# Fisheries

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**Getting "Sex" Right**

**Mimicking Beaver in Stream Restoration**

**Financial Information for Prospective Graduate Students**

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# Fisheries

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Cover: *Castor canadensis*, Minette Layne

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# Emulating Riverine Landscape Controls of Beaver in Stream Restoration

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**ABSTRACT:** *Stream and floodplain restoration at the reach scale has ranged from expensive, heavy-handed modification of the channel and floodplain to simple, longer-term revegetation efforts. We have developed and implemented a simple approach that emulates the ecosystem engineering effects of beaver. This approach is less expensive and disruptive than typical large-scale engineering efforts and has the potential to restore both fish habitat and floodplain vegetation more rapidly than simply revegetating and waiting for the riparian zone to mature. The approach involves constructing log flow-choke structures that mimic the hydraulic function of a natural beaver dam during flooding. By placing these structures throughout a naturally entrenched stream reach at locations promoting increased frequency of flood connection with floodplain swales and relict channels, we set the stage to restore the riparian corridor and floodplain more quickly than could be achieved through revegetation alone. Monitoring shows that within just one to two years of implementation, beaver are building more persistent dams in close proximity to our structures, and we are seeing increased hydraulic connectivity with the floodplain. Our technique may therefore provide a cost-effective, natural process–based restoration tool with potential large-scale benefits.*

## Emulación del control de paisajes fluviales ejercido por castores bajo un contexto de restauración ribereña

**RESUMEN:** *El gradiente de restauración ribereña y de planicies de inundación puede ir desde una importante modificación artificial de canales y llanuras inundables, hasta esfuerzos de reforestación a largo plazo. En este estudio se desarrolló e implementó un enfoque que emula los efectos a nivel de ecosistema que tienen las construcciones hechas por los castores. Este enfoque es menos costoso e invasivo que los típicos esfuerzos de ingeniería a gran escala, y tiene el potencial de poder restaurar tanto el hábitat de los peces como la vegetación de las planicies de inundación más rápidamente que la práctica de sólo reforestar y esperar a que el área ribereña madure por sí misma. Este enfoque consiste en la construcción de estructuras hechas a base de troncos que controlan el flujo de agua, emulando la función hidráulica de las presas construidas por los castores. La colocación de dichas estructuras en lugares donde el agua se confina de forma natural a lo largo de sitios que promueven la comunicación con canales tributarios y llanuras de inundación, representa la infraestructura que sirve para restaurar el corredor ribereño y las planicies de inundación más rápidamente que lo que pudiera lograrse sólo mediante la reforestación. Un seguimiento muestra que tras dos años de la implementación del enfoque, los castores están edificando presas más resistentes en sitios próximos a las estructuras, y se aprecia un incremento en la conectividad hidráulica con las llanuras de inundación. Esta técnica, por lo tanto, representa una herramienta de restauración de bajo costo y basada en un proceso natural con beneficios potenciales observables a gran escala.*

## INTRODUCTION

Beaver (*Castor canadensis*) are ecosystem engineers that have important influences on riparian and aquatic habitats, river morphology and valley channel grade (Ruedemann and Schoonmaker 1938; Gurnell 1998; Westbrook et al. 2011). Their dams and impoundments can control the composition and density of riparian and wetland plants, quality and quantity of fish habitat, and fluvial erosion and sedimentation (Naiman et al. 1988; Pollock et al. 2007; Burchsted et al. 2010). Historic beaver trapping decimated many populations, and various management activities, such as maintaining culverts under roads and reclamation of land for grazing or development, resulted in the killing or relocation of beaver (Naiman et al. 1988). Clearing of riparian forests for grazing, timber harvest, and other purposes resulted in widespread loss of riparian forests and scrub–shrub wetland vegetation critical to establishment and maintenance of beaver populations. Beaver-generated off-channel water bodies provide significant juvenile salmonid rearing habitat, and their loss has had potentially profound effects on salmonid production (Murphy et al. 1989; Pollock et al. 2004; Rosell et al. 2005). More broadly, beaver are important for maintaining ecosystem richness at the landscape scale because they provide habitats for obligate wetland species that might otherwise not exist within the riparian zone (Wright et al. 2002; Rosell et al. 2005). Restoration efforts across the United States and Canada have recognized these important influences of beaver,

even when struggling with the need to balance restoration efforts with the potential nuisance effects of beaver dams (e.g., Finnegan and Marshall 1997; Wilson 2001).

