Year 5 (2014) Monitoring and Maintenance Report

Project Name:	Chinook Bend Floodplain Reconnection Project
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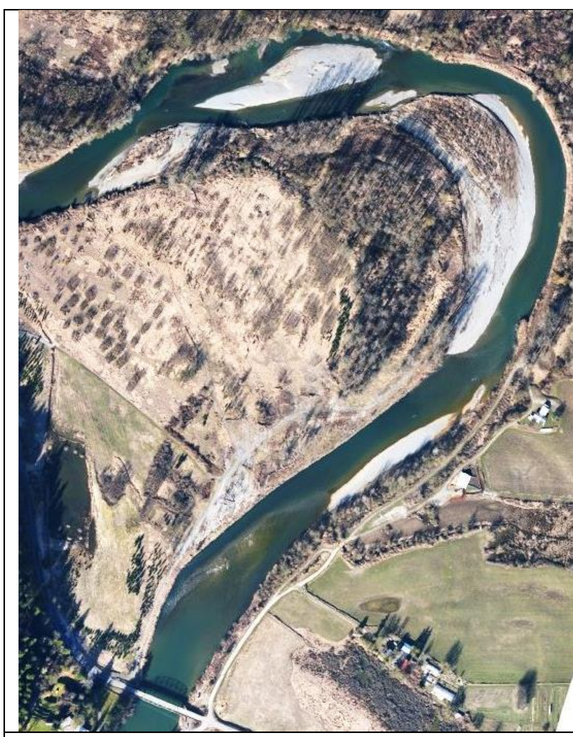
Executive Summary

This report details the Year 5 (2014) monitoring results for the Chinook Bend Floodplain Reconnection Project on the Snoqualmie River, WA. A final report will be issued in 2019.



2009 Pre-Project

2015 Post-Project

DESCRIPTION

The Chinook Bend Floodplain Reconnection Project was implemented by King County Water and Land Resources Division (KC WLRD).

- **Pre-Planting:** Revegetation began after the site was donated by Nestlé, Inc. in 2003;
- **Phase I:** In 2009, the project removed levees from the left bank, and placed logjams;
- **Phase II:** In 2011, another section of levee was removed from the downstream end of the site and a buried setback revetment was installed;
- **Phases III and IV**: In 2012 and 2015, additional rock and spoils were removed.

The project goal was to enhance fluvial processes in the river and floodplain of the Chinook Bend Natural Area (River Mile 20.75 to 21.75) to:

- **Improve connectivity**: Allow more frequent overbank flooding in the Natural Area;
- **Restore process**: Allow the river to migrate laterally through the floodplain;
- **Increase complexity**: Promote complex riverine and floodplain habitat for salmonids.

The project was expected to put the river reach on a trajectory leading to a self-sustaining, dynamic natural system, rather than to a static endpoint.

ACHIEVEMENTS

- Increased fish habitat for sub-yearling juvenile Chinook salmon;
- Increased floodplain connectivity;
- Wood quantities doubled and most of the site has been planted with native vegetation.
- Knotweed extent has been reduced approximately 90%.
- The channel is moving slowly, though at a slow rate.
- Recreation has not been impacted; the reach is navigable.

ISSUES

- A more complex channel pattern, similar to the 1936 condition, was expected to develop soon after project completion, but this appears unlikely to happen for a long time.
- Unexpected bank erosion has occurred on the right bank, perhaps owing to the formation of mid-channel bar that appears to push the river toward the right bank.

LESSONS

- Thoroughly remove rock during construction to avoid needing subsequent removals.
- Leveed reaches may be highly resistant to change; major interventions may be needed.

FUNDERS:

King County
Department of Natural Resources and Parks
Water and Land Resources Division

Washington State Recreation and Conservation Office
Salmon Recovery Funding Board

KCD King Conservation District

King County Department of Natural Resources and Parks, Water and Land Resources Division

King Conservation District provided funding for the project and for effectiveness monitoring

Washington Salmon Recovery Funding Board (directed by WRIA 7)

CITATION:

King County. 2017. Chinook Bend Floodplain Reconnection Project Effectiveness Monitoring Report: Year 5 (2014). Prepared by J.J. Latterell and D. Eastman, King County Water and Land Resources Division. Seattle, WA.

CONVERSIONS:

1 centimeter (cm) = 0.3937 inches (in)

1 meter (m) = 3.2808 feet (ft) *or* 1.0936 yards (yd)

1 kilometer (km) = 3280.840 ft *or* 0.6214 miles (mi)

1 hectare = 10,000 square meters (m^2) *or* 2.4711 acres *or* 11,959.901 square yards (yd^2)

1 cubic meter = 35.3147 cubic feet (ft^3) *or* 1.308 cubic yards (cu. yds or yd^3)

Contents

1. Project Description

The Chinook Bend Floodplain Reconnection Project was completed by King County Water and Land Resources Division (Figure 1). The project began after the project site was donated to King County by Nestlé, Inc. in 2003.

Figure 1. Chinook Bend project site, looking downstream. Photo from October 29, 2014. Discharge at USGS 12149000 was 7,500 cfs (212 cms).

The overall project goal was to enhance fluvial processes in the river and floodplain of the Chinook Bend Natural Area (River Mile 20.75 to 21.75) to achieve the following results:

- Allow more frequent overbank flooding within the Natural Area, and;
- Allow the river to migrate laterally through the floodplain in order to;
- Promote the formation of complex riverine and floodplain habitat for rearing and spawning salmonids.

The reach was expected to move on a trajectory towards a self-sustaining, dynamic natural system, rather than a static endpoint. Many acceptable future conditions could occur over time. The specific, interrelated goals of the project led to a design in which King County removed approximately 1500 feet of rock revetment and levee, and installed pile-based logjams in the floodplain (Table 1; Figure 2). The project was completed in two main phases, with two additional phases of adaptive management to improve project performance (Table 2).

Table 1. Project goals and objectives.

Goal	Objective
Promote the formation of complex riverine and floodplain habitat for rearing and spawning salmonids	All project actions detailed below
Restore lateral channel migration along the left bank.	Remove ~1500 feet of rock revetment along the left (west) bank of the Snoqualmie River in the upstream portion of the project reach, and ~500 feet of revetment in the downstream reach
Restore channel and floodplain hydraulics and connectivity	Remove 1500 feet of levee, allowing the river to flow into the floodplain at 10,000-15,000 CFS, which is approximately the bank full discharge and an annual occurrence – instead of 40,000 CFS (10 year flood event).
Restore the natural sediment transport regime	
Increase channel splitting and avulsion potential	
Increase wood recruitment and accumulation	
Moderate future migration by encouraging the formation of natural logjams along the mainstem channel margin	Install live cottonwood piles in a staggered pattern to rack floating wood, form jams, create roughened bank before channel encounters them. The structures will deflect high velocity flows to the east, toward the primary overbank flow path (east). Install at least 75 feet from OHWM. Densely plant around them.
Restore diverse riparian corridor of native plants	Enhance and maintain native plant communities throughout the floodplain
Do not increase the risk to public infrastructure or private property from flooding or bank erosion	Leave 530 feet of revetment in place along the left bank downstream from Stossell Bridge. Construct a 600-ft long, buried setback revetment to protect Carnation. Deflect high velocity flow and associated potential for erosion and channel formation, from the Carnation wastewater outfall and Camp Korey property.

Table 2. Restoration design elements.

Phase	Completed	Project element	Quantity
I	2009	Upstream revetment and levee removal	1,420 linear feet
I	2009	Log piling structures	14 clusters; 150-200 boles
I	2009/10	Floodplain plantings	Various
II	2011	Downstream revetment and levee removal	456 linear feet
II	2011	Downstream buried setback levee	80 x 40 x 8 feet
III	2012	Additional rock removal from upstream revetment	4,350 cu. yds.
IV	2015	Remove culvert, spoils, remaining revetment	700 cu. yds, 180 linear feet

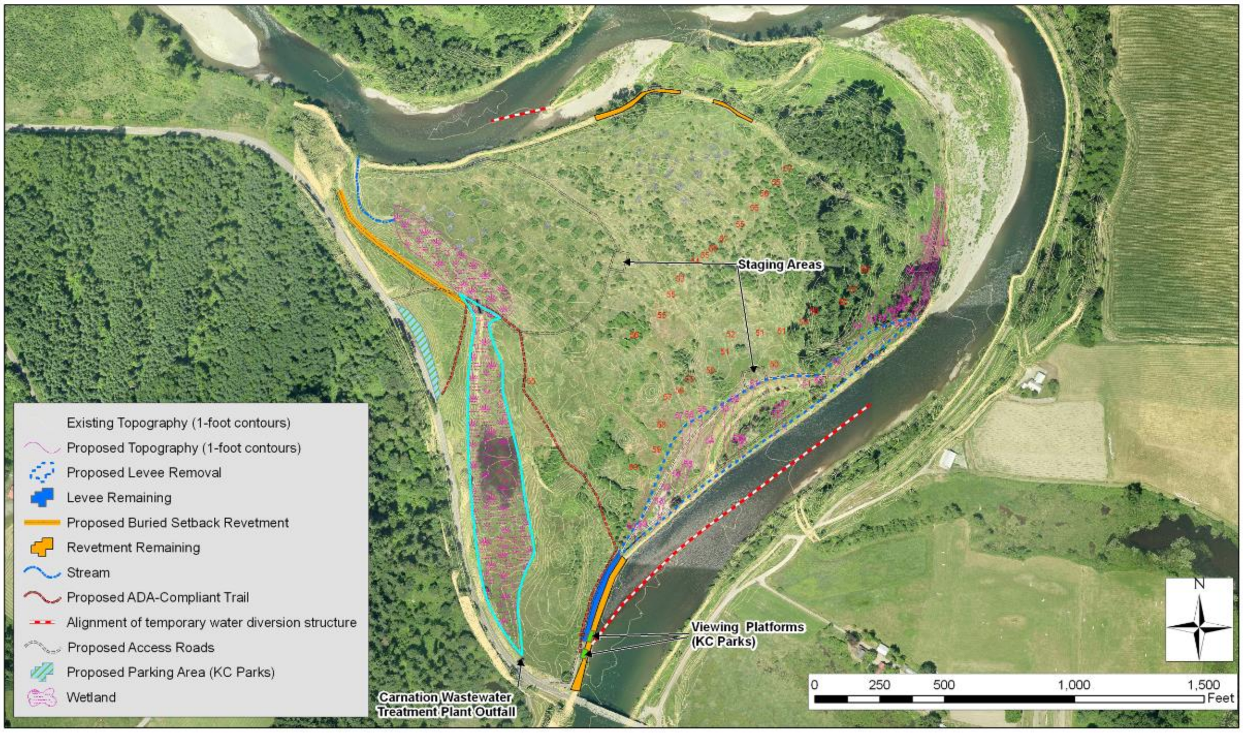


Figure 2. Restoration actions at Chinook Bend.

1.1. Location

The project site is located in the Snohomish River basin near the City of Carnation, Washington (Figure 3). The site can be accessed from NE Carnation Farm Road, near the Stossel Bridge. The site is located in Parcel 092507-9008; a 74-acre (30-hectare) natural area owned and maintained by King County Parks. It is located in the NW quarter of Section 9, Township 25, Range 7.

1.2. Site Characteristics

This section outlines the basic physical and ecological characteristics of the watershed and the project site.

1.2.1. Watershed

The 84-mile-long (135 km) Snoqualmie River drains 938 mi^2 (2,429 km^2) of the north-Central Cascades, falling from 4,900 to 20 feet (1,493 to 6 meters) in elevation where it joins the Skykomish River to become the Snohomish River. The basin contains three forks, which join above the 267-foot-tall (81 meters) Snoqualmie Falls.

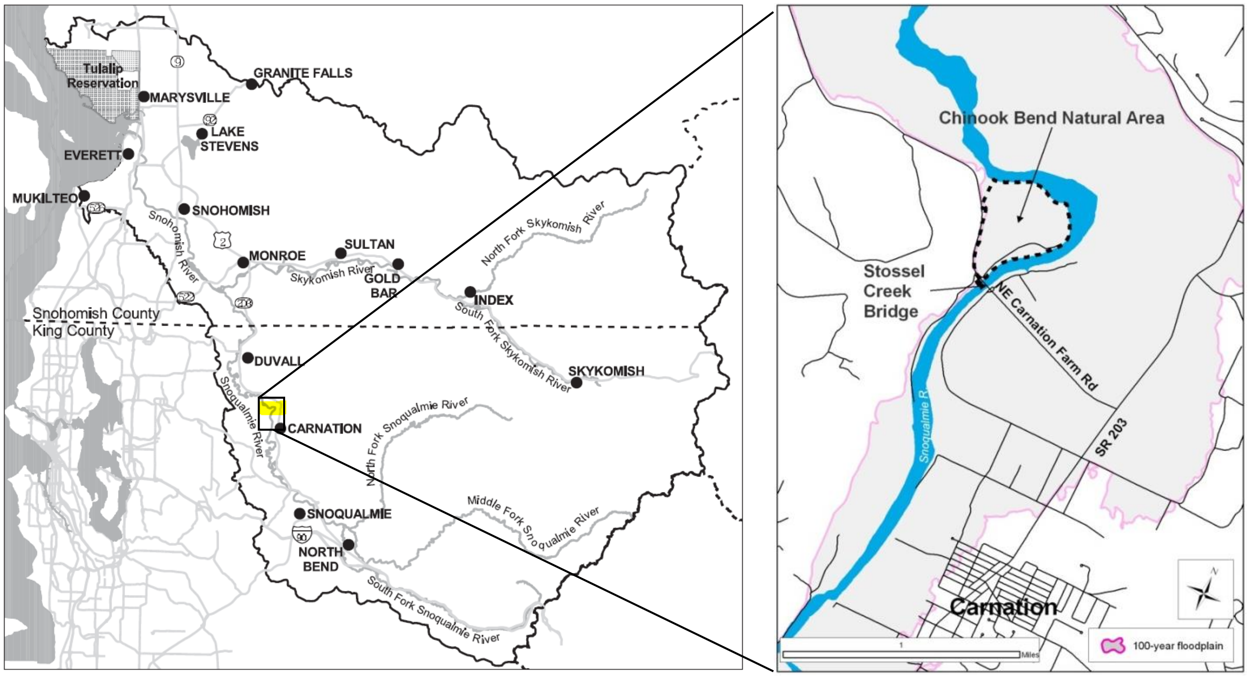


Figure 3. Vicinity Map. Left panel is from Snohomish River Basin Salmon Conservation Plan (2005).

Downstream from Falls, the river enters a wide glacial valley in the Puget lowland; an area defined by lowland sedimentary fill from ice advances in the Pleistocene (Collins and Montgomery 2011). The floodplain and channel averages 5,715 ft (1,742 m) and 217 ft (66 m) wide, respectively (Collins and Montgomery 2011). The valley has a gentle slope (0.047%); falling only 100 feet (30 meters) over 40 river miles (64 km). The meandering channel has a sinuosity of 1.7 (Collins and Montgomery 2011), typical of channels in oversized glacial valleys (Collins and Montgomery 2011). Channel migration is slow, averaging three feet (one meter) per year since 1872, but faster immediately below major tributaries (Collins and Montgomery 2011). Only medium sands (0.3 mm diameter) pass over the Falls, so coarse sediment in the lower river originates from three tributaries: the Tolt River (i.e., 3,000 cubic yards or 2,294 m^3 of bedload per year; Booth et al. 1991), Tokul Creek, and the Raging River (Martin et al. 2004). The valley also contains small tributaries and agricultural waterways.

Most of Snoqulamie watershed is either private or public timberlands. Development is concentrated in the cities of Snoqualmie, Fall City, Carnation, and the Snoqualmie Ridge urban planned development. Agriculture dominates the valley below the Falls, along with several thousand acres of parks and natural areas.

Winters are mild and wet. Summers are warm and dry. Precipitation ranges from 60 inches near the project site to 180 inches at the Cascade crest, mostly falling from November through March. Flows are not regulated by dams, except for the South Fork Tolt River, which contains a run-of-the-river facility to supply Seattle with water.

Flooding is usually caused by warm winter storms in November through February. Snowmelt runoff contributes to high, sustained flows in spring. The highest annual peak discharge from Oct 1, 2009 to Oct 1, 2015 –the period of this study—was 51,600 cfs on Jan 17, 2011 (Table 3).

Table 3. Estimated flood recurrence intervals at the project site, based on USGS 12149000, and the number daily maximum flow exceedances from Oct 1, 2009 to Oct 1 2015.

Recurrence interval	Discharge in cfs (cms)	Exceedances (cumulative)	Dates
5-year	44,903	3	2011: Jan 17-18
2-year	30,359	10	2010: Dec 12 and 13 2011: Jan 16, Mar 1, Apr 1 2012: Feb 22 and 23
1.50-year	24,823	12	2014: Mar 9 and 10
1.25-year	20,363	20	2011: Jan 14-15, Apr 2, Mar 30 2014: Nov 26-29
1.01-year	9,823	178	*Many*

1.2.2. Project Site

The project site is a low-gradient (0.0013 or 0.13%) meander bend (Figure 4) within an alluvial ridge extending downstream from the Tolt river fan. In this reach, natural levees cause river banks to rise 10 to 16 feet (three to five meters) above the adjacent valley floor (Collins and Montgomery 2011). Channel migration rates were historically faster at this site, than the rest of the lower Snoqualmie mainstem (Collins et al. 2003), which contributed to an island-braided pattern (ca. 1870 to 1936; Figure 5).

The project site was modified by agricultural land uses and channelization. By 1936, the low terrace on the left bank had been mostly cleared. The Stossel Bridge was constructed in 1951 (Figure 5). Soon after, both banks were armored with rock, and a 1,200-foot-long, 10-foot-tall levee was constructed. Gravel fill constricted the channel. These modifications degraded fish habitat by preventing channel migration, limiting floodplain connectivity, and by reducing slow-water rearing habitat.

1.3. Salmon Recovery Context

This section describes salmon recovery planning efforts at four scales: Puget Sound, the Snohomish River; the sub basin, and the project site.

