The Once and Future Streams: Recreating Bailey and Karnowsky Creeks, Central Oregon Coast Range, USA

Johan Hogervorst
Siuslaw National Forest, Florence, Oregon[1]

Barbara Ellis-Sugai
Siuslaw National Forest, Corvallis, Oregon

The Bailey Creek Project reconstructed over one mile of meandering stream channel in a low-gradient valley on the central Oregon Coast. The original channel was moved, straightened and diked to accommodate agriculture over the last century. After it was straightened, the channel velocity increased, leading to incision and bank erosion, degrading water quality and fish habitat. The project's focus was restoring wetland, stream and floodplain functions to a stream that once provided excellent rearing habitat for coho salmon (*Oncorhynchus kisutch*). The new, meandering channel was built in 1999 and water was introduced in 2000. From 1999 through 2003, native trees and shrubs were planted and wood was added to the stream. Monitoring results document five times the number of juvenile coho in the project area compared to a control reach. Lessons learned from Bailey Creek were applied to Karnowsky Creek, a tidally influenced, Siuslaw River tributary with a channelization history similar to Bailey Creek. Over two miles of meandering main-stem channel were constructed in late summer 2002. In 2003, ditches were filled, water was turned into the new channel and over 130 large whole trees were placed in the new channel and floodplain by helicopter. A variety of native trees and shrubs have been planted on the valley floor. In 2004-2006, two tributaries with valley gradients of 3-5% are being restored by building new channels with step-pool morphology. Project monitoring consists of 22 channel cross-sections to track changes in the new channels' geometry, groundwater wells, photo points, low-elevation aerial photography, spawning surveys and juvenile fish snorkel counts.

Keywords: *coarse woody debris, coho salmon, channel geomorphology, fish habitat, riparian vegetation, stream reconstruction, stream restoration, wetlands*

All photos, maps and figures were taken/created by authors.

Introduction

The Siuslaw National Forest, Oregon, in collaboration with partners, has restored two low-gradient, channelized streams in the central Oregon Coast Range by constructing new, meandering streams to replace the existing ditches. Bailey Creek flows through Enchanted Valley into Mercer Lake, and then about five miles (8 km) out to the ocean just north of Florence, Oregon. Karnowsky Creek flows into the Siuslaw River estuary between the towns of Florence and Mapleton, Oregon, approximately nine river miles (14.5 km) from the ocean. Both streams flow through flat-bottomed valleys and share a similar homesteading history. The valley land was cleared for agriculture in the late 1800s, and in the early to mid-1900s the streams were channelized into ditches along the sides of these valleys to provide more pasture.

As a result of the channelization, sinuosity decreased, and stream gradients and water velocity increased. The stream downcut into the valley floor creating high, erosive banks. At Bailey Creek, sedimentation into Mercer Lake increased, creating a large delta into the lake. A repeated topographic survey of this delta from 1998-2000 showed that the delta grew over 3 meters laterally during this period. The Bailey Creek ditch was also attempting to re-create meanders in the ditch, which increased bank erosion and sediment production. At Karnowsky Creek, the larger tributary streams to the valley with gradients from 3-5% had also been channelized, and these tributaries had severely downcut three meters or more to match the main valley ditch incision.

M Furniss, C Clifton, and K Ronnenberg, eds., 2007. *Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004*, PNW-GTR-689, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

1 Now at the Willamette National Forest, Eugene, Oregon

In general, the restoration of these two streams involved a process that used reference data, local flow equations, stream classification, dimensionless ratios, and cross-checking using Manning's equation. It must be stressed that this process is iterative and not linear. Many of the steps loop back or occur simultaneously due to the complex interactions of stream processes that are being recreated. When one variable changes, so do all the others. The thought process weaves all the factors together at once as opposed to following a cookbook recipe.

For both Bailey and Karnowsky Creeks, questions to be answered included the following: What type of stream should be built to fit the valley type and landscape? What should the dimensions of the new channel be, including the width, depth, cross-sectional area, gradient, sinuosity and pool depth and length? In general, the steps in the design processes for both Bailey and Karnowsky Creeks are as follows :

1. Find a relatively undisturbed stream with similar characteristics to serve as a guide for the new channel design and measure its parameters.
2. Determine the bankfull discharge of the new channel.
3. Determine the cross-sectional area for the new channel, which determines the capacity of the stream to carry its flow and maintain the channel's dimensions.
4. Determine the new channel's slope and sinuosity, which may vary downstream through the valley. Slope is the main parameter influencing a stream's energy, which in turn determines the sediment transport capacity and potential for erosion.
5. Refer to Rosgen's (1996) stream channel classification system to see if the values chosen for the new channel fall within the range of variability for the chosen channel type. This step serves as a useful reality check.
6. Determine the minimum, maximum and average radii of curvature for the meanders in the new channel. The radius of curvature influences shear stresses on banks, and will partly determine the layout of the new channel.
7. Lay out the design on a base map, and then on the ground. An accurate survey is essential for this step. Test the design, checking the sinuosity, gradient, shear stresses, and capacity of the channel to carry the predicted bankfull flows. Manning's equation, among others, is useful for this step. The layout may have to be modified several times before a satisfactory design is finished.