A positive feedback cycle may exist where historic beaver trapping and removal of trees and shrubs used by beaver have resulted in local extirpation or significant reductions in beaver population size. In this event, neither beaver populations nor beaver-generated fish habitat will recover until riparian vegetation is restored (Pollock et al. 2004; Figure 1). Recovery of beaver-generated floodplain wetlands and their wet meadow, scrub–shrub, and forested plant communities is dependent upon the restoration of lost hydraulic linkages between the channel and its floodplain through annual flood pulses and a locally high water table (Westbrook et al. 2006). However, water availability may not be sufficient in some environments, including arid or semi-arid climates, entrenched and incised channels, and locations where soil characteristics restrict infiltration and water retention for spring plant growth. In such circumstances, beaver were likely the historic mechanism that supplied riparian vegetation with sufficient water to establish and maintain trees and shrubs. Importantly, this codependent mechanism is not adequately recognized or utilized in the stream restoration toolbox (Pollock et al. 2011).

"Plant-it-and-they-will-come" restoration strategies focus on restoring riparian vegetation with the assumption that beaver populations will reestablish when plant communities are capable of supporting them (Albert and Trimble 2000; Pollock et al. 2011; U.S. Forest Service 2011). However, successful beaver recolonization and riparian vegetation restoration may require long periods of time when the positive feedback mechanism (Figure 1) has been activated. We present a case study demonstrating this problem and the stream restoration method that we used to provide an ecosystem "kick-start" that emulates the mechanisms driving natural floodplain connectivity. We also

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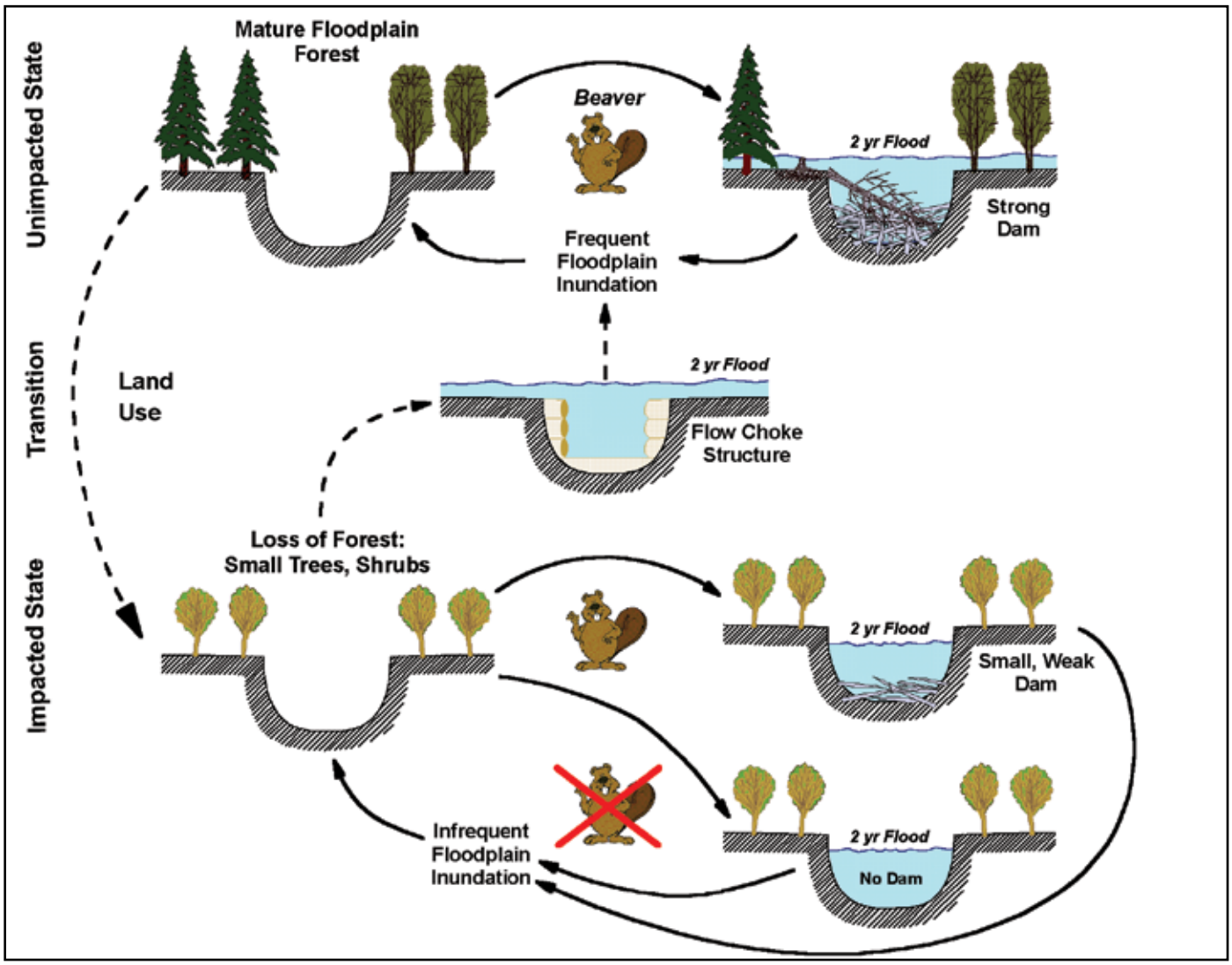


**Figure 1. Conceptual model of the feedback cycle between beaver, flood levels, and floodplain forests in natural and impacted stream systems, illustrating how the structures discussed in this article can be used to restore the system. Dashed lines represent transition paths between natural and impacted states.**

briefly discuss preliminary monitoring to assess the effectiveness of our method and guide future restoration designs. We believe that our simple approach has the potential to simultaneously restore riparian plant communities, along with fish and beaver habitat, and that it can do so in less time than replanting alone in many regions of Western North America.

