Case Study 17

Stream Barbs on the Calapooia River, Oregon

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Cover photo: Historic channel traces of the Calapooia River in Oregon

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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Introduction

In January 2002, the Carbajal Streambank Stabilization project was funded through the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP). The project was approved to provide design and technical assistance to stabilize approximately 1,000 feet of riverbank (fig. CS17–1) along the Calapooia River in Linn County, Oregon. The river had 10-foot vertical banks and was eroding laterally at an average rate of 10 feet per year, with localized areas in excess of 20 feet per year. The Calapooia also has several salmonid species including the threatened Chinook salmon and winter steelhead. The district conservationist, engineer, and landowner developed the following project objectives:

- reduce bank erosion and loss of productive agricultural lands
- provide fish habitat and habitat diversity for endangered species
- not impact upstream and downstream landowners
- establish a stable riparian buffer strip

Design options were developed in accordance with NRCS standards, project objectives, and statewide programmatic biological opinion for endangered species. The final design was four rock barbs incorporating large wood, two engineered log structures, bank shaping, and vegetative planting. The project experienced a 5- to 10-year flow event 3 months after completion, and no noticeable erosion was observed along the riverbanks. In addition, significant areas of biodiversity were developed as a result of scour around the barb structures and proliferation of vegetation along the enhanced riverbanks. Total project cost was approximately $70 per foot of streambank stabilized.

Figure CS17–1 Calapooia River project (*Photos courtesy of Scott Wright*)

(a) Preproject conditions looking downstream at outside bank during summer low flows

(b) Postproject conditions looking downstream at outside bank during summer low flows

Fluvial geomorphology

The Calapooia River drains a 366-square-mile watershed area on the western foothills of the Cascade Range, with a mean annual precipitation of 60 inches. The river is more than 70 miles long with headwaters at an elevation of approximately 5,200 feet and a confluence elevation of 200 feet at the Willamette River. The river system contains several anadromous salmonid species including spring Chinook and winter steelhead that are listed as threatened under the Federal Endangered Species Act (ESA) of 1999.

Based on the Calapooia Watershed Assessment by the local watershed council, significant channel alterations had been performed from 1900 to 1980. Figure CS17–2 illustrates typical work in the watershed.

An aerial photo from 1966 (fig. CS17–3 (modified from U.S. Army Corps of Engineers (USACE) photo)) shows a dike just downstream of the project site constructed from excavated instream materials placed to cut off a meander bend. In addition to the channel realignment at the project site, another cutoff dike was constructed two meander bends upstream from the project site to cut off another meander.

To document historic channel alterations and natural changes, a composite picture of channel alignments was assembled. Figure CS17–4 shows the historic channel alignments from 1936, 1956, 1965, 1967, and 2001, superimposed on the 2001 aerial photo. The river's response to the 1966 meander cutoff dikes is readily visible as the meander phase shifted 180 degrees based on a sine curve relationship. The current river location mirrors the predike conditions in 1965. Analysis of traces of the historic channel highlights the heavily altered state of the river and the dynamic response to stream modifications. Based on nearly 70 years of channel traces, the meander belt width measures approximately 1,000 feet.

It is clear from the analysis of the historic channel that the project area is located near the outer edge of the historic meander migration zone. This allows for more streambank stabilization options because the stabilization will not have an impact on overall planform, nor would it affect flood plain connectivity since the project would not change top-of-bank elevations.

Figure CS17–2 Channel alterations in the Calapooia River in 1950s

Figure CS17–3 Aerial view of project area in 1966 showing dikes used to cut off meanders