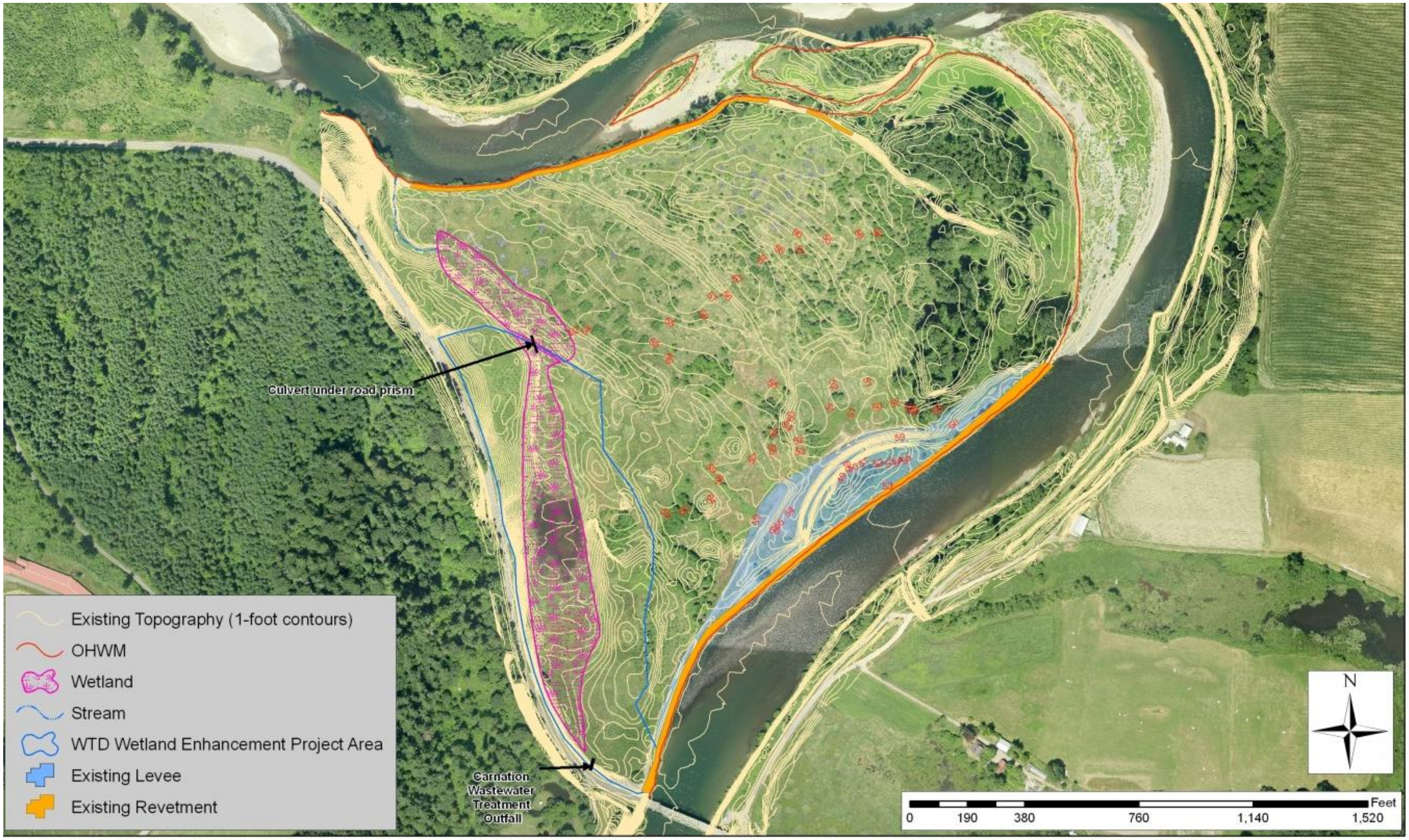
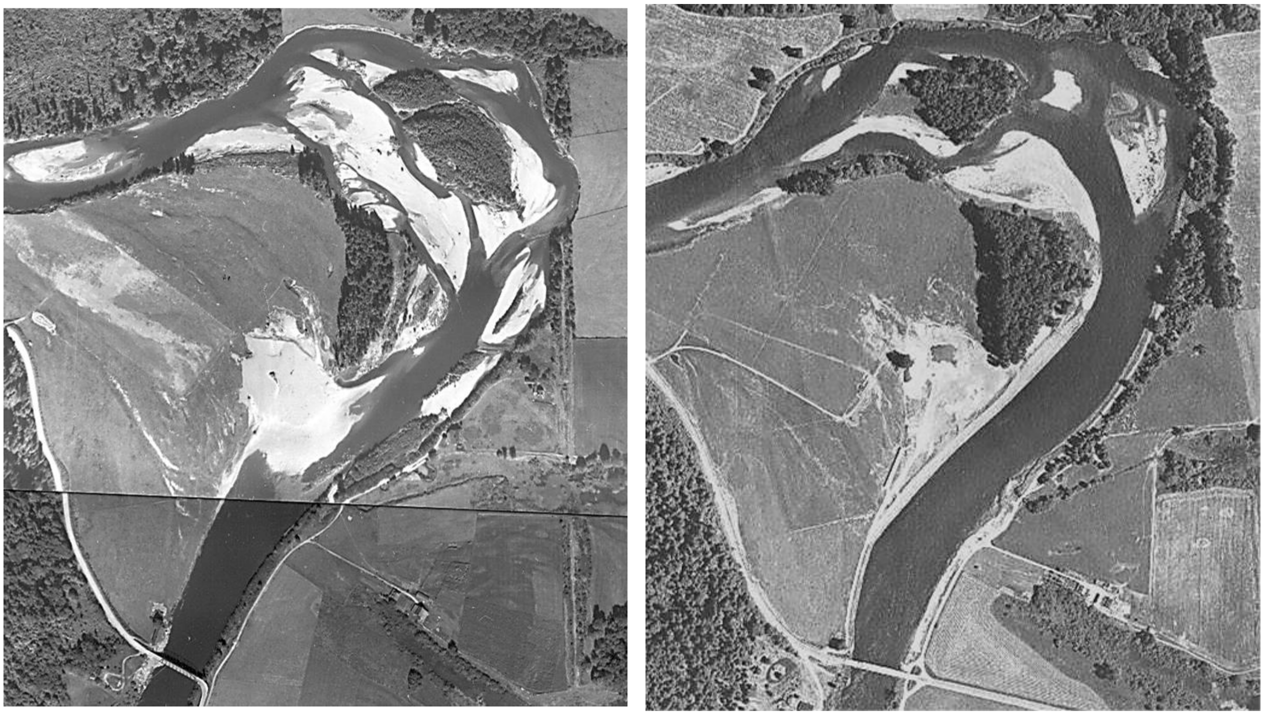


Figure 4. Existing conditions at the Chinook Bend site.



1936 Pre-levee **1964 Post-levee**

Figure 5. Historical channel conditions at Chinook Bend. The Stossel Bridge (ca. 1951) is shown on the 1964 image.

1.3.1. Puget Sound

Puget Sound Chinook salmon were classified as 'threatened' on March 24th, 1999 (64 FR 14308). The Puget Sound Evolutionarily Significant Unit (ESU) contains 22 populations[1] in five biogeographical regions or Major Population Groups (MPGs; NOAA, 2011), including all naturally-spawned Chinook salmon in Puget Sound and the Straits of Juan DeFuca, and numerous hatchery programs. To avoid extinction, each population must improve, two to four must attain a low extinction risk, and one must be viable. The ESU is at moderate, not immediate, risk of extinction (NOAA 2011). Natural-origin escapement trends are stable, though total natural-origin recruit abundance and productivity is declining (NOAA 2011). From 2001-2010, nine of the 22 populations (including the Snoqualmie River) experienced significant decreases in numbers.

1.3.2. Snoqualmie Chinook Salmon

The Snohomish River supports two Chinook salmon populations (Snohomish River Basin Conservation Plan, 2005). In 2005, the Snoqualmie Chinook salmon population was at approximately 6% of historic levels. From 1987-2001 an average of 2,900 Chinook salmon returned to spawn (range: 19-6,514; Good et al. 2005). Recovery targets are 3.6 'recruits per spawner' and 1.3 to 2.1 million outmigrants; a 50- to 100-fold increase over existing levels.

[1] Historically, 31 populations were thought to have existed, but nine of these – mostly spring-run stocks – are extinct. (Good et al., 2005).

1.3.3. Snoqualmie Subbasin Planning Area

The project site lies within the Mid-Mainstem Snoqualmie sub basin planning area, where projects are expected to 1) protect spawning areas, 2) improve juvenile rearing habitat (complex edge, riparian forests, and connected off-channel areas), and 3) protect forest cover. The project reach is a "core area" in that it supports salmonid spawning, juvenile rearing and outmigration, adult migration and holding, and refuge (Martin et al. 2004).

The Chinook Bend Floodplain Reconnection Project originated from *Snoqualmie 2015*, a 10-year plan which aims to restore 5.5 miles of edge habitat, 125 acres of riparian forest, 70 acres of off-channel habitat, and install 20 large wood structures. Restoration of fluvial processes and floodplain reconnection is expected to support the productivity of freshwater life stages of salmonids (Bjornn 1971, Hillman et al. 1987).

2. Monitoring Plan

Effectiveness monitoring was initiated as a part of a larger reach-scale effort by King County: the Snoqualmie at Carnation (or SAC) Study, which was also intended to include nearby restoration projects: Camp Gilead; Chinook Bend; Stillwater.

The study was set up as a Before-After-Control-Impact (BACI) design, though most of the analyses presented here are simple before-after comparisons. The treatment reach encompassed the portion of the Snoqulamie extending from just above the Lower Tolt River, downstream past Kamp Korey. The control reach included what is now termed the ‘Fall City Reach’ to the Neal Road boat ramp.

This section describes self-imposed (optional) performance standards established by King County WLRD; none were required by environmental permits. Performance standards *in italics* were not established by the project team in the Basis of Design Report, but were instead proposed *after the project was constructed*. These standards should not be used to evaluate project success. Instead, they provide an opportunity to learn more about the effects of levee removal, in general.

2.1. Goal 1. Promote the formation of complex river and floodplain habitat for rearing and spawning salmonids.

Habitat benefits were inferred from changes in edge habitat area, redd locations, and the linear extent of suitable spawning substrate. Edge habitats (i.e., bars, banks, backwaters, and side channels) integrate varied physical changes, “effectively stratify microhabitat characteristics and seasonal abundances of juvenile salmonids”, and “(1) sensitive to anthropogenic change and (2) reasonable predictors of juvenile salmonid abundances” (p. 727, Beechie et al. 2005).

Performance standards for salmonid habitat improvement.	**Documentation**
1.1 The summed area of 'edge habitat' (bar, bank, backwater and side channel units) increases relative to pre-project conditions.	Edge habitat maps at multiple flow levels.
1.2. Increased spawning activity downstream from the site of levee removal.	Redd maps in the project reach; percentage of total redds in project site
1.3. Increase in the longitudinal extent of suitable spawning habitat.	Pebble counts on bars in study reach and estimated extent of suitable and optimal spawning gravels.

2.1.1. Protocol for Measuring Edge Habitat

The extent and distribution of 'edge' habitat was mapped at the Chinook Bend project site at multiple flow levels (Beechie et al. 2005). Targets for the initial survey were based on March flow percentiles (Table 4). Flood refuge could not be safely measured.

Table 4. Target flows for edge habitat mapping (USGS 12149000).Flow percentiles are based on March statistics for mean daily flows.

Approx. March flow percentile	Method	2009	2011
$<5^{th}$	Field survey	604	990
20^{th}	Field survey	2,260	2,150
50^{th}	Field survey	3,720	3,440
90^{th}	Field survey	7,490	7,280
$>95^{th}$	Oblique airphoto	*No data*	16,400

Edge habitat was mapped extent and distribution of medium (<45 $cm \cdot s^{-1}$) to low (<15 $cm \cdot s^{-1}$) velocity edge habitat on both banks (Beechie et al. 2005, Bisson et al. 2006). Each unit was mapped along the edge of water and visible current shear line, where velocities exceed 15 cm/s. Excluded hydromodified edges and areas narrower than one meter.

2.1.2. Protocol for Mapping Redd Locations

Chinook salmon redd mapps were obtained from WDFW (Washington Department of Fish and Wildlife). Redd density was normalized using the total redd density for the Snoqualmie River to account for inter-annual variability in adult returns.

2.1.3. Protocol for Measuring Substrate

Changes in longitudinal patterns of particle size distributions were quantified by sampling surface sediments with modified Wolman method (Wolman 1954) adapted from (Booth et al. 1991). Pebble counts were performed on point and mid-channel bars during low flow, at standardized locations representing materials in transport in the main flowpath (Booth et al. 1991). For point bars, counts were performed on the upstream half of the bar, midway between the upstream end of the bar and the mid-point. For mid-channel bars, pebble counts were conducted from a starting point 25 m downstream from the tail of the riffle associated with the bar head.

Once the center point was established with GPS, a 40- to 50-m transect was extended parallel and adjacent to the wetted channel margin. Two surveyors walked in opposite directions from the start, selecting clasts with the blind 'heel-to-toe' method, using a sharpened pencil to choose individual clasts, to reduce bias against small particles. Intermediate diameter of each clast was measured with a ruler (to 1 mm) until each technician sampled 25 clasts. Surveyors then turned and faced the starting point, moved laterally a few meters, creating a parallel offset transect, and sampled an additional 25 clasts each, until 100 clasts were measured. Substrate photos were taken at center and endpoints of the pebble count transects at a common scale determined by a pipe and monofilament quadrat frame with inside dimensions of 44 x 66 cm.

2.2. Goal 2. Restore lateral channel migration along the left bank and restore the natural sediment transport regime.

Performance standards for channel migration and planform adjustment.	**Documentation**
2.1. Lateral channel migration will occur on the left bank.	Map bank retreat
2.2.a. Within one to five years, channel planform in the project reach will resemble the 1936 channel.	Map changes in channel planform.
2.2.b. A chute cut-off may occur across the eastern portion of the bend. Channel splitting and wood and sediment in the existing mainstem could re-direct flow. A new mainstem may form on the west side of the constructed island.	Interpret observed channel changes from orthophotos
2.3. The mainstem channel will aggrade adjacent to and upstream from the site of the former levee, and form new gravel bars forcing leftward migration.	Map of aggradation and scour based on comparison of bathymetric surfaces
2.4. The channel will become wider and shallower.	Comparison of channel cross-sections over time

Bank retreat indicates the rate at which the river is migrating or widening. Moderate rates of migration are assumed to help create and maintain complex morphology in the streambed and floodplain, and to promote complex hydraulics. Channel movement may also manifest as an avulsion—all or part of the channel relocates into one or both of the existing floodplain channels.

Channel planform is a representation of the channel viewed from above, usually divided into straight, meandering, or braided types (Leopold and Wolman 1957), though at least 14 patterns are now recognized (Knighton 1998). It is an obvious characteristic of channel geometry for evaluating whether the river is becoming more geometrically and ecologically complex.

The cross-sectional form of the channel refers to the cross-sectional view, expressed at a point or an average (Knighton 1998). Changes in cross-sectional form help explain how the channel is adjusting and becoming more complex.

2.2.1. Protocol for Measuring Channel Migration

LiDAR-based ground surface models (GSMs) were used to map the top of the river bank, or the edge of the unvegetated channel and compared among years to identify areas of bank retreat.

2.2.2. Protocol for Mapping Channel Planform

Orthoimagery and LiDAR GSMs were used to digitize the boundaries of the wetted and unvegetated portion of the river channel as a polygon at 1:300 scale in Arc GIS.

2.2.3. Protocol for Mapping Channel Cross-sectional Form

Cross-sectional form was measured by surveying bathymetric cross-sections perpendicular to the bankfull channel at approximately 100-foot (15.2-m) intervals along the channel centerline, starting upstream of the Stossel Bridge and extending past the project site. A multi-source GSM was generated by integrating the bathymetry with a topographic surface from the same year.

Elevation changes were calculated using ArcMap (grid math) to compare pre- and post-project elevations. Volumetric changes were calculated using 3D Analyst. Analyses were limited to changes ≥±1 foot (0.3048 m) to eliminate small changes within the margin of error in the topographic and bathymetric surveys.

ArcMap was also used to measure bankfull channel width, depth, cross-sectional area, and thalweg elevation using the cross-section tool along transects aligned with the location of the original bathymetric survey, to reduce extrapolation errors. This was done by digitizing a polyline shapefile with z-values in the NAVD 88 Geoid 03 vertical datum. The transects extended beyond the margins of the bankfull channel. Elevations from the GSM were added to polylines using the 'Interpolate Shape' tool, and then converted to ASCII. Profile data was added to a table, and the results were plotted to illustrate cross-section elevations at each station.

A chart was created to visualize each cross-section and identify the each bank[2]. The maximum elevation of the lower of the two banks was identified as a reference point for estimating the bankfull depth at a single cross-section. The bankfull depth at each point between the banks was estimated by subtracting the measured elevation from the elevation of the lowest bank. Channel width was estimated at the cross-section by calculating the distance between the left and right banks. Cross-sectional area of the bankfull channel was estimated by multiplying the depth at each point inside the channel by the distance between measurement points and summing all measurements. Cross-sectional area estimates are not based on hydraulic analysis and so do not represent flood-conveyance channel capacity. Thalweg elevation was determined by finding the minimum elevations of each transect. These analyses were repeated for each cross-section and year, and then calculate the change between years at each cross-section and in reach-averaged values.

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[2] F. Lott, River and Floodplain Management Section has since developed a semi-automated process to significantly improve efficiency; contact Mr. Lott for details

2.3. Goal 3. Restore channel and floodplain hydraulics and connectivity.

Performance standards for floodplain connectivity	Documentation
3. Floodplain behind levee will be inundated at 10,000-15,000 cfs at USGS Carnation gage.	Time-lapse photography

Habitat benefits are assumed to increase with floodplain connectivity. The frequency of overbank flow through the low swale was chosen as an indicator to evaluate whether the project allows for more natural inundation of the floodplain. Levee removal is expected to reduce the river's competence for sediment transport. Consequently, alluvium is expected to aggrade adjacent to and upstream of the levee removal site. This outcome would probably promote overbank flow across Chinook Bend at lower flood stages, lateral channel migration, and channel splitting and/or avulsion processes.

2.3.1. Protocol for Measuring Floodplain Connectivity

A time-lapse camera was temporarily installed in low swale to determine the minimum discharge level required to initiate overbank flows from the mainstem.

2.4. Goal 4. Increase large wood recruitment and accumulation.

Performance standards for large wood recruitment and accumulation	Documentation
4.1. Substantial accumulations of wood will form along river margins and in the floodplain via trapping on existing vegetation, the constructed island, and new gravel bars and islands.	Map of wood based on orthophotos, tally of wood amounts over time
4.2. Mature cottonwood trees will be undercut on-site and be retained within the project reach, forming bar-apex jams over time.	Recruitment rates based on potential wood inputs eroded forest patches
4.3 Placed wood structures will trap floating wood during overbank flows to moderate channel migration.	Percentage of mapped wood associated with placed wood structures

Large wood influences river pattern and hydraulics, and provides cover for juvenile salmonids (Naiman et al. 2002). Benefits should be positively related to the amount of wood in the site.

Assessments of wood function indicate whether roughness in the channel and floodplain has increased, and habitat benefits were provided. Substantial amounts of wood were expected to accumulate along the river margins and throughout the floodplain.

Large wood recruitment from on-site can initiate logjams by trapping wood from upstream. As the river undercuts trees from on-site, logjams may form. Trees ≥24 inches DBH (61 cm) and longer than 100 ft (30 m) were expected to remain on-site. Smaller trees may be entrained and move downstream. This process is an indicator of connectivity between the channel and floodplain, and contributes to edge habitat and channel complexity.

Large wood trapping on pile structures indicates the structures are performing their intended function: to capture wood during floods and form logjams, and associated habitat benefits.