## THE RIVER AND RIPARIAN RESTORATION PROBLEM IN BENEWAH CREEK, IDAHO

### Physical Setting

Benewah Creek drains to Benewah and Coeur d'Alene lakes in northwestern Idaho (Figure 2). The stream supports adfluvial and resident populations of westslope cutthroat trout (*Oncorhynchus clarkii*) and flows through several mountain meadow valleys that likely provided large quantities of high-quality spawning and rearing habitat in the past. However, extensive land clearing and grazing activities have resulted in bank erosion and widespread loss of riparian vegetation, leading to elevated water temperatures and fine sediment levels, loss of in-stream wood, and subsequent changes in channel morphology. These changes have in turn resulted in the loss of in-channel and riparian habitat and have likely contributed to fish population declines (Meehan 1991).

The channel is entrenched in many locations, and higher frequency floods during the critical spring snowmelt period no longer inundate the floodplain, resulting in a groundwater table during spring and summer that is approximately 1.2 m below the floodplain surface (June–August average, 2008–2010; Coeur d'Alene Tribe data). Reestablishment of riparian vegetation is hindered by insufficient water at or near the surface to support historic wetland wet meadow, scrub–shrub, and riparian gallery forests. Initial efforts to restore the riparian zone have therefore met with limited success, because the growth of plantings is inhibited by water availability in this semi-arid environment. In addition, impacts to the historic floodplain forest, which provided root cohesion to stream banks, has resulted in reduced stream bank stability and consequent lateral bank failures throughout the course of Benewah Creek. Until a mature native floodplain forest is established, aquatic habitat will remain degraded.

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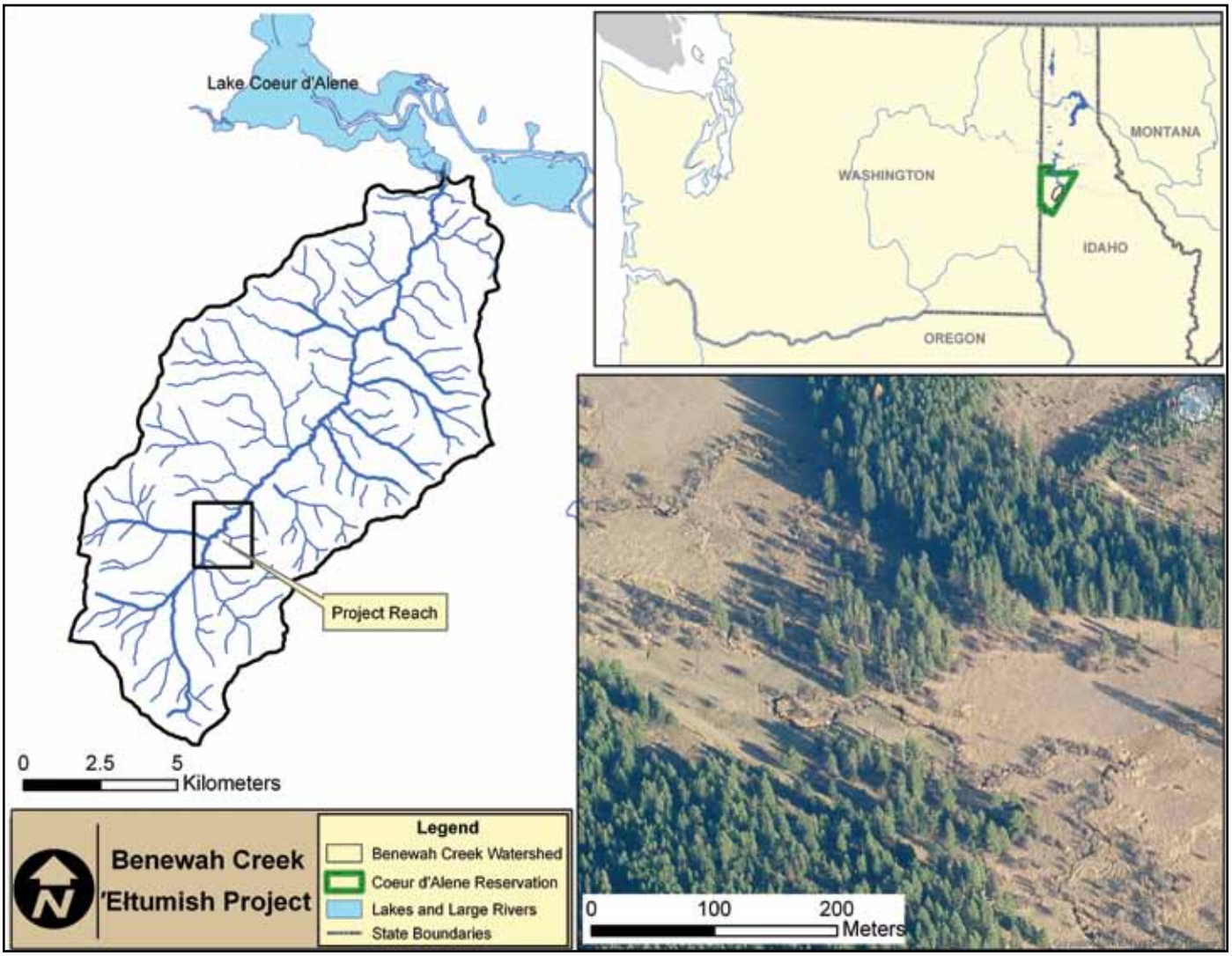


