former residents of the project site, and any need for emergency response to chronic flooding. However, potential benefits could also be realized from the second phase of the project, through a reduction in the erosive forces against remaining facilities on the left bank. If erosive force is reduced, the project could help to reduce long-term maintenance costs.

To evaluate this potential benefit, the Rainbow Bend project team solicited TetraTech—an environmental consulting firm—to develop a two-dimensional model, utilizing RiverFLO 2D V.2, of the project site and surrounding area. The model was used to reflect existing conditions, as-built conditions, as well as a relatively probable future geomorphic scenario¹⁰.

There is also widespread interest in the effects of levee removal on flood water surface elevations. Changes in water surface elevations were evaluated using continuous water-level loggers at the upstream and downstream ends of the project site. The upper logger was on the left bank opposite the inlets to the new side and cutoff channels. The lower logger was placed in the constructed backwater feature. Water levels were recorded at 15-minute intervals, from 2012 to the time of this writing.

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⁹ An ecological trap forms when the attractiveness of the habitat increases disproportionately to its value for survival and reproduction (Robertson and Hutto 2006); the habitat becomes a sink, rather than a source. If environmental cues are disrupted, fish may fail to disperse or seek refuge at the right times. A trap could also be created when fish are attracted to a certain type of habitat (e.g., newly-constructed channels), but that habitat is actually riskier than a natural one. A trap could also occur if dispersal triggers—environmental cues—are impaired. Altering the rate of change in flows (e.g., a prolonged freshet followed by a sharp decrease) could interfere with the dispersal triggers that cause fish to evacuate off-channel habitats. In that case, both naturally-formed and constructed features could potentially function as traps. It could also be that stranded fish are poorly-adapted to their environment. Selective pressures will favor fish that gain the benefits from living in off-channel areas but also respond to changing flow levels in time to survive.

¹⁰ Results and discussion of model validation are summarized in a memo by Tom Spangenberg, April 23, 2013.
V. Ecological Study Design

A Before-After-Control-Impact experimental design was used, with the addition of one reference reach. One year of pre-project (before) topography and bathymetry was measured at the project site (impact reach; 4,200 feet at 0.31 slope), at the Taylor Creek Reach (control), and at the Dorre Don Reach (reference) (Error! Reference source not found.).

The Taylor Reach (3,700 feet at 0.41 slope) is nearly identical in planform to the baseline condition at the project site except that it remains confined and developed, and is located only 6,200 feet upstream. The similarity in historical alterations, planform, and comparable gradient and the close proximity makes the Taylor Reach a reasonably good control site.

The Dorre Don reach (4,200 feet at 0.48 slope) on the Cedar River was selected as the reference reach, primarily for its complex side channel on the inside bend. The purpose of the reference reach is to evaluate the progress of the project site toward an attainable and satisfactory target condition. Dorre Don does not represent an ideal condition, but it does provide some indication of what conditions are possible under existing and ongoing constraints (e.g., altered regimes for flow, sediment, and wood).

VI. Methods

1a. Edge habitat

Edge habitat was mapped at multiple discharges to quantify the relationship between flow and edge habitat area. Three flow percentiles\textsuperscript{11} from January-June were initially targeted to characterize an important rearing period for juvenile Chinook salmon:

- 50\textsuperscript{th} percentile flow (756 cfs; USGS 12117500): Typical conditions that juvenile salmon will experience during freshwater rearing.
- 75\textsuperscript{th} percentile flow (1,012 cfs): Upper end of the interquartile range. As an annual peak flow rate, this value has a recurrence interval (RI) of approximately 1.01 years (King County, 2009).
- 90\textsuperscript{th} percentile flow (1,283 cfs): The RI for 1,283 cfs is between 1.01 and 1.25 years. Phase I flooding begins at 1,800 cfs\textsuperscript{12}.

\textsuperscript{11} Landsburg gage used instead of Renton owing to close proximity to sites.
The extent and distribution of medium (<45 cm/s) to low-velocity (<15 cm/s) edge habitat was mapped using a Trimble GPS on both banks of impact, control, and reference reaches (Beechie et al. 2005, Bisson et al. 2006). The boundary between fast and slow-to-moderate velocity units was located either with a flow meter, or by visually interpreting the current shear line, often with the assistance of a wading pole. Rip-rap banks along levees and revetments were excluded, as were areas narrower than the horizontal accuracy of the GPS after differential correction (e.g., <1 m).

Each unit was classified in the field (Beechie et al. 2005, Bisson et al. 2006).

- **Bars**: Slow channel unit located where channel meets a shallow, gently-sloping shore;
- **Banks**: Slow channel unit located where channel meets a deep, nearly vertical shore;
- **Backwaters**: Slow, partially-enclosed channel unit along a mainstem bank at the downstream end of a disconnected floodplain channel or secondary channel;
- **Side channels**: Channelized flow of emergent hyporheic groundwater in flood channels, or channels connected to the mainstem at both ends containing <50% of the discharge.

**1b. Fish Use**

The objective of fish sampling was to quantify fish density in edge habitats in the lower Cedar River. When combined with edge habitat maps that quantify the type and area of available habitat, measurements of fish density can be used to estimate changes in habitat capacity that result from a restoration project (Figure 6). In addition, relative differences in density between edge habitat types may indicate how habitat use varies among species or life history stages.

_Figure 6. Illustration of how edge habitat maps and fish density estimates were combined to evaluate changes in habitat capacity resulting from the project._

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12 Flood refuge is important at much higher flows, but it cannot be safely mapped in the field.
This study examined three of the many sources of variation\(^\text{13}\) in juvenile salmonid density; species, edge type, and month (which relates to body size). Fish surveys were intended to address these questions:

- How does fish density vary among edge habitat types in the lower Cedar River?
- What is the average density of each fish species in each type?
- How does density vary by from April to June?

Answers to these questions can be used to evaluate how the restoration project has affected habitat capacity, given observed changes in habitat availability.

**TABLE 3. SAMPLE SIZE FOR SURVEYS OF FISH USE OF EDGE HABITATS.**

<table>
<thead>
<tr>
<th>Edge habitat type</th>
<th>Sample size (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank</td>
<td>17</td>
</tr>
<tr>
<td>Rip-rap bank</td>
<td>6</td>
</tr>
<tr>
<td>Bar</td>
<td>28</td>
</tr>
<tr>
<td>Backwater</td>
<td>19</td>
</tr>
<tr>
<td>Side channel(^\text{14})</td>
<td>16</td>
</tr>
</tbody>
</table>

Fish density was quantified in edge habitats at four sampling locations and then pooled to generate mean and median values: Rainbow Bend (RM 11.4), Belmondo (RM 10.5), Herzmann (RM 6.5), and Dorre Don (RM 16.5) (Tables 3 and 4; King County 2015). Four sites were used because no single site contained a sufficient diversity and number of discrete edge habitat units.

**TABLE 4. SNORKEL SURVEY DATES (2014), LOCATIONS, AND DISCHARGE (USGS 12117500; LANDSBURG).**

<table>
<thead>
<tr>
<th>Month</th>
<th>Day</th>
<th>Discharge (cfs)</th>
<th>Rainbow Bend</th>
<th>Dorre Don</th>
<th>Belmondo</th>
<th>Herzmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>14</td>
<td>800</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>755</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>852</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>19</td>
<td>715</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>680</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>260</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>11</td>
<td>270</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>460</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>260</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>260</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

The experimental units were edge habitats (Table 3). Units were selected opportunistically, instead of probabilistically, and so the population of inference is limited to the four study sites, in a strict sense, and may not be representative of the Cedar River as a whole. Each site was sampled three to five times (Table 4). Nighttime snorkel surveys were used to count fish in each edge habitat type (King County 2015). Density was estimated by species, habitat type, date, and location. Species-specific estimates of

\(^{13}\) Other sources of variation that may also be important but were not evaluated in this study include: river discharge, edge habitat quality (cover and depth), proximity to the mainstem, year-over-year variation, longitudinal position (e.g., river mile or proximity to confluences).

\(^{14}\) Sampling efficiency is likely diminished in side channels owing to complexity and visual obstructions.
fish density were compared using a Kruskal-Wallis One-Way ANOVA based on ranks to determine if fish density varied among habitat type ($p < 0.05$). Post-hoc pairwise comparisons (Dunn’s method) were used to identify homogeneous groups ($p < 0.05$).

2a. Lateral channel migration rate
Lateral channel migration rate was primarily evaluated by measuring changes in the position of the bank from annually-collected high-resolution orthophotos. Supplemental measurements were collected with a GPS in the field by mapping the top of the river bank, or the edge of the unvegetated channel. In both cases, the average rate of lateral bank retreat in each reach was estimated in terms of area and linear distance. Linear distance was calculated as eroded area divided by the initial length of the eroded bank.

2b. Mainstem planform, channel width and depth
Channel dimensions were measured in ArcGIS, using LiDAR, bathymetry, and ground survey to create an integrated digital elevation (terrain) model of the mainstem channel and floodplain. Changes in channel form were assessed by calculating changes in ground surface elevation over time. Cross-sections and polylines were used to measure changes in channel width, thalweg depth, average bed elevation, and channel capacity. Metrics were compared among reaches and with baseline conditions.

2c. Stability of Large Wood Structures 1 and 2
The stability of large wood structures was assessed visually with photopoints that illustrate annual changes in structures 1 and 2.

2d. Stability of Large Wood Structures 3 and 4
The stability of large wood structures 3 and 4 were assessed in the same way as Structures 1 and 2.

