The Beaver Restoration Guidebook

Working with Beaver to Restore Streams, Wetlands, and Floodplains

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Photo credit: Worth A Dam Foundation (martinezbeavers.org)

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We have tried to identify, recognize, and fully acknowledge the work and ideas of others, but undoubtedly, there are omissions. If there are statements, facts, figures, or images that are not properly attributed, please let us know and we will make the appropriate corrections on the next version. Please send corrections to Gregory Lewallan at glew2@pdx.edu.

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About This Guidebook

Michael M. Pollock, Janine Castro and Greg Lewallen

Beaver as a Partner in Restoration

More and more, restoration practitioners are using beaver to accomplish stream, wetland, and floodplain restoration. This is happening because, by constructing dams that impound water and retain sediment, beaver substantially alter the physical, chemical, and biological characteristics of the surrounding river ecosystem, providing benefits to plants, fish, and wildlife. The possible results are many, inclusive of: higher water tables; reconnected and expanded floodplains; more hyporheic exchange; higher summer base flows; expanded wetlands; improved water quality; greater habitat complexity; more diversity and richness in the populations of plants, birds, fish, amphibians, reptiles, and mammals; and overall increased complexity of the riverine ecosystems.

In many cases these effects are the very same outcomes that have been identified for river restoration projects. Thus, by creating new and more complex habitat in degraded systems, beaver dams (and their human-facilitated analogues) have the potential to help restoration practitioners achieve their objectives. Beaver can be our new partner in habitat restoration.

Yet even though the potential benefits of restoring beaver populations on the landscape are numerous, so, too, is the potential for beaver/human conflicts. These conflicts can arise from an overlap of preferred habitats by both humans and beavers, misunderstandings of how beavers modify their habitats, and a lack of planning or use of adaptive management on restoration projects. Reviewing the information provided in this guidebook will help interested parties approach beaver-based restoration from a more informed perspective, so that they can manage expectations and increase success.

Goals of This Guidebook

This guidebook provides a practical synthesis of the best available science for using beaver to improve ecosystem functions. If you are a restoration practitioner, land manager, landowner, restoration funder, project developer, regulator, or other interested cooperator, this guidebook is for you.

Our overall goal is to provide an accessible, useful resource for those involved in using beaver to restore streams, floodplains, wetlands, and riparian ecosystems. Although the guidebook summarizes current information about how to use beaver in restoration and conservation, the knowledge base on this subject is rapidly expanding. This means that not all of the information provided has been peer-reviewed in scientific journals; some of it is instead based on the real-life experience of restoration practitioners who are conducting ongoing experiments on using beaver to restore habitat. Thus the guidebook is a compilation of the current best available science, and we expect to update it regularly as the science progresses, readers provide information from their ongoing restoration experiments, or from restoration efforts of which we are currently unaware. See Table 1 for the different types of data presented in this document and the relative ranking we used for assessing scientific credibility.

Much of the information presented here is applicable across the beaver's range, but the guidebook focuses on beaver restoration in the western United States. Much of the interest in beaver restoration is occurring in the context of restoring habitat for declining populations of Pacific salmon and trout while simultaneously improving stream flows, particularly in drought-prone regions.

Structure and Content

The chapters of this guidebook fall into two broad sections; beaver ecology (chapters 1-3) and beaver restoration and management Chapters 4-10. The "Beaver Ecology," chapters discuss both the general life history characteristics and the effects that beaver dams have on physical and biological processes within river ecosystems. This is includes "Frequently Asked Questions" about beaver (Chapter 2) and beaver "Myth Busters" (Chapter 3), which dispel common myths or misperceptions about beaver, including those that, unfortunately, can influence funding and permitting decisions. Readers already familiar with beaver ecology may opt to skip the first section and move directly to the latter portion of the guidebook, which addresses topics related to beaver restoration and management.

Chapters 4 through 8 discuss common emerging techniques for using beaver and beaver dams (both natural and human created or assisted dams) to improve ecosystems; Chapter 9 describes methods for mitigating the unwanted effects of beaver activity; Chapter 10 introduces the Beaver Dam Viability Matrix, which grew out of the Project Screening Risk Matrix—one of several tools generated by the River Restoration Analysis Tool Project (RiverRAT), a broad federal effort to more efficiently and effectively evaluate stream management proposals; and Chapter 11 presents real-life examples of pioneering practitioners who have used beaver restoration tools in the field.These case studies include lessons learned that will help guide future restoration efforts.