**Figure 2. Map showing the location of the Benewah Creek Restoration Project near the community of Benewah, Idaho, and a representative view of the floodplain.**

## Assessing the Problem and Developing a Solution

We focused on developing channel, floodplain, and plant community restoration designs for an approximately 2.7-km entrenched reach of Benewah Creek flowing through a wide valley bottom with 0.4% gradient. Riparian vegetation is dominated by mountain alder (*Alnus incana*), black hawthorn (*Crataegus douglasii*), and reed canary grass (*Phalaris arundinacea*). Remnant willow (*Salix* spp.) communities and cottonwood gallery forests (*Populus balsamifera* spp. *trichocarpa*) are also found in the basin, but intensive grazing resulted in their general absence within the project reach. Bank erosion is also extensive in heavily grazed locations (Figure 3).

**A plausible hypothesis was that beaver historically played an important role by constructing dams that raised water levels during spring runoff.**

We based our initial restoration designs on a prevailing hypothesis that the entrenched channel form was the result of incision caused by land use. This hypothesis was based in part on the observation that floodplain inundation is presently restricted to flows higher than the approximately 5-year return interval event, whereas a more typical alluvial channel would have been expected to overflow onto the floodplain at an approximately 1.5- to 2-year interval (Leopold et al. 1995). The corresponding level of incision was estimated to be approximately 1 m. Conventional solutions to this problem include (1) extensive earthwork construction of raised grade controls and riffles in the incised channel and/or (2) relocating the stream to relict or new channels. We settled initially on the second approach, using valley-wide floodplain stratigraphy to define the appropriate riffle control elevation for design. In doing so we hypothesized that if the channel had incised as suggested by flood hydrology, there would be stratigraphic layers of alluvial gravel in the adjacent floodplain located at elevations that were higher than in the present channel. The elevation of alluvial gravel deposits in relict channels would accordingly define the design thalweg elevation and new channel width needed to convey bank-full flow. Woody debris structures would be constructed in the channel to provide energy dissipation, bank protection, grade and channel meander control (if necessary), and fish habitat until a mature riparian plant community was restored.

To test this hypothesis, test pits were excavated at four relict channel locations distributed across the valley floor to determine the depth to historic alluvial gravel deposits. Three test pits were dug at each location, one at the relict channel centerline and one on the floodplain to each side of the relict channel. However, test pit results provided direct evidence of an alternative channel forming process, leading us to reconsider the historic mechanism whereby floods may have engaged the floodplain on an approximately annual basis. Floodplain stratigraphy did not indicate alluvial gravel deposits at elevations consistent with geologically recent (i.e., within the past 200 years) incision. Instead, test pit excavations consistently revealed a cobble-gravel layer at elevations comparable to those found in the current channel thalweg at cross-valley riffle and eroding stream bank locations. The soil profile above the cobble-gravel or silt clay loam layer was classified in soil maps as a relatively uniform, poorly draining silt loam originating from loess, volcanic ash, and alluvial deposits (Weisel 1980). The silt loam soil that was consistently found in all test pits and soil auger samples that we collected during wetland delineations indicated that the upper soil profile was formed predominantly through wind-borne deposition (i.e., loess). Two ash layers were consistently found below the surface in the test pits, representing deposition from the Mount St. Helens and Mount Mazama eruptions. Prominent alluvial deposits of silty sand were not found in any of the test pits above the gravel and silty clay loam mantle, indicating that valley soils were predominantly loess deposits and that relict channels may have been inactive for thousands of years. Charcoal fragments and dead roots were also found at depths between 0.1 and 1.3 m in all test pits, indicative of woody vegetation and fire occurring historically throughout the valley bottom. Finally, aerial photography indicated that channel location and sinuosity have not changed substantially in the reach since the 1930s.