Bailey Creek Restoration

Enchanted Valley was acquired by the USDA Forest Service in 1991, and planning began on the Bailey Creek restoration project in 1995. Goals of the project included: improving rearing habitat for coho salmon (*Oncorhynchus kisutch*), a threatened species on the Oregon Coast; reconnecting the channel with its floodplain; restoring riparian vegetation; and reducing sedimentation into Mercer Lake, which was a major concern for homeowners along the lakeshore. Public concerns about the project included reduction of elk (*Cervus elapus roosevelti*) forage in the valley, skepticism of the project's purpose and need, and possible increased sedimentation into Mercer Lake caused by constructing a new channel. Six public working group meetings held in 1997 were aimed at working through these concerns with the public, and a compromise was reached where only the lower half of the cleared and channelized valley would be rehabilitated while the upper valley would be maintained for elk forage.

Methodology

The first step in the planning process was gathering data on existing conditions, and comparing Bailey Creek to a similar stream that had not been cleared and channelized. We enlisted a professional Forest Service surveyor to create a topographic map of the valley floor with a one-foot (0.3-m) contour interval, and we used this topographic map as our base map. Other data collected included several cross-sections of the existing ditch, pebble counts at the cross-section locations, a longitudinal profile of the ditch, and cross-sections and pebble counts of Bailey Creek upstream of the channelized section. For reference on pre-channelized conditions, we had a 1955 aerial photo. Although channelization had already occurred, the original stream channel was still visible in the pasture of the upper valley. We used this photo to determine the historic sinuosity and meander geometry. We also measured cross-sections on Leitel Creek, which flows into Tahkenich Lake, another coastal lake south of Florence, Oregon. Although Leitel Creek is surrounded by early seral industrial forestland, the valley bottom has not been cleared for agriculture and the stream has not been straightened. Given that this valley has a similar geomorphology and setting to Enchanted Valley, Leitel Creek served as a reference stream for our design.

Determining the bankfull or "design" flow was the most challenging aspect of data collection, and we used several sources of information. A master's thesis by Giese (1996) correlated flow measurements to 16 years of rainfall records for Bailey Creek. This flow information was

used along with discharge measured in the field during winter flow events, and with data from nearby gauged watersheds. Where reed canarygrass (*Phalaris arundinacea*) overhung straightened ditches at Bailey Creek, there were no discernable bankfull indicators, which greatly hampered determination of bankfull discharge in the ditch.

Once parameters of sinuosity, channel gradient, cross-sectional area, and design discharge were obtained, they were fit together into an appropriate channel geometry. Similar to our observed reference stream, Leitel Creek, the desired future condition of the new channel was one that floods frequently during the winter to re-establish seasonal wetland characteristics, but maintains a stable cross section that would not be prone to heavy bank erosion. A decision had to be made whether the new channel would be a Rosgen (1996) "C" (wide, shallow channel) or "E" channel type (deep, narrow channel). Based on the low gradient of the valley, the geomorphic setting (an old lake bed), and the cross-sections from Leitel Creek, a Rosgen "E" channel type was chosen.

To make sure that the stream frequently overtopped its banks during winter flows, riffle cross sections of the upper 1,341 meters (4,400 feet) of channel were designed 30% smaller than the existing ditch. Also, knowing that Mercer Lake backs up into the lower third of the project area every winter, the bottom 335 meters (1,100 feet) of channel was undersized by an additional 50% to facilitate inundation and sediment drop out in the floodplain. Pools and riffles were not built in the "pilot" channel at the lower end. See Tables 1-3 for the measurements of the pre-project ditch, the new design channel and the pilot channel.

The next step was translating the design parameters to a map view of the new channel. Using the newly surveyed topographic map of the valley floor as a base map, a piece of string was cut to the scale representing the length of the new channel and then taped to the upper and lower end of the project area on the map. The string was laid out so that the channel followed the low spots of the valley, and the meander length and radius of curvature averaged about 74 m (240 feet) and 16 m (52 feet), respectively. This step took several trials. Once satisfied with the layout, the "string" map was digitized onto an electronic map using a geographic information system. Points were added that represented stakes to survey on the ground. A surveyor then translated the staking points to coordinates based on the bench marks put into the original topographic survey. With these coordinates input into the total station survey equipment, the surveyor moved personnel into the stake locations by trial shots until the proper coordinates were located and center-line channel stakes were pounded in. When it was discovered that the new channel would cut through some high ground, resulting in banks that would be higher than the rooting depth of the grasses and sedges, that portion of the channel was redesigned and moved into

Table 1. Enchanted Valley specifications.