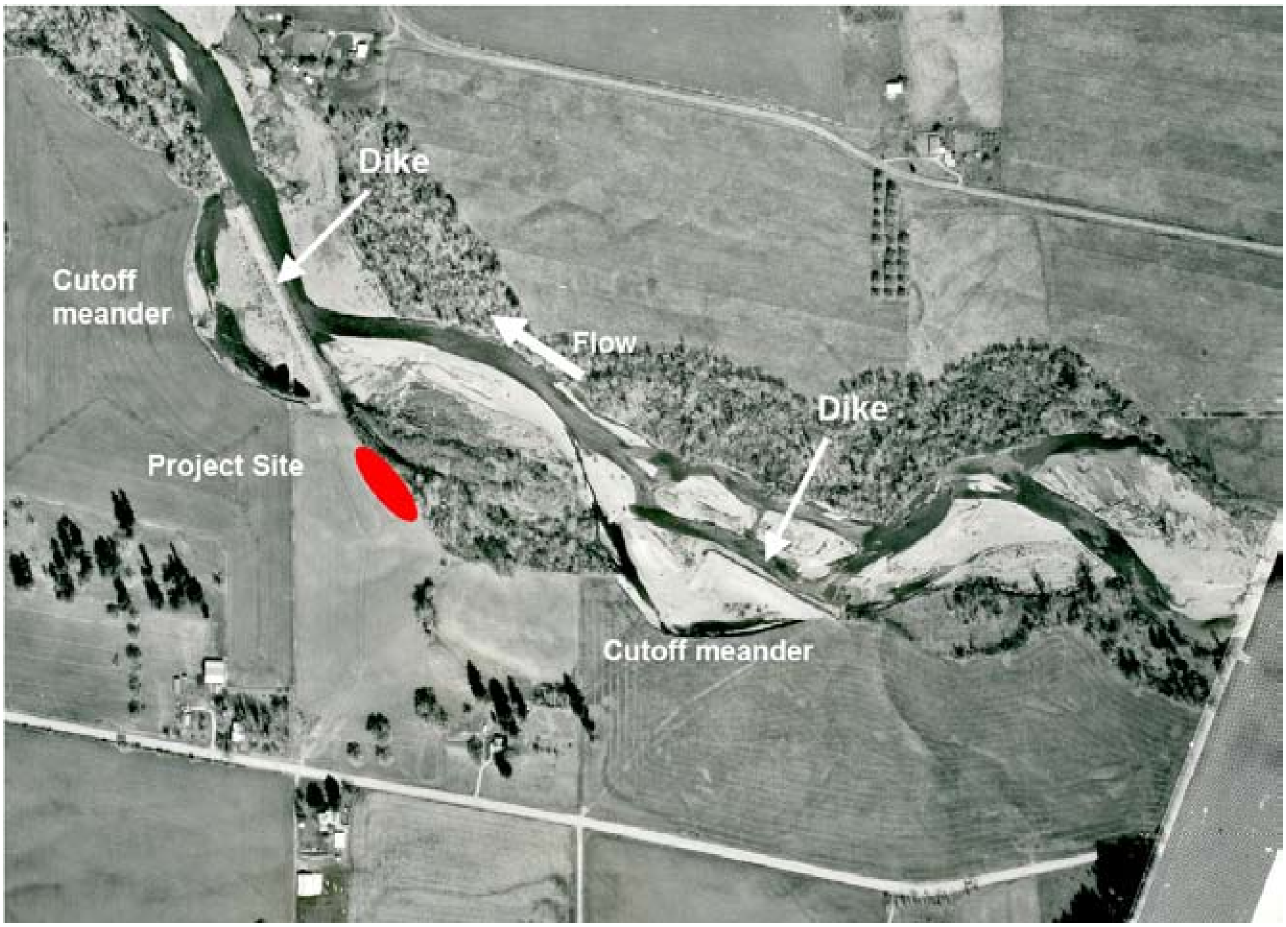
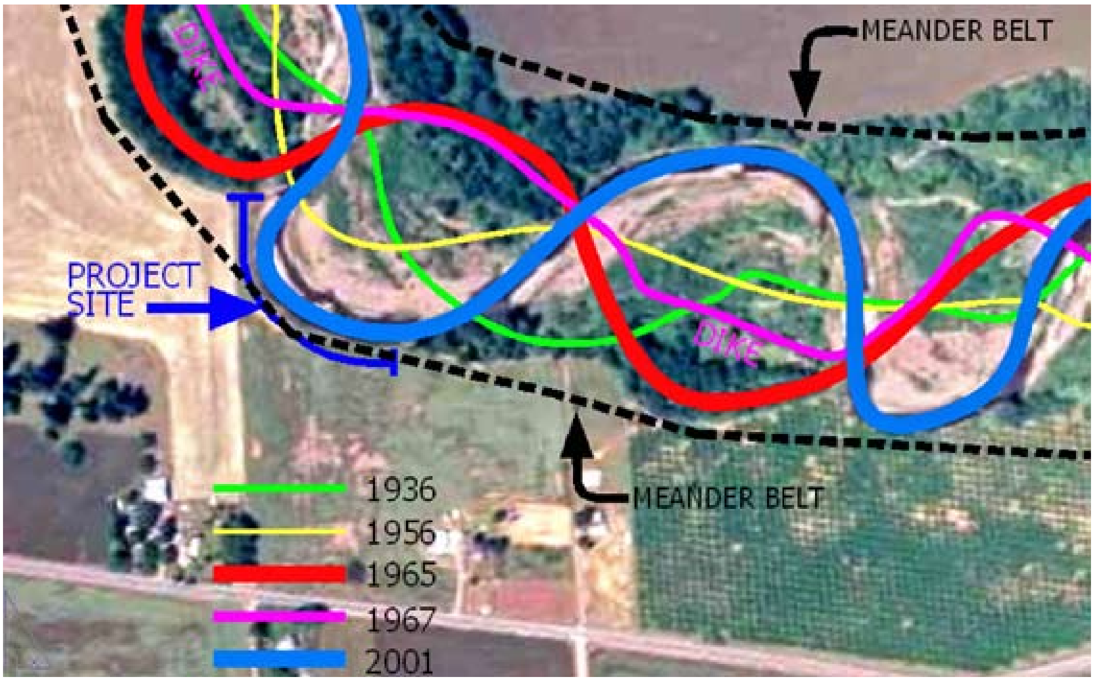