Given these findings, we concluded that the project reach floodplain was not predominantly alluvial, the channel had likely not incised significantly, historic channel migration had occurred slowly, and the natural width : depth ratio was likely narrower than would be expected for a typical alluvial channel. In view of the relatively long return period of floods needed to inundate the current floodplain and the evidence of an extensive historic floodplain forest in poorly drained soil, some process other than alluvial channel mechanics must have supplied overbank water for woody vegetation growth and maintenance during spring runoff.

A plausible hypothesis was that beaver historically played an important role by constructing dams that raised water levels during spring runoff (Ruedemann and Schoonmaker 1938; Naiman et al. 1988; Rosell et al. 2005). The resulting flow obstructions would have provided a mechanism for floodplain connectivity, thereby promoting maintenance and growth of riparian vegetation (Figure 1; Westbrook et al. 2006). Following removal of the valley forest, beaver trapping, and 70+ years of cattle grazing, the effective flood level control provided by flow obstructions, along with the associated upstream gravel accumulations, was likely removed, resulting in less frequent and shorter duration inundation of the valley floor during spring runoff events. This may, in turn, have hindered recovery of the floodplain forest, thereby decreasing the availability of large wood. Indeed, the lack of large wood throughout the project reach may explain in part the high rates of annual dam turnover and the apparent overall instability of active beaver dam complexes that have been documented in recent surveys (Vitale and Firehammer 2011). Only 26% of dams surveyed were built with or upon stable materials such as large woody debris. Most were built using small alder pieces and were either substantially compromised or destroyed during ice breakup and peak flow periods that occurred during winter rain-on-snow events and spring runoff. Dams that persisted were generally located

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**Figure 3. Tall banks eroding in the project reach have a generally undifferentiated silt loam mantle over a gravel layer. Photo credit: Paul DeVries.**

in areas with a relatively intact riparian forest and large wood present in the channel. Given these changes and observations, we felt that a means of increasing flood frequency and duration should be included in restoration planning to accelerate the recovery of woody floodplain vegetation. Assuming that these functions were historically supported by beaver dams, we then decided that a highly efficient solution may be to construct temporary structures that would emulate the hydraulic effects of beaver dams and to ensure that they would persist long enough for larger trees to become established that could subsequently be used by beaver (Figure 1).

## EMULATING EFFECTS OF A BEAVER DAM TO PROVIDE AN ECOSYSTEM KICK-START

We began with an assessment of existing beaver dams in Benewah Creek, which are constructed primarily of small mountain alder pieces (generally the only material available) and are sited primarily at riffle crests, conceivably to minimize material needs and dam building effort. We then attempted to emulate the flow obstruction effects of beaver dams and natural wood jams by installing flow-choke structures constructed of large logs. The structures were designed to promote more frequent and extensive channel–floodplain connections during spring floods. It would also be cost effective compared with the more disruptive and expensive excavation methods used to construct raised bed riffles and new channels. For example, channel reconstruction (as described above) was completed at an average cost of US$260/m in downstream reaches. Installation of flow-choke structures cost about US$2,700 per structure, which equated to an estimated US$25/m to US$50/m for an equivalent level of flood flow engagement for a 0.4% stream gradient (time and materials).

Structures were sited primarily at locations where a raised backwater would increase the frequency with which key floodplain flow paths were connected during floods (Figure 4). In locating a structure, we used the Hydrologic Engineering Centers River Analysis System (HEC-RAS; U.S. Army Corps of Engineers) and compared the results with a light detection and ranging (LiDAR)-derived topographic contour map to project the upstream extent of the backwater effect at the estimated bank-full flow rate. This was also used to avoid impacts to private property where increased flooding might be perceived as a negative result. We are currently following this approach in stages, where the first structures were installed in the most obvious locations based on floodplain topography. The locations of additional structures will be based on monitoring of completed structures and flooding patterns, as well as the observed spacing of natural beaver dams. We noted in our surveys that 80% of the observed dams ranged between 15 and 90 m apart, with a median spacing of 52 m.

Because we were not able to identify an optimal structure design a priori, we experimented with two types of engineered flow-choke structures as a form of design hypothesis testing. Both designs used log "walls" with an appropriate hydraulic constriction to back up water to the floodplain level at approximately the target bank-full flow. The first, simpler design functioned by choking stream flow from the sides and directing weir flow over a sill log (Figure 5a). The second, more complex

design utilized both weir (over-) and orifice (through-) flow, with lateral as well as vertical constriction, and sufficient depth over the weir log to permit passage of ice jams and floating debris at the bank-full level (Figure 5b). The weir was designed to direct water flowing over it into the jet flowing out of the orifice situated underneath, thereby disrupting and dissipating energy during high flows. General weir and orifice flow equations were integrated in a spreadsheet to estimate total flow rate for a given width and depth of weir overflow and orifice through-flow (e.g., King et al. 1948). The spreadsheet was used to identify suitable combinations of width and depth of the orifice and weir specifications. All structures extended deep enough to account for predicted scour depths and extended far enough into the floodplain to preclude lateral erosion around the structure. Bank-full flows were constrained by the top logs to remain within the intended bank-full width. Rock was placed downstream as a scour countermeasure, to protect the integrity of the structure. The rock was sized to result in an acceptable scour pool depth. The scour pool provides energy dissipation, pool habitat, and a leaping pool for upstream trout passage. A deposit of finer gravel, sized to be comparable to stones occurring naturally in the river banks and bed, was placed on the bed of the upstream side of the structure to reduce turbulence of the approach flow, seal the structure against piping, and provide cutthroat trout spawning habitat. The resulting morphology resembled gravel deposits observed on the upstream side of natural logs in Benewah Creek.