Basin size	11.4 km^2 (4.4 mi^2)
Bankfull flow	5.1-6.8 m^3/s (180-240 ft^3/s)
Average high flow	Approx. 2.3-2.5 m^3/s (80-90 ft^3/s)
Average winter base flow	Approx. 0.7 m^3/s (25 ft^3/s)
Low summer flow	Approx. 0.03 m^3/s (1 ft^3/s)
Valley slope	0.0034
Valley length	954 m (3100 ft)
Stream bank substrate	60% silt/clay, 40% sand

Table 2. Bailey Creek measurements. (based on cross-sections above channelized section)*

Parameter	Historic Channel	Ditch	Design Channel (1,340 m)	Pilot Channel (335 m)
Sinuosity	1.66	1.1	1.8	1.8
Gradient	0.0022	0.0032	0.0019	0.0019
Bankfull width	8.5-12 m (28.5-40 ft)*	4-4.5 m (13-15 ft)	6.4 m (21 ft)	3.0 m (10 ft)
Belt width	68-85 m (220-275 ft)	Not applicable	46-77 m (150-250 ft)	46-77 m (150-250 ft)
Meander length	average 77 m (250 ft)	Not applicable	average 73 m (239 ft)	average 73 m (239 ft)
Radius of curvature	average 25 m (82 ft) range 12-43 m (40-140 ft)	Not applicable	average 16 m (52 ft)	average 16 m (52 ft)
W/D ratio	No information	lower valley, 2-3 above channelized, 25	7.0	3.3
Riffle cross-sectional area	No information	8.4 m^2 (90 ft^2)	6.3 m^2 (60 ft^2)	2.8 m^2 (30 ft^2)

Table 3. Bailey Creek new channel design specifications, Enchanted Valley Stream Restoration.

Design flow	2.8 m^3/s (100 ft^3/s)	Channel cross-section area	5.6 m^2 (60 ft^2)
Flood frequency	12-20 days per year	Bankfull width	6.5 m (21 ft)
Design velocity	0.3-0.4 m^3/s (1.0-1.3 ft^3/s)	Bankfull depth	0.9 m (3 ft) in riffles, 1.5 m (5 ft) in pools
Channel length	1,684 m (5,474 ft)	Width/depth ratio	7
Rosgen type	E	Meander wave length	74 m (239 ft)
Sinuosity	1.8	Radius of curvature	16 m (52 ft) (2.5 x channel width)
Slope	0.0019 (overall)	Pool/riffle spacing	32-45 m (105-147 ft)

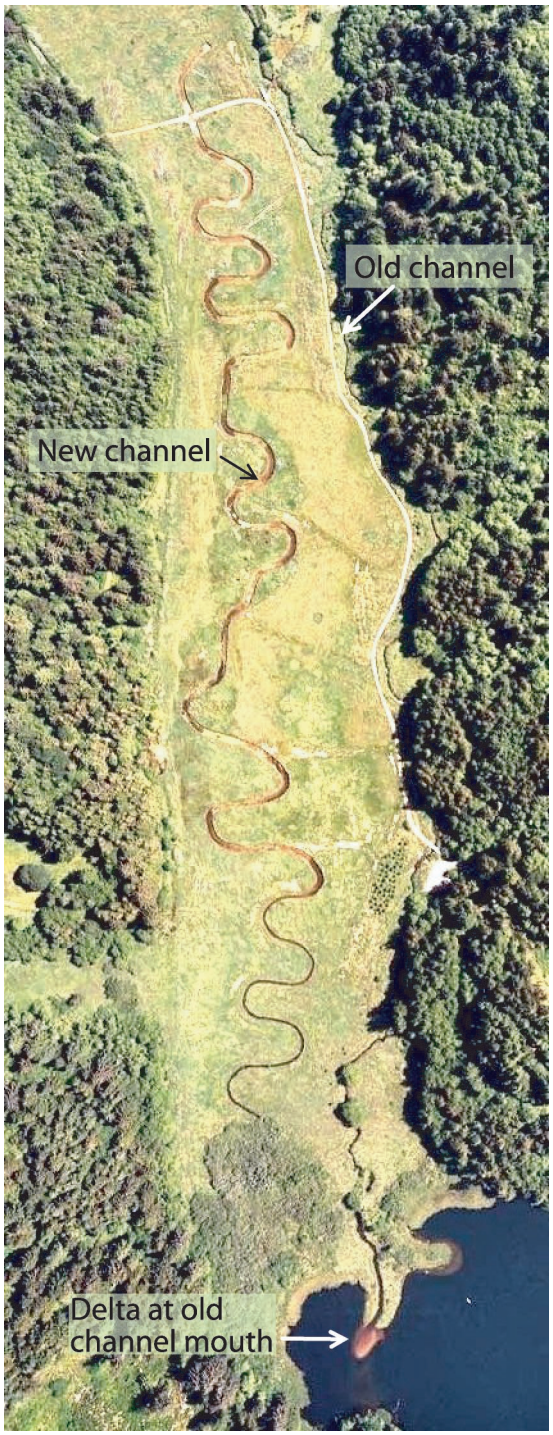


Figure 1: Low-elevation aerial photograph of the new Bailey Creek channel before connection to stream flow. September 2000.

the lower spots, being careful to maintain the calculated length and gradient of the new channel.