3a. Inlet elevations
Topographic mapping was used to measure thalweg elevations in constructed side channels and to quantify changes among years. Time-lapse cameras documented inflows. Photos were cross-referenced to discharge records to quantify the duration and frequency of connectivity or inflow.$^{15}$ A water surface elevation logger was installed on the left bank opposite the channel inlets to document changes in stage-discharge relationships.

4a. Natural wood abundance
An annual census of large wood (LW) was conducted using a visual classification technique (Montgomery 2008). All visible LW was counted and classified by length (7 classes) and diameter (5 classes)$^{16}$. Separate tallies were kept for the active mainstem channel, each side channel, and the floodplain. A measuring staff was used to classify pieces that were nearly tied between size classes.

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$^{15}$ A near-continuous video record exists for the cutoff channel, but the camera observing the side channel was stolen soon after installation, but after it documented changes in the first year.

$^{16}$ Excluding the A length class (<1 m) and the “1” diameter (<10 cm) class.
4b. Function of two large jams
The functionality of the two large jams was visually evaluated and photo-documented. Specifically, field observations were used to ascertain whether jams were performing any of the following functions: a) moderating channel migration; b) creating safe sites for vegetation establishment; c) directing overbank flows into floodplain channels; d) reducing sheet flow in the floodplain; e) retaining transported wood, and/or: f) forcing flow divergence and promoting an island-braided channel form.

5a. Riparian survival and cover
A controlled experiment was established in 2011 to measure the cost-effectiveness of irrigating cottonwood live stakes (Figure 7), which were planted to increase floodplain roughness.17

Pairs of study plots (n=24) were established at spatially randomized locations in each planting stratum. Plot dimensions were 4 x 16 m, encompassing an average of 77 stakes (range: 49-109). Stakes were six feet long and either 1-2 inches or 3-5 inches in diameter, planted at a density of three feet on-center (o.c.). Irrigation treatments were assigned at random to one of each pair, totaling 12 plots. These 12 plots were irrigated three times in the first summer (2011) with approximately 1.5 gallons of water each time. Survival was measured in 2011 and 2012. Several of these plots were subsequently intersected by construction access roads in 2013, but intact plots may be surveyed a final time in 2016 to estimate native woody cover using point-intercept methods.

5b. Invasive cover
In 2012, invasive weeds were mapped as polygons and points. Points are defined as small clusters or single plants covering <100 feet² and >25 feet away from another knotweed patch. Knotweed patches

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17 A second experiment was initiated in two single-acre blocks to test methods promoting the passive establishment of native plants on new gravel spoils. The design consists of a 2x2 factorial design with control with random plot assignment with the blocks. Treatments include two levels of weed management (active vs. none) and irrigation (water vs. no water), for a total of 4 treatment combinations. Response metrics will be native and invasive tree stem density and height (1 m² plots) and invasive vs native plant cover (3 m² plots). This study is led by Kate Akyuz and will be reported separately.
are clusters separated by at least 25 feet\textsuperscript{18}. The number of points and the area of major weed patches was estimated prior to chemical treatment. Weeds were mapped again in 2015 and cover was qualitatively described as ranging from ‘very light’ to ‘heavy’. A comparison of the 2012 and 2015 maps was used to qualitatively evaluate changes in invasive cover.

6a: Juvenile stranding in closed depressions.
Juvenile stranding was estimated in July 19, 2013, prior to construction, and again on September 25\textsuperscript{th}, 2013, at both the Rainbow Bend and Dorre Don reaches. At each site, all closed depressions\textsuperscript{19} were located, mapped, flagged, and the maximum depth was measured. High-definition underwater video (960p) was used to determine whether each depression contained juvenile salmonids\textsuperscript{20}. Sampling effort was standardized: pan and pause for 10 seconds each, then move to the limit of the field of view and repeat until the entire depression had been sampled. Fish in each closed depression were counted and identified to family and/or genus, if possible, using the recorded video. The results were used to determine the frequency, occupancy rate, and survival rate for closed depressions at each site. Frequency was calculated as the number of closed depressions per-unit mainstem channel length. Occupancy rate was calculated as the percentage of closed depressions containing juvenile salmonids. Survival rate was calculated as the average difference between the numbers of fish in July vs. September at each site. In addition, temperature loggers were installed in the two occupied depressions at each study reach, representing the shallowest and deepest units. Loggers were attached to re-bar stakes and placed at maximum depth. The purpose was to determine whether lethal temperatures\textsuperscript{21} occur in the depressions.

6b: Adult passage in the mainstem.
In the event of a split channel, an inspection will be performed in late September and early October to identify and photograph any likely barriers to upstream adult migration.

VII. Results
1a. Edge habitat
Edge habitat targets have been met as the result of both post-project channel adjustments and the creation of deformable features, including the backwater habitat, the floodplain side channel, and the cutoff channel.

Edge habitats were mapped three times in 2013, prior to construction, and four times in 2014\textsuperscript{22} after the project was completed (Table 5). Each 2013 survey was within the targeted flow ranges, but in 2014

\textsuperscript{18} Alternatively, track weed management costs, assuming the effort and volume of herbicide applied is linearly and positively related to the extent of invasive cover, and the level of effort is consistently applied per unit invasive cover among years.

\textsuperscript{19} Wetted area that does not have a surface connection to the mainstem

\textsuperscript{20} HD GoPro Camera with flat-screen underwater housing

\textsuperscript{21} Dissolved oxygen was not measured, but may also be an important determinant of survival.

\textsuperscript{22} The two 2014 surveys that occurred prior to the March 2014 flood may underestimate the current amount of edge habitat because the channel changed significantly after the flood.
sampling did not strictly adhere to those limits. Dorre Don was only sampled twice in 2013 but not in 2014. The Taylor Reach (control) was not surveyed because access was limited.

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1 (2014)</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Year 5 (2018) or after three 2-year recurrence interval (RI) floods, the summed area of ‘edge habitat’ (i.e., bar, bank, backwater and side channel units) increases by at least 50%, relative to either pre-project conditions or the control reach. Alternatively, the summed area is at least 50% of reference levels, measured at approximately 760 cfs at Landsburg.</td>
<td>ACHIEVED</td>
<td>Summed area of edge habitat increased by 82% over baseline conditions at approximately 760 cfs. The summed area is 57% of reference levels at Dorre Don.</td>
</tr>
</tbody>
</table>

Excavated features—the side channels and backwaters—appear to have contributed most of the new edge habitat to date. Before the project was completed, edge units were small and widely distributed along the mainstem margins (Figure 8). After the project, new edge habitats were observed in the backwater, the floodplain side channel, and—at higher flows (>900-1,200 cfs at Landsburg)—in the cutoff channel (Figure 8). Edge habitat area increased across the range of observed flows (Figure 9). Approximately 20,000 square feet of new edge habitat was available to fish by Year 1 (2014).

**TABLE 5. TARGET AND ACTUAL DISCHARGES (AT LANDSBURG) AT WHICH EDGE HABITATS WERE MAPPED BEFORE (2009) AND AFTER (2011, 2014) PROJECT COMPLETION.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Flow perc</th>
<th>Target in cfs (+/- 5%)</th>
<th>Discharge (cfs/cms)</th>
<th>Survey dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2013</td>
<td>2014</td>
</tr>
<tr>
<td>Rainbow Bend</td>
<td></td>
<td>(supplemental)</td>
<td>756</td>
<td>615</td>
</tr>
<tr>
<td>50&lt;sup&gt;th&lt;/sup&gt;</td>
<td>756 cfs (718-794)</td>
<td>760</td>
<td>615</td>
<td>Feb 04</td>
</tr>
<tr>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
<td>1,012 cfs (960-1,063)</td>
<td>1,010</td>
<td>943</td>
<td>Mar 27</td>
</tr>
<tr>
<td>90&lt;sup&gt;th&lt;/sup&gt;</td>
<td>1,283 cfs (1,219-1,347)</td>
<td>1,230</td>
<td>1,240</td>
<td>Mar 26</td>
</tr>
<tr>
<td>Dorre Don (ref)</td>
<td></td>
<td>760</td>
<td>-</td>
<td>Feb 26</td>
</tr>
<tr>
<td>50&lt;sup&gt;th&lt;/sup&gt;</td>
<td>756 cfs (718-794)</td>
<td>-</td>
<td>-</td>
<td>Feb 26</td>
</tr>
<tr>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
<td>1,012 cfs (960-1,063)</td>
<td>927</td>
<td>-</td>
<td>Jan 22</td>
</tr>
<tr>
<td>90&lt;sup&gt;th&lt;/sup&gt;</td>
<td>1,283 cfs (1,219-1,347)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Most of the change (2013 to 2014) resulted from the creation of the floodplain side channel, the cutoff channel, and the backwater habitat (Figure 10). Backwater area increased with discharge. In contrast, side channel habitat was most abundant at high and low discharge, but most scarce at approximately the median daily flow level (Figure 10). Side channels were only present at the highest flows prior to project completion, but after construction at least 10,000-21,000 feet$^2$ of side channel habitat was available across the range of flows. The abundance of bank habitat varied with flow in 2014, but no systematic relationship with flow was evident. Bank habitat declined after project completion, at least at higher flows. Bar habitat continued to be abundant at low discharge.
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No target or survey.</td>
<td>410 cfs (cms)</td>
</tr>
<tr>
<td></td>
<td>760 cfs (21.5 cms)</td>
</tr>
<tr>
<td></td>
<td>710 cfs (20.1 cms)</td>
</tr>
<tr>
<td></td>
<td>1,010 cfs (28.6 cms)</td>
</tr>
<tr>
<td></td>
<td>943 cfs (26.7 cms)</td>
</tr>
<tr>
<td></td>
<td>1,230 cfs (34.8 cms)</td>
</tr>
<tr>
<td></td>
<td>1,240 cfs (35.1 cms)</td>
</tr>
</tbody>
</table>