Figure CS17–4 Historic channel traces with corresponding year designated by color



Hydrology and hydraulics

The project site is located in a compound meander that starts with a radius of 450 feet and tightens at the downstream end of the project to a radius of 175 feet. The radius tightening causes high shear forces and scour on the streambank, eroding the bank toe. As the toe material is eroded, the cohesionless soil above the gravel-sand-silt mixture is unable to resist additional shear forces, and the weight of the soil causes mass-block failures on vertical planes. Channel migration, human alterations, and farming practices have left the existing stream corridor void of vegetation to help resist additional erosion. As a result, lateral channel migration at the project site was 10 to 20 feet per year.

A thorough topographic survey of the project reach was performed with a Topcon GTS–211D total station, equipped with a handheld HP–48 data collector. Survey points were downloaded from the data collector into Eagle Point Civil Design software. The data points and breaklines were used in the CAD environment to generate contours and a base map (fig. CS17–5) used for design and construction drawings. River cross sections were exported to HEC–RAS (USACE 1995a) to create a hydraulic model of the site.

Based on field data and a reach analysis, table CS17–1 lists the physical characteristics of the project site.

The drainage basin for the project site was delineated using U.S. Geological Survey (USGS) maps in ArcGIS. The drainage area was proportioned to a stream gage, located 5 miles upstream of the site, to develop peak discharge flows and recurrence intervals. Based on the gage records, the flows were developed (table CS17–2).

A steady-state HEC–RAS model was developed based on topographic site survey and hydrologic conditions. The model was used to generate hydraulic characteristics of the site, as well as velocity distributions. In addition, the bankfull flow was determined based on physical features from the site survey combined with the HEC–RAS model and peak flow records. A typical velocity distribution cross section from HEC–RAS is shown in figure CS17–6 at bankfull stage.

HEC–RAS is a one-dimensional hydraulic model that does not account for meander mechanics that result from curvature and channel width. The 1991 USACE Engineering Manual (EM) 1110–2–1601 (Engineering and Design – Hydraulic Design of Flood Control Channels) summarizes research showing that the vertical (or spiraling) velocity can exceed the longitudinal stream velocity by more than 35 percent. Therefore, average longitudinal velocities from HEC–RAS are multiplied by 1.5 or 2.0 for design of rock barb structures. This factor of safety accounts for meander effects and turbulent burst velocities.

Knighton (1998) identifies a consistent relationship between meander parameters and channel width (w) where the latter operates as a scale variable of the channel system. The term tortuosity is introduced as an index of the effect of meander geometries on these forces and is defined as the radius of meander curvature (Rc) divided by the channel top width (Rc/w). The channel radius is measured through the meander bend along the thalweg, and the width is taken as the water surface top width at bankfull stage in the uniform section upstream of the meander. Due to the compound nature of the meander bend, the tortuosity of the upstream portion of the project was 3.3, while the downstream end was 1.3. This is significant because when tortuosity is below 3, cross-stream flows become an important consideration for design, in addition to the spiraling, meander-caused flows. This means that flow can impinge on the bank in between barbs, and additional bank protection may be required.

Design

Alternatives such as streambank soil bioengineering with plants and geosynthetics, bank roughness with large wood, and rock structures were evaluated. Based on fluvial geomorphology, hydrology, hydraulics, site survey, and permitting considerations, it was determined that bank shaping, rock barbs, and engineered log structures, in concert with vegetation establishment, would meet project goals. Bank shaping and rock barbs provide immediate stability and reduce hydraulic forces on the bank, thereby allowing vegetation time to grow and establish a solid root system. The vegetal growth, in turn, helps secure long-term stability of the site and enhances the biodiversity of the riparian corridor. Engineered log structures provide immediate habitat for endangered salmonid species and help recruit additional large wood to enhance the stream corridor near the project site.