For the 1,341 meters of upper channel (design channel), a pool-riffle morphology was designed for the stream bottom, with the pools occupying approximately half of the stream length on the outside of meander bends. The entire new channel was excavated in late summer 1999, taking about a month to construct with an excavator and 18-yard dump truck (Figure 1). We used a laser level to check the gradient during the construction of the entire 1,676-meter-long channel. The outside bends of meanders were revegetated with willow (*Salix* spp.) stakes in early spring of 2000, and the new channel was connected to water in the October 2000. Also in 2000, the abandoned ditch was intermittently plugged with fill material that had been stockpiled during channel construction, leaving ponds in the unfilled areas. Since then, wood has been added to the channel, tributary channels from the valley side slopes have been connected to the main channel, and elderberry (*Sambucus racemosa*), red alder (*Alnus rubra*), Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), and several other native species have been planted in the riparian zone along the new channel.

Monitoring

Twenty-four permanently monumented cross-sections are surveyed and photographed each year to track channel morphology and vegetative changes. Low-elevation aerial photographs are flown semi-annually. Additionally, vegetation transects, spawning surveys and juvenile fish surveys are conducted yearly, and water quality surveys are done either yearly or concurrent with large storms.

Results and Lessons Learned

During the first two winters after connection, the stream overflowed its banks during peak flows, but not to the extent hoped for in the design channel section. Wood placed directly into pool cross sections in 2002 has significantly improved floodplain inundation in the design channel section. Ongoing bank erosion from the ditched channel above the project area inputs such high sediment loads during winter flows that point bars and mid-channel bars are being formed in the new channel. The channel is deepening in some places, and aggrading in others, but even as the shape of the bed adjusts, the overall cross sectional area remains fairly stable. After five years of tracking geomorphic changes in cross sections, the net overall change in cross-sectional area for the entire project reach is an estimated 0.02 m^2, well within measurement error (2004 Enchanted Valley Monitoring Report [USDA 2004]). See Figures 2-4 for changes to the constructed channel over time.

One area of concern is the connection between the old, downcut channel that was eight feet (2.4 m) below the valley floor and the new channel that is only three to four feet (0.9 to 1.2 m) deep. It was assumed that sediment would drop out upstream of the diversion point as water

Figure 2: New Bailey Creek channel at photo point 7, in (a) 1999, and (b) 2004.

Figure 3: Over bank winter flow in Bailey Creek interacting with added large wood in channel, winter 2003.

Figure 4: Willows and conifers planted along the bank of the new Bailey Creek channel, 2003.

slowed to enter the new channel at a lower gradient, and the old ditch would aggrade. Instead, a tail cut began to develop downstream of the diversion point, as the channel's longitudinal profile came into equilibrium between the two elevations (See Figure 5 for a cross sectional comparison). This situation is being monitored, but it may be necessary to remedy this cutting by adding larger substrate to the channel at the diversion point to smooth out the longitudinal profile and armor the channel bed. The existing stream bed at the old channel junction and in the rest of the constructed channel is silt loam.

Spawning numbers have been strengthening between 2000 and 2004, averaging 124 fish per kilometer per year compared to an average of 44 fish per kilometer per year during the four-year period before that (1996-1999). From 2002 to 2003 alone, there was an increase of 50 fish per kilometer. The 2003 spawning adults were the first juveniles reared in the project area that went to the ocean in the spring of 2001. The assumption is that juveniles of this year's class took advantage of both good rearing conditions in the new channel and good ocean conditions to produce the 2003 spawning numbers. Looking at other spawning counts in the surrounding area, Bailey Creek was one of the few areas that had an increase in 2003.

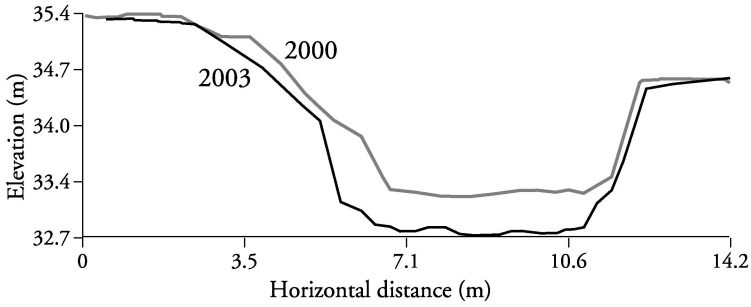


Figure 5: Permanent cross-section #24 in new Bailey Creek channel just below diversion from the old ditch to new channel. Between 2000 and 2003, the new channel down cut into silt loam bed material approximately one-third of a meter.