FIGURE 9. EDGE HABITAT MAPS BEFORE AND AFTER PROJECT COMPLETION.
Edge surveys at the Dorre Don were useful for measuring the progress of the Rainbow Bend project site toward a presumably achievable future condition. Two surveys were completed at Dorre Don; February 26, 2013 (760 cfs) and January 22, 2014 (927 cfs). In each survey, side channel area composed 60-67% of the total edge habitat area, with backwaters composing an additional 10-17%. The total amount of edge habitat area at approximately 700 cfs (USGS 12117500) at Rainbow Bend, prior to the project completion, was only 31% of the total at Dorre Don. After the project was completed, the project site contained 57% of the 2013 totals at Dorre Don.
1b. Fish Use
Backwaters and side channels supported the highest densities of juvenile Chinook and coho salmon, based on snorkel surveys conducted in 14 sampling events over three months in 2014 at 8623 discrete habitat units spread across four sites throughout the lower Cedar River (Table 6; Figure 12). This finding is helpful in generating a quantitative estimate of the ecological significance of year-over-year change in edge habitat availability that results from the restoration project. A total of 2,599 juvenile Chinook salmon, 5,086 juvenile coho salmon, and 224 trout were observed.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Performance Standard</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b: Fish use</td>
<td>None specified;</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Species-specific differences were evident (Table 6). The density of juvenile Chinook salmon was highest in backwaters and lowest along rip-rap banks. Median density values for juvenile Chinook salmon differed among edge habitat types (p =0.001). Density values were not normally distributed (i.e., Shapiro-Wilk test). High variability made it difficult to isolate multiple groups that differ from the others using pairwise comparisons; backwaters and side channels were each higher than banks, and backwater.

Juvenile coho salmon generally occurred at higher densities than Chinook salmon, but exhibited similar distribution; highest densities were in backwaters (Figure 12). Like Chinook salmon, coho juvenile densities varied among habitat types (p<0.001), with the highest density occurring in backwaters and side channels. Coho salmon densities in backwaters and side channels were indistinguishable, but each was higher than all other edge types. Bars and rip-rap banks were indistinguishable. Trout densities also varied by habitat types, though the strength of the evidence was weaker (p=0.013).

![Figure 12. Salmonid density across all projects by species and habitat type in 2014 (from King County, 2015). The average density is shown as a red crossbar. The median density is the black crossbar. The boxes contain the middle 50% of the density values (interquartile range; 25th – 75th percentiles). The whiskers show the 90th percentiles, within which lies 90% of all observed densities. Outliers are shown as black dots.](image)

23 Excludes engineered log structures which were also sampled at Belmondo.
Unlike the other salmonids, trout densities were highest in side channels, but also relatively high along rip-rap banks (Figure 12). This analysis conflates juvenile and adult trout, unlike the evaluations of Chinook and coho salmon. However, the qualitative findings for trout under 100 mm in fork length remain similar to those presented for all size classes combined.

Changes in habitat capacity can be estimated as the product of edge habitat area and the median density of juvenile salmonids in each habitat type (Figure 13Figure 6). Based on this simple calculation, habitat capacity for juvenile Chinook salmon may have increased by approximately 700 to 1,000 fish in the first year after construction, depending on the flow level (Figure 13, upper panel). The capacity for Chinook, coho, and trout (all salmonids) may have increased by at least 3,000 to 5,000 fish (Figure 13, lower panel) from 2013 to 2014.

**FIGURE 13. CHANGES IN HABITAT CAPACITY AT THE RAINBOW BEND PROJECT FROM 2013 TO 2014.**
TABLE 6. MEDIAN FISH DENSITIES BY EDGE HABITAT TYPE.

<table>
<thead>
<tr>
<th>Edge habitat type</th>
<th>Chinook</th>
<th>Coho</th>
<th>Trout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backwaters</td>
<td>0.57</td>
<td>2.67</td>
<td>0.00</td>
</tr>
<tr>
<td>Side channels</td>
<td>0.36</td>
<td>1.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Bars</td>
<td>0.03</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Banks</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Rip-rap</td>
<td>0.08</td>
<td>0.06</td>
<td>0.10</td>
</tr>
</tbody>
</table>

2a. Lateral channel migration rate

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1/2 (2014/15) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Year 5 (2018) or after three two-year recurrence interval floods, rates of bank</td>
<td>n/a</td>
<td>Average lateral rate of widening from Fall 2013 to Spring 2015 was 25</td>
</tr>
<tr>
<td>retreat are similar to reference conditions (e.g., rates are within the middle 50%</td>
<td></td>
<td>linear feet.</td>
</tr>
<tr>
<td>- the interquartile range - of observed rates at reference sites).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The mainstem channel began widening with the first flood after the project was completed, and progressed most rapidly during prolonged high discharge in March 2014 (Figure 14). The most pronounced widening occurred in the vicinity of the former levee (Figure 15). A total of 0.38 acres (1,534 m²) was eroded from the right bank. In the mainstem, the average lateral rate of widening from fall 2013 to spring 2015 was 25 linear feet (7.6 m). The upper left bank portion of the floodplain side channel also widened, by an average of 16 feet (4.9 m).

Bank erosion on the right bank was documented with time-lapse video recordings during the March 2014 flood. Bank retreat progressed steadily as flows rose, but most retreat occurred during the peak of the flood. Subsequent high flow events, which have been lesser in magnitude<sup>24</sup>, have not caused notable changes to the right bank. Minor retreat has been observed and photo-documented but not yet quantified. Observations indicated that relatively little channel migration occurred during the 2015 flood.

<sup>24</sup> But note that a slightly larger flood occurred in late November, 2015. The effects of that flood have been observed and photo-documented but not yet quantified.
observed on the right bank in the lower half of the project site, but these changes were limited to channel widening.

Before levee removal: October 30, 2012 (10:30 AM) 656 cfs

After levee removal: October 1, 2013 (09:31 AM) 947 cfs

After first flood: April 9, 2014 (09:31 AM) 1,090 cfs

FIGURE 15. COMPARISON OF RIGHT BANK BEFORE AND AFTER THE FIRST FLOOD SEASON. DISCHARGE LEVELS REFER TO USGS 1219000 (RENTON).
2b. Mainstem planform, channel width and depth

<table>
<thead>
<tr>
<th>Performance Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1/2 (2014/15)</td>
</tr>
<tr>
<td>Status</td>
</tr>
</tbody>
</table>

By Year 10 (2023) or after three two-year recurrence interval (RI) floods, the channel planform is transitioning from single-thread to island-braided with stable forested islands, mainstem gets wider, shallower, more uneven in profile, relative to baseline & control.

Channel planform is similar to the as-built condition; no new channels or mid-channel bars. Transition to island-braided condition is incomplete. Mainstem is wider and shallower adjacent to site of levee removal.

The channel planform of the mainstem has adjusted slightly since construction was completed, but few new planform features are evident at the site-scale (Figure 16).

In the reach where the levee was removed, the river eroded four to seven vertical feet of sediment from the floodplain along 500 linear feet, converting low river terrace to stream channel, and washing the displaced material downstream (Figure 17). Congruently, the mainstem channel elevations increased by one to seven feet over an area measuring roughly 600 feet in length.

**FIGURE 17.** WITHIN-CHANNEL CHANGE IN GROUND AND STREAMBED SURFACE ELEVATIONS FROM AS-BUILT CONDITIONS (2014) TO 2015 AT THE RAINBOW BEND PROJECT SITE. ATTRIBUTABLE TO RIVER ACTION ONLY, AFTER PROJECT-RELATED EXCAVATION WAS COMPLETED. CHANGES LESS THAN ONE FOOT NOT SHOWN. AERIAL PHOTO FROM 2015.
The March 2014 flood resulted in a net loss of sediment, including banks, from all three reaches in this study (Table 7). Even though 6,000 cubic yards of material deposited in the channel at the Rainbow Bend site, a greater volume (17,000 cubic yards of alluvial material\(^{25}\)) was exported. Approximately 11,000 cubic yards were exported from the project site. Normalized to linear feet, the net export from Rainbow Bend exceeded the control (Taylor) reach by 120% (Table 7).

### TABLE 7. VOLUMETRIC ESTIMATES OF EROSION AND DEPOSITION FROM PROJECT COMPLETION TO 2015. VOLUMES INCLUDE ALL CHANGES GREATER THAN ZERO FEET IN MAGNITUDE. ALSO SEE FIGURE 18 FOR MAPS OF ANALYSIS EXTENT.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Mainstem channel length (ft)</th>
<th>Type</th>
<th>Vol. (yd(^3))</th>
<th>Vol. (yd(^3)/lf mainstem)</th>
<th>Net (yd(^3))</th>
<th>Net (yd(^3)/lf mainstem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainbow Bend</td>
<td>5,300</td>
<td>Deposited</td>
<td>6,165</td>
<td>1.2</td>
<td>-11,195</td>
<td>-2</td>
</tr>
<tr>
<td>Reach</td>
<td>5,300</td>
<td>Eroded</td>
<td>-17,360</td>
<td>-3.3</td>
<td>-11,309</td>
<td>-2</td>
</tr>
<tr>
<td>Taylor Reach</td>
<td>3,600</td>
<td>Deposited</td>
<td>2,006</td>
<td>0.6</td>
<td>-3,342</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>3,600</td>
<td>Eroded</td>
<td>-5,342</td>
<td>-1.5</td>
<td>-3,337</td>
<td>-1</td>
</tr>
<tr>
<td>Belmondo Reach</td>
<td>4,035</td>
<td>Deposited</td>
<td>6,502</td>
<td>1.6</td>
<td>-7,793</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>4,035</td>
<td>Eroded</td>
<td>-14,295</td>
<td>-3.5</td>
<td>-7,563</td>
<td>-3</td>
</tr>
</tbody>
</table>

Most of the adjustments occurred in the sub-reach adjacent to the site of the levee removal (Figure 18, 19). In this location, erosion and deposition were nearly equivalent, even though the quantities were higher than other nearby locations. In both the upstream and downstream sub-reaches, erosion greatly exceeded the rate of deposition (Figure 18).