Figure CS17–5 Existing topographic drawing used for making HEC–RAS model and construction drawings

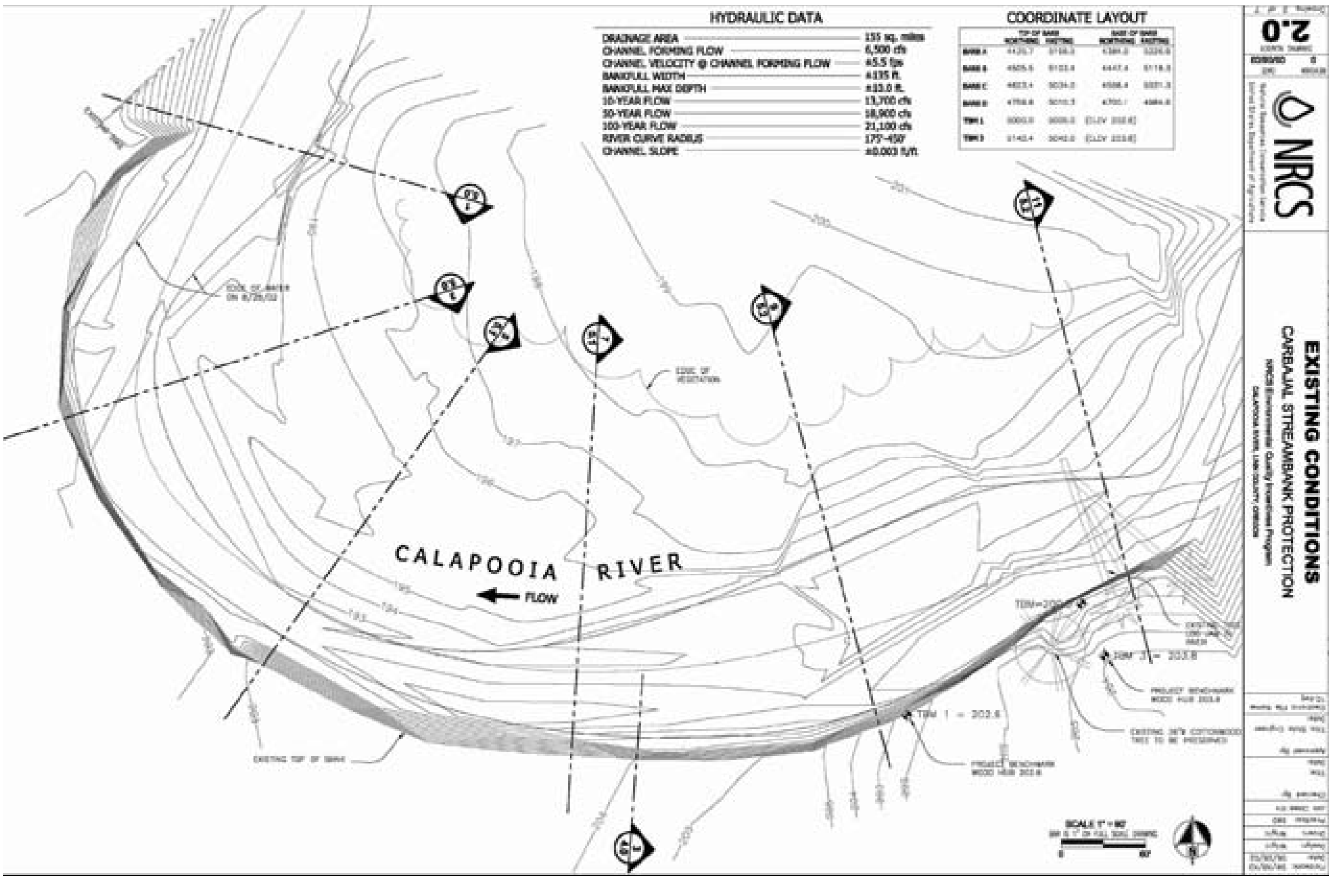


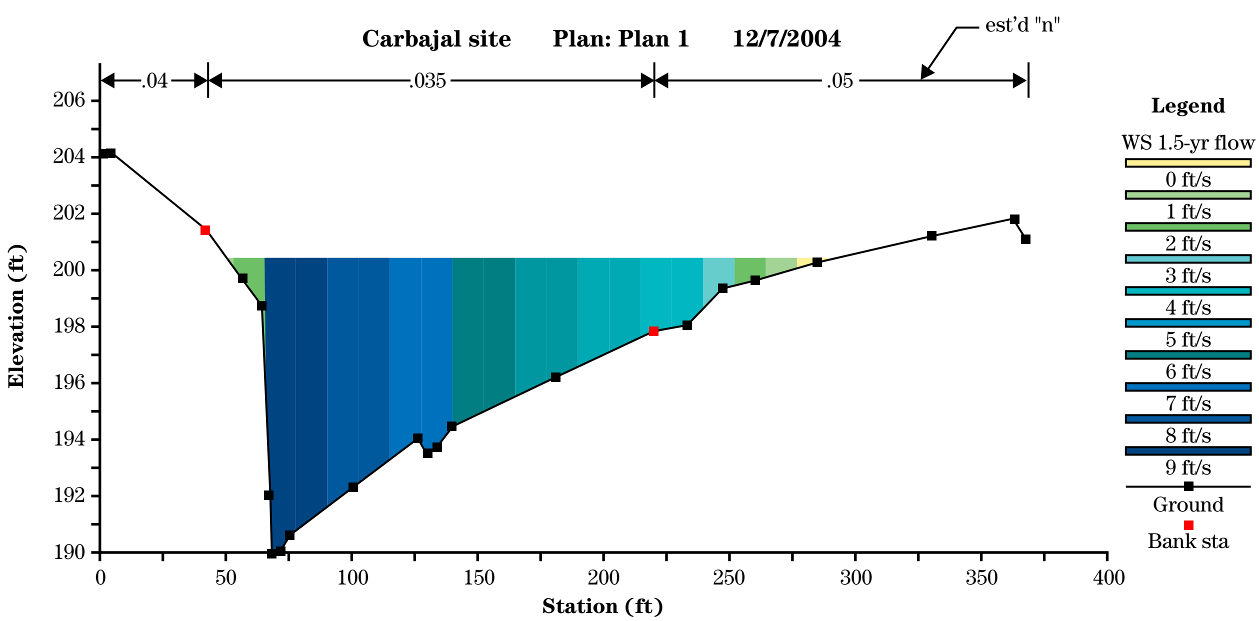
Table CS17–1 Project area characteristics

Reach characteristics	
Drainage area	155 mi^2
Bankfull width	135 ft
Sinuosity	1.4
Channel slope	0.003 ft/ft
Historic meander belt width	900 ft
Typical curve radii	450 ft
Meander wavelength	1,600 ft
D_{50}	60 mm (2.4 in)

Table CS17–2 Peak discharge estimates and recurrence interval

Recurrence interval (years)	Peak flow (ft^3/s)
1.5-yr bankfull (estimate)	6,500
2-yr	7,900
5-yr	11,400
10-yr	13,700
25-yr	16,700
50-yr	18,900
100-yr	21,100

Figure CS17–6 HEC–RAS velocity distribution output for a typical cross section



Rock barbs

Barb geometry and rock sizing were done in accordance with Oregon NRCS Technical Note 23, Design of Stream Barbs, which is similar to NEH654 TS14H. Barb rock size and gradation used for construction are summarized in table CS17–3.

The rock barbs were the first component to be constructed. The barbs were staked out using steel “T” posts driven into the riverbed along the design alignment. This practice allowed the contractor to work on the streambank and have a constant view of the proper barb alignment. Figure CS17–7 shows the two downstream barbs immediately after construction and prior to any bank shaping.