The new channel increased overall length by one-third, and the square meter pool volume doubled. Control data taken in the ditched channel above the project indicates that from 2001-2003, there were 1.5-2.0 times the number of juvenile coho compared to the two previous years sampled. At the same time, there was roughly a ten-fold increase in numbers of juvenile coho in the project area in 2001-2003. On a per-square-meter basis for 2003, the control estimate was 0.5 coho/m^2 while the project area estimate was 1.1 coho/m^2.

Although heavily browsed by elk, willows and planted vegetation are making progress in the riparian area of the design channel. Predictably, riparian vegetation in the pilot channel area has not done well due to the absolute dominance of reed canary grass in the lower valley that excludes all other species of plants, shrubs and trees. In the future, attempts may be made to establish willow in the pilot channel by using long willow stakes up to three inches in diameter pushed deep into the valley floor.

The Forest Service, Oregon Watershed Enhancement Board and the Oregon Department of State Lands spent $250,000 for the on-the-ground construction of 1.8 km (1.1 miles) of new meandering channel. The Forest Service spent another $250,000 on planning, design, implementation and monitoring through 2003 for an estimated total cost of $500,000.

Karnowsky Creek

The Karnowsky Creek watershed was acquired by the Forest Service in 1992. From the start, partnerships with the local Siuslaw Watershed Council and Soil and Water Conservation District were developed to assist in the restoration of the watershed. This collaboration resulted in the hiring of a student intern team to develop a whole-watershed restoration plan for the Karnowsky Creek watershed during the summer of 2001. The student team researched the history of the area, the potential for fish and wildlife habitat and plant communities, and wrote a well-researched and illustrated restoration proposal. Using this proposal, the partnership applied for funds from the Oregon Watershed Enhancement Board and the National Forest Foundation to implement the plan.

The goals of the Karnowsky Creek restoration project are similar to those in Bailey Creek: increase the amount and quality of coho salmon rearing habitat, reconnect the channel with its floodplain, and restore riparian vegetation. In addition, a network of groundwater monitoring wells is being measured on a monthly basis to see if replacing a downcut ditch with a meandering stream successfully raises the water table. Unlike Bailey Creek, there is less concern about downstream sediment deposition, which allowed a higher degree of freedom in the design from permitting agencies.

Methodology

As with Bailey Creek, the first step was producing a topographic map of the main valley and tributary valley floors with a contour interval of one foot (0.3 m) (Figure 6). Other data collected in the Karnowsky Creek watershed included several channel cross sections on the main ditch and tributary ditches, and discharge measurements taken during winter flow events. Part of the historic channel was still visible on a 1953 aerial photo, although much of that evidence of the historic channel had since been obliterated due to 70 years of agricultural use. Where the old channel was visible, it was used as a template for the new channel. Hoffman Creek was used as a reference stream, given that it is a nearby tributary of similar size and geomorphic setting that also drains into the lower Siuslaw River. Cross sections, pool dimensions, meander radius of curvature, pool/riffle ratio and reach gradient were measured throughout lower Hoffman Creek.

Unlike the pre-project ditch in Bailey Creek, there was more certainty that the main stem ditch in Karnowsky Creek had come into equilibrium with bankfull flows, and the size of the ditch would be a more accurate guide to the size of the new channel than using a flow equation. Bankfull discharge was calculated for the existing ditch by comparing results from a regional equation for small watersheds developed at Oregon State Univeristy (Adams et al. 1986), regional U.S. Geological Survey equations, and Manning's equation. As with Bailey Creek, a channel that overtops its banks frequently was the desired future condition, therefore, the new channel's cross-sectional area was designed 33% smaller than the ditch. It was assumed that the channel could more easily adjust to increase its cross-sectional area if it was undersized, than to decrease its cross-sectional area if it had been oversized.

Desired width/depth ratio, slope, and sinuosity of the new channel also had to be determined. The width/depth ratio is important, given that it is a major control on shear stresses on the banks and velocities within the channel. To determine whether the stream should be a Rosgen "C" (width/depth ratio > 12) or an "E" channel (width/depth ratio < 12) (Rosgen 1996), we used the width/depth ratio from Hoffman Creek (9.5), and referred to Rosgen's (1996) classification system to make our choice. We ran several width/depth combinations through Manning's equation and shear stress equations to compare the existing ditch's estimated discharge and shear stress with that calculated for the new channel. We decided on a width/depth ratio of 9.3; in other words, a relatively narrow channel. The