2.4.1. Protocol for Measuring Large Wood Accumulation

Visible pieces were mapped and classified with alphanumeric codes (E4-G6 only), recognizing there was a strong selection bias against short and small-diameter pieces owing to the limited resolution of the orthoimagery (Table 5). Each potential key piece was assigned a list of attributes using photo interpretation:

- Type: individual piece or logjam (defined as containing a key member and at least one racked piece larger than 0.4 m diameter and 8-m long);
- Location: mainstem, wetted channel, floodplain, backwater;
- Trapping mechanism: channel margin, vegetated bar, mid-channel bar, point bar, side channel, vegetated island;
- Geomorphic function: pool scour, bar formation, bank stabilization, flow splitting, meander geometry, sediment trapping, vegetation regeneration, bed elevation;
- Habitat function: juvenile cover, refuge, holding;

Table 5. Classification scheme for large wood surveys (Montgomery 2008).

				Diameter		
Length		**10-20 cm**	**20-40 cm**	**40-80 cm**	**80-160 cm**	**160-320 cm**
		3.9-7.9 in	7.9-15.7 in	15.7-31.5 in	31.5-63.0 in	63.0-126.0 in
1- 2 m	3.3-6.6 ft	B2	B3	B4	B5	B6
2-4 m	6.6-13.1 ft	C2	C3	C4	C5	C6
4-8 m	13.1-26.2 ft	D2	D3	D4	D5	D6
8-16 m	26.2-52.5 ft	E2	E3	E4	E5	E6
16-32 m	52.5 -105.0 ft	F2	F3	F4	F5	F6
> 32 m	>105.0 ft	G2	G3	G4*	G5	G6

2.4.2. Protocol for Measuring On-site Large Wood Recruitment

Wood recruitment via forest erosion was calculated as the product of the eroded area of a given unit type and the average number or volume of trees ≥ 10 cm DBH per unit area. Forested areas were digitized from orthoimagery at 1:3,000 scale. Overlay analysis was used to identify forested areas eroded after project implementation. Eroded forest patches were visually classified by either red alder or cottonwood-dominated.

Average tree numbers and volumes were estimated for each patch type using riparian surveys at (Van Pelt 2006).

Two study plots were established in existing forests within the project site to estimate the potential wood loading per unit area. All the trees larger than 10 cm DBH were tallied by species, and their diameters were measured with a DBH tape (to 1 cm). Downed logs and snags were also tallied.

- Plot 1: 80 x 30 m (0.24 hectares)
- Plot 2: 70 x 26 m (0.18 hectares)

2.4.3. Protocol for Measuring Placed Wood Functions

The percentage of total wood storage trapped against the structures was estimated.

2.5. Goal 5. Restore a diverse riparian corridor of native plants.

Performance standards for riparian plantings	Documentation
5.1. The area of forested pioneer bars will increase within the project reach.	Maps of new pioneer bars
5.2. Planted areas will not be dominated by reed canarygrass, blackberry or knotweed.	Maps of knotweed

The presence of pioneer bars–depositional features covered by young, pioneering (shrubby) vegetation, occurring anywhere in floodplain but often on point bar margins (Latterell et al. 2006)—indicate bars are forming and native trees and shrubs are regenerating, contributing to a diverse age-structure in the riparian plant community (Naiman et al. 2010).

Strong rhizomatous invaders (e.g., *Polygonum* spp, and *Phalaris*; knotweed and reed canarygrass) reduce species diversity and alter community structure by displacing native plants (Kim et al. 2006; Urgenson et al. 2012). Weed control focused on getting plantings established. Control efforts targeted knotweed to preventing its spread and reduce its extent.

2.5.1. Protocol for Measuring Pioneer Bars

New pioneer bar areas formed since project implementation were mapped from orthoimagery. Establishment rates were calculated as pioneer bar area per year, normalized by river length.

2.5.2. Protocol for Measuring Knotweed Extent

Knotweed was mapped from orthoimagery.

2.6. Goal 6. Do not increase the risk to public infrastructure or private property from flooding or bank erosion.

Performance standards for flooding and erosion risks.	Documentation
6.1. Neither the water surface elevation during flood events nor the overbank flood frequency on the right bank will increase as the channel adjusts.	Zero-rise analysis and field observations during floods
6.2. The project will not contribute to bank erosion downstream of the project site, excluding the first ¼-mile (where left-bank erosion is desirable).	Orthoimagery interpretation
6.3. Fewer than three feet of scour will occur in the channel bed underneath Stossel Bridge.	Comparison of bathymetric surfaces under the bridge
6.4. The left bank revetment continues to protect the bridge, the road, and the constructed wetland from erosion.	Visual observation of the status of each left bank feature
6.5. The buried setback revetment prevents erosion to the Carnation Farm Road.	Visual observation of the status of the road

Changes in the elevation of the channel bed elevation indicate whether there bed degradation under the Stossel Bridge.

2.6.1. Protocol for Measuring Risk to Infrastructure or Private Property

Examine orthophotos and LIDAR for bank retreat upstream, downstream, and along the site.

2.7. Goal 7. Maintain current level of recreational opportunities available to the public.

Performance standards for recreational safety	Documentation
7.1. The project reach is navigable, at least by experienced boaters.	Visual interpretation of aerial photos to evaluate hazard, egress, and sight lines.

The navigability of the stream reach is expected to decline, but should remain passable for kayaks, canoes, drift boats, or motor boats.

2.7.1. Protocol for Measuring Recreation Conditions

Orthoimagery and field visits were used to qualitatively assess the difficulty of navigating the reach.

3. Permit-Related Monitoring Requirements

Only two agencies, King County Parks and Washington Department of Fish and Wildlife, stipulated monitoring conditions (Table 6). Both conditions are satisfied by the monitoring efforts outlined in this report. No reporting was required.

Table 6. Monitoring requirements.

Permit	Conditions	Reporting Requirements	Year 5 Status
KC DPER Clearing and grading permit L09CG101	No conditions.	None.	Not applicable
Washington Department of Fish and Wildlife Hydraulic Project Approval (HPA) 116683-1, 116683-2	King County WLRD shall conduct monitoring and maintenance according to the 'Chinook Bend Floodplain Enhancement Project, Monitoring and Maintenance Plan,' dated May 20, 2009.	None	Partially complete; no report needed.
Parks NRL Site alteration permit (SAP)	The permittee shall provide a copy of all monitoring reports submitted to DPER to Parks.	None.	Not applicable
U.S. Army Corps of Engineers; NWS-2009-131	No conditions.	None.	Not applicable
Washington Department of Ecology Stormwater permit WAR011614	No conditions.	None.	Not applicable

4. Monitoring Results

4.1. Goal 1. Promote the formation of complex river and floodplain habitat for rearing and spawning salmonids.

Performance standards for salmonid habitat improvement.	Year 5 Status	Details
1.1 The summed area of 'edge habitat' (i.e., bar, bank, backwater and side channel units) increases relative to either pre-project conditions.	Target met	Edge habitat increased at each flow level
1.2. Increased spawning activity downstream from the site of levee removal.	Target unmet	Spawning activity did not increase
1.3. Increase in the longitudinal extent of suitable spawning habitat.	Target unmet	Spawning habitat decreased

4.1.1. Edge Habitat

Edge habitat was mapped at three flow levels in 2009 and at four in 2011 (Table 7). Edge area increased from 2009 to 2011 (Figure 6, Figure 7), mostly in banks and backwaters (Figure 8). The most comprehensive edge surveys were completed in 2011 (Figure 6). Edge habitat area declined with increasing discharge, except at the highest flows, which exceeded bankfull discharge. In 2011 demonstrated the overall area of low-velocity habitat was highest at the lowest and highest mapped discharges and declined between 5,000 to 10,000 cfs (Figure 7).

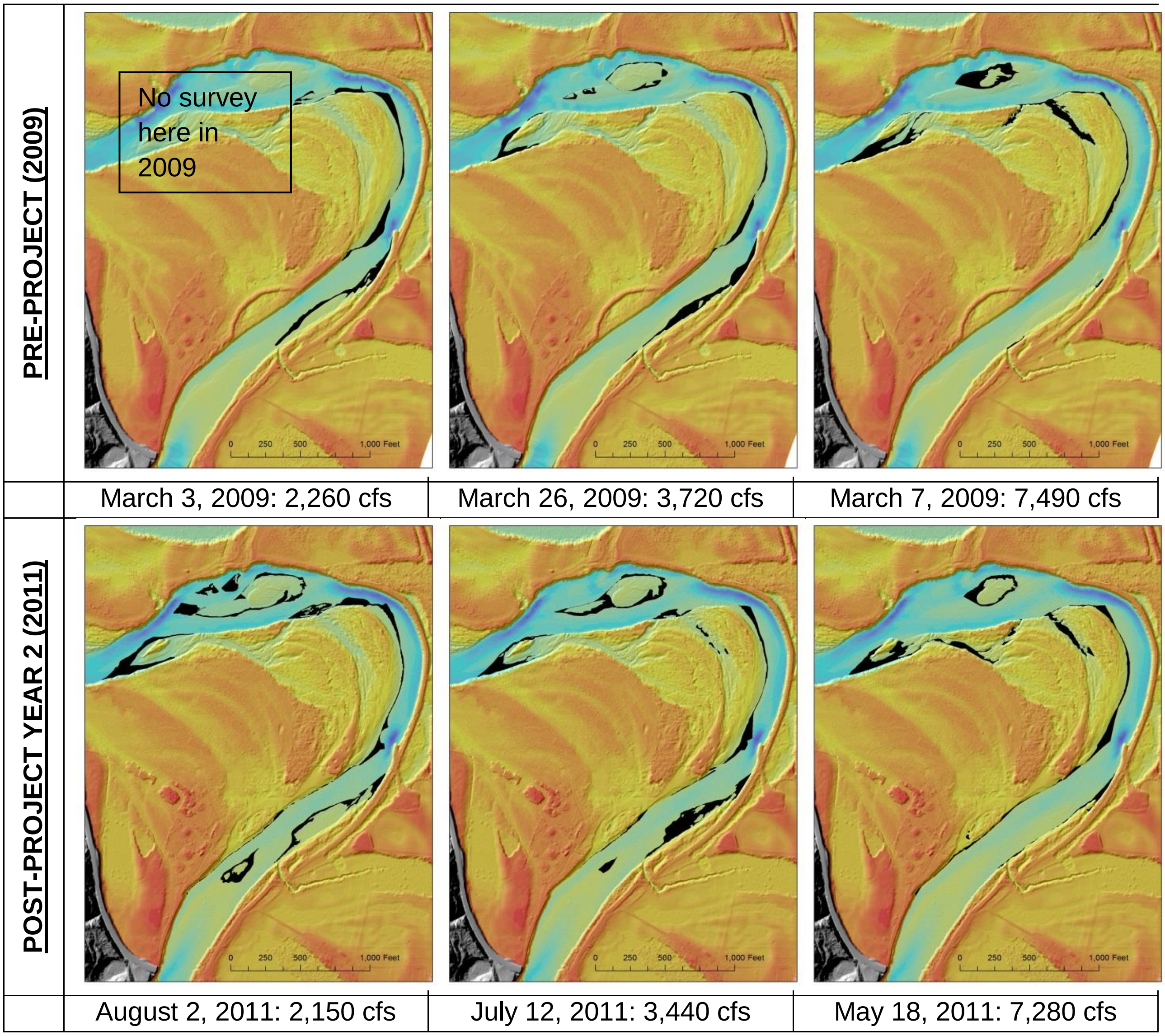


Figure 6. Comparison of edge habitat (black shapes), before and after project completion. Background images represent elevations (25-65 feet ASL NAVD88) in the corresponding years, increasing from blue to red.

Table 7. Discharges during edge habitat mapping.

Approx. flow percentile	**Method**	**Discharge (cfs)**		**Survey dates**	
		2009	**2011**	**2009**	**2011**
<5th	Field survey	No survey	990	None	Oct 4
20th	Field survey	2,260	2,150	Mar 3	Aug 2
50th	Field survey	3,720	3,440	Mar 26	July 12
90th	Field survey	7,490	7,280	Mar 7	May 18
>95th	Oblique	Estimate	16,400	none	Dec 29

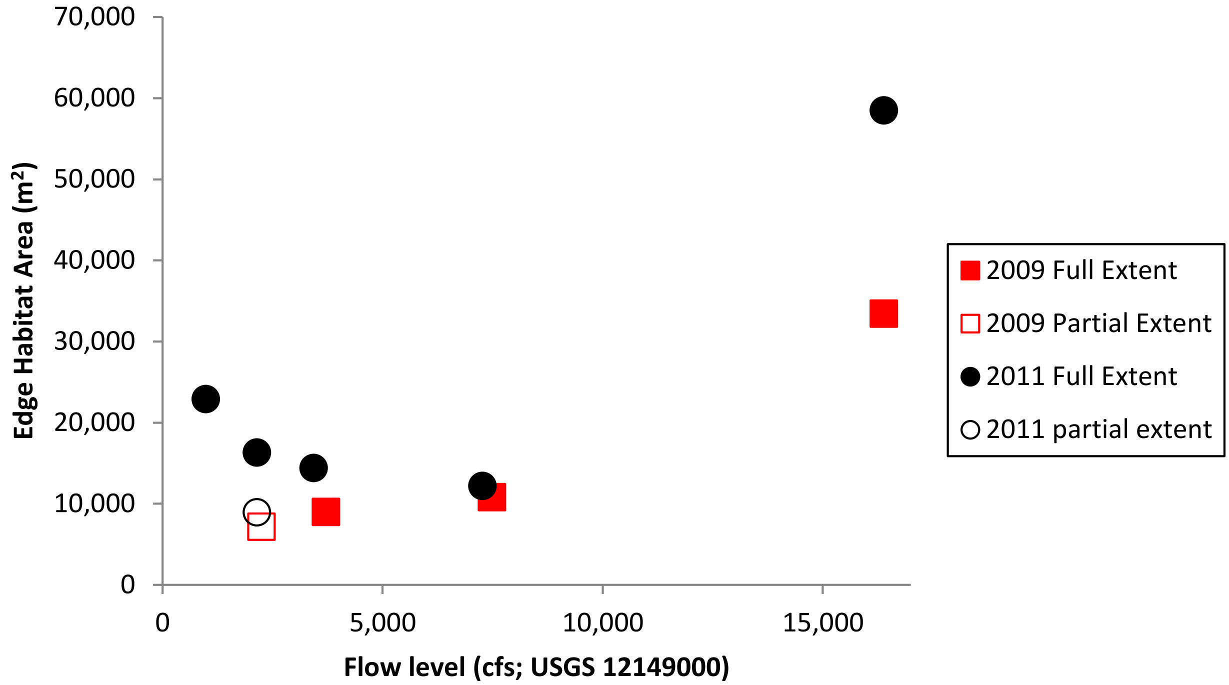


Figure 7. Relationship between edge habitat area and discharge before (2009) and after (2011) the project was completed. Full extent encompasses 5,700 linear feet of channel. One survey in 2009 did not include the full extent of the other surveys and is labelled ‘partial extent’. The comparable extent was extracted from the 2011 survey to permit a year-over-year comparison.

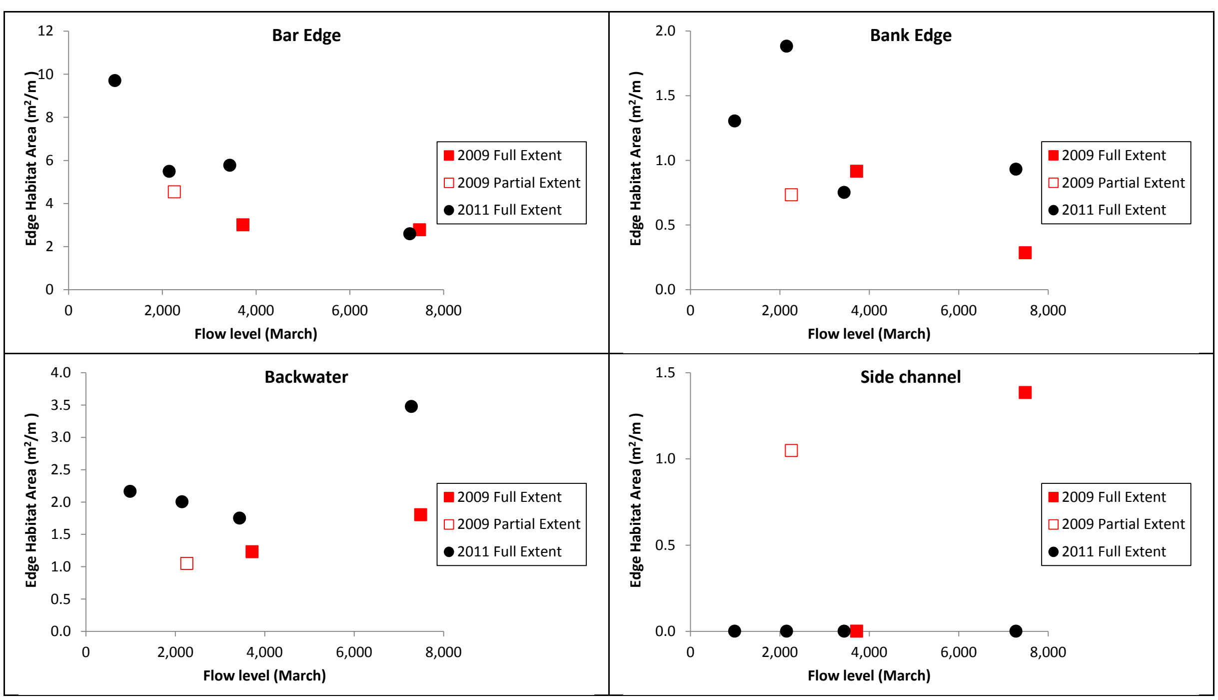
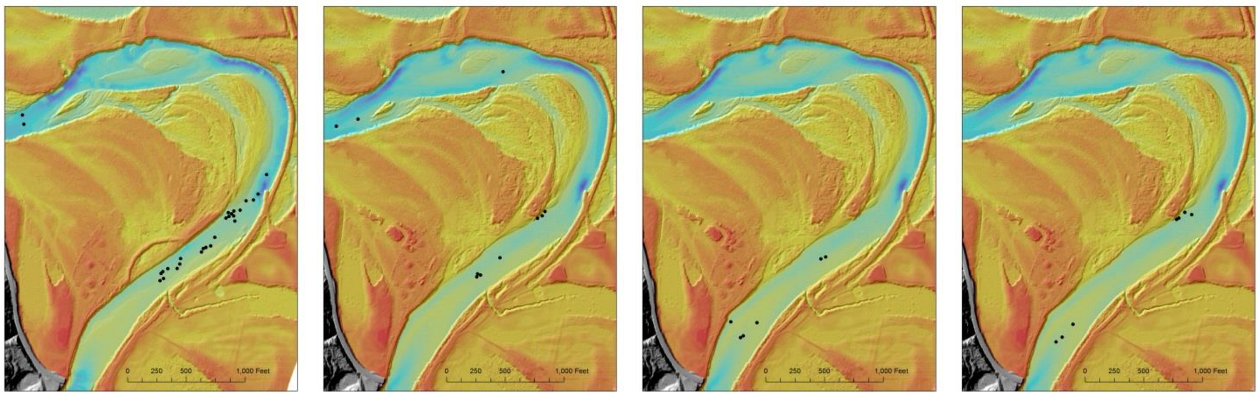


Figure 8. Relationship between edge habitat area by type, normalized by reach length and discharge before (2009) and after (2011) the project was completed.