Engineered log structures

Engineered log structures were installed at each end of the project to provide immediate fish habitat, provide a mechanism for catching large woody material, and act as anchor points to reduce the erosion potential and reduce the likelihood of flanking the barbs. Logs with rootwads were placed together to form a structure that was ballasted with large rock. The ballast rock was designed using D’Aoust and Millar’s (2000) performance-based research which is similar to NEH654 TS14J. These authors state “lateral drag forces do not need to be considered explicitly and the factor of safety against buoyancy can be used as a simple design criterion” for multiple log structures that are tied together. Therefore, a buoyancy calculation was used as the design basis for the log structures (fig. CS17–8).

Figure CS17–7 Looking downstream at initial installation of two barbs before bank shaping, during low summer flows (*Photo courtesy of Scott Wright*)

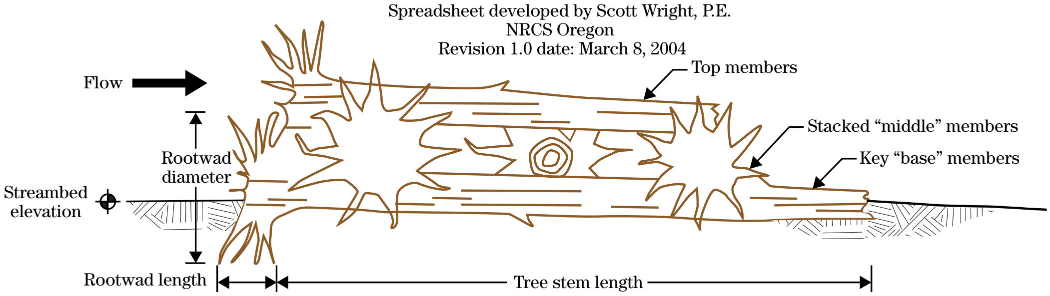
Table CS17–3 Summary of rock gradation used for barb construction