The sill elevation of each orifice or weir was designed to emulate low-flow control elevations established by beaver dams present in the reach while avoiding conditions that may constrain upstream fish passage or cause excessive sedimentation problems. Median depths of existing dams in the reach were 0.35 m at the riffle crest and 0.98 m below the floodplain (Figure 6). These values served as natural, reference design criteria for specifying the sill control elevation and the depth of impounded gravel upstream. Should beavers seal up the structure using available materials, it was hypothesized based on the transient nature of similarly constructed, existing dams that they would break down during floods and not result in substantial additional impoundment depth or sedimentation over the near term until the natural cycle depicted in Figure 1 was restored. In addition, assuming that beaver dams built atop the structures would not survive spring floods, the head difference between the groundwater and stream channel during low-flow summer months would also not be reduced substantially from current conditions. This was viewed as important given that groundwater inputs at the site are crucial for maintaining favorable summer water temperatures in the absence of a riparian forest. Downstream, where the valley width is more confined and thus groundwater inflow rate is expected to be less, summer temperatures more frequently exceed an optimal growth criterion for trout (>17°C; Figure 7; see Bear et al. 2007). Once the riparian forest is reestablished, we hypothesize that additional ponding by stronger beaver dams will have less of an adverse effect on summer water temperatures.

Another important consideration is fish passage, which can be a problem at low flows over a flat log. Designing for a low-elevation sill and a scour pool allows fish to jump upstream over the log sill during low flow. A small V-notch can also be cut into the sill log where upstream passage is a concern during low summer flow. At other flow levels, the sill is designed to be low enough that fish can swim upstream through the opening. A sill elevation that is too high can be avoided by narrowing the orifice and weir openings to choke high flows. To date, none of our structures appear to have presented an upstream passage barrier.

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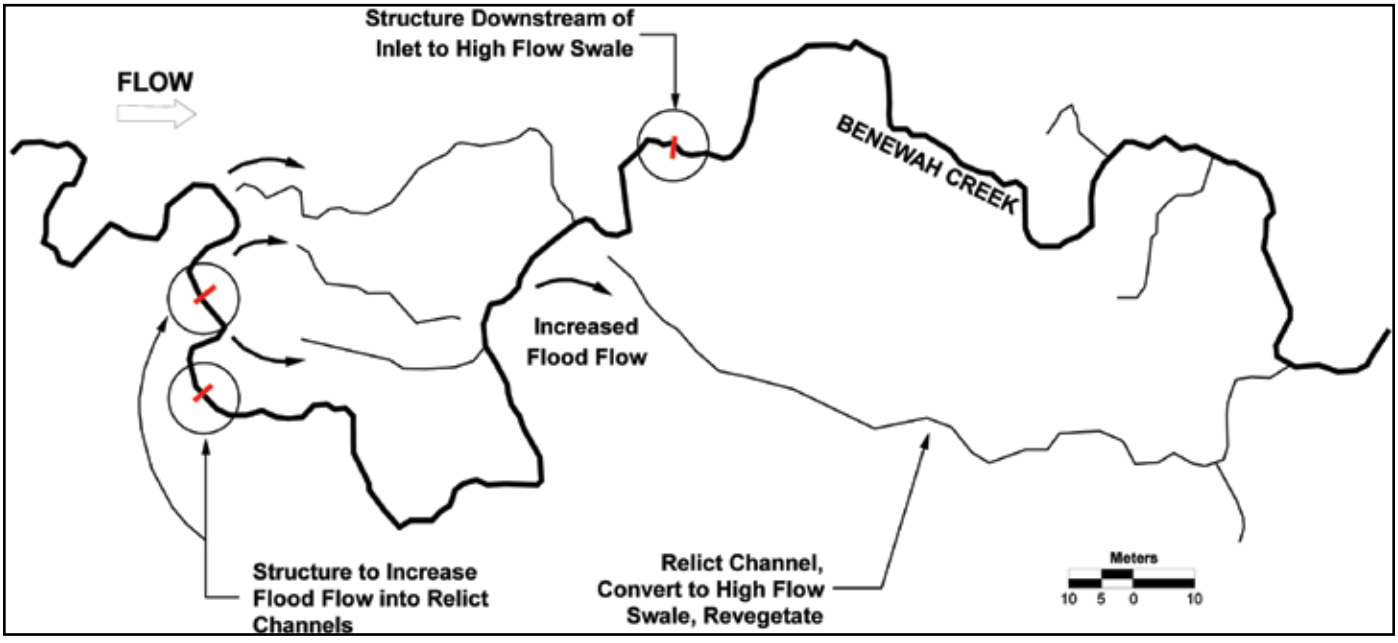