4.1.2. Spawning Activity

In 2008 and 2009, the site hosted approximately 1% of the total number of naturally-spawning Chinook in the Snoqualmie River (Figure 9). In 2010, this number dropped to 0.3%, but climbed back to 1% in 2011.



Year:	2008	2009	2010	2011
Spawners:	2,560	895	1,788	700
Perc. redds:	1.1%	1.1%	0.03%	1.0%

Figure 9. Chinook redd locations before (2008) and after levee removal (2009-2011). The total number of natural spawners in the Snoqualmie River is listed in parentheses.

4.1.3. Spawning Habitat

Mainstem substrate texture did not appear to change as a result of the project[3] (Figure 10). Strong upstream-downstream (longitudinal) gradients in substrate diameter and variability were observed. Diameter declined by approximately 11 mm-per-mile and variability declined from RM 24 to 19.

Table 8. Longitudinal extent of optimal and suitable gravels for spawning, based on Kondolf and Wolman (1993). Gravel size (D_{50}) is estimated from linear regression models of the relationship between observed D_{50} and River Mile (RM).

Year	Optimal (D_{50} 22 mm-48 mm)			Suitable (D_{50} 11 mm-80 mm)		
	DS limit (RM)	US limit (RM)	Distance (mi)	DS limit (RM)	US limit (RM)	Distance (mi)
2008	19.9	22.3	2.4	18.9	23.8	4.9
2009	19.6	22.0	2.3	18.6	23.8	5.1
2011	20.0	22.1	2.1	19.2	23.8	4.6

[3] Levee removal began near River Mile 21.79. The downstream end of the project site, near Phase II construction was at River Mile 20.89

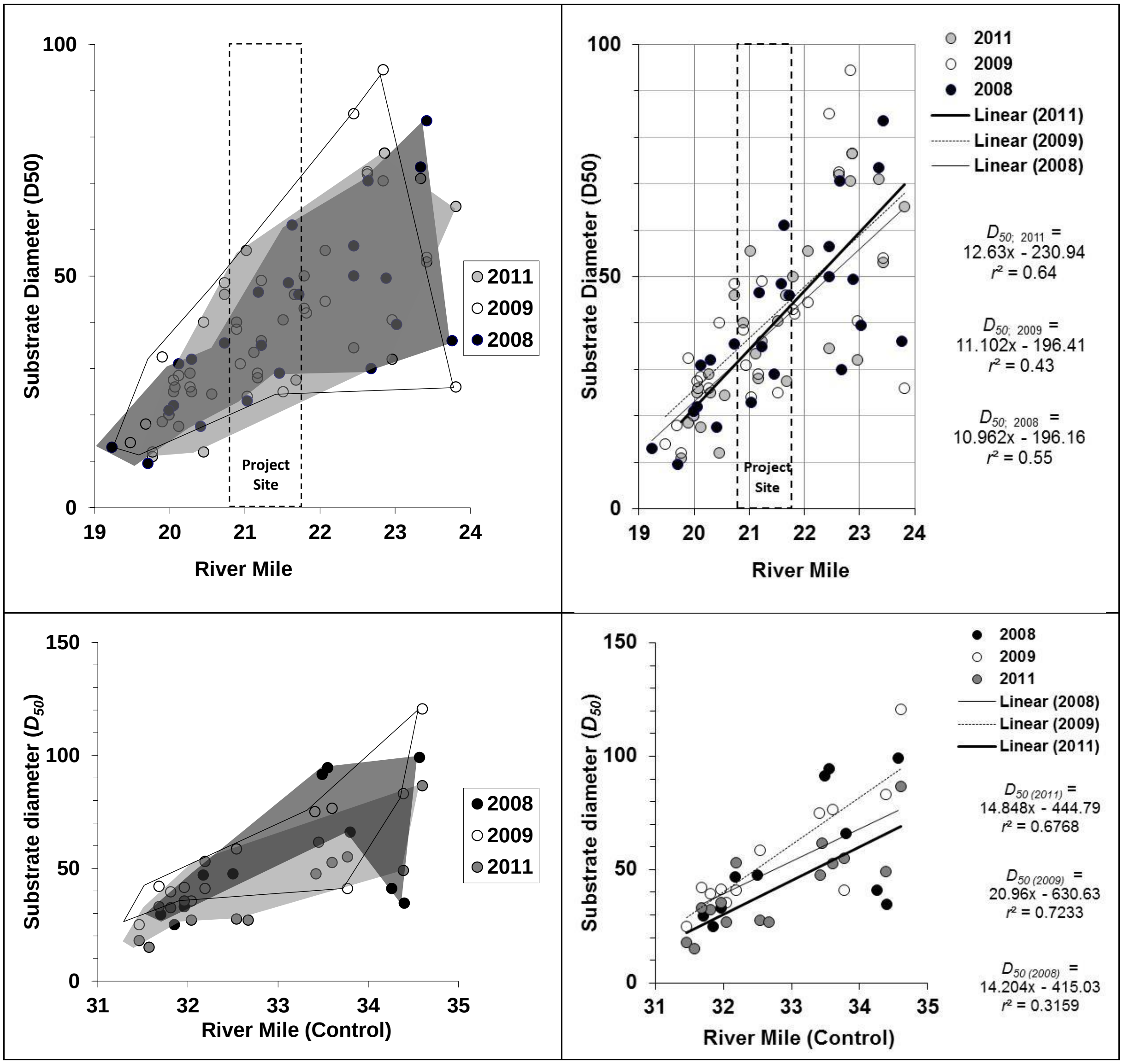
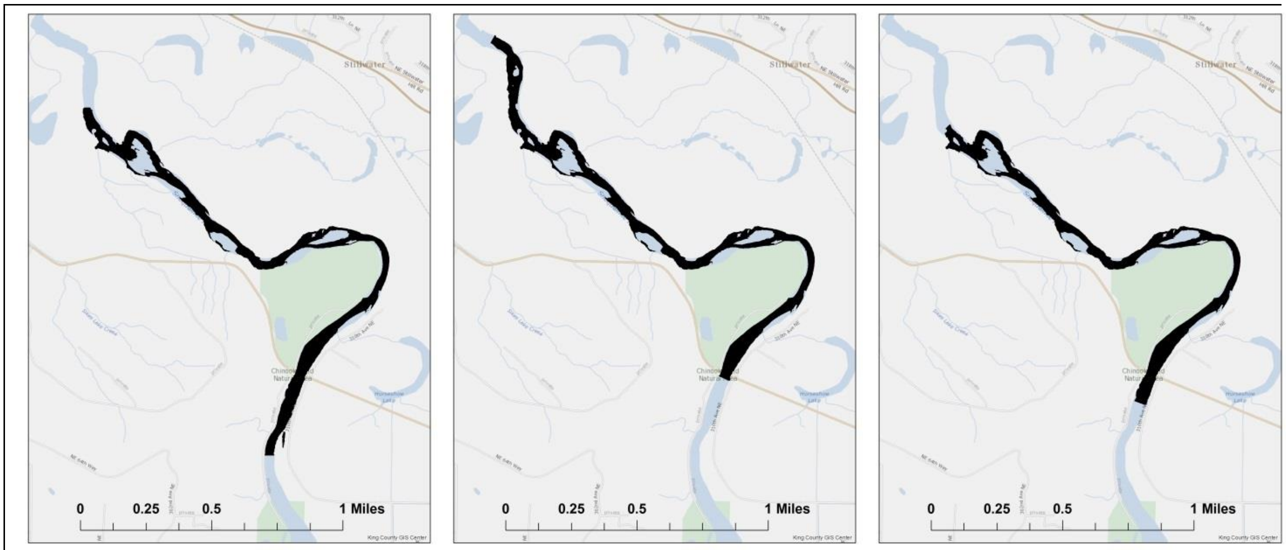


Figure 10. Longitudinal patterns in substrate size in the project reach (top panels) and the upstream control reach (bottom panels). The *x*-value in regression equations refers to river mile. Panels on the left show the median diameter of measured particles at each sampled bar by year and RM; polygons are simply visual aids to show the range of observations. Panels on the right show the same observations with the addition of linear regression models illustrating the relationship between substrate diameter and RM for each year.

Regression relationships in Figure 10 approximate the extent of optimally-sized spawning gravels for Chinook salmon (Kondolf and Wolman 1993) (Figure 11). Spawning gravels adjacent to the project site were optimal both before and after the project was completed (Table 8; Figure 11). The potential changes were slight, if any, and were upstream or downstream of the project site.



2008	2009	2011

Figure 11. Estimated extent of optimally-sized spawning gravel for Chinook salmon (22-48 mm), based on linear regression models of the relationship between D_{50} and RM.

4.2. Goal 2. Restore lateral channel migration along the left bank and restore the natural sediment transport regime.

Performance standards for channel migration and planform adjustment.	**Year 5 Status**	**Details**
2.1. Lateral channel migration will occur on the left bank.	Target met	Lateral bank erosion occurred on left bank
2.2.a. Within one to five years, channel planform in the project reach will resemble the 1936 channel.	Target not met	Only minor changes in planform
2.2.b. A chute cut-off may occur across the eastern portion of the bend. Channel splitting and wood and sediment in the existing mainstem could re-direct flow. A new mainstem may form on the west side of the constructed island.	*No target*	Outcome has not occurred
2.3. The mainstem channel will aggrade adjacent to and upstream from the site of the former levee, and form new gravel bars forcing leftward migration.	Target met	Aggradation has occurred, and gravel bars have grown; possibly contributing to right bank erosion
2.4. The channel will become wider and shallower.	Target met	Bankfull width has increased in places

4.2.1. Channel Migration

From 2009-2013, bank retreat occurred over two widely-separated locations on the left bank, and one area on the right bank, opposite the Phase II location of the project (Figure 12). At levee removal site, the bank toe moved landward an average of 37 feet over a 1,360-foot section of bank from 2009 to 2011, through a combination of excavation and river migration. In the subsequent two years, from 2011-2013, this bank toe retreated another ten feet, on average, over a 440-foot distance near the downstream end. The maximum lateral distance of bank retreat is 76 feet, measured perpendicular to flow.

Another location on the left bank exhibited retreat, as well (Figure 12). Here, the bank toe moved landward an average of 53 feet between 2009 and 2011 over a bank section 1,170 linear feet long. From 2011-2013, another 25 feet was eroded, on average, from an 830-foot section of bank at the same location. A small area of bank retreat downstream resulted from rock removal in Phase II.

4.2.2. Channel Planform

Mid-channel and point bars exhibited minor year-over-year adjustments, but there was no obvious change in either the planform or sinuosity of the wetted channel from 2009 to 2014 (Figure 13). In 2009, the primary channel was approximately 6,160 linear feet long. Secondary channels summed to 2,290 linear feet, for a total combined channel length of 8,450 feet (1.6 miles.) In 2015, the primary channel length was virtually identical: 6,200 feet. Secondary channel length increased by 650 feet in length: to 2,940 linear feet. The total combined channel length was 8,690 feet (1.6 miles); an increase of approximately 240 feet (3%).

4.2.3. Changes in Cross-sectional Form

This subsection presents changes measured from comparison of topographic and bathymetric surfaces, cross-sections, and longitudinal profiles.

4.2.3.1. Three-dimensional analyses

The area of analysis was limited to the 2011 bankfull channel (Figure 14), excluding the landward portion of the levee (41.1 acres; 16.6 hectares). Accounting for all changes in elevation, including those ≤ 1 ft (0.3048 m) a net volume of 11,000 yd^3 (8,000 m^3) of alluvium was deposited within the area of analysis from 2009 to 2011. This estimate is based on a comparison of integrated ground surface models of topography and bathymetry.

- Erosion: 38,000 yd^3 (29,000 m^3).
- Deposition: 49,000 yd^3 (37,000 m^3)

When only elevation changes greater than one foot (30.5 cm) are included deposition and erosion from 2009 to 2011 within the project reach were essentially in equilibrium, differing by approximately 200 yd^3 (153 m^3); a quantity ostensibly within the margin of error.

- Deposition: 21,700 yd^3 (16,600 m^3)
- Erosion: 21,500 yd^3 (16,500 m^3)

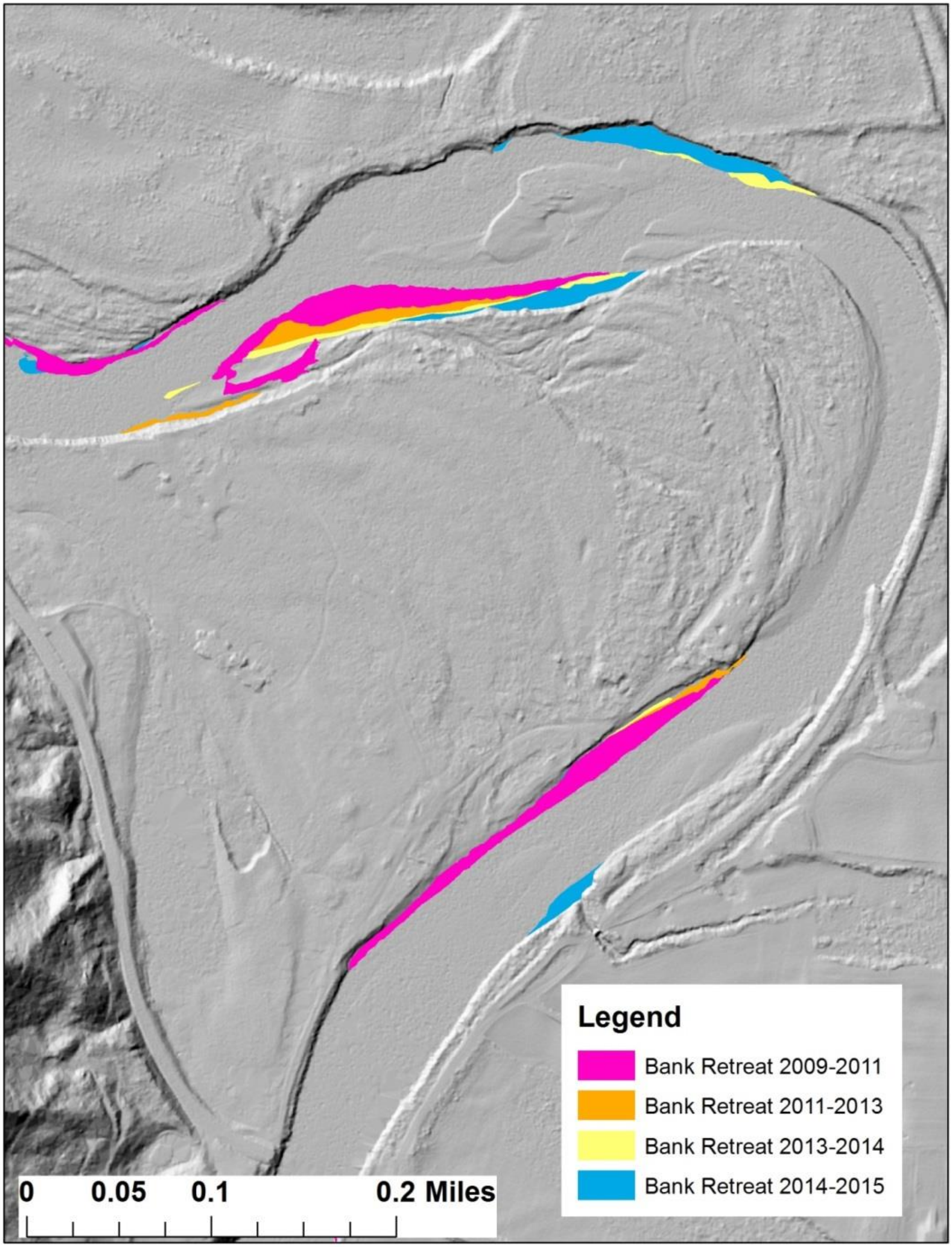


Figure 12. Bank retreat from 2009 to 2015. Hillshade is from 2015.

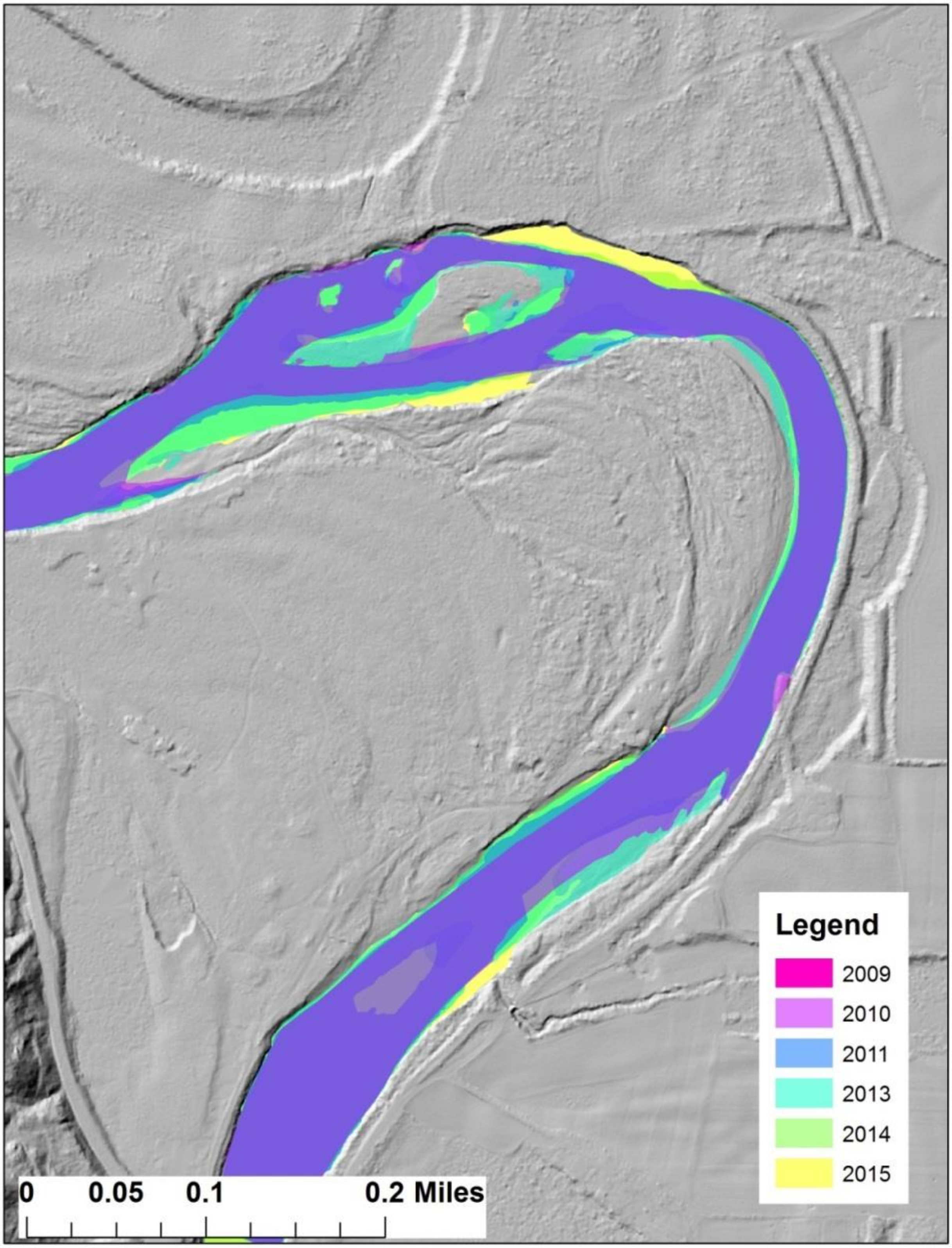


Figure 13. Changes in channel planform, 2009-2015. Hillshade is based on 2015 elevations.