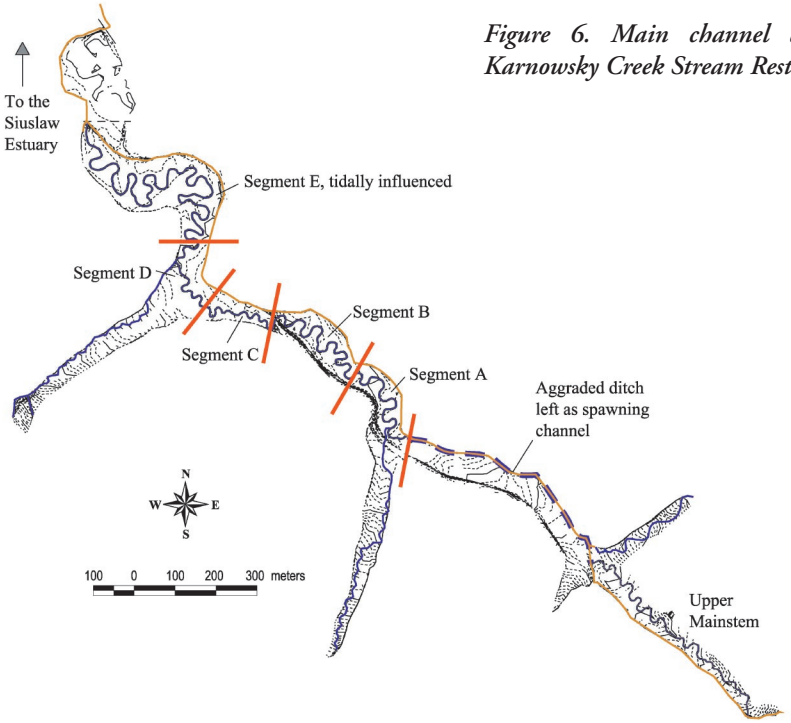


Figure 6. Main channel design segments, Karnowsky Creek Stream Restoration.

rationale was that the vegetation and root strength present in the valley will support the higher shear stresses and velocities found in an "E" channel, and a narrower, deeper channel would result in less direct solar heating in the stream in summer. Unlike the design for Bailey Creek, more variation in the size and shape of the meanders was included in the design for Karnowsky Creek (Williams 1986). Table 4 shows the new channel's dimensions and Table 5 shows the results of analysis with Manning's equation.

Slope and sinuosity are directly related. The upper part of the valley is slightly steeper, while the lower, tidally influenced part of the valley has a very low gradient. To fit the valley, the gradient of the newly designed stream gradually decreases from 0.39% at the homestead site to 0.11% in the tidally influenced zone. Sinuosity also increases down valley, from 1.9 to 2.8. In the tidally influenced zone, where frequent winter flooding occurs, we wanted to create as much fish habitat as possible. Therefore, two meanders were designed with narrow necks,

Table 4. New Karnowsky Creek channel dimensions by segments shown in Figure 6.

Channel Segment	Width	Riffle Depth	W/D Ratio	Cross-sectional Area	Gradient	Sinuosity	New channel length
A	4.3 m (14 ft)	0.46 m (1.5 ft)	9.3	5.6 m^3 (21 ft^3)	0.0039	1.9	393 m (1,278 ft)
B	4.3 m (14 ft)	0.46 m (1.5 ft)	9.3	5.6 m^3 (21 ft^3)	0.0028	2.2	546 m (1,773 ft)
C	4.3 m (14 ft)	0.46 m (1.5 ft)	9.3	5.6 m^3 (21 ft^3)	0.0038	1.6	356 m (1,157 ft)
D	4.3 m (14 ft)	0.77m (2.5 ft)	5.6	10.8 m^3 (35 ft^3)	0.0020	1.6	226 m (733 ft)
E	4.3 m (14 ft)	0.77m (2.5 ft)	5.6	10.8 m^3 (35 ft^3)	0.0011	2.8	1,356 m (4,406 ft)

Table 5: Testing the design parameters for the new Karnowsky Creek channel with Manning's equation.*

Channel Segment	Hydraulic Radius ("R")	Slope	Discharge "Q", m^3/s (ft^3/s)	Velocity "V", m/s (ft/s)	Calculated Ditch Bankfull Discharge m^3/s (ft^3/s)	Percentage of Bankfull Flow New Channel Will Carry
A	1.016	0.0039	14.93 (49)	0.72 (2.35)	26.51 (87)	56
B	1.016	0.0028	12.80 (42)	0.61 (1.99)	26.51 (87)	48
C	1.016	0.0028	17.37 (57)	0.50 (1.65)	26.51 (87)	66
D	0.983	0.0013	16.15 (53)	0.33 (1.07)	31.38 (103)	51
E	0.983	0.0011	13.10 (43)	0.37 (1.22)	31.38 (103)	42

**Manning's Equation: $Q = 1.486/n * AR^{2/3}S^{1/2}$, $V = 1.486/n * R^{2/3}S^{1/2}$*
n=roughness coefficient, 0.04 for Karnowsky Creek; A = cross-sectional area; R = hydraulic radius; S = slope

giving the stream an opportunity to cut off meanders and develop oxbows in the floodplain over the next several decades to a century. The loss of stream length would have a negligible effect on overall gradient and sinuosity.

Once the slope and sinuosity were established, the new channel was laid out on the base map and translated to the ground using the same methods developed in the Bailey Creek restoration. The new channel was fitted to the low points in the valley as much as possible. Developing the plan view involved several iterations. Points on the new channel's centerline were translated into survey coordinates, and the new channel's location was staked on the ground with the help of a professional surveyor (Figure 6). The centerline was fine-tuned and changes were resurveyed.