Average gradation blend						
Percent passing	**Diameter (in)**	**Weight (lb)**	**Percent of sample**	**Weight to make sample (lb)**	**Average rock weight (lb)**	**Number of rocks (ea)**
93	48	8,064				
			25.0	178,750	5,733	31.2
68	36	3,402				
			27.5	196,625	2,205	89.2
40	24	1,008				
			17.5	125,125	717	174.6
23	18	425				
			15.0	107,250	276	389.1
8	12	126				
			7.5	53,625	63	851.2
0	0	0				

Figure CS17–8 Typical spreadsheet for calculating factor of safety against log structure buoyancy

Buoyancy calculations for engineered log jam

Spreadsheet developed by Scott Wright, P.E.
NRCS Oregon
Revision 1.0 date: March 8, 2004



Key "base" members

Number of logs with rootwads	N_L =	4	
Specific gravity of large wood	S_L =	0.45	
Average rootwad diameter	D_{RW} =	8	feet
Average rootwad length	L_{RW} =	3	feet
Proportion of voids in rootwad	p =	0.45	decimal
Tree stem average diameter	D_{TS} =	2	feet
Tree stem average length	L_{TS} =	20	feet

% $F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \times (1-p) \right) \times \rho_W g (1 - S_L) \times N_L$ ↑

F_BL = **20,008** pounds

Stacked "middle" members

Number of logs with rootwads	N_L =	2	
Specific gravity of large wood	S_L =	0.45	
Average rootwad diameter	D_{RW} =	6	feet
Average rootwad length	L_{RW} =	2	feet
Proportion of voids in rootwad	p =	0.45	decimal
Tree stem average diameter	D_{TS} =	2	feet
Tree stem average length	L_{TS} =	30	feet

% $F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \times (1-p) \right) \times \rho_W g (1 - S_L) \times N_L$ ↑

F_BL = **8,602** pounds

Top members

Number of logs with rootwads	N_L =	2	
Specific gravity of large wood	S_L =	0.45	
Average rootwad diameter	D_{RW} =	6	feet
Average rootwad length	L_{RW} =	2	feet
Proportion of voids in rootwad	p =	0.45	decimal
Tree stem average diameter	D_{TS} =	2	feet
Tree stem average length	L_{TS} =	20	feet

% $F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \times (1-p) \right) \times \rho_W g (1 - S_L) \times N_L$ ↑

F_BL = **6,446** pounds

Boulder ballast

Specific gravity of boulders	S_S =	2.65	
Diameter of boulder	D_B =	3.5	feet
Number of boulders unsubmerged	N_{BU} =	0	
Number of boulders fully submerged	N_{BS} =	24	

$$W' = \frac{\pi D_B^3 L_{rs}}{6} \times \rho_W g (S_L - 1)$$

W = **3,712** pounds per boulder unsubmerged ↓
W'= **2,311** pounds per boulder submerged

Total weight for all boulders (submerged and unsubmerged) = **55,469** pounds

Factor of safety: buoyancy

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the logjam are fully submerged. In addition, the logjam and boulders act as a composite structure and are assumed fully connected. W ater velocity inside the logjam is hi ghly turbulent and near zero, therefore, vertical uplift forces are assumed negligible.

$$FS_B = \frac{W + W'}{\sum F_{BL}}$$

= 1.58 **FS_B =** **1.58**

D'Aoust and Millar (2000) recommend a minimum factor of safety of 1.5 against buoyancy for log structures. Based on experience using log structures in Oregon, this minimum factor of safety against buoyancy is an adequate design parameter. However, it is recommended that the factor of safety be closer to 2.0 and that the large wood be connected together to allow the structure to act as a single unit. These connections also provide better stability in the structure for placing ballast material. The higher factor of safety also allows for greater flexibility during construction when working with imperfect and irregular logs.

Bank shaping and vegetation

The existing bank consisted of noncohesive material and was geotechnically unstable. Therefore, the bank was shaped and excavated from the summer low-water elevation to the catch point of the existing ground at a 3H:1V slope. This slope creates a stable bank and provides an optimal surface to plant vegetation. Annual grass seed was planted, along with a 3-year, degradable erosion control blanket. The blanket provided immediate stabilization of the soil and exposed bank until the vegetation could establish (fig. CS17–9). The erosion control blanket had a permissible shear stress of 2.25 pounds per square foot that easily exceeded the 10-year flow maximum shear stress of 1.2 pounds per square foot predicted in the HEC–RAS model.