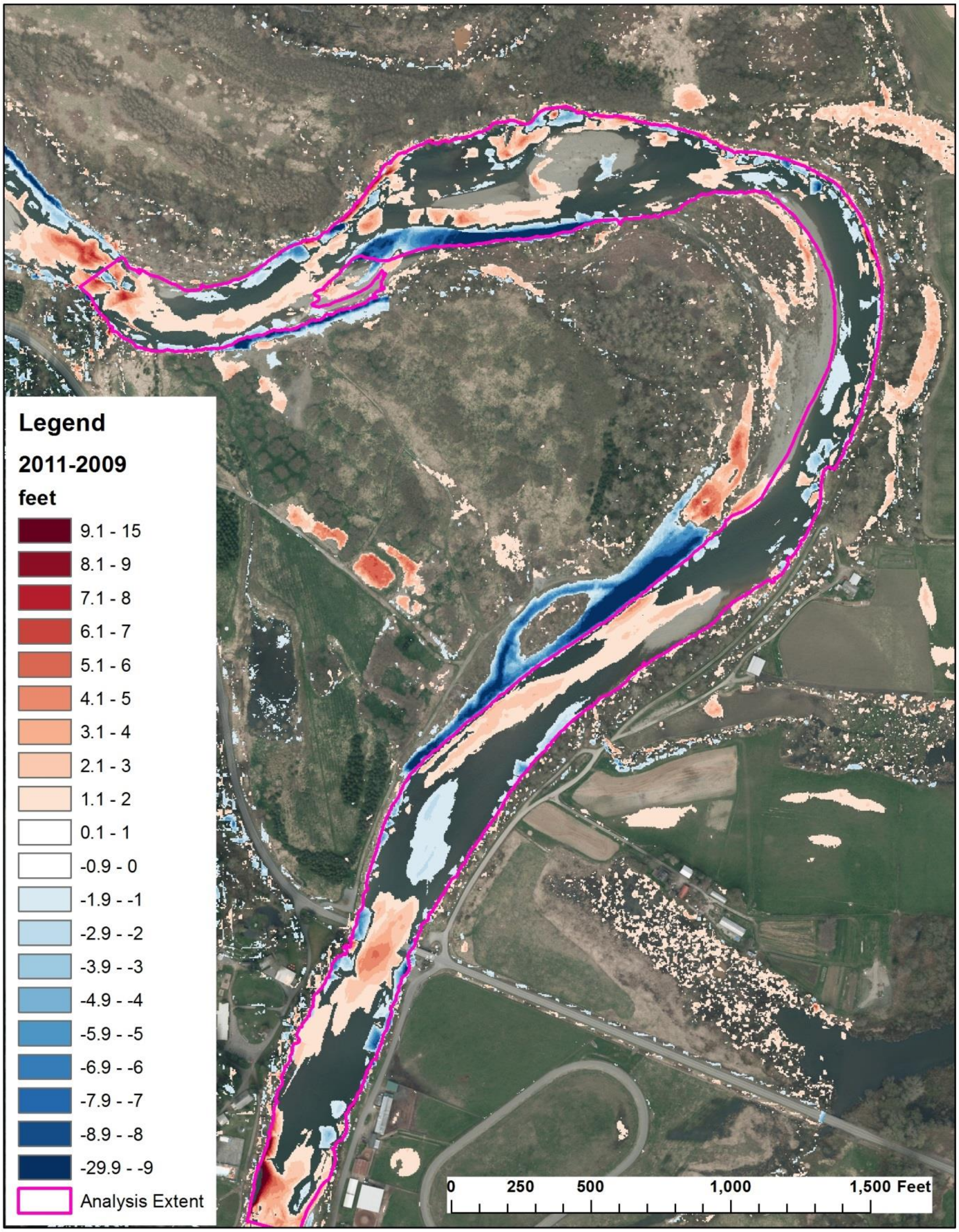


Figure 14. Map of erosion and deposition within the wetted and unvegetated channel and floodplain from 2009-2011.

4.2.3.2. Two-dimensional analyses

Cross-section based analyses were performed at 131 cross sections (Figure 15), which was a subset of the full extent of bathymetric survey in 2009 and 2011 (Figure 16).

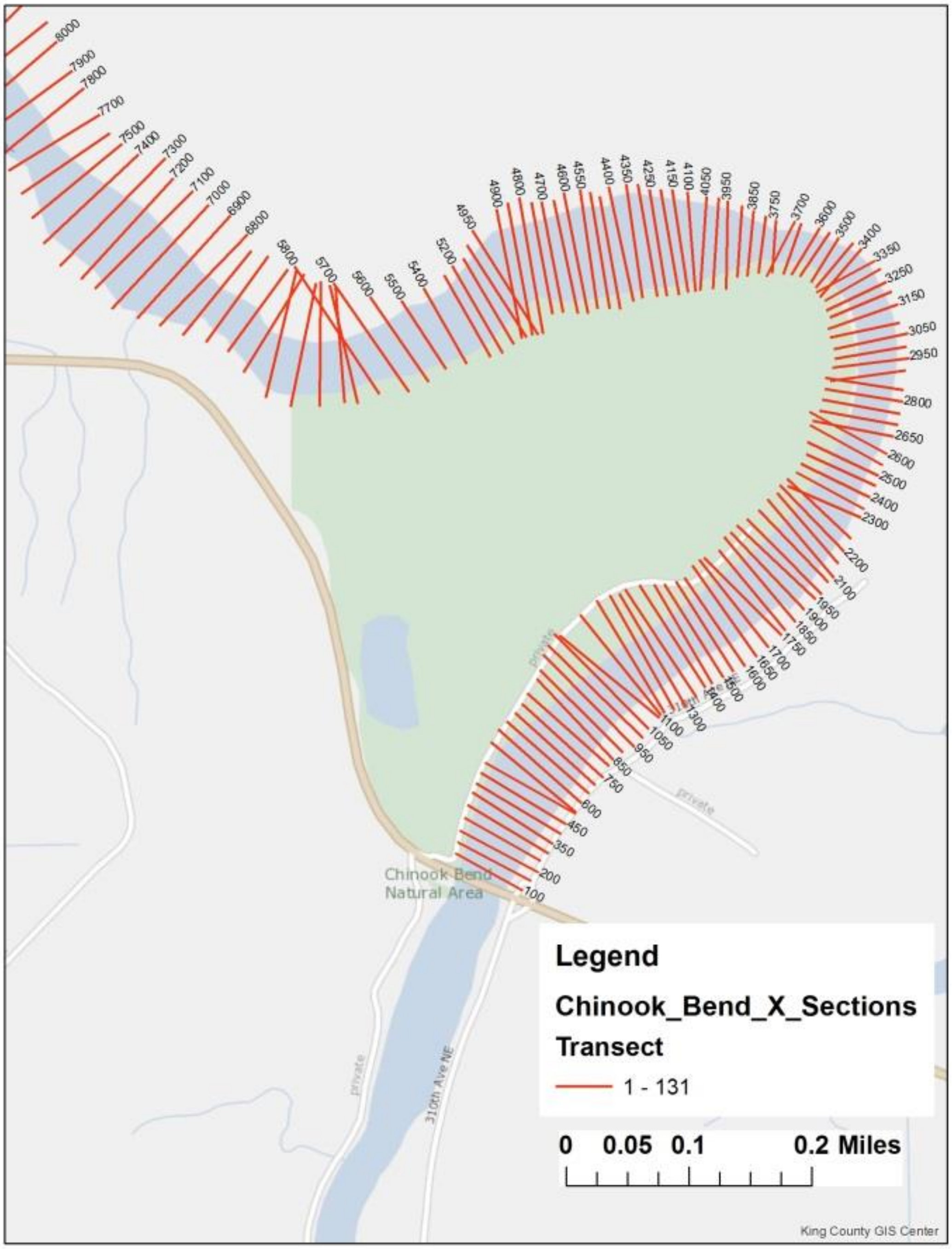


Figure 15. Cross-sections used in change analysis at the project site.

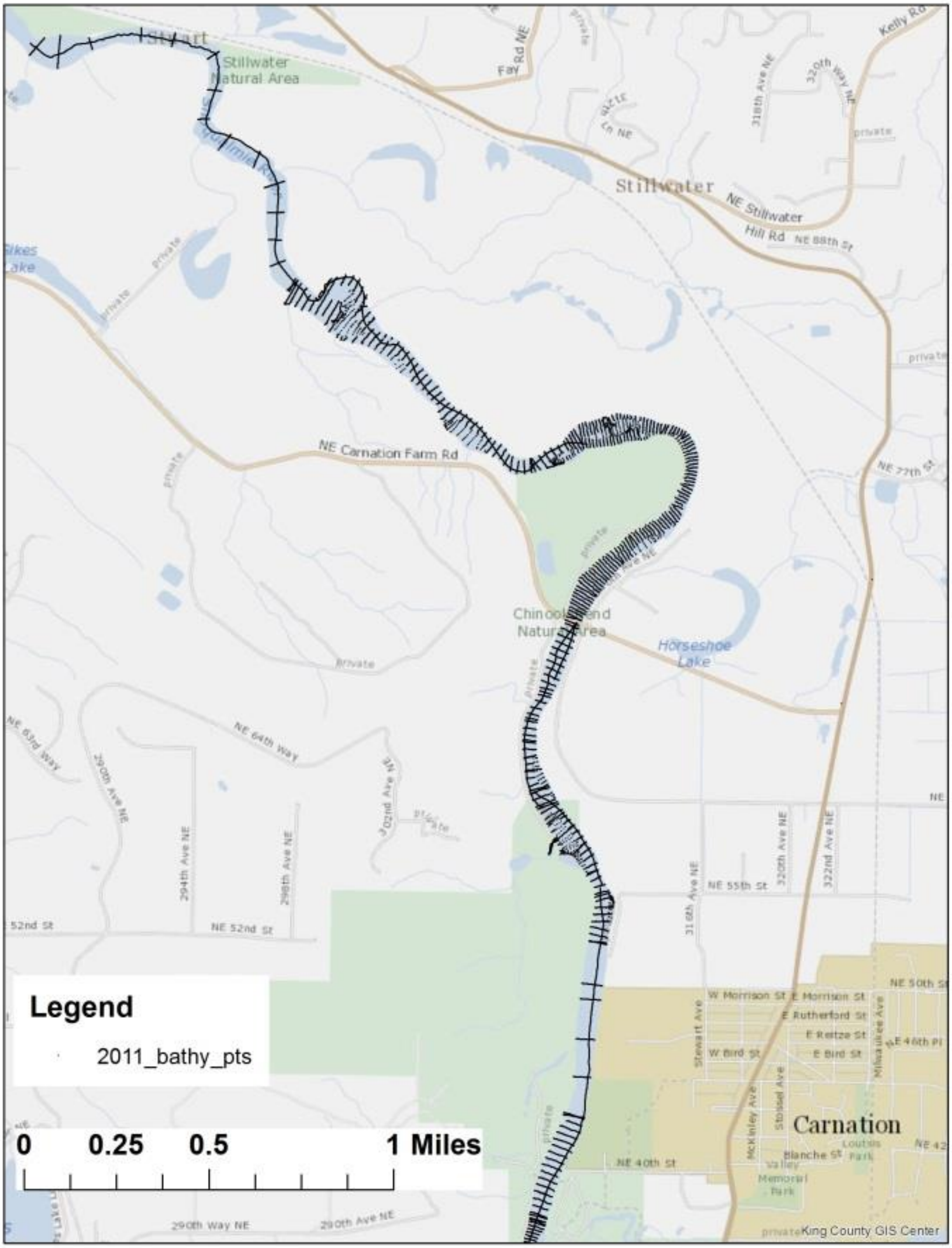


Figure 16. Cross-sections used for analysis at the reach-scale.

4.2.3.3. Bankfull channel width

Bankfull channel width exhibited localized changes near the levee removal site, attributable to both earthwork and channel adjustments (Figure 17). No change was observed in the mean bankfull channel width from 2009 to 2011.

- 2009 average: 371 ft (±16; 95%CI) or 113 m (±5; 95%CI)
- 2011 average: 374 ft (±17; 95%CI) or 114 m (±5; 95%CI)

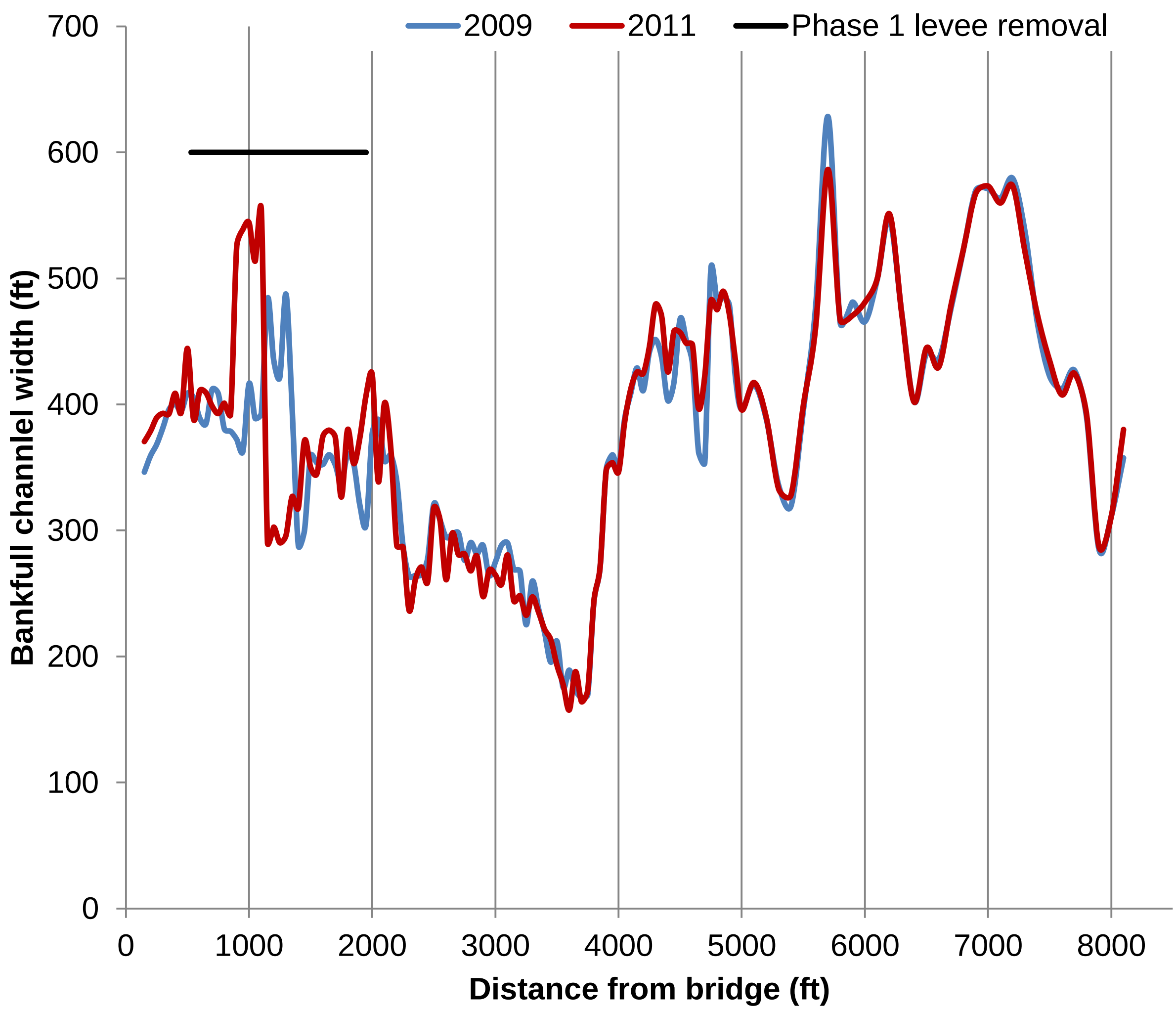


Figure 17. Longitudinal patterns of change in bankfull channel width, 2009-2011.

4.2.3.4. Bankfull channel depth

Bankfull channel depth exhibited more change than channel width (Figure 18), decreasing in an area between 700-1800 feet (210-550 m) downstream from the Stossel bridge. Depth increased in the section downstream from the levee removal site beyond 1800 feet (550 m) downstream from the bridge, to approximately 3600 feet (1100 m). Even so, no change was observed in the mean bankfull channel depth from 2009 to 2011.