Bedload sediments exported from the project site are expected to move downstream at approximately 2,000 to 2,500 feet per year (J. Bethel, pers. comm, based on Beechie 2001). If so, the bedload that left the Rainbow Bend site is probably distributed within the Belmondo Reach, immediately downstream. Indeed, total deposition rates at the Belmondo Reach were slightly higher than that observed at the Rainbow Bend site (Figure 20).

Erosion exceeded deposition in the upstream control reach (Taylor Reach) but the ratio of deposition to erosion was much greater in the project reach (Figure 20). The Belmondo Reach, which is adjacent to and immediately downstream from Rainbow Bend (Figure 18), showed a similar pattern of erosion and deposition to the Rainbow Bend site. A small portion of the left bank within the larger Belmondo Reach was the site of a bank-hardening project that included two large deflectors intended to push the channel toward the opposite bank and to scour pools in the adjacent streambed (the Belmondo project is stable and functioning as intended). The reach above and below the project site is more dynamic than the Taylor Reach upstream, which more closely resembles the pre-project condition of Rainbow Bend.

\(^{25}\) The proportion of this volume composed of silt, sand, and gravel has not been estimated.
FIGURE 18. SUB-REACHES FOR GEOMORPHIC CHANGE ANALYSIS AT THE RAINBOW BEND PROJECT SITE (TOP), THE BELMONDO REACH (MIDDLE), AND TAYLOR REACH (BOTTOM).
FIGURE 19. WITHIN-CHANNEL EROSION AND DEPOSITION VOLUMES BY SUBAREA OVER THE FIRST TWO WINTERS AFTER CONSTRUCTION (2014 AND 2015). TOTAL VOLUMES WERE STANDARDIZED (DIVIDED) BY REACH LENGTH TO ALLOW COMPARISONS.

FIGURE 20. WITHIN-CHANNEL EROSION AND DEPOSITION VOLUMES BY SUBAREA (AS-BUILT TO 2015). TOTAL VOLUMES WERE STANDARDIZED (DIVIDED) BY REACH LENGTH TO ALLOW COMPARISONS. TAYLOR REACH IS THE CONTROL, RAINBOW BEND IS THE TREATMENT, AND BELMONDO IS IMMEDIATELY DOWNSTREAM FROM RAINBOW BEND.

Cross-sectional changes to the mainstem river channel

Bankfull channel width of the mainstem Cedar River increased by 30-70 feet in the portion of the river where the levee was removed (Figure 21). The largest increases in channel width were immediately downstream of the upper end of the levee removal footprint. Relatively small increases in channel width were also observed in the 500-1,000-foot section of river channel downstream from the lower limit of levee removal. Channel width changed little or not at all in the reaches upstream and downstream of the project site.
Thalweg elevation decreased over much of the study reach. In contrast, a large increase occurred where the levee had been removed (Figure 22). Only minor adjustments in thalweg elevations were observed at the upstream control reach (Taylor) (Figure 23). Erosion was far more prevalent than deposition in the upper half of the Taylor reach, where the river still runs along a levee. Little to no change was evident in a 1,000-foot-long section of the reach near the downstream end of the Taylor site.

Changes in the floodplain side channel

The floodplain side channel widened in four main locations in the lower half of the channel, but remained relatively unchanged at the mouth (Figure 24). However, the cross-sectional area of the channel widespread increased as the bank angle became nearly vertical in many locations.

FIGURE 23. CHANGES IN THALWEG ELEVATION AT THE UPSTREAM CONTROL SITE (TAYLOR) AFTER TWO WINTERS.

Virtually all of the changes in bankfull channel width were limited to approximately 10 feet in magnitude, with two notable exceptions; thirty feet of widening was observed at the inlet of the channel, and approximately 40 feet of widening occurred at the 750-foot mark (Figure 24).
Cross-section 34 (40 feet downstream of inlet; 1,300 feet upstream from outlet). Channel aggraded by approximately one foot and banks became vertical, but relatively little widening. Invert elevation (the elevation controlling flow into the side channel at low flow) is 220.1 ft.

Cross-section 20 (590 feet downstream from inlet; 750 feet upstream from outlet). Channel incised by approx. three feet, migrated to the right bank and more than doubled in width.

Cross-section 5 (1,180 feet downstream from inlet; 160 feet upstream from outlet). Channel incised by approximately two feet, migrated toward left bank and widened by approximately 10 feet.


2c. Stability of Large Wood Structures 1 and 2

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1 (2014)</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Status</td>
<td></td>
</tr>
<tr>
<td>Until at least Year 5 (2018), key members of the jams are initially stable upon contact with channel, and become more stable as they trap additional wood.</td>
<td>Provisionally achieved</td>
<td>Only one jam is in contact with the channel, so stability has not been severely tested.</td>
</tr>
</tbody>
</table>

The two large jams at the project site remain stable (Photo 3), but only large wood structure 2 is continuously touching the river flow. Both were vandalized several times soon after construction, which has continued into 2014. In spite of damage, no follow-up repairs were deemed necessary to restore the jams to the as-built condition. The basis for this decision was that the damage to the structures did not cause them to be unstable or non-functional.

PHOTO 1. LARGE WOOD STRUCTURES (LWS) 1 AND 2 IN 2013 AND 2014.
2d. Stability of Large Wood Structures 3 and 4

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1 (2014)</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Until at least Year 5 (2018), upon contact with channel, jams remain stable long enough to reduce lateral channel migration rate.</td>
<td>Not yet contacted by the channel, but have remained stable. It may far longer than anticipated for these jams to be contacted by the migrating channel owing to the dissipation of hydraulic energy by the side and cutoff channels.</td>
<td></td>
</tr>
</tbody>
</table>

Large wood structures 3 and 4 are not yet in contact with the river channel (Figure 5). Structure 3 was vandalized by chainsaws, but remains mostly intact. No vandalism has been observed on Structure 4.

PHOTO 2. LARGE WOOD STRUCTURES 3 AND 4 IN 2013 (AS-BUILT) AND 2014 (YEAR 1).
### 3a. Inlet elevations

**Floodplain Side Channel**

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1/2 (2014/15) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Year 5 (2018) or after three 2-yr RI floods, inlets to side channel and Wetlands B &amp; D do not fill in from deposition.</td>
<td>ACHIEVED</td>
<td>Inlets have aggraded but not filled in to the point that they have lost or greatly diminished connectivity to surface flows from the mainstem.</td>
</tr>
</tbody>
</table>

The inlet of the floodplain side channel has aggraded (e.g., Station 1200-1450 feet; Figure 26), but the remainder of the length is incised one to three feet, especially along Stations 180-650 feet. A knickpoint appears to exist halfway upstream from the downstream confluence, near Station 700 feet.


Changes in the channel planform and thalweg elevations of both the mainstem and the side channel have resulted in the floodplain side channel being almost continuously connected since the sandbag weir was removed September 29, 2013 (13:15). Discharge at that time was 504 cfs at Renton, lagged by five hours, to account for the distance between the stream gauge and project site.
The channel has never completely de-watered, but no water was flowing into the channel from the inlet during two periods:

- December 1st-3rd 2013: Inflow stopped for three days when flows dropped below 661 cfs. This means that connectivity of the channel initially declined from the as-built condition. The channel remained wetted during the lowest discharge observed during this three-day period (Approx. 600 cfs; Photo 6).

- December 12th-21st: Inflow stopped for nine days when flows dropped below 713 cfs. The channel thalweg remained wet throughout this period, in which minimum discharge was 540 cfs (Photo 6).

- December 21, 2013: Inflow began overnight (probably at approximately 700 cfs). The channel has continuously flowed since that day.

Cutoff channel

Unlike the floodplain side channel, geomorphic adjustments in the cutoff channel have been relatively minor and the connectivity of this feature has remained constant, based on direct observation with
time-lapse cameras. Inflow to the cutoff channel begins and ends at approximately 1,200 cfs (Renton\textsuperscript{25}), though there was variability in the first few months after construction (Table 8). There is no evidence for hysteresis; inflow begins and ends at the same discharge level. Hysteresis would be evident if the discharge initiating inflow differed between the ascending and descending limb of the hydrograph.

The first inflow to the cutoff channel occurred at 8:50 AM on November 18\textsuperscript{th}, 2013, at 1,290 cfs (at USGS Renton, lagged by five hours). In Water Year 2014 (Oct. 1, 2013-Sept. 30, 2014), the cutoff channel flowed 88 days in total; 74 days in January through June, when juvenile Chinook were rearing in the river. In WY 2015, the cutoff channel flowed 72 days; 34 of those were in the Chinook rearing period. The longest period of uninterrupted inflow was 28 days, in March 2014. Long-duration inflow events were uncommon. One-third lasted five days or less, and nearly three-quarters ended in 10 days or less.

**TABLE 8. FLOW CONNECTIVITY OF CUTOFF CHANNEL.** Discharge is based on measured flows at Renton five hours after the inflow began or ended at the project site. The actual habitat value of the cutoff channel is greater than reported here, because hyporheic upwelling frequently kept a portion of the cutoff channel wet past the end of inflow. Records were current to March 10\textsuperscript{th}, 2015.