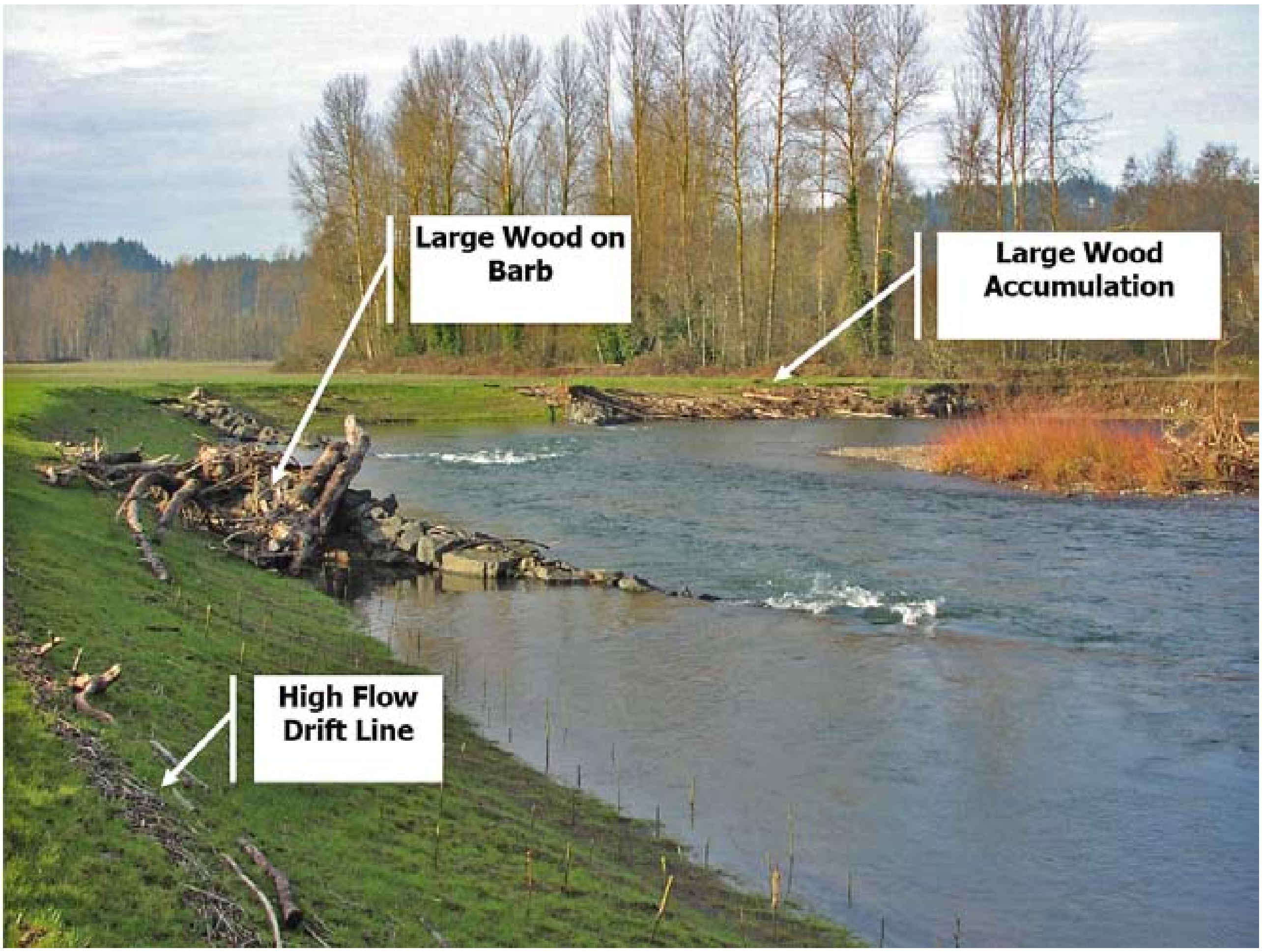
Performance

Just 3 months after project completion, a gaged storm event occurred that measured between a 5- and 10-year peak flow. The project withstood the storm event with no noticeable erosion or adverse effects to the surrounding area (fig. CS17–10). Large amounts of wood collected on top of each barb and especially near the downstream third of the meander bend—at the engineered log structure (fig. CS17–11).