- 2009 average: 11 ft (±0.4; 95%CI) or 3.4 m (±0.1; 95%CI)
- 2011 average: 11 ft (±0.4; 95%CI) or 3.4 m (±0.1; 95%CI)

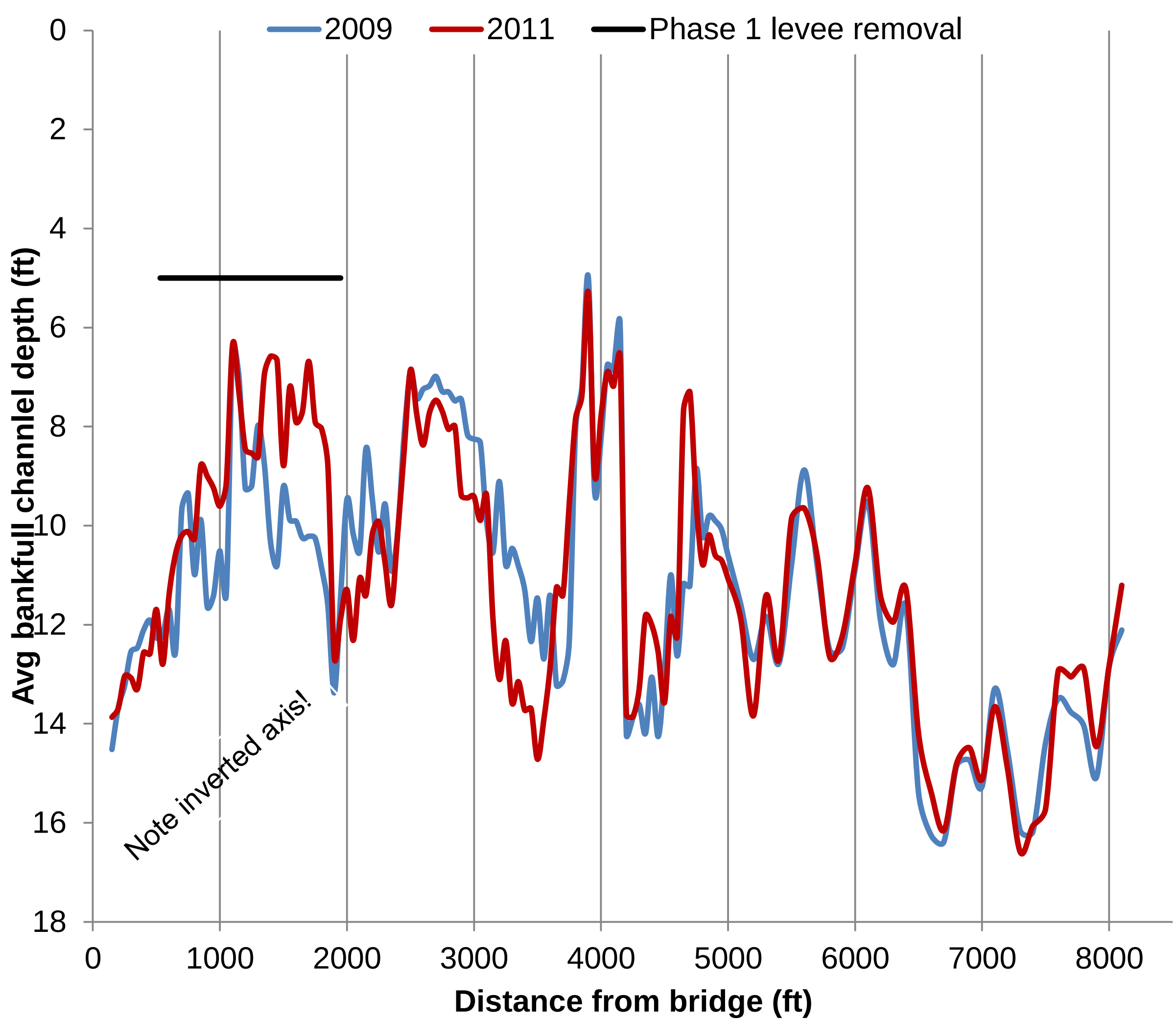


Figure 18. Longitudinal patterns of change in bankfull depth, 2009-2011.

4.2.3.5. Bankfull channel cross-sectional area

Bankfull cross-sectional area exhibited localized changes in the vicinity of the levee removal site (Figure 19). Channel cross-section area decreased in places located between 1000-1800 feet (305-550 m) downstream from the Stossel Bridge. Small increases in cross-sectional area were observed approximately 2000 feet (610 m) and 3200 feet (975 m) downstream from the bridge. Similar to bankfull depth, no change was observed in the mean cross-sectional area from 2009 to 2011.

- 2009 average: 4,162 ft^2 (±280; 95%CI) or 387 m^2 (±26; 95%CI)
- 2011 average: 4,125 ft^2 (±286; 95%CI) or 383 m^2 (±27; 95%CI)

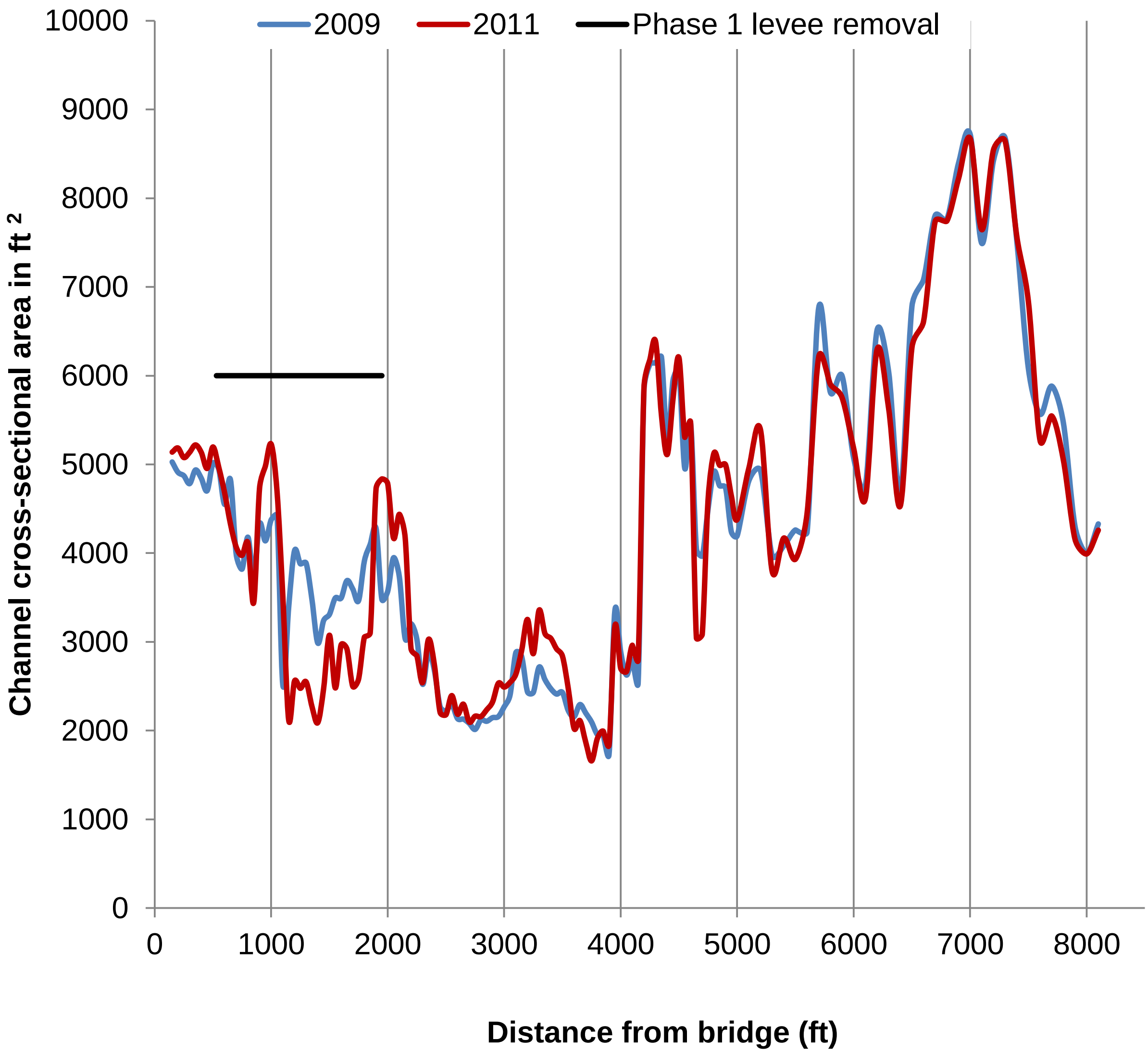


Figure 19. Longitudinal patterns of change in channel cross-sectional area, 2009-2011.

4.2.3.6. Thalweg elevation

Thalweg elevation exhibited localized increases in the vicinity of the levee removal site (Figure 20), but only very small changes were observed downstream. No change was observed in the mean thalweg elevation from 2009 to 2011 in the area of analysis.

- 2009 average: 36.5 ft (±0.8; 95%CI) or 11.1 m (±0.2; 95%CI)
- 2011 average: 36.8 ft (±0.9; 95%CI) or 11.2 m^2 (±0.3; 95%CI)

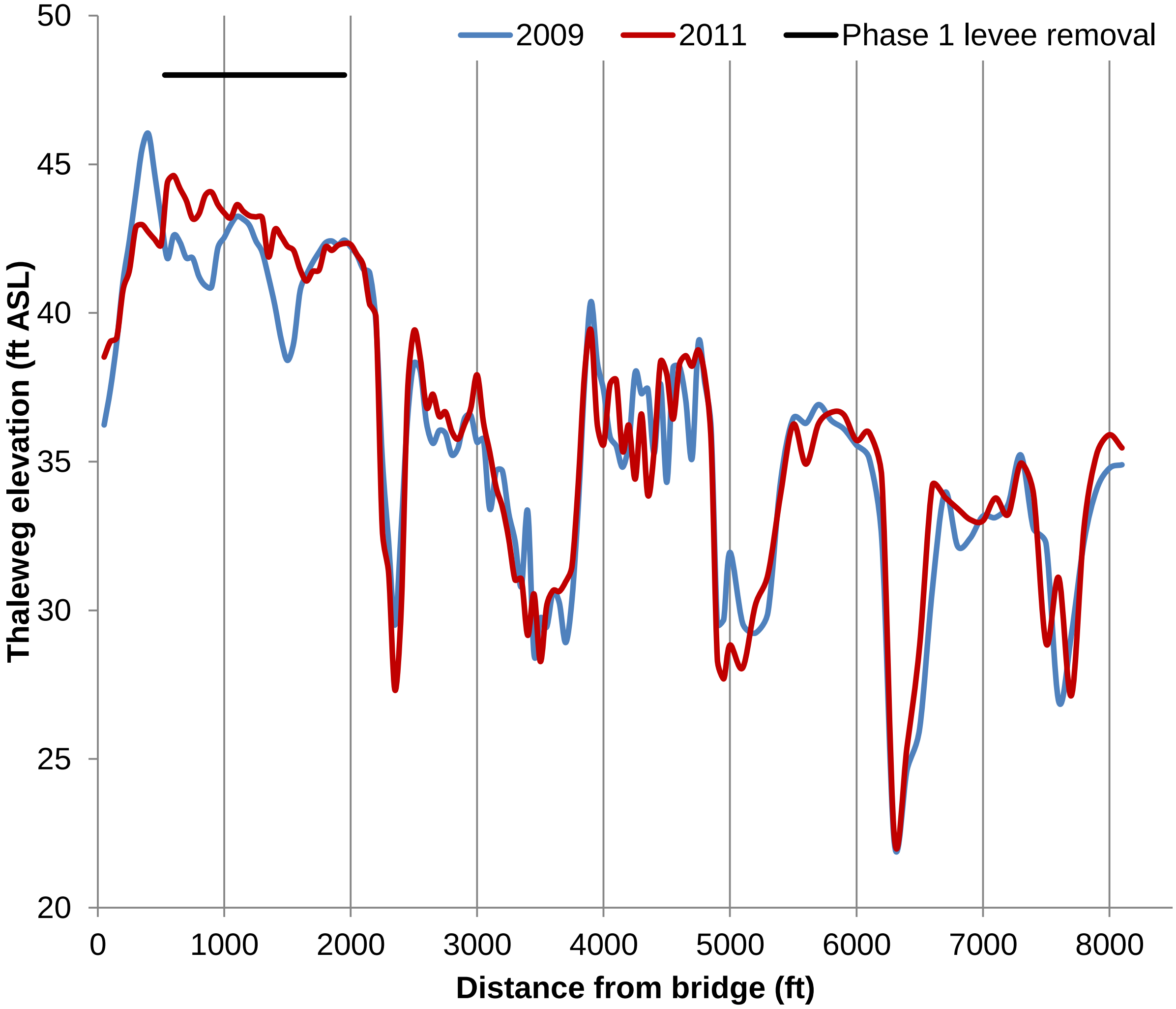


Figure 20. Longitudinal patterns of change in thalweg elevation, 2009-2011.

4.3. Goal 3. Restore channel and floodplain hydraulics and connectivity.

Performance standards for floodplain connectivity	Year 5 Status	Details
3.1. Floodplain behind levee will be inundated at 10-15,000 cfs at USGS Carnation gage.	Target met	Water began flowing into the low swale at approximately 13,000 cfs.

Overbank flooding in the project site was abruptly increased by levee removal, as expected. Prior to levee removal, the site was backwatered from downstream during floods, beginning at approximately 20,000-23,000 cfs (at USGS 12149000; Snoqualmie at Carnation). This discharge level is a 1.25 to 1.50-year flood. The levee overtopped between 30,000 and 40,000 cfs, slightly less than a five-year flood. After the levee was removed, backwatering was unchanged, but water began flowing overbank into the low swale at downstream across the low swale at 13,300 cfs (a 1.01 to <1.25-year RI event), as verified by time-lapse video from the swale (Figure 21). Maximum daily discharge has exceeded 13,300 cfs on approximately 3% of the all days since October 1, 2009. On January 5th, 2015, water was flowing through the swale at depths >1-2 ft during discharge levels of approximately 17,400 cfs.

13,100 cfs	
13,300 cfs Onset of overbank flow	

Figure 21. Time-lapse images of the onset of overbank flow after levee removal. Footage is from March 13, 2013 on the ascending limb of a high-water event.

Once discharge reaches a 1.5-year flood level (24.000-25,000 cfs; Figure 23), floodwaters are flowing across the swale, and inundating a large portion of the floodplain. Photopoint comparisons illustrate how this alteration increased the extent and depth of floodwaters in the swale during frequently-experienced discharges (Figure 22 and Figure 24).

BEFORE LEVEE REMOVAL: 24,100 cfs (January 7th, 2009); ascending limb. Swale is probably backwatered from downstream.	
AFTER LEVEE REMOVAL: 24,000 cfs (December 14, 2010); descending limb. Swale is flowing.	

Figure 22. Comparison of floodplain connectivity before and after levee removal. Photopoint 6.

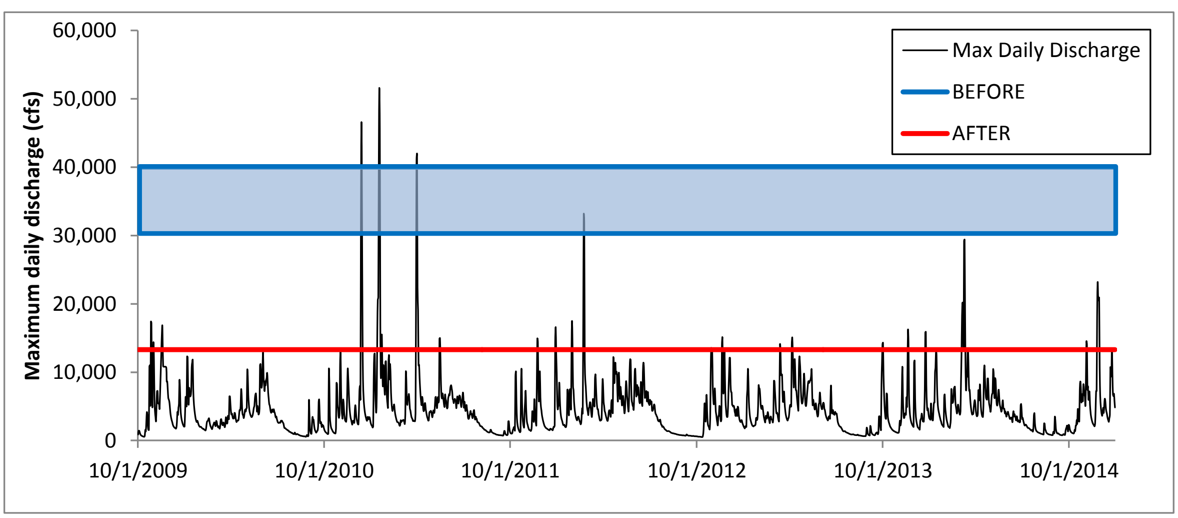


Figure 23. Hydrograph showing maximum daily discharge for the period after project completion in 2009. The blue box indicates the approximate discharge levels at which overbank flows began before the levee was removed. The red line indicates the onset of overbank flows after levee removal.

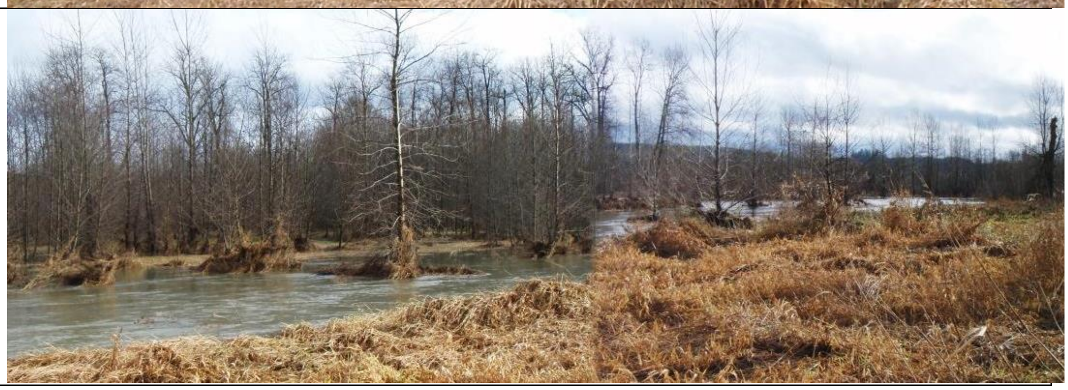
BEFORE: 24,400 cfs (January 7th, 2009); ascending limb. backwatered from downstream.	
AFTER LEVEE REMOVAL: 23,800 cfs (December 14, 2010); descending limb. Swale is flowing from upstream to downstream.	

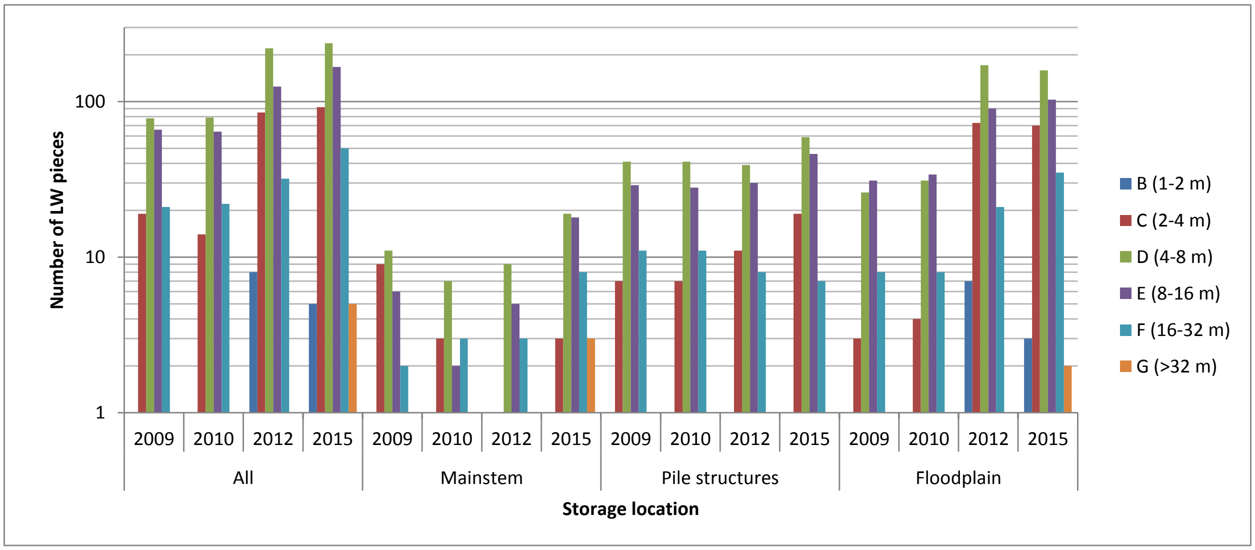
Figure 24. Comparison of floodplain connectivity before and after levee removal. Photopoint 7 Southeast.