<table>
<thead>
<tr>
<th>Water Year</th>
<th>Connection</th>
<th>Start of inflow</th>
<th>End of inflow</th>
<th>Starting discharge (cfs)</th>
<th>Ending discharge (cfs)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WY 2014</td>
<td>1</td>
<td>11/18/13</td>
<td>11/28/13</td>
<td>1290</td>
<td>~900</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12/22/13</td>
<td>12/24/13</td>
<td>1300</td>
<td>1300</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1/3/14</td>
<td>1/3/14</td>
<td>1150</td>
<td>1210</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1/8/14</td>
<td>1/11/14</td>
<td>1230</td>
<td>1300</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1/13/14</td>
<td>1/21/14</td>
<td>1300</td>
<td>1270</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>6</td>
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<td>2/25/14</td>
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<td>1100</td>
<td>28</td>
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<td>8</td>
<td>4/17/14</td>
<td>4/19/14</td>
<td>1200</td>
<td>1200</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9</td>
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<td>1200</td>
<td>1200</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5/5/14</td>
<td>5/5/14</td>
<td>1200</td>
<td>1200</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>5/6/14</td>
<td>5/14/14</td>
<td>1200</td>
<td>1100</td>
<td>9</td>
</tr>
<tr>
<td>WY 2015</td>
<td>12</td>
<td>11/1/14</td>
<td>11/13/14</td>
<td>1200</td>
<td>1200</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>11/25/14</td>
<td>12/10/14</td>
<td>~1200</td>
<td>1200</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>12/24/14</td>
<td>1/1/15</td>
<td>1200</td>
<td>1200</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1/5/15</td>
<td>1/20/15</td>
<td>~1200</td>
<td>~1200</td>
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<td>1/23/15</td>
<td>1/29/15</td>
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<td>2/4/2013</td>
<td>~1200</td>
<td>1200</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>2/6/15</td>
<td>2/14/15</td>
<td>1200</td>
<td>1250</td>
<td>9</td>
</tr>
</tbody>
</table>

Thalweg profiles of the cutoff channel demonstrate that the inlet of the cutoff channel aggraded by approximately 0.5-1.5 feet over the upper 215 feet (Figure 27). It is also evident that the mainstem elevations increased by 3.6 feet at the inlet. Aggradation of the mainstem channel exceeded the

\textsuperscript{26} Note that this connectivity analysis uses discharge values from Renton, in contrast with the edge habitat surveys, which were correlated with flows at the Landsburg gage.
aggradation in the cutoff channel inlet, and this appears to have allowed the cutoff channel to maintain a high level of connectivity. Little to no change in streambed elevation has occurred in the lower 600 feet of the cutoff channel, except for the lower 50 feet of the channel.

![Figure 27: Thalweg Elevations in the Cutoff Channel Prior to Construction (2013), After Construction (2014), and Post-Flood (2015). Mainstem bed elevations at the inlet are shown at the far right side of the figure.](image)

The cutoff channel is most likely to offer habitat to salmonids early in the rearing period, such as January and February, when flows tend to be relatively high. This time period corresponds to a period in which both fry and parr are still in the river (Kiyohara and Anderson, 2015). For example, the daily probability of inflow to the cutoff channel can be approximated from the USGS-estimated percentiles of mean daily discharge. If the 75\textsuperscript{th} percentile flow level (corresponds to a 25\% exceedance flow) for a particular day exceeds 1,200 cfs, the probability of inflow on that day of the year is at least 25\% (Figure 28). This suggests that there is at least a 1-in-20 chance that the cutoff channel will be flowing on any given day while juvenile Chinook are rearing in the Cedar River, with the probability of inflow declining most sharply between March and April.

![Figure 28: Probability of Inflow to Cutoff Channel Based on Flow Percentiles, Assuming Inflow Begins at 1,200 CFS (Renton USGS 12119000). The channel may also provide habitat when hyporheic inflow is the sole source of water, so this represents the minimum habitat availability.](image)
Changes in the Stage-Discharge Relationship

Changes in the stage-discharge relationship at the project site were evaluated by comparing the water surface elevations at the project site with the mean daily discharge estimates from the Renton gauge (USGS 12119000). Changes in this relationship may influence the connectivity of each side channel. The period of record for on-site measurements included water years 2011 through 2015.

Major changes in the stage-discharge relationship were evident in two years, including WY 2011 and WY2014 (Figure 29). In each case, water surface elevations at the project site rose after the occurrence of moderate to large floods. In WY 2011, instantaneous peak flows reached 5,870 cfs on January 18, 2011, causing the stage at the project site to rise by approximately 0.25-0.5 feet. The change in stage-discharge relationship was short-lived, however. Water surface elevations decreased to baseline (pre-flood) conditions in WY 2012. Peak flows remained below 2,800 cfs for two years. By the early part of WY 2014, the stage-discharge relationship returned to a condition similar to pre-flood conditions.

---

On March 11, 2014 instantaneous peak flows reached 3,860 cfs. By this time, the project had been implemented, so the bank could erode and a portion of the discharge could divert through the floodplain side channel and cutoff channels. Accordingly, this flood caused a major shift in the stage-discharge relationship; the post-flood stage at a given discharge increased across the range of flows (Figure 30). This shift has persisted through WY 2016.

Prior to the peak flow, water surface elevation at the project site was 218.45 feet when discharge at Renton was 500 cfs (or 22.4 after square-root transformation was used to linearize the relationship). After the peak flow and shift in the rating curve, water surface elevations at that same flow increased to 219.14; an increase of 0.69 feet. A similar shift was observed in response to the most recent peak flow in mid-November, 2016.

Similarly, if the stage-discharge relationship from WY 2012 is compared with that of WY 2016\textsuperscript{27} it is clear that the magnitude of the shift in the relationship varies with flow (Figure 31).

Eq. (1) \[ Stage_{WY2012} = 0.0939 \times \sqrt{Q} + 216.21 \]

Eq. (2) \[ Stage_{WY2016} = 0.063 \times \sqrt{Q} + 218.19 \]

where \( Q \) is mean daily discharge at USGS Renton (12119000).

One of the most important findings in this analysis of stage-discharge relationships is that the stage of the river is locally higher at low discharges, and appears to be reduced at levels near the upper end of the observed range (Figure 31). An increase in stage at low discharge may benefit fish by increasing the connectivity of the floodplain side channel and cutoff channel, and by enlarging the wetted area of the river during low flow. Increased water levels could also benefit riparian vegetation by making water more accessible in the rooting zone during the dry season. Conversely, a decrease in water levels at high discharge—above 4,000 cfs at Renton, which roughly corresponds with bankfull discharge prior to the project—means that the frequency of overbank flows could be slightly reduced, relative to pre-project conditions. Larger floods are required to overtop the streambanks and inundate the floodplain. In any case, the observed decrease is small and based on few observations; it should be regarded with caution until additional flood events are observed.

\textsuperscript{27} This equation is based on mean daily flow values that occurred after the peak flow in November 2016 to best represent current conditions.
The same analysis was performed on stage measurements at the downstream end of the project site (right bank), but no obvious changes in the stage-discharge relationship were observed (Figure 32). It appears the stage-discharge relationship at the downstream location in 2014 and 2015 is indistinguishable from that of WY 2010-2013.

**FIGURE 32.** CHANGES IN THE STAGE-DISCHARGE RELATIONSHIP AT DOWNSTREAM END OF RAINBOW BEND, WATER YEARS 2011-2015. POINTS REPRESENT THE SQUARE ROOT-TRANSFORMED MEAN DAILY FLOWS (AT RENTON) AND CORRESPONDING MEAN DAILY ELEVATION OF THE WATER SURFACE IN THE BACKWATER FEATURE.

### 4a. Natural wood abundance

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1/2 (2014/5) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Year 5 (2018), wood abundance increases relative to the baseline, exceeds the control reach, and is similar to previously surveyed reference reaches.</td>
<td>ACHIEVED</td>
<td>Large wood has increased each consecutive year as the result of both transport into the site from upstream and from local recruitment through bank erosion.</td>
</tr>
</tbody>
</table>
Large wood (LW) abundance increased from 2013 to 2015 in each length and diameter size class (Figure 33). Large wood abundance was inversely related to piece length and diameter, so the site was dominated by short, small-diameter pieces.


Large wood abundance increased by 30%, overall, from upstream sources and erosion on the right bank near LWS 2 (Table 9). Numbers were stable or increasing across all length and diameter categories, with the percent change ranging from 0 to 1,200%. The largest percent increase was in the F length-class and the 4 diameter-classes.
Large wood quantities are well below targets proposed by Fox and Bolton (Table 10). Roughly one to three dozen additional large logs would be needed for the site to reach recommended levels. If smaller pieces are included, and additional 1,000 to 2,000 pieces would be needed to reach the target.