After we obtained the final survey data for the channel location and existing ground elevations, we entered it into a spreadsheet and calculated the expected bank heights in the new channel, assuming a constant stream gradient through a reach. The upstream and downstream locations for pools and riffles were added to aid channel excavation on the ground. As in Bailey Creek's new channel, all of the gradient change is taken up in riffles, and the upstream and downstream ends of pools are at the same elevation in the designed pool/riffle sequence.

Constructing the new mainstem channel took place in the late summer of 2002 (Figure 7). In the lower part of the valley, where wet soil conditions persist throughout the year, the excavated material was piled in mounds on the valley floor. This eliminated the need for dump trucks to haul the material, and the soil compaction that would have resulted. These mounds also provide topography in the floodplain that could be planted with spruce and cedar, allowing some elevation advantage over reed canary grass in the tidal zone.

During the first winter after construction, willow stakes were planted in the banks, and the floodplain was planted with trees and shrubs. Water was not flowing in the main channel, which gave the willows a chance to root and become established. During the second summer (2003), ditches were strategically plugged in several locations, and water was diverted into the new channel. Lessons learned in Bailey Creek were applied here. At the point of diversion, the new channel gradually slopes up from the old ditch's bed elevation, about a 0.6 m difference in elevation. Large logs were buried at grade in the new channel just downstream of the connection to prevent downcutting. In the fall of 2003, 130 large, whole trees were added to the new channel and floodplain by helicopter to create habitat and cover for fish (Figures 8 and 9).

Work during the summers of 2003 and 2004 included recreating step-pool channels in both the upper mainstem valley and three tributaries to the main valley (Figure 6).

Figure 7. Channel construction in lower Karnowsky Creek with a walking backhoe, summer 2002. Fill material taken from the constructed channel was shaped into floodplain hummocks that would later be planted with native trees and shrubs.

Figure 8. The new Karnowsky Creek channel with large wood added, winter 2003. New conifer seedlings are planted along the bank and protected by plastic tubing.

Figure 9: Lower Karnowsky Creek at high flow in new channel with added wood, spring 2004.

These intermittent channels flow through 3-5% valley gradients, and buried wood and boulders to serve as grade control are critical to channel reconstruction here. These channels were also seeded with gravels of the appropriate size for the slope and channel form of constructed riffles. Filling in of the extremely incised ditches on the valley margins was much more labor intensive than ditch filling in the lower valley. This required more haul by dump truck of borrowed fill material and layer placement of this fill in ditches to prevent robbing of the much needed water table in these side valleys and the upper mainstem. Work done in these intermittent channels will be ongoing through 2006.

Monitoring

As with Bailey Creek, annual monitoring includes low-elevation aerial photographs, 22 permanently-monumented cross sections, photo points, fall spawning surveys, and summer juvenile fish population monitoring. In addition, a network of 36 groundwater wells, set up before the project began, are being measured monthly to track changes in groundwater levels.

Results and Lessons Learned

Although the new Karnowsky Creek channel is too young to have significant monitoring results, we are already seeing abundant coho smolts and fry in the new channel. The channel functioned well through the first winter, with frequent floodplain inundation, particularly in the tidally influenced area (Figure 9). The willows and other riparian vegetation are growing very well, especially on constructed hummocks near the main channel. Point bars are already being deposited on the inside of meander bends in the lower channel, developing a natural channel morphology. Little, if any, bank erosion is evident. Some additional lessons learned include the following:

1. A strong collaborative partnership makes a large-scale restoration much stronger. Bailey Creek was primarily a Forest Service endeavor while Karnowsky Creek has many strong partners, and the second has far exceeded the success of the first.
2. Size the channel cross section based on both flow and bankfull cross section measurements if available. Accurate flow prediction is difficult in the Oregon Coast Range.
3. Variation and complexity of meander geometry is better. In nature, radius of curvature can vary from one to seven times bankfull width (Williams 1986). Much more variation was designed into Karnowsky's new channel than Bailey's, with better results.
4. Incorporating hummocks in the floodplain from construction fill can save on haul cost, limit soil compaction and provide needed elevation so native plants can out-compete exotics.
5. Armor abrupt elevation changes where water flows. Use natural materials and check elevations with a laser level to assure that neither head cutting nor downstream cutting will occur in high flow.
6. Contracts that pay equipment by the hour should be favored over lump sum construction contracts. In our case, we incurred a third of the cost using hourly contracts on the Karnowsky project. The added flexibility to make changes is also key to successful implementation.

The Forest Service, Oregon Watershed Enhancement Board and the National Forest Foundation spent $435,000 on channel construction, native vegetation recovery and helicopter wood placement on over 4.8 km (3 miles) of new meandering stream channel. When the project is completed, the Forest Service and partners will have spent an additional $165,000 on planning, design, monitoring and implementation of the design for an estimated total cost of $600,000.