Future Resources

We originally intended to include a chapter on "Beaver Rules and Regulations" as they pertain to restoration in western states, but the process of researching this subject revealed a confusing patchwork of state, federal, tribal, and even local rules governing beaver and beaver dams that varies by land ownership, state and federal agencies, and other factors. Untangling the web of rules and policies into a tractable discussion was beyond the scope of this initial document, but we hope to pursue this topic in the future and appreciate any relevant information that readers want to provide.

We have also developed a comprehensive beaver ecology library of more than 1,400 references from scientific journals, "gray" literature, websites, legislation, regulations, and presentations that is available for readers either in Endnote or as a text document. We have copies of many of the articles and are building a library of beaver articles, with particular emphasis on the more obscure references that are difficult to obtain from the Internet. Yet, as comprehensive as this library might sound, many references related to beaver ecology are not yet included, particularly those from the gray literature. We look forward to including additional references as they are provided by readers.

Finally, since this is a "living document", we will be updating regularly, including the addition of other beaver restoration-related products so please check the US Fish and Wildlife website for the latest information: **http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Beaver.asp**

We will also be sending out occasional notices when updates to the beaver restoration guide become available or additional tools are produced. It won't be quite as smooth as the automatic software updates on your phone or computer, but we will do our best. Thank you for your interest. We hope that this guidebook facilitates beaver restoration approaches underpinned by sound scientific principles, such that a more comprehensive, evidence-based understanding of beaver ecology, restoration, and management emerges.

Table 1. Common sources of scientific information (adapted from Washington Administrative Code 365-195-905). Information can be considered scientific if its source has the characteristics in Table 1. Table 1 provides a general indication of the characteristics of valid scientific information typically associated with common sources of scientific information and in general order of reliability. Each source of information (including peer-review articles) needs to be evaluated carefully to ensure it contains the characteristics described below.

	Characteristics					
Sources of Scientific Information	Peer Review	Methods	Logical Conclusions, Reasonable Inferences	Quantitative Analysis	Context	References
A. Research. Research data collected and analyzed as part of a controlled experiment (or other appropriate methodology) to test a specific hypothesis.	X	X	X	X	X	X
B. Monitoring. Monitoring data collected periodically over time to determine a resource trend or evaluate a management program.		X	X	O	X	X
C. Inventory. Inventory data collected from an entire population or population segment.		X	X	O	X	X
D. Survey. Survey data collected from a statistical sample from a population or ecosystem.		X	X	O	X	X
E. Modeling. Mathematical or symbolic simulation or representation of a natural system. Models are generally used to understand and explain occurrences that cannot be observed directly.	X	X	X	X	X	X
F. Assessment. Inspection and evaluation of site-specific information by a qualified scientific expert. May or may not involve collection of new data.		X	X		X	X
G. Synthesis. A comprehensive review and explanation of pertinent literature and other relevant existing knowledge by a qualified scientific expert.	X	X	X		X	X
H. Expert Opinion. Statement of a qualified scientific expert based on his or her best professional judgment and experience in the pertinent scientific discipline. The opinion may or may not be based on site-specific information.			X		X	X

X = The characteristic must be present for the information derived to be considered scientifically valid and reliable; O = The presence of the characteristic strengthens the scientific validity and reliability of the information derived but is not essential to ensure scientific validity and reliability. Note: Many sources of information usually do not produce scientific information because they do not exhibit the necessary characteristics for scientific validity and reliability. Information from these sources may provide valuable information that supplements scientific information, but it is not an adequate substitute for scientific information. Nonscientific information should not be used as a substitute for valid and available scientific information. Common sources of nonscientific information include (1) anecdotal information (i.e., one or more observations that are not part of an organized scientific effort, such as "I saw a grizzly bear in that area while I was hiking"), (2) nonexpert opinion (i.e., the opinion of a person who is not a qualified scientific expert in a pertinent scientific discipline, such as "I do not believe there are grizzly bears in that area"), and (3) hearsay (i.e., information repeated from communication with others, such as "At a lecture last week, Dr. Smith said there were no grizzly bears in that area").