<table>
<thead>
<tr>
<th>Source</th>
<th>Large wood minimum size criteria</th>
<th>Qualifying size classes in this study</th>
<th>Observed value in 2014</th>
<th>Guidelines or targets</th>
<th>Percent achieved</th>
<th>Additional pieces to reach standard at 3,400-foot reach scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Marine Fisheries Service</td>
<td>15.2 m long and 0.6 m in diameter (50 ft x 24 in)</td>
<td>E4-6; F4-6; G4-6</td>
<td>51 per mi (32/km)</td>
<td>&gt;80 per mi (&gt;50/km)</td>
<td>64%</td>
<td>18</td>
</tr>
<tr>
<td>Fox and Bolton (2007)</td>
<td>2 m long and 10 cm in diameter (6.6 ft x 4 in)</td>
<td>All except B class</td>
<td>592 per mi (370/km)</td>
<td>&gt;3,315 per mi (&gt;2,071/km)</td>
<td>18%</td>
<td>1,752</td>
</tr>
<tr>
<td>Key pieces</td>
<td>G4; E5-G5; D6-G6</td>
<td>8 per mi (4/km)</td>
<td>&gt;64 per mi (&gt;40/km)</td>
<td>12%</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 9. LARGE WOOD ABUNDANCE AT THE RAINBOW BEND PROJECT SITE.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>158</td>
<td>175</td>
<td>190</td>
<td>18</td>
<td>23</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>+42</td>
<td>27%</td>
</tr>
<tr>
<td>C</td>
<td>132</td>
<td>145</td>
<td>161</td>
<td>23</td>
<td>24</td>
<td>34</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>+45</td>
<td>34%</td>
</tr>
<tr>
<td>D</td>
<td>25</td>
<td>29</td>
<td>40</td>
<td>35</td>
<td>42</td>
<td>49</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>+34</td>
<td>136%</td>
</tr>
<tr>
<td>E</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>9</td>
<td>10</td>
<td>17</td>
<td>+8</td>
<td>67%</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>11</td>
<td>+12</td>
<td>1200%</td>
</tr>
<tr>
<td>G</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Proportion (%)</td>
<td>71</td>
<td>69</td>
<td>67</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>181</td>
<td>64</td>
</tr>
<tr>
<td>% Change</td>
<td>+77</td>
<td>+31</td>
<td>+30</td>
<td>+3</td>
<td>+141</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 10. COMPARISON OF OBSERVED LARGE WOOD QUANTITIES IN 2015 WITH TARGETS PROPOSED BY OTHERS. ONLY THE MAINSTEM IS CONSIDERED IN THIS ANALYSIS.
4b. Logjam functions

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1 (2014)</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>For at least 10 years (2023), placed jams create ‘safe sites’ for vegetation establishment; direct overbank flows into floodplain channels, reduce sheet flow in floodplain; retain transported wood to increase jam size; force flow divergence to create an island-braided channel.</td>
<td>PARTIALLY ACHIEVED</td>
<td>All jams are intact but only Logjam #2 contacts the channel, so functions of the others are yet realized or tested.</td>
</tr>
</tbody>
</table>

Only logjam #2 has been contacted by the active channel (Table 11). Jams 1, 3, and 4 remain intact but are only wetted during overbank flows and so these jams are not yet fully functional.

**TABLE 11. FUNCTIONS PERFORMED BY LOGJAM #2.**

<table>
<thead>
<tr>
<th>Function</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderating channel migration?</td>
<td>The logjam has slowed channel widening in the immediate vicinity along a portion of the right bank.</td>
</tr>
<tr>
<td>Creating safe sites for vegetation establishment?</td>
<td>The logjam has created a protected zone in its lee, but little or no fine sediment has deposited behind it. No notable vegetation establishment has occurred.</td>
</tr>
<tr>
<td>Directing overbank flows into floodplain channels?</td>
<td>The logjam directs flood flows into the floodplain side channel. Overbank flows have not yet occurred, so more observations will be needed when larger floods occur.</td>
</tr>
<tr>
<td>Reducing sheet flow in floodplain?</td>
<td>(same as above)</td>
</tr>
<tr>
<td>Retaining transported wood?</td>
<td>By October 2\textsuperscript{nd}, 2014, Logjam 2 had accumulated a large amount of small wood and four additional pieces of large wood.</td>
</tr>
<tr>
<td>Forcing flow divergence and promoting an island-braided channel form?</td>
<td>The primary function of logjam 2 is to force flow divergence, which helps to sustain the floodplain side channel. Currently, the channel planform does not exhibit an island-braided morphology.</td>
</tr>
</tbody>
</table>

5a. Riparian survival and cover

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Status (Year 3, 2013)</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Year 3 (2013), survival of plantings is at least 50% and native cover is at least 50%. (First round of planning was in 2011)</td>
<td>PARTIALLY ACHIEVED</td>
<td>Year 3 survival of first round of plantings was 70%.</td>
</tr>
<tr>
<td>By Year 5 (2015), stem density is higher than as-built in planted areas, owing to natural recruitment.</td>
<td>NO DATA-Measure in Year 6 (2016)</td>
<td>Survival and cover not measured for the last round of plantings, nor for Year 5.</td>
</tr>
</tbody>
</table>

In each year of the experiment, cottonwood stake survival was indistinguishable between plots that had been watered once in the first growing season (wet) and unwatered (dry) plots (Figure 34). Average
survival was 70% across all plots by the end of the third growing season. Although the survival rate was consistently higher in the wet plots, the difference was small relative to the variability among plots. If a person were to conclude there was a real, albeit marginal, benefit to watering, there would be a good chance of mistakenly rejecting a true ‘null’ hypothesis; in other words, getting a false positive, leading to wasted effort. One important factor that caused the variability to increase over time was vandalism and construction-impacts, which destroyed six dry plots and three wet plots.

Against expectations, annual mortality rates did not diminish by Year 3 (Figure 35). The survival curve might transition to a sigmoidal relationship with time, but that pattern has not been evident in the first three years.
Canopy cover in Year 3 appeared to be positively related to survival (Figure 36). However, cover estimates are imprecise and prone to bias because plot cover was visually estimated at the plot scale using ordinal ranges. The majority of the wet plots had 75-100% cover and good vigor by Year 3. By comparison, most dry plots had 50-75% cover and only fair vigor. Cover generally did not exceed 50% unless survival was >80%. Cover will be evaluated quantitatively in the next round of monitoring to help inform future decisions about watering at other project sites.

**FIGURE 36. RELATIONSHIP BETWEEN SURVIVAL DENSITY AND THE MIDPOINT VALUE OF VISUALLY-ESTIMATED CANOPY COVER CLASSES IN YEAR 3.**

In summary, watering cottonwood stakes in the first growing season did not increase survival by Year 3, but it may have slightly improved cover and vigor. The cost of watering three times in a single growing season ranged from $1 to $3 per stake, which grows to a substantial cost at sites with thousands or even tens of thousands of plantings.

There are a few factors that may have affected the results. Springtime rains were heavy and above average in the first growing season, which might have helped the trees in the dry plot to survive at a higher rate without additional water. Site characteristics may also have contributed significantly to the outcome.
5b. Invasive cover

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1/2 (2014/15) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>For at least 10 years, knotweed cover is lower than baseline conditions (2010) and is decreasing over time.</td>
<td>ACHIEVED</td>
<td>Knotweed has been controlled at this site and it is very uncommon, relative to initial conditions.</td>
</tr>
</tbody>
</table>

Prior to treatment, knotweed was abundant in five distinct locations throughout the site – coincident with blackberry—covering a total area of approximately 15 acres (Figure 37). Treatment and control efforts were extensive and effective throughout the site.

FIGURE 37. 2012 INVASIVE COVER MAP. POLYGONS ARE CLASSIFIED BY WEED COMPOSITION AND LABELS INDICATE ACREAGE OF COVER.
Knotweed control was very effective in the lower half of the project site, reducing a 13-acre patch of knotweed and blackberry to a fraction which contained only a light amount of knotweed (Figure 38). Heavy treatment was still required in areas with full exposure to the river, where propegules from upstream land and establish new infestations (e.g., riverward of the cutoff channel). Garlic mustard has been located on the site, and is being systematically eradicated. Blackberry persists in light to medium accumulations throughout the site but is being treated as well.

---

**FIGURE 38. 2015 INVASIVE COVER MAP. POLYGONS SHOW THE COVERAGE AND WEED COMPOSITION. AREAS ARE NOT SHOWN.**

6a: Juvenile stranding in closed depressions.

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1 (2014) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>For at least three years (through 2016), new habitats are not ecological traps; use, risks and benefits are similar to reference conditions. This means that by late spring (early June), closed depressions in the impact reach are inhabited by salmonids at similar frequencies, and contain similar species as closed depressions in the reference reach (Dorre Don).</td>
<td>Baseline established but post-project conditions not yet evaluated.</td>
<td>Closed depressions were more abundant at the Dorre Don reference reach; over-summer survival was estimated at 29% in these features. A single pre-existing depression at Rainbow Bend was inhabited by fish and none of these appeared to survive the summer.</td>
</tr>
</tbody>
</table>
Baseline assessments at the Dorre Don reach – the natural analogue for Rainbow Bend – identified 11 closed depressions in a side channel network approximately one km long (in 2013). Eight of these (73%) contained salmonids – about 200 fish in total, mostly coho (Table 12). In four of those units, all the fish died by the end of the summer. But in the other four units, which were maintained by groundwater upwelling, many stranded fish survived. The overall survival rate of stranded fish at Dorre Don was estimated to be approximately 30%.