Figure CS17–9 Looking downstream at completed project showing barbs and erosion control mat during summer flow (*Photo courtesy of Scott Wright*)

Figure CS17–10 Winter baseflow with planted willows and grass

Figure CS17–11 Looking downstream at completed project area after 10-year storm event (*Photo courtesy of Scott Wright*)



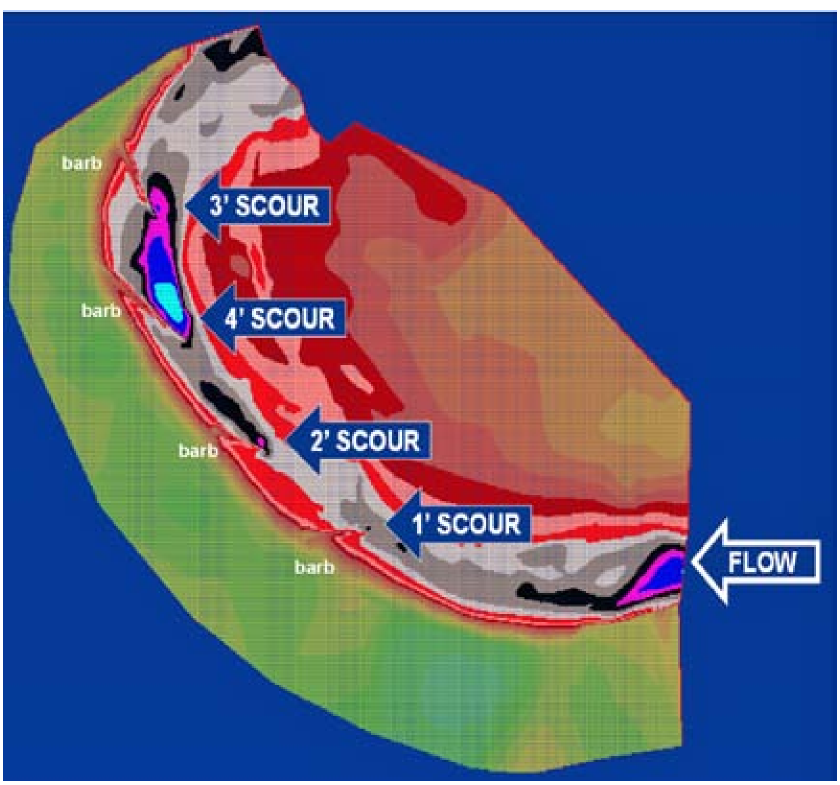
Detailed topographic information was collected pre- and postconstruction to identify actual geomorphic effects of the stream barbs and overall performance. Figure CS17–12 identifies the actual scour that occurred around each barb and the streambed.

Because of the barbs, no scour or erosion occurred along the outside bank of the meander. As illustrated in figure CS17–12, the hydraulic effect of the barbs caused local scour and constriction scour. The scour pattern begins around the tip of the barb and extends downstream in an elliptical shape. This pattern is similar to other observations made in Oregon around barb groups on C3 and C4 gravel-bed rivers.

Energy dissipation within the project reach is caused by scour and a hydraulic jump at each barb. Figure CS17–13 shows the distinct hydraulic jump as water flows over the barb. This jump is progressive with stage because of the crest slope of the barb weir. Based on this project and several other observations of barbs, a 15H:1V slope appears to be an optimal weir slope to enact the hydraulic jump throughout various discharge stages.

The barbs reduced near bank flow velocities, created scour areas that enhanced fish habitat, provided reach diversity, collected large wood, and dissipated hydraulic energy within the project reach without translating

Figure CS17–12 Actual scour around each barb following 5- to 10-year peak flow event. Each color band gradient represents a 1-foot elevation increment. (*Photo courtesy of Scott Wright*)



erosion problems downstream. Figure CS17–14 shows the completed project 3 years after construction. A significant number of willows now grow in the reach corridor and further reduce near bank flow velocities. The vegetation provides habitat to promote biodiversity that was not present in the preproject state.

Cost

The stabilization techniques included four rock stream barbs, two engineered log structures, bank excavation and shaping, and an erosion control blanket. The protected length of streambank was approximately 900 feet with a construction cost of $60,000. The cost included mobilization, materials, installation of all structures, and final clean up. All excess soil from bank shaping was disposed of onsite, and the project was easily accessible with machinery. Rock for the barbs was transported in standard dump trucks from a quarry 25 miles from the site. Large wood for the structures was purchased and transported to the site. The landowner provided all materials, labor, and supplies for the willow and riparian buffer plantings.

Summary

After three winters and a 5- to 10-year peak flow event, the project has performed well and exceeded landowner expectations. Biologists and regulatory agencies are pleased by project performance and the much improved habitat and species diversity. An ongoing research study will provide quantitative data on the biological impacts of stream barbs on the riverine environment.

Figure CS17–13 Example of energy dissipation from a hydraulic jump formed over one of the project barbs during winter baseflow (*Photo courtesy of Scott Wright*)

Figure CS17–14 Looking downstream 3 years after project completion with extensive vegetation growth (*Photo courtesy of Scott Wright*)