Section I - Beaver Ecology

Photo Credit: Bob Armstrong (www.naturebob.com)

Chapter 1—Effects of Beaver Dams on Physical and Biological Processes

Greg Lewallen, Michael M. Pollock, Chris Jordan and Janine Castro

In most of the temperate Northern Hemisphere, beaver historically altered low-gradient, smallstream ecosystems by constructing millions of dams made primarily of wood. Almost every northern temperate ecosystem that had trees or shrubs growing along streams also once had beaver dams. In Eurasia, evidence of beaver has been found in streams as far south as Iraq and Turkey, in the Arctic, and stretching from Scotland in the west to Kamchatka in the east (Halley and Rosell 2002). In North America, beaver were once found far south into the arid environments of Arizona and northern Mexico along rivers such as the San Pedro, Colorado, and the Rio Grande (Pattie 1833, Leopold 1972) and occupied all biomes north of the border from coast to coast, except for the Arctic, the tip of peninsular Florida, and the dry Great Basin and desert country of Nevada and southern California (Figure 1).

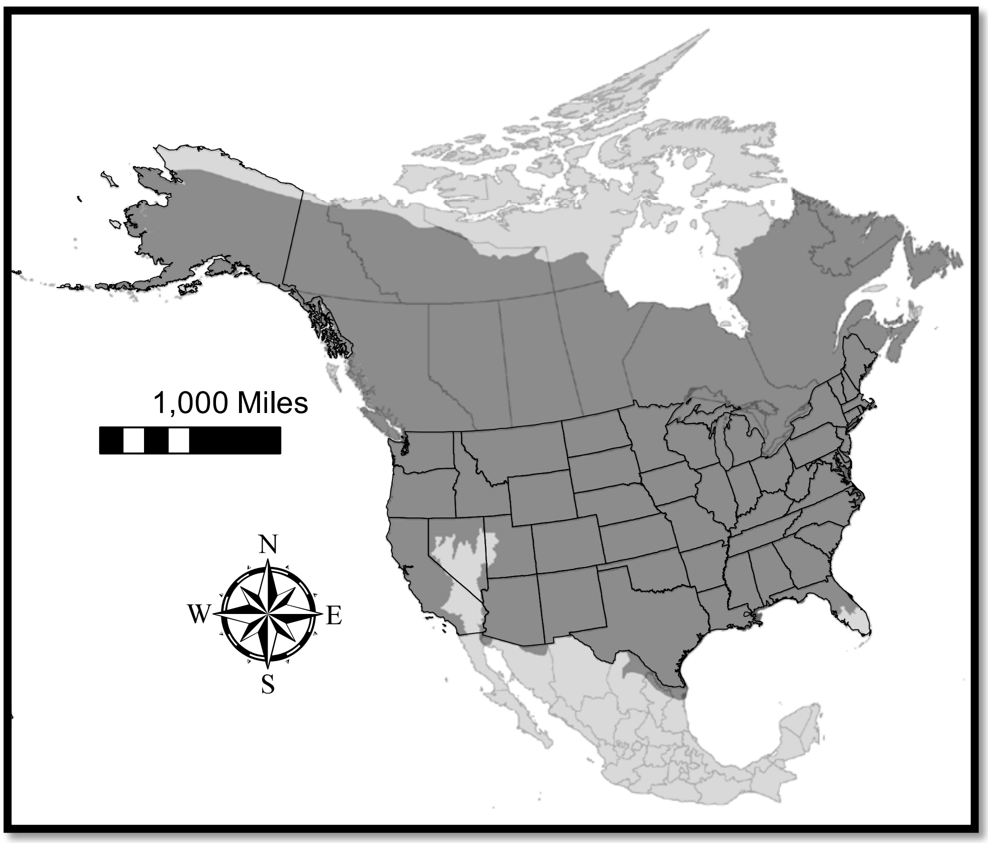

Figure 1: Probable historic range of the North American beaver. Adapted from Pollock et al. (2003), as modified by Lanman et al. (2012, 2013) and James et al. (2012) for California, and Layne (1965) for peninsular Florida. Absence of historic beaver evidence in the Great Basin, interior southern California, and southern Florida streams, is not evidence of historic absence of beaver in these regions.

Historically, beaver dams created streams systems with slow, deep water and floodplain wetlands dominated by emergent vegetation and shrubs. Geomorphology and plant communities of small low-gradient streams were much changed throughout much of the Northern Hemisphere after reduction of beaver populations (Rea 1983, Naiman et al. 1988b).