4.4. Goal 4. Increase large wood recruitment and accumulation.

Performance standards for large wood recruitment and accumulation	Year 5 Status	Details
4.1. Substantial accumulations of wood will form along river margins and in the floodplain via trapping on existing vegetation, the constructed island, and new gravel bars and islands.	Target met	Large wood storage increased by 202% by 2015, mostly in the floodplain.
4.2. Mature cottonwood trees will be undercut on-site and be retained within the project reach, forming bar-apex jams over time.	Target met	Erosion undercut 0.55 acres of mature forest and recruited 13-27 large cottonwood trees to the river.
4.3 Placed wood structures will trap floating wood during overbank flows to moderate channel migration.	Target partially met	Wood accumulations on the structures increased 50%. Too soon to determine whether channel migration is moderated

4.4.1. Large wood accumulation

Total large wood storage increased by approximately 200% from 2009 to 2015 (Table 9, Figure 25), as wood was trapped in the floodplain (Figure 26). Results of 'as-built' large wood surveys in 2009 identified a total of 184 pieces in the channel, floodplain, and in installed pile structures, over a 6,100-foot (1,859 meter) reach (Table 9); approximately three pieces per 100 feet of river (9.9 pieces per 100 m). Most (78%) pieces were in length classes D and E (4-16 meters long, respectively); only 11% were in the F-G length classes (32 meters and >32 meters, respectively). Smaller pieces were abundant, but underrepresented in orthoimagery-based counts. Post-project surveys in 2015 identified a total of 556 pieces over the same reach (Table 9), which equated to nine pieces per 100 feet (30 pieces per 100 m). Increases were observed in all length classes, but the largest increases were in the number of pieces in the two to eight-meter length classes (Figure 25).



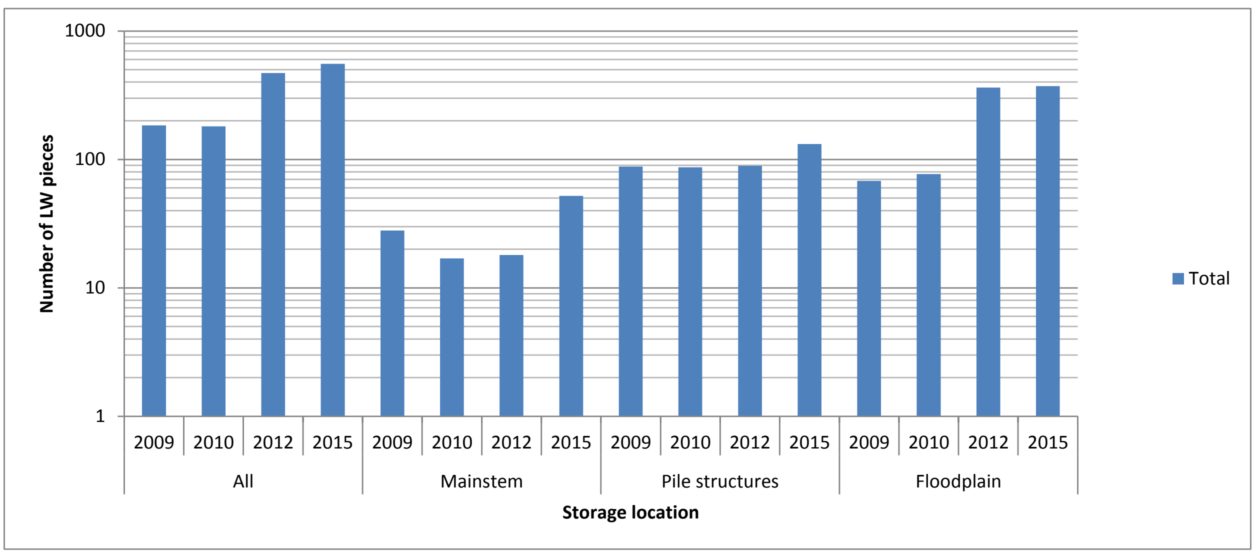


Figure 25. Large wood quantities by length classes, 2009-2015.

A large flood in January 2015 deposited several long pieces of wood (Figure 25). Year-over-year increases were observed in all size classes over two meters in length, suggesting project has increased wood trapping and retention.

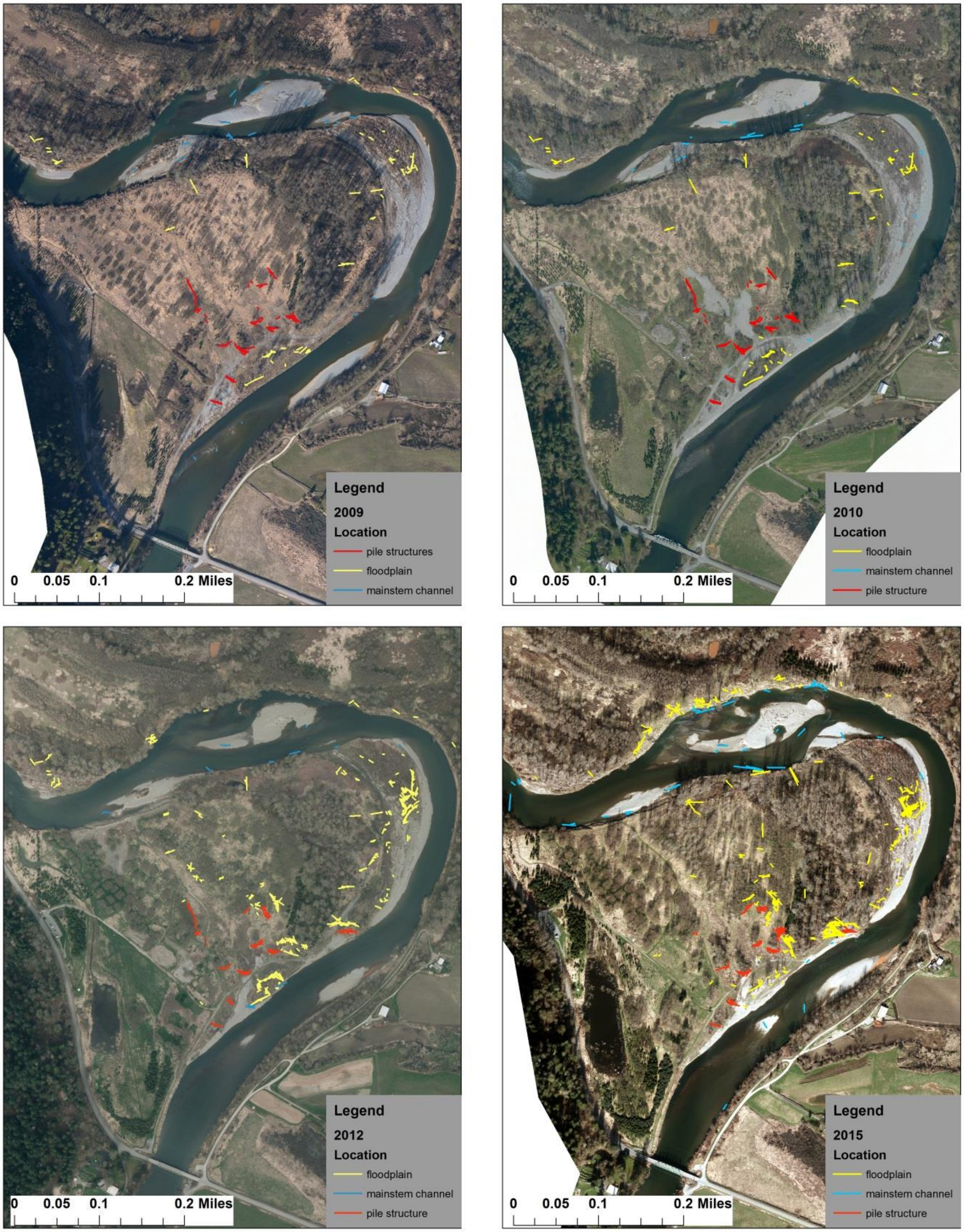


Figure 26. Oblique aerial photos of changes in large wood accumulations at the Chinook Bend project site (2009-2015).

Table 9. Large wood storage in the mainstem channel, pile structures, and floodplain of the 6,100-foot long Chinook Bend reach, using the alphanumeric coding by Montgomery (2008).

	Mainstem channel				Pile structures (not including piles)				Floodplain				Total					
Length Class	**2009**	**2010**	**2012**	**2015**	**2009**	**2010**	**2012**	**2015**	**2009**	**2010**	**2012**	**2015**	**2009**	**2010**	**2012**	**2015**	**Change**	**Perc. Change**
B	0	1	0	1	0	0	1	1	0	0	7	3	0	1	8	5	**5**	
C	9	3	1	3	7	7	11	19	3	4	73	3	19	14	85	92	**73**	**384%**
D	11	7	9	19	41	41	39	59	26	31	171	70	78	79	220	237	**159**	**204%**
E	6	2	5	18	29	28	30	46	31	34	90	159	66	64	125	167	**101**	**153%**
F	2	3	3	8	11	11	8	7	8	8	21	103	21	22	32	50	**29**	**138%**
G	0	1	0	3	0	0	0	0	0	0	1	35	0	1	1	5	**5**	
Subtotal	28	17	18	52	88	87	89	132	68	77	363	2	184	181	471	556	**372**	**+202%**
Change	**24**				**44**				**304**				**372**					
Percent Change	**+86%**				**+50%**				**+447%**				**+202%**					

Table 10. Comparison of observed wood quantities with guidelines from either ‘properly functioning condition’ (NMFS) or the 75^{th} percentile of large wood quantities observed in unmanaged rivers of comparable size (Fox and Bolton 2007).

Source	LW minimum size criteria	Qualifying size classes in this study (approx.)	Observed value in 2015 (approx.) MAINSTEM	Observed value in 2015 (approx.) IN ALL LOCATIONS	Guidelines or targets	Percent achieved	Additional pieces needed in to reach standard at 6100-foot (1859-m) (MAINSTEM ONLY)
National Marine Fisheries Service	15.2 m long and 0.6 m in diameter (50 ft x 24 in)	E-G	25 per mile	192 per mile	>80 per mile	31%	63
Fox and Bolton (2007)	2 m long and 10 cm in diameter (6.6 ft x 4 in)	All except B class	3 per 100 m (328 ft)	34 per 100 m (328 ft)	>206 per 100 m (75^{th} centile)	1%	3,774
					106 per 100 m (median)	3%	1,915
	Key pieces where bankfull width >50 m (164 ft); key piece volume is 10.75 m^3 (14.1 yd^3)	G	0.006 per 100 m (328 ft)	0.03 per 100 m (328 ft)	>4 (75^{th} percentile)	<1%	74
					1.3 (median)	<1%	74

Existing quantities of wood are below guidelines (Table 10). Current wood storage is approximately 3% of the median levels of large wood and <1% of the key pieces observed in comparably-sized, reference rivers of Washington State (Table 10). Nearly two-thousand additional pieces (≥ 2 m long and ≥ 10 cm diameter or 6.6 ft long and 3.9 in diameter), including 74 key pieces, would have to accumulate in the project reach to attain the median level reported by Fox and Bolton (2007)[4].

4.4.2. Large wood recruitment from on-site

Cottonwood dominated both plots, composing 83-86% of all stems, so other species were excluded from this analysis, for simplicity. Cottonwood stem density ranged from 23 to 49 per acre. A height-diameter relationship was established for cottonwood from the field data collected during a 2007 study of riparian forest structure on the Green River (Figure 27; from Latterell 2008). This relationship was used to estimate the height of trees surveyed in the study plot on the basis of their diameter. Wood volume was then calculated as a circular truncated cone with a small end diameter of 10 cm and the large end corresponding to the DBH.

From 2009 to 2015, approximately 24,000 square feet (0.55 acres or 0.22 hectares) of cottonwood-dominated forest was eroded from the left bank. This eroded area was well-downstream from the levee removal project, however, and may be coincidental rather than a project outcome. The eroded forest area resembled the study plots in age, structure and composition; dominant trees were approximately 150-foot tall cottonwoods.

Accordingly, forest erosion eroded forest is estimated to have delivered 13 - 27 cottonwood trees to the river. To characterize the likely total volume of trees entering the river, all measured trees were pooled and a random sample of 13-27 trees was drawn 10 times. For each random draw, the total volume was summed and the average was calculated across the ten runs.

Accordingly, the total volume of large wood entering the site from localized bank erosion from 2009-2015 was estimated to be 1,700-3,600 cubic feet (48-102 cubic meters), or roughly 300 to 600 cubic feet (9-17 cubic meters) per year; a volume equivalent to one or two mature cottonwood trees.

4.4.3. Function of placed wood

The primary functions currently being performed by the large wood at the projects site include: wood trapping and flow splitting at high discharge levels. Relatively few pieces provide fish cover except during overbank flows into the floodplain.

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[4] Fox and Bolton (2007) recommend attainment of the 75th percentile at restoration sites to help account for shortfalls elsewhere in a managed river.

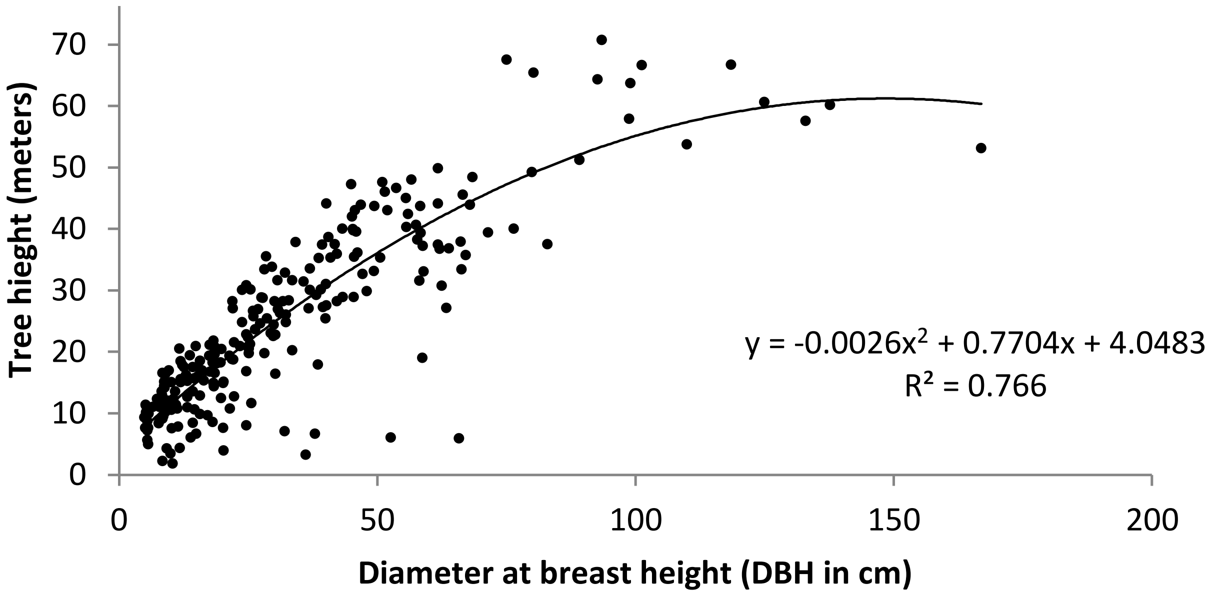


Figure 27. Relationship between height and diameter for black cottonwood from Latterell (2008).

Even so, large wood storage has increased from at least 88 pieces in 2009, immediately after construction, to 132 pieces in 2015. Nearly all of the additional pieces visible in orthoimagery appeared onsite between 2012 and 2015, and can be attributed to the January flood of 2015, which caused overbank flow and wood transport (J. Latterell and D. Eastman, *pers. obs*.). In 2009, the large wood in the pile structures composed 48% of the total in the project area. By 2015, this percentage declined to 24%, but not because of losses from the structures. Rather, this shift in the relative distribution was the result of increased storage in the floodplain.

4.5. Goal 5. Restore a diverse riparian corridor of native plants.

Performance standards for riparian plantings	**Year 5 Status**	**Details**
5.1. The area of forested pioneer bars will increase within the project reach.	Target unmet	No new pioneer bars formed yet
5.2. Planted areas will not be dominated by reed canarygrass, blackberry or knotweed.	Target met	Knotweed area declined from 2.9 acres to 0.45 acres

4.5.1. Pioneer Bars

The height of trees on existing pioneer bars increased substantially (i.e., by more than 30 feet in some cases), but no new pioneer bar areas formed in the project site from 2009 to 2015.

4.5.2. Invasive Weeds

Knotweed covered approximately 2.9 acres during baseline conditions in 2007/2009. knotweed control efforts reduced knotweed on the left bank to 0.45 acres in 2015;. Virtually all the remaining knotweed was on the vegetated island at the apex of Chinook Bend, which probably was mistakenly not treated. Treatment is ongoing.

4.6. Goal 6. Do not increase the risk to public infrastructure or private property from flooding or bank erosion.

Performance standards for flooding and erosion risks.	Year 5 Status	Details
6.1. Neither the water surface elevation during flood events nor the overbank flood frequency on the right bank will increase.	Target met	No concerns or occurrences with maximum flows during the monitoring period in excess of 40-50 thousand cubic feet per second.
6.2. The project will not contribute to bank erosion downstream of the project site, excluding the first ¼-mile.	Target partially met	No project-related erosion on private property downstream. However, unforeseen right bank erosion has been detected and is being actively monitored
6.3. Fewer than three feet of scour will occur in the channel bed underneath Stossel Bridge.	Target met	Area beneath the bridge has been mostly depositional
6.4. The left bank revetment continues to protect the bridge, the road, and the constructed wetland from erosion.	Target met	No damage to bridge, road, or constructed wetland
6.5. The buried setback revetment prevents erosion to the Carnation Farm Road.	Target met	No damage to road

4.6.1. Off-site flooding

No problems with off-site flooding have been reported or observed.

4.6.2. Off-site bank erosion

Off-site erosion occurred in several places, but only one was potentially problematic (Figure 28): three unarmored locations on the right bank; a mid-channel bar; along the left bank upstream. The problematic erosion occurred on the right bank opposite the former levee (Figure 29) in the 2015 water year. It may result from medial bar growth and a corresponding shift in the thalweg. The eroded area was 600 feet long and approximately 50 feet wide, at maximum. It was reported to the River and Floodplain Management Section for evaluation and response.

4.6.3. Bridge scour

No bridge scour has been observed.

4.6.4. Left bank infrastructure

No damage to left bank infrastructure has been sustained.

4.6.5. Buried setback function

The buried setback revetment has not launched, as it has not been contacted by the river.