**Figure 4. Locations of proposed flow-choke structures (red lines) relative to floodplain flow paths and floodplain restoration goals in Benewah Creek.**

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**Figure 5. Two types of flow-choke structures were built: (a) with a simple contracted weir and (b) with a combined orifice and weir. Both structures impound water during high flow and are strong enough to withstand ice jams. Photo credits: Paul DeVries and Angelo Vitale.**

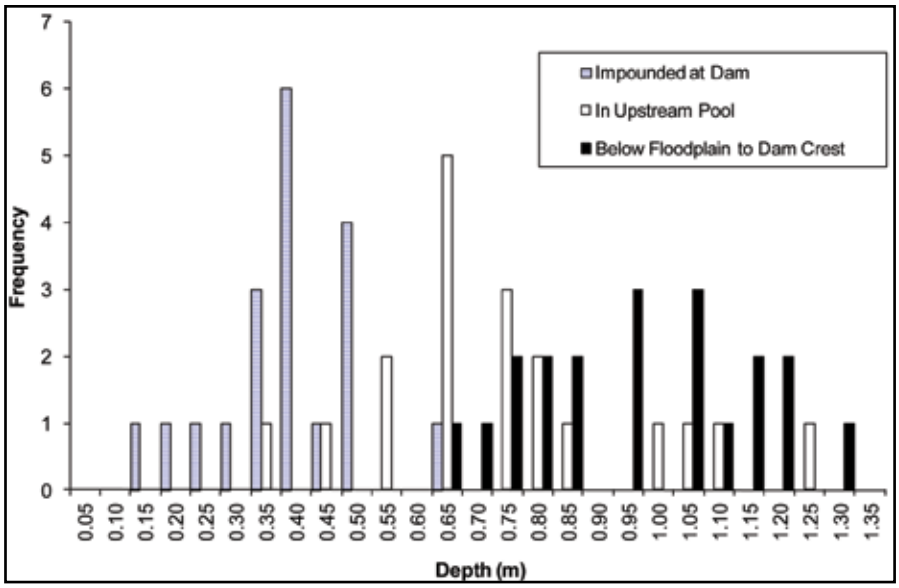


**Figure 6. Frequency distributions of water depths at and in pools upstream of beaver dams in Benewah Creek and depths from the general floodplain elevation down to the dam crest. Data were obtained prior to restoration and provided design guidance for the structures.**

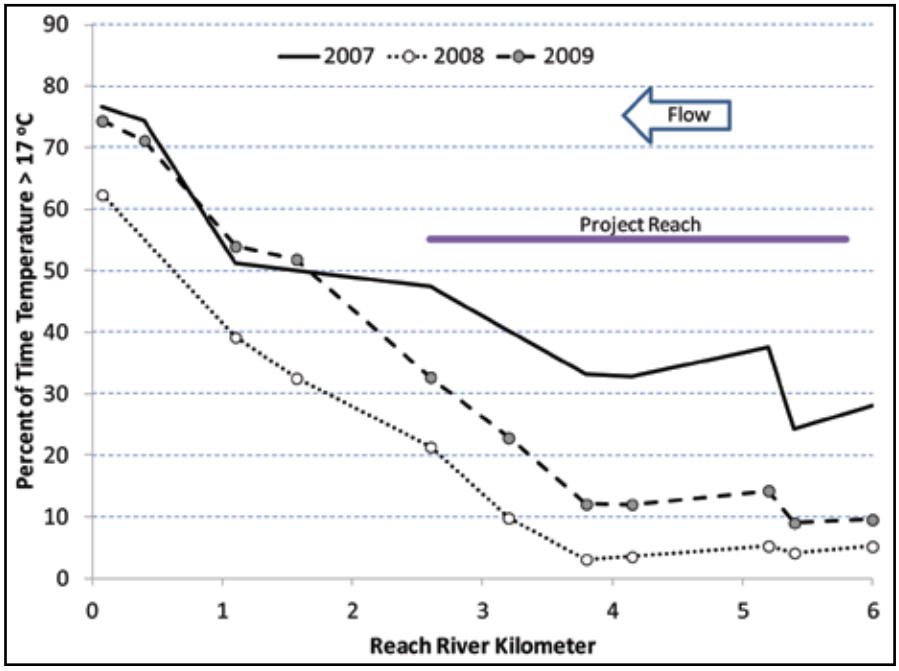


**Figure 7. The frequency with which water temperatures exceed that needed for optimal growth of cutthroat trout (>17 °C; Bear et al. 2007) during July and August, the warmest part of the year in upper Benewah Creek.**