In both Eurasia and North America, beaver populations have generally declined as human populations have increased. In both continents, only small populations survived by the end of the 19th century (Seton 1929, Nolet and Rosell 1998, Halley and Rosell 2002). The primary reasons for the declines were that people trapped beavers either because they were resources for fur or oil or competitors for productive valley bottom lands (MacDonald et al. 1995, Mackie 1997, Halley and Rosell 2002).

More recently there has been widespread recognition that beaver dams play a vital role in maintaining and diversifying stream and riparian habitat (Pollock et al. 1994, Gurnell 1998, Collen and Gibson 2000, Burchsted and Daniels 2014). In the past century, land managers throughout the Northern Hemisphere have attempted to reintroduce beaver in areas where they have been extirpated. Today, beaver populations are rebounding throughout North America, with the population estimated to be about 10 million and reoccupying most of its former range (Naiman et al. 1988b).

Beaver are found across a wide range of aquatic habitat types, but they do have preferences:

- Beaver prefer to build dams on small- to medium-sized, low-gradient streams (<6% slope) that flow through unconfined valleys, and generally populate the lowest gradient (slope < 1-2%) sites first.

- Beaver generally avoid constrained valleys with high-gradient streams (reviewed in Pollock et al. 2003) but will colonize this less-preferred habitat if their population densities are high (Müller-Schwarze and Schulte 1999).

- Beaver also occupy large rivers but restrict their dam-building to off-channel habitat fed by hyporheic flow, groundwater channels, and tributary channels that flow across the floodplains of the larger river channel (Gurnell 1998, Baker and Hill 2003, Pollock et al. 2003). They also will build seasonal dams across large rivers during low flow conditions.

- Beaver also build dams on lakes, wetlands, estuaries and just about any water body where additional water can be retained and thus habitat improved (from a beaver's perspective) by building a dam.

In addition to these physical habitat attributes, beaver make use of streams with developed riparian areas that contain (1) vegetation for food, and (2) potential construction materials to build dams and lodges. Although beavers use a wide variety of trees, shrubs, substrate, and herbaceous vegetation as construction material, for food they prefer species from the genera *Populus* and *Salix* (i.e. aspen, cottonwood, and willows).

Hydrology

Increased Water Retention and Base Flows

Beaver impoundments change the spatial distribution of water (groundwater, pond, or stream), as well as the timing of its release and residence time in the watershed. Beaver dams impound water in ponds and pools, and these impoundments slow the flow of the stream; this holds the water within the stream reach for longer periods and can increase base flows (reviewed in Pollock et al. 2003). Indeed, some perennial streams transform into intermittent and/or ephemeral streams following the removal of beaver dams (Finley 1937, Wilen et al. 1975).

Conversely, reintroduced beaver have transformed some intermittent streams back to perennial streams (Dalke 1947, Pollock et al. 2003), and recolonizing beaver have transformed slightly losing streams to gaining streams ((Majerova et al. 2015). Losing streams are characterized by surface water flowing into the subsurface and not returning to the channel, usually associated with local water tables that are lower in elevation than the stream surface. Gaining streams, conversely, are characterised by high local water tables where subsurface water flows into the stream. Additionally, the ponded water expands the saturated surface area of riparian zones, converting previously upland plant communities into wetland plant communities. Thus, beaver create wetlands. Slower water velocities, lateral spreading, and larger areas of soil saturation contribute to increases in both the surface and subsurface water present in a watershed (Naiman et al. 1986, Syphard and Garcia 2001, Pollock et al. 2003, Cunningham et al. 2006, Westbrook et al. 2006, Hood and Bayley 2008).

Storage of water within the stream reach is particularly important for many aquatic species during low-flow periods, when direct hydrologic inputs are limited. When beaver recolonize stream systems, their impoundments increase base flows, as well as recharge and elevate the water table (Pollock et al. 2003). Furthermore, given that climate change is expected to increase drought and reduce snow pack, water storage from beaver impoundments may be an effective tool to help mitigate the associated reductions in water resources (see Rosemond and Anderson 2003, Lawler 2009). Climate change is of particular concern in areas that currently depend on glacial and snow-melt runoff. As water storage in the form of glaciers and snow decreases, surface and groundwater storage behind beaver dams high in watersheds may provide a buffer for base flows (Beechie et al. 2013).