**TABLE 12. BASELINE STRANDING RATE IN CLOSED DEPRESSIONS AT THE PROJECT SITE (RAINBOW BEND) AND A REFERENCE SITE (DORRE DON).**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Date</th>
<th>Dorre Don</th>
<th>Rainbow Bend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of closed depressions</td>
<td>2013</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>Not surveyed</td>
<td>Not surveyed</td>
</tr>
<tr>
<td>Depressions occupied by salmonids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/19/2013</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9/25/2013</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Occupation rate (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/19/2013</td>
<td>73%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>9/25/2013</td>
<td>36%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Average juvenile salmonid density (fish/m²) in occupied units</td>
<td>7/19/2013</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>9/25/2013</td>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td>Over-summer survival (maximum)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July-Sept</td>
<td>100%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Over-summer survival (minimum)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July-Sept</td>
<td>0%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Over-summer survival (average)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July-Sept</td>
<td>29%</td>
<td>0%</td>
<td></td>
</tr>
</tbody>
</table>

The Rainbow Bend project site prior to construction had fewer closed depressions than the Dorre Don site. During the baseline survey in Summer 2013, only one of four depressions at Rainbow Bend contained salmonids, and none of the fish appeared to have survived the summer. Only baseline stranding surveys have been completed; post-project stranding assessments will be completed in summer 2016 to evaluate project effects on fish stranding, if any, compared to the reference site; of particular interest is a large, pre-existing wetland in the floodplain interior.

**6b: Adult passage in the mainstem.**

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>Year 1/2 (2014/15) Status</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>For at least 10 years, no geomorphic changes will cause a barrier to upstream passage by adult Chinook salmon.</td>
<td>ACHIEVED</td>
<td>No passage concerns</td>
</tr>
</tbody>
</table>

No adult passage concerns were noted in either the mainstem or the floodplain side channel; both remained easily passable throughout the spawning season (Photo 7). On the contrary, extensive spawning activity has been observed in both locations. For example, 19 Chinook redds were observed in
the floodplain side channel in the Fall of 2014, or approximately 10% of all known Chinook redds in the Cedar River; Dan Lantz and K. Burton, pers. comm.).

PHOTO 5. SPAWNING PAIR OF ADULT CHINOOK SALMON IN THE FLOODPLAIN SIDE CHANNEL AT RAINBOW BEND, OCTOBER 2014.

Flood Hazard Reduction
Flow models predicted decreases in water surface elevations resulting from the improved distribution of flood flows across the floodplain. For example, in the as-built condition, the 2-D flow model predicted that the elevation of the water surface during a 100-yr flood would decrease by greater than 2.5 feet at the current inlet to the side channel. At the downstream face of the Cedar Grove Road Bridge and at the bend where the Cedar River encounters the Trail Site 6 revetment, more modest decreases in the elevation of the 100-yr flood were predicted.

Predicted channel velocities were reduced by approximately one foot per second (fps) near the toe of the Trail Site 6 revetment at that bend, and shear stress was reduced by approximately 0.5 lbs. per sq. foot, when compared to pre-project model conditions. This is likely a minimum estimate of the actual reduction in shear stress along the Trail Site 6 facility, because substantially more flow is being diverted through the floodplain side channel than was originally modelled in the as-built condition.

As detailed on Pages 54-58 and Figures 29-32, a localized change in the stage-discharge relationship was evident after the project was completed, but only at the upstream end. Specifically, water surface elevations increased at a given discharge level within the banks of the mainstem channel (Figure 31). However, at flood flows that approached bankfull levels (e.g. approximately 4,000 cfs at Renton), water surface elevations were similar or slightly lower than prior to the project. Given that the risk of localized flooding was eliminated in the first phase of the project, this change does not affect flood risk at the project site, though it may help to inform future projects at sites where residents remain.

As stated previously, the restoration phase of the project emphasized floodplain reconnection. To date, the observed changes mainly affect the connectivity of the constructed channels and the inundation of within-channel features such as bars and logjams. It appears that flood water surface elevations have at least temporarily been slightly reduced. The stage discharge relationship at the site is expected to continue shifting as the river adjusts over time.
VIII. Conclusions

Is the project meeting its ecological objectives?

Objective 1: Increase and improve rearing habitat for juvenile salmonids by restoring floodplain functions and processes that create and maintain riverine habitat.
The Rainbow Bend Floodplain Reconnection Project is meeting its goals in the first two years after completion (Photo 8). The project has restored some of the floodplain functions and processes that provide for natural development of riverine habitat and aid salmon recovery:
- Rearing habitat increased, and was enhanced by additional large wood;
- New flood refuge was provided by the cutoff channel and by the diversion of flood flows into the floodplain interior via the side channel, where it enters a forested wetland and runs overland into the new backwater.

Objective 2: Allow the river to expand and migrate toward the right bank at moderate rates.
The following goal is being achieved: the channel widened an average of 25 feet after the levee was removed (up to spring 2015). The rate of migration peaked during a high flow event in March 2014, and has since diminished to rates that are similar to other unconfined reaches of the lower Cedar River (Gendaszek et al. 2012).

Objective 3: Divert flows across the floodplain and reconnect historic side channels and wetland B
Flows follow new paths across the floodplain throughout the entire hydrograph; the floodplain side channel carries flow year-round, while the cutoff channel is usually wetted when discharge exceeds 1,200 cfs at Renton.

Objective 4: Increase roughness in the channel and floodplain
Floodplain roughness increased from the survival and growth of tens of thousands of plantings, interactions with one of the placed logjams, recruitment and trapping of new wood, and from channel adjustments that produced a wider and shallower channel.

Objective 5: Reestablish riparian forests
As of the end of the 2015 growing season, it appears that the cottonwoods have survived at a high rate and have established significant forest cover. However, plantings throughout the floodplain interior survived at a lower rate, owing at least in part to the extreme drought in summer 2015, the first growing season. Supplemental plantings may be needed in the floodplain interior.
PHOTO 6. AERIAL VIEW OF THE PROJECT SITE PRIOR TO CHANNEL ADJUSTMENT. PHOTO TAKEN IN OCT 29 2013 500 CFS AT LANDBURG.

Is the project meeting permit obligations?
Attainment of permit conditions is described in Table 13.

<table>
<thead>
<tr>
<th>Agency</th>
<th>Type</th>
<th>Requirements</th>
<th>Actual Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Permitting and Environmental Review (DPER)</td>
<td>Clearing and grading permit</td>
<td>Year 3 survival &gt;50% and native woody cover &gt;50% in planted areas; Quantitative monitoring of the cottonwood stakes installed in 2011 demonstrated that survival by Year 3 was 70%, overall. Average cover was 56%, overall. By Year 5, stem density higher than as-built in planted areas owing to natural recruitment N/A. Will be tested in Year 5 on last round of plantings.</td>
<td></td>
</tr>
<tr>
<td>Washington Department of Fish and Wildlife (WDFW)</td>
<td>Hydraulic Project Approval 129141-1</td>
<td>80% or greater survival of each species or a contingency species approved by AHB. Survival of the cottonwood stakes planted in 2011 was 70%, which means that the 80% survival target was not achieved, but the variance was only 10% and most of the site remains heavily vegetated.</td>
<td></td>
</tr>
</tbody>
</table>
Is the project contributing to flood risk reduction?
Most of the flood risk reduction benefits of the Rainbow Bend project were accomplished in the first phase of the project. Home buyouts and assisted relocations reduced the risk to public safety. Localized flooding no longer threatens residences or endangers people. Flood hazards have been reduced, and maintenance and emergency response costs have been avoided by helping residents move to safer homes.

The second phase of the project diverted a portion of the river flow away from the flood facility on the left bank, which flow models indicated would reduce shear stress along the left bank. This diversion reduces the chance of damaging erosion and the need for future maintenance because it helps to slow down the water along the left bank facility.

The levee removal and new channels also contributed to a small decrease in flood water surface elevations at the upstream end of the project site. Specifically, the water level is an inch or two lower than before the project was completed, at discharge levels in excess of approximately 4,000 cubic feet per second (at Renton). Even though lowering the flood water surface elevation was not a project objective, it is an outcome of interest and will continue to be monitored over time as the river continues changing.

IX. Lessons learned

• **Deformable channels and backwaters have provided most habitat benefits to date:** Increases in edge habitat area, and thus rearing and refuge habitat, can largely be attributed to the creation of deformable channels and the new backwater feature. The floodplain cutoff channel provided a large amount of refuge habitat during high flows; velocities in that channel were very low or moderate and channel depth was shallow when flows reached approximately 1,200 cfs at Renton. The floodplain channel contained relatively little edge habitat, owing to the lack of instream structure, low sinuosity, and steep gradient. The channel was fast and deep, except during summertime low flows. However, this channel appeared to play an indirect but critical role in habitat creation in the mainstem: by diverting a significant amount of flow into the floodplain side channel, transport capacity in the mainstem channel was reduced. This likely promoted gravel and wood deposition downstream of the diversion, which resulted in more mainstem edge habitat.

• **The habitat capacity of the project site appears to have roughly doubled, from approximately 600 to nearly 1,600 juvenile Chinook at the highest sampled discharges:** Most of these gains can be attributed to increases in the amount of backwater and side channel habitats, which supported the highest densities of juvenile Chinook and coho salmon. Habitat capacity is expected to continue to change as the river channels evolve through time and cause edge habitat availability to change.

• **Deposition in the mainstem channel enhanced the connectivity of the side channel:** A substantial amount of streambed gravel was deposited in portions of the mainstem adjacent to the side
channel inlet. This deposition was likely promoted by both channel widening and by the diversion of flow through the new channels. In any case, this deposition compensated for the aggradation of the channel inlets and allowed the floodplain side channel to remain connected to surface flows year-round. This change appears to have promoted the connectivity of both of the deformable channels.

- **Leaving the side channel initially unobstructed probably helped to keep it connected to the mainstem:** The design decision to not place large wood in the floodplain side channel in order to ensure a high level of connectivity to surface flows appears to have been validated. The side channel is connected year-round and, as it widens, has begun to undercut and topple large trees from the floodplain, which will enhance habitat conditions over time.