We also utilized a passive approach by placing two to four large logs in the channel to provide a more durable foundation that beavers could use in dam construction (i.e., "beaver assist structures"). This was based on observations that the most persistent, existing dams throughout the Benewah Creek stream corridor are built with mountain alder integrated with remnant in-channel large wood. MacCracken and Lebovitz (2005) found that this technique can work when the channel is unconfined with a wide floodplain, there are no logjams nearby, and deep pools and banks suitable for beaver dens are nearby. Individual logs were placed across the channel bottom at riffle crest locations between the engineered structures and wedged between small boles driven vertically into the substrate. Fresh black cottonwood and Aspen cuttings were also placed along the stream banks above the log structures to encourage beavers to complete dam construction (Muller-Schwarze and Sun 2003).

## PROJECT PERFORMANCE

A key strength of our design is that it is an experimental approach to emulating the effects of beaver dams on channel and floodplain processes. Accordingly, we are monitoring the hydrologic and hydraulic performance of the flow-choke structures, beaver assist structures, and local floodplain wetland response to assess whether we have succeeded in emulating the geomorphic and ecological effects of beaver dams, and to provide us with empirical data to guide future design revisions. For example, we noted after the second year of monitoring that downstream scour protection is more critical for the orifice–weir combination structure than for the simple weir. The flow patterns are more complex for the combination structure, where the weir overflow nappe appears to interact with the orifice jet to create more turbulence near the bed than was anticipated. The simple weir structure has been found to have smaller scour depths downstream that are more consistent with predictions based on hydraulic engineering literature.

We note that the choke structures were not designed to increase summer pool habitat. This is important because natural beaver dams can increase the surface area and depth of pool habitat in Benewah Creek. Our surveys indicate, however, that most dam building activity occurs later in the summer, suggesting that trout may not benefit from increased thermal refugia and habitat cover during the warmest mid-summer periods (e.g., Ebersole et al. 2003; Firehammer et al. 2010). The loss of unstable dams during high flows and ice breakup may also contribute to poor overwinter survival in mainstem habitats because both juvenile and adult cutthroat trout are known to use deep pools as winter refugia in small stream systems (Brown and Mackay 1995; Jakober et al. 1998; Harper and Farag 2004; Lindstrom and Hubert 2004). Our observations to date indicate that persistence of natural dams and the benefits they provide to trout (i.e., summer and winter pool habitat) are greater when located within the high-flow inundation zone created by our engineered structures.

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Importantly, from the riparian floodplain restoration perspective, we have documented overbank flows across the valley bottom at discharges equal to the approximately 1.5-year return interval flood in the vicinity of our structures. Other reaches without stable beaver dams require much higher discharge for overbank flow. Thus, we are already seeing intended results, where floodplain flow path swales and relict channels are more frequently engaged and those that have been replanted are already showing good growth. The Coeur d'Alene Tribe Fisheries Department will continue to monitor the project and report results in the future.

## SUMMARY

Natural beaver activity can be an efficient tool to restore stream channels when abundant food and dam building materials are available (e.g., Ruedemann and Schoonmaker 1938; Olson and Hubert 1994; Albert and Trimble 2000). However, our approach can be applied in streams where riparian resources are insufficient to support beaver reintroduction. Installing structures that emulate the hydraulic effects of beaver dams should facilitate accelerated recovery of natural channel and riparian forest in reaches where a positive feedback mechanism exists between beaver activity, flood frequency and extent, and riparian tree growth. This technique can potentially be used in any stream disconnected from its floodplain where vegetation restoration is desired in conjunction with either beaver reintroduction or beaver nuisance control strategies. Notably, this method may allow more rapid and cost-effective restoration of dynamic riverine, floodplain, and wetland ecosystems than basic replanting efforts. Furthermore, by not substantially raising the low-flow water surface elevation, it should have a minor or negligible effect on groundwater inflow rates and can therefore help to maintain cool summer water temperatures for trout until the riparian canopy is restored. Our approach is simple and relatively inexpensive and should greatly accelerate restoration of riparian habitats and the organisms that depend on them.

## ACKNOWLEDGMENTS

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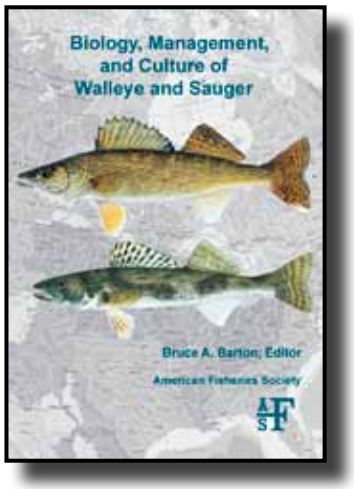
## Biology, Management, and Culture of Walleye and Sauger

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