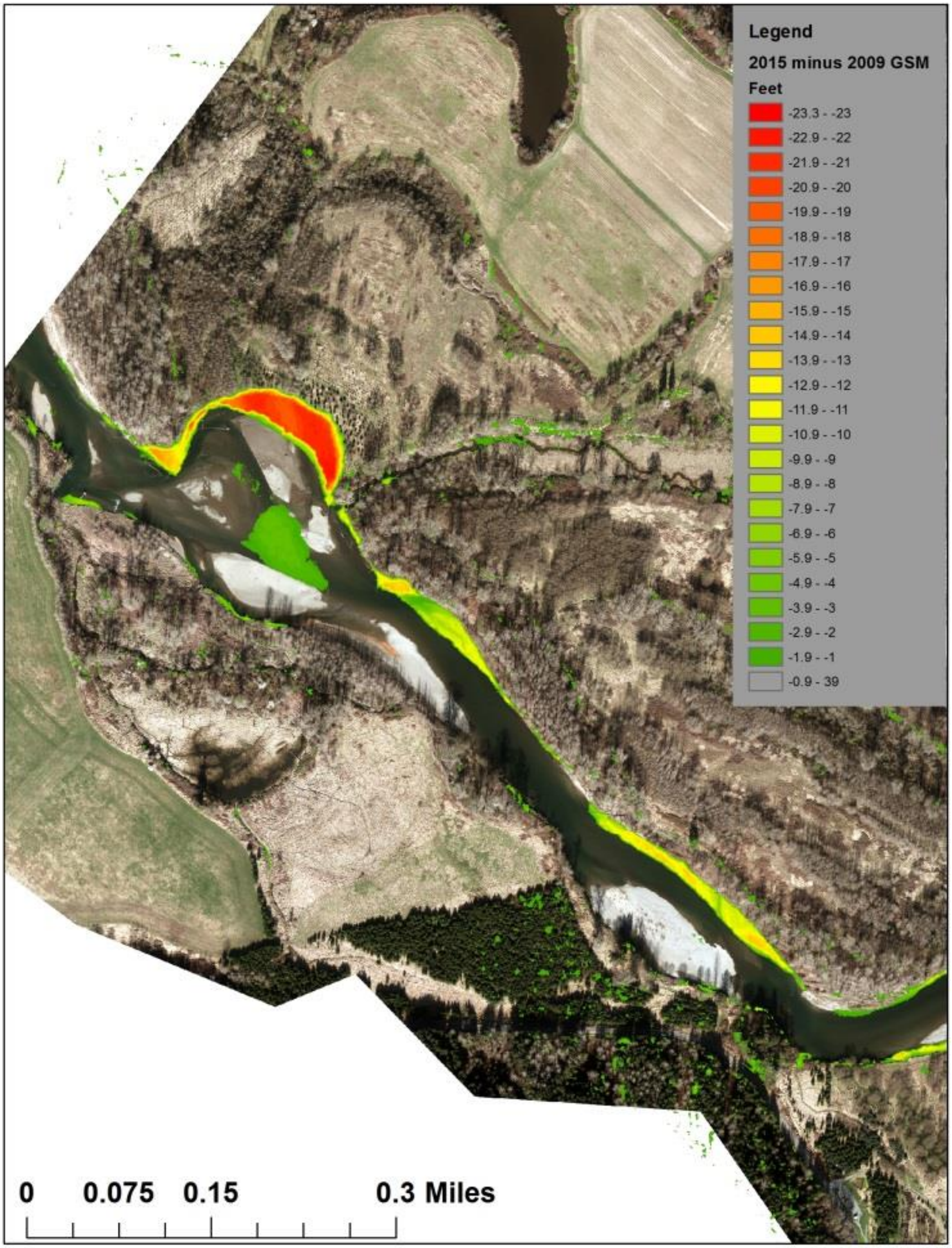


Figure 28. Areas eroded (or in some cases excavated and eroded) between 2009 and 2015.

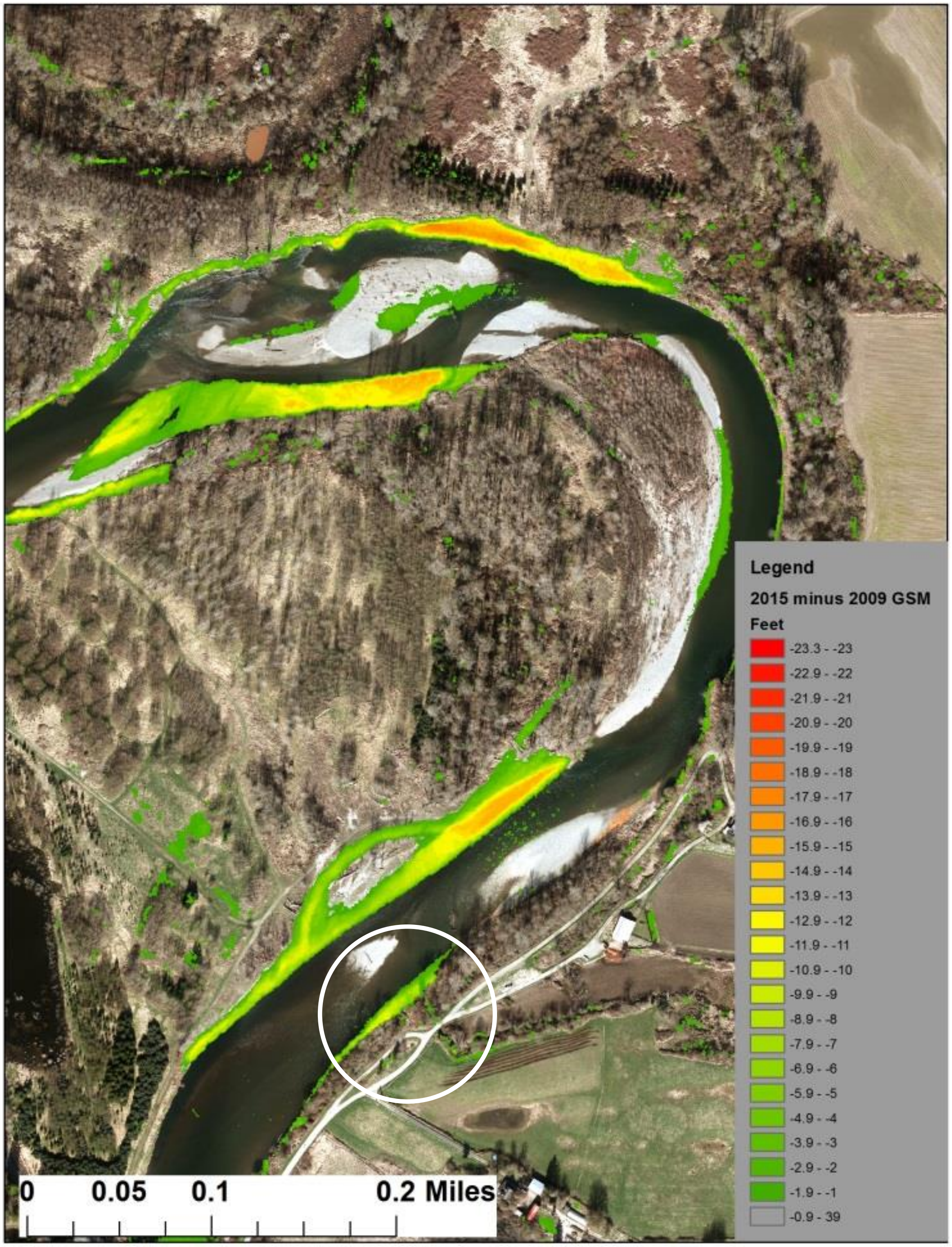


Figure 29. Areas eroded (or in some cases excavated and eroded) between 2009 and 2015. Note right bank erosion in circled area. This graphic differs from Figure 14 by showing the results over a larger analysis extent, rather than being confined to the 2009 active channel.

4.7. Goal 7. Maintain the current level of recreational opportunities available to the public.

Performance standards for recreational safety	Year 5 Status	Details
7.1. The project reach is navigable, at least by experienced boaters.	Target Met	The reach is navigable

Safely navigation of the project reach is facilitated by multiple channels with few obstructions (Figure 31). Two wood accumulations have formed near the apex of the meander (Figure 30). A small wood accumulation was present on the left bank, prior to the project. By 2015, a new, larger wood accumulation formed along that bank. Even so, river users could navigate through an 80-foot-wide opening, or choose to float the north channel split.

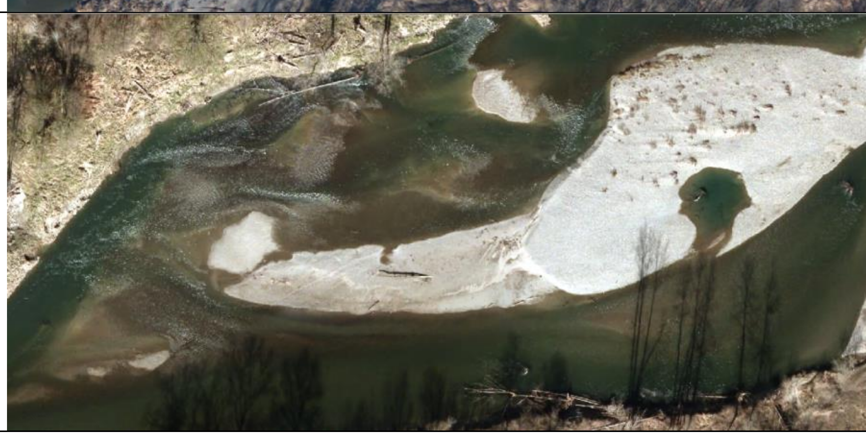
Before	
After (2015)	

Figure 30. Comparison of large wood accumulations before and after the Chinook Bend project. A single tree has fallen into the channel near the upstream end of the project site. This tree apparently originated from erosion on the adjacent right bank. It is pointing downstream and allows for easy navigation to the left of the log.

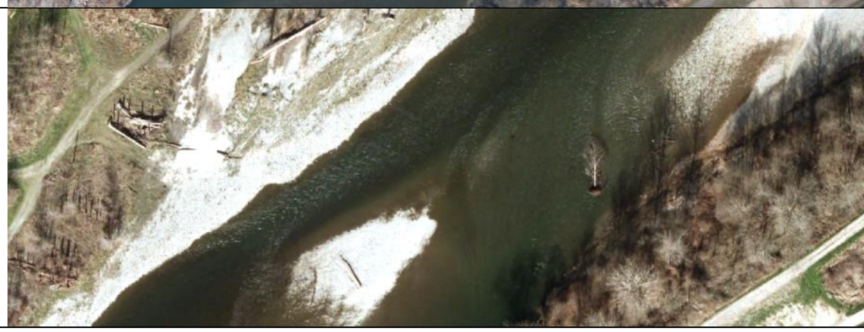
Before (2009)	
After (2015)	

Figure 31. Comparison of large wood accumulations before and after the Chinoook Bend Project.

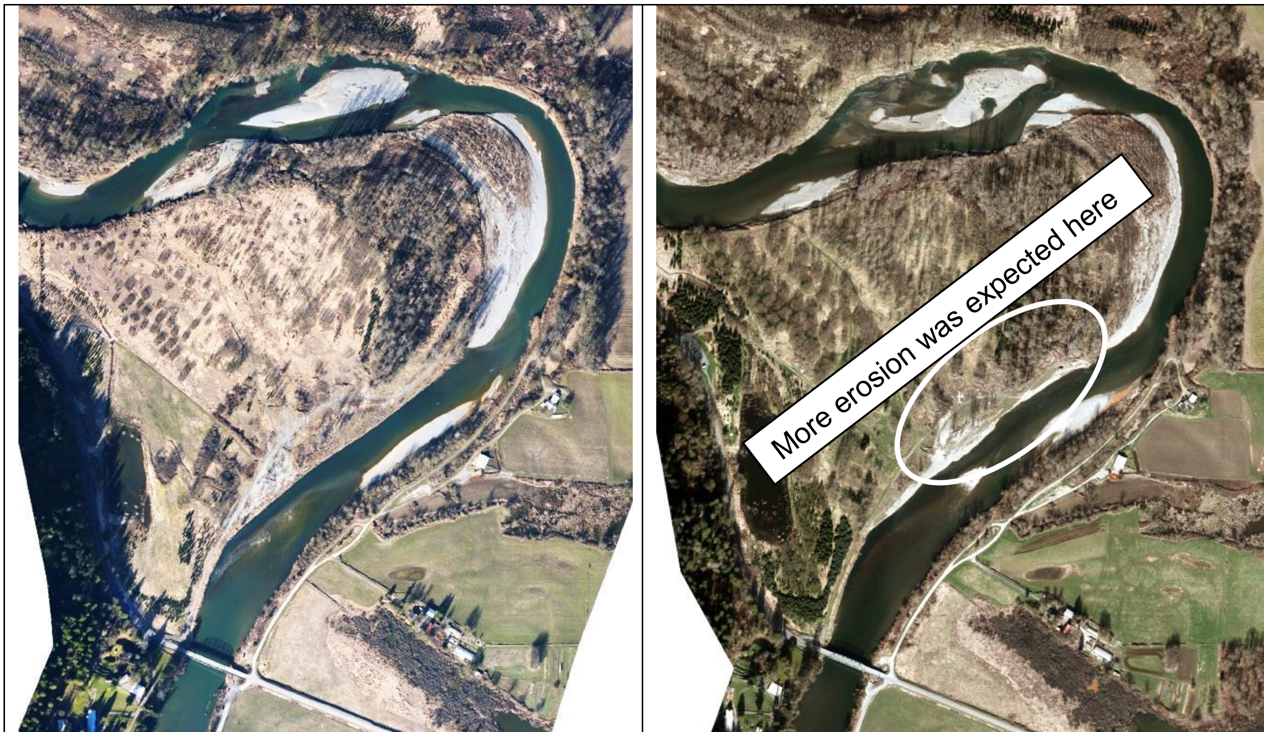
5. Conclusions and Recommendations

Five years of monitoring and observations have yielded preliminary answers to the key questions about project performance. Future changes are likely to result in new insights and perhaps even contrasting conclusions.

5.1. Summary of Year 5 (2014) Conditions

The Chinook Bend project is meeting KC WLRD-imposed performance standards (Figure 32) except for the following: redds, substrate size, channel planform, pioneer bars, and off-site erosion. Most notably, channel adjustments have been less than expected, even after numerous floods. As a result, gains in complexity and low-velocity edge habitat area have been small, relative to expectations. Edge habitat has not been mapped since 2011, so current conditions may differ. Even so, the low degree of planform change since 2011 suggests the existing planform is quite entrained and resilient in a simple and undesirable state.

In the near term, habitat availability may increase following the completion of a levee removal project along the right bank of the meander bend—the Stillwater project—completed by the Wild Fish Conservancy and partners. A greater amount of planform adjustment could materialize in the next five years since the channel is less constrained throughout the reach.



2009 Pre-Project	2015 Post-Project

Figure 32. Comparison of orthophotos from before and six years after the project.

5.2. Performance Concerns:

5.2.1. Low Rates of Channel Migration

The design team speculated increased complexity and channel-splitting in eastern end of bend was likely—but not guaranteed—within one to five years. The project reach was expected to resemble the 1936 channel soon after project completion, perhaps including a channel split at the constructed island persisting during low flow. The team also expected the meander bend would move north faster than has been observed to date. These things have not happened, and do not seem likely to occur anytime soon. Coarse lag deposits associated with the original levee may remain and protect the left bank from rapid erosion. Flow splitting may also reduce the energy available to promote channel migration.

However, the design team accurately predicted wood would accumulate on the constructed island and the stand of mature cottonwoods to the west of the island. Over time, this wood may yet promote a channel split and mainstem aggradation.

5.2.2. Unexpected Erosion of the Right Bank

Bank retreat on the right bank, opposite the location where the upstream levee was removed is an outcome of concern and was not expected. The cause of this bank erosion is not immediately clear, but it appears to be related to the growth of a mid-channel bar which has pushed more flow toward the right bank during low to moderate discharge levels, consequently eroding laterally into the right bank by tens of feet.

In response, King County ERES conducted a site inspection to take measurements and photos. The results of the investigation were shared with the Snoqualmie Basin Team in the King County Rivers and Floodplain Management Section. An Emergency Plan was developed by RFMU in January 2017 and the facility is scheduled to be repaired in 2017. In the meantime, ERES continues to monitor the condition of the bank periodically.

5.3. Preliminary Lessons for Future Projects

This project has provided the opportunity to learn a few important—though preliminary—lessons learned, for the benefit of future projects and adaptive management at the site (Table 11).

Table 11.Project-related lessons learned from the first five years after project completion.

Be aggressive in rock armor removal in the first effort or risk having to re-mobilize heavy equipment to remove more after floods.
Large-scale interventions—in excess of levee removal—may be needed to achieve substantial increases in edge habitat; in some cases, the channel planform may be quite resilient and the desired level of geomorphic change may not occur in the performance period.
Habitat capacity was lowest when flows were at or slightly above the median discharge during the period of freshwater rearing for subyearling Chinook salmon. If these events create population bottlenecks, project designs improving capacity at those flow levels could have significant benefits.
Flood fences can be effective at trapping wood during overbank floods and represent—at least in some cases—a feasible method for forming logjams at much lower cost than a typical engineered log jam.
Channel migration rates may be reduced at or downstream of a newly-formed flow divergence, which may be caused by the removal of a levee, as the energy to erode the bank may be reduced or redistributed into the floodplain.

5.4. Lessons for Future Monitoring Efforts

This study was part of King County's first effort to intensively monitor a large-scale floodplain restoration project and several valuable lessons were learned (Table 12).

Table 12. Key lessons from monitoring efforts.

Lessons Learned	Rationale
Use the Basis of Design Report to inform performance standards	Accurately characterize expectations. Ensures project goals are testable and there is a logical bridge between evidence (a change in an indicator) and a claim. Helps to make sure results are useful in solving real problems at the project site, or ones encountered in future projects.
Case-studies are useful, even if they are not broadly representative.	Valuable lessons can be learned from a single site to improve the selection and design of future projects, even if the population of inference and certainty in the outcomes has not been strictly defined.
Train staff in using the equipment to map and classify habitat units.	This is required to standardize the protocols and to have accurate and precise measurements. Discuss protocols in the field to ensure consistency.
Measure connectivity with time-lapse cameras and water-level loggers.	Periodic site visits during floods are effective ways to assess floodplain connectivity but are unlikely to precisely detect the discharge at which flows begin to spill over bank.

6. Maintenance

The goal of project maintenance is to ensure the performance standards are met. The Maintenance Plan is in effect for the first ten years after construction, and a site management plan (SMP) will be in effect thereafter. Maintenance has focused on weed control.

6.1. Maintenance Record

Table 13. Maintenance Log from date of project completion to time of this writing.

Year	Activity	Labor hours	Cost (dollars)
2009-2011	Treat Invasives Water	(Project cost)	n/a
2012	Treat invasives Apply PlantSkyd	87.5 58.5	$8,639
2013	Treat invasives Watering	27 61.5	$4,317
2014	Treat invasives Remove 720 lbs of landscape fabric	35	$2,851
2015	Treat Invasives	32	$2,000
2016	Install 40 cu yds of hogfuel at newly-planted spoils stockpile and removal area Treat invasives	74	$4,500
	Total	375.5	$22,307

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