- **The project changed the stage-discharge relationship at the upper end of the project site:** The stage-discharge relationship at the upstream end of the project site has shifted so that water surface elevations have increased when discharge at Renton is below 4,000 cfs. This change is significant for a number of reasons. One reason is that it promotes increased connectivity with both constructed channels. It may also cause at least a local change in the groundwater levels—though this has not been verified—which would potentially benefit riparian vegetation during the dry season. At higher discharges, there appears to have been a reduction in water surface elevations, meaning it takes larger flows to cause overbank flooding. In general, this is a notable outcome with relevance to future projects in which shifts in the stage-discharge relationship may have both favorable and unfavorable consequences for ecological performance and nearby properties.

- **Geomorphic effects of levee removal coincided with the highest post-project flow event, and the changes were limited to a small portion of the mainstem channel:** Most of the geomorphic effects of levee removal were confined to the vicinity of the facility. Downstream changes were less pronounced and similar to changes that occurred in the control reach (i.e., net scour and erosion). Almost all of the change was observed during an approximately two-week high flow event in March 2014, and probably even within a single day during that event, coinciding with the peak discharge.

- **Erosion and deposition rates were higher near the site of the levee removal than in adjacent stream reaches and at nearby sites.** During the period of observation, it appears that erosion has exceeded the volume of instream deposition at the Rainbow Bend site, as well as at the upstream control site (Taylor) and the reach immediately downstream. The particle size distribution of the eroded material has not been determined, but would have contained a mixture of silt, sands, and gravels—only the latter would be transported as bedload into the reach immediately downstream.

- **The floodplain side channel has grown substantially wider and deeper downstream of the inlet, but the cutoff channel remains relatively unchanged:** In some locations, the side channel has down-cut by three feet and more than doubled in width, at least downstream of the inlet.
Logjams 3 and 4 were not optimally placed, in that it appears unlikely that the river will contact them in the near-term. The design team anticipated that the cutoff channel would be the site of more significant geomorphic change and planform adjustment than was actually observed. To date, relatively little channel migration has occurred near those two structures, meaning they only interact with flood flows at this time. This outcome illustrates the difficulty of predicting future channel positions with any certainty or precision.

This project site is vulnerable to vandalism, owing to its close proximity to residences, arterial roadways, and regional trails: This project site has been subjected to extensive vandalism and dumping. Vandalism has been occurring since construction and includes, but is not limited to logjam cutting, tree-felling, and wood harvesting. Dumping, poaching, and car prowling has also been problematic. Unfortunately, relatively few options exist for preventing and responding to these kinds of activities, even with the involvement of the King County Sheriff’s office. Future project teams would be wise to mitigate for similar levels of vandalism and dumping at similar project sites and explicitly consider and address the potential risk to engineered structures and to plantings. For example, teams may weigh the potential consequences from removal of former access barriers (e.g., private residences, blackberry thickets, and similar) that previously prevented such problems.

X. Weed Control and Other Maintenance
This section mostly details post-project plant maintenance activities, but weed treatment was also performed prior to construction, to reduce the spread of knotweed. Only weed-related maintenance activities are detailed here, but substantial time and resources have also been spent detecting and responding to vandalism, dumping, and theft at the project site.

FIGURE 39. WEED TREATMENT AREAS.
The entire 40-acre site (Figure 39) was inspected and the following weeds, if present, were chemically treated in either using standard practices at optimal times of year. Aquatic formulations were always used. Where glyphosate was required, Rodeo or Aquamaster was used. Where imazapyr was needed, Habitat was used. Competitor was used as a surfactant for both. If the weed was within five feet of a newly-planted seedling or live stake and foliar spray application was needed, the stovepipe method was used to avoid drift and off-target damage. Boot cleaning was required when leaving the site to avoid spreading garlic mustard seed.

- Yellow archangel (*Lamiastrum galeobdolon*)
- Thistle
- Garlic mustard (*Alliara petiolata*)
- Knotweeds (*Polygonum* spp.)
- Butterfly bush (*Buddleia davidii*)
- Cherry laurel (*Prunus laurocerasus*)
- Field bindweed (*Convolvulus arvensis*)
- Bittersweet nightshade (*Solanum dulcamara*)
- Blackberry (*Rubus* spp.)
- Yellow flag iris (*Iris pseudacorus*)
- Tansy ragwort (*Senecio jacobaea*)

**TABLE 14. MAINTENANCE LOG. PRE-2015.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Action</th>
<th>Dates</th>
<th>Total hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Weed treatment</td>
<td>May 7 &amp; 8; May 21, 22, 28; July 25</td>
<td>171 labor</td>
</tr>
</tbody>
</table>

Additional maintenance issues for 2016:

- Evaluate the condition, density, and species composition of surviving plants in the floodplain interior in 2016. Assess the need and scope of a possible supplemental planting effort to replace plants that did not survive 2015 growing season.
- Continue to monitor the site for vandalism to trees and logjams, as well as trash dumping. Access was blocked with large rock at the gate in December 2015 after several large conifers and several mature cottonwood trees were cut down and partially stolen. Vandals were able to cut the lock on the gate and gain vehicular access.
- Evaluate the complexity of the side channel to determine whether additional wood placement is warranted.
XI. References


King County. 2013. 2013 Flood Hazard Management Plan Update: King County, Washington. King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington.

King County. 2009. Preliminary Assessment for January 2009 Flood Magnitudes for King County Watersheds. Prepared by Jeff Burkey and Kyle Comanor. P.E. King County Department of Natural Resources, Seattle, Washington.


Mansfield, W., J. Hansen, D. Eastman, J. Bethel, and T. Thinley. 2013. Rainbow Bend Floodplain Restoration Project Design Report. King County Department of Natural Resources and Parks, Water and Land Resources Division, Seattle, WA.


WRIA 8 Steering Committee and Forum, 2005. Final WRIA 8 Chinook Salmon Conservation Plan, Seattle, WA.
APPENDIX A. Salmon Recovery Planning Context

The Rainbow Bend project was proposed as Project C235/236 in the WRIA 8 Chinook Salmon Conservation Plan (WRIA 8, 2005).

The Plan established four ‘ecosystem objectives’ to guide salmon habitat protection and restoration:

1. Maintain, restore, or enhance watershed processes that create habitat characteristics favorable to salmon.
2. Maintain or enhance habitat required by salmon during all life stages and maintain functional corridors linking these habitats.
3. Maintain a well-dispersed network of high-quality refuge habitats to serve as centers of population expansion.
4. Maintain connectivity between high-quality habitats to allow for population expansion into recovered habitat as degraded systems recover.

Three tools were used to develop hypotheses about the problems facing Chinook salmon and how to address them to restore population viability (Figure 40).

![Diagram](image)

**FIGURE 40.** WRIA 8 CONCEPTUAL MODEL OF HOW HABITAT CHANGES ARE LINKED TO IMPROVEMENTS IN POPULATION VIABILITY (VSP). EXCERPTED FROM WRIA 8 (2005). VSP STANDS FOR VIABLE SALMONID POPULATION.

Tool 1: An analysis of population abundance, productivity, diversity, and spatial structure: These are the constituents of the Viable Salmonid Population framework or VSP (McElhany et al. 2000). The Cedar River population is at the greatest risk of extinction and warrants a higher priority than other populations in WRIA 8; it exhibits low abundance and downward trends in abundance which contributes to potential compensatory effects in scarce spawning adults have difficulty locating mates, leading to reduced production of offspring. The prevailing hypothesis is that Chinook population abundance steeply declined because of reduced habitat productivity and the potential loss of an in-stream juvenile
rearing life history strategy. Reduced habitat productivity is attributed to habitat degradation, and life history diversity – instream juvenile rearing life history trajectory – is reduced by habitat loss.

**Tool 2: Watershed Evaluation:** Habitat factors of decline were identified (Table 15) and divided the WRIA into three subareas or ‘Tiers’. Tier 1 areas, including the Rainbow Bend site are considered to be the highest priority.

**TABLE 15. HABITAT-LIMITING PROBLEMS (FACTORS) IN WRIA 8.**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altered flow regime and basin hydrology</td>
<td>Altered mainstem flow regime, low base flows, higher peak flows following storms, and increased flashiness</td>
</tr>
<tr>
<td>Loss of floodplain connectivity</td>
<td>Reduced access to side-channels or off-channel areas due to bank armoring and development close to shorelines</td>
</tr>
<tr>
<td>Lack of riparian vegetation</td>
<td>Clearing and development</td>
</tr>
<tr>
<td>Disrupted sediment processes</td>
<td>Too much fine sediment deposited in urban streams, or sources of spawning gravel disconnected from the river channel</td>
</tr>
<tr>
<td>Loss of channel and shoreline complexity</td>
<td>Lack of woody debris and pools</td>
</tr>
<tr>
<td>Barriers to fish passage</td>
<td>Road crossings, weirs, and dams</td>
</tr>
<tr>
<td>Degraded water and sediment quality</td>
<td>Pollutants and high temperatures</td>
</tr>
</tbody>
</table>

**Tool 3: Ecosystem Diagnosis and Treatment or EDT Model:** The model diagnosed limiting factors. In Tier 1 subareas, the model indicated that fry colonization and pre-spawning migrants could be limited by pool habitat area (habitat quantity) and habitat quality (channel confinement, impaired riparian function and lack of large wood). Three recommendations were proposed:

1. Restore riparian vegetation to provide sources of large wood that can contribute to pool habitat.
2. Channel confinement has reduced floodplain connectivity and reduced the amount of pools and small cobbles. Reach-level restoration actions should focus on setback or removal of dikes and levees, the addition of large wood to create pools, and planting riparian vegetation.
3. In the long-term, potential large wood source areas upstream should be restored.

One result of these analyses was the proposal to remove the levee at Rainbow Bend (Project C235/236).