Conclusions

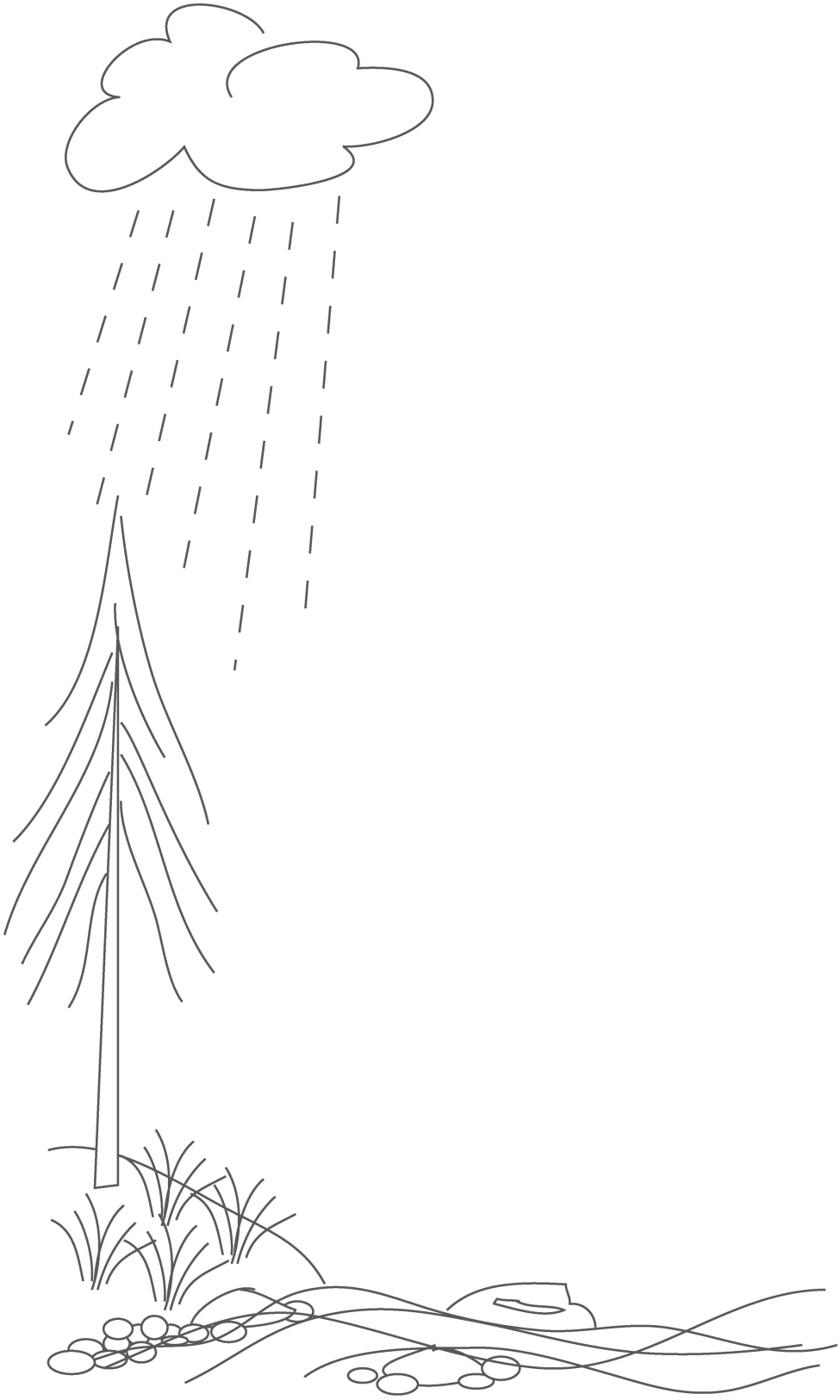
The restoration of meandering channels at Bailey and Karnowsky Creeks has created more productive fish habitat, and appears to be on track to meet the other goals of restoring wetland habitat and reducing overall sediment production. Projects like these require an intensive data-gathering and planning effort by an interdisciplinary team of hydrologists, geomorphologists, fisheries biologists, and surveyors, and benefit from review by other technical experts.

Literature Cited

Adams, PW, AJ Campbell, RC Sidle, RL Beschta, and HA Froelich. 1986. Estimating stream flows on small forested watersheds for culvert and bridge design in Oregon. Research Bulletin 55, Corvallis OR: Forest Research Lab, College of Forestry, Oregon State University, 8 p.

Giese, TP. 1996. Phosphorus export from the Clear and Mercer Lake watersheds, Oregon State University, M.S. Thesis, 136 p.

Rosgen, D. 1996. Applied River Morphology, Pagosa Springs, CO: Wildland Hydrology.

U.S. Department of Agriculture Forest Service, 2004. 2004 Enchanted Valley Monitoring Report, South Zone, Siuslaw National Forest, 27 p.

Williams, GP. 1986. River meanders and channel size. *Journal of Hydrology*. 88:147-164.