Hood and Bayley (2008) studied how temperature, precipitation, and beaver activity influenced the area of open water in east-central Alberta, Canada, over a 54-year span that included many periods of drought. The presence of beaver had a substantial effect on the amount of open water in wetlands within the study area. Hood and Bayley's results indicate that beaver played a larger role in maintaining open-water areas than did temperature, precipitation, and climate. The authors found that, as sites cycled through beaver occupation and abandonment, beavers caused a nine-fold increase in open-water area compared to the same sites without beaver. Their findings indicate that "beaver could mitigate some of the adverse effects of climate change due to their ability to create and maintain areas of open water." Hood and Bayley conclude by suggesting that "the removal of beaver from aquatic systems should be recognized as a wetland disturbance equivalent to in-filling, groundwater withdrawal, and other commonly cited wetland disturbances."

Decreased Peak Flows

Beaver activity within a watershed generally reduces peak flows and spreads flows out over longer time periods. Reducing peak stream flows provides water quality benefits in terms of sediment reduction and also retention of water within the watershed as surface or groundwater. By slowing the stream flow, beaver impoundments reduce erosive energy and increase retention time. During floods, energy is dissipated as the water flows through multiple small channels on the downstream side of the beaver dam (Pollock et al. 2003). Floodplain vegetation alongside and below the dam further dissipates energy as the water works its way back to the stream channel (Li and Shen 1973, Woo and Waddington 1990, Dunaway et al. 1994, Pollock et al. 2003).

Beaver impoundments attenuate flood peaks by retaining water behind dams and in the subsurface. Beedle (1991) estimated that a single full beaver pond on a southeastern Alaska island reduced peak flows by more than 5 percent. A series of five large ponds could reduce peak flows of a 2-year event by 14 percent and peak flows of a 50-year event by 4 percent. Also, because ponds are not always at capacity, they can allow for additional storage of flood water. For streams with dozens of dams, further reductions in peak flows and stronger cumulative effects should be expected (Scheffer 1938, Smith 1950, Naiman et al. 1986, Pollock et al. 2003).

Expansion of Habitat Area and Complexity

Beaver dams can create very large and numerous surface pools and ponds, transforming moving-water habitats to a combination of moving- and slow-water habitats (Naiman et al. 1988b, Martell et al. 2006). This increase in surface and subsurface water leads to an expansion of riparian and wetland habitats along streams (see Johnston and Naiman 1990ab, Pollock et al. 2007, Hood and Bayley 2008). Repeated colonization of sites by beaver followed by abandonment creates habitat complexity, or heterogeneity, within the watershed (Burchsted et al. 2010). After abandonment, open-water wetlands drain and may transform into wet meadow habitats called "beaver meadows" (see the subsection below: Habitat-vegetation). In beaver-modified habitat, the continual creation, modification, and abandonment of wetland patches creates a mosaic of wetlands with a large range of ages and successional stages (Wright et al. 2003). The increased heterogeneity, in turn, increases the diversity of habitat types and plant and animal species, as well as the resiliency of the system to disturbance, specifically flooding (Naiman et al. 1988b) and drought (Hood and Bayley 2008).

Surface water area is most dramatically affected directly upstream of beaver dams, where it is collected in ponds and pools. The amount of surface water collected in these low-gradient areas ranges greatly, depending on the size and topography of the catchment, the channel form, and the water regime of the region. Typically the amount of surface water present increases with the number of beaver dams on a stream reach (Johnston and Naiman 1990ab). The ponds and pools formed from beaver dams provide important slow-water habitat for birds, waterfowl, fish, aquatic invertebrates, mammals, and amphibians. By increasing the amount of riparian area, beaver ponds typically provide important habitat for both terrestrial and aquatic plants and animals.

Increased Wetland Area

As ponds and pools fill and become deeper, the impoundments force flow laterally, causing overbank flow onto floodplains and creation of side channels, as water flows around beaver dams (Westbrook et al. 2006). These side channels and distributaries provide benefits such as alternative aquatic passage, dissipation of stream energy, hydrologic reconnection to the floodplain, and increases in the soil saturation area. All of these attributes help to create an intricate network of multi-threaded channels and wetlands.

Evidence of surface water and wetland expansion caused by beaver dam construction is plentiful. Many studies have documented creation of and changes in surface water and wetland habitats that have resulted from increases in beaver populations. For example, when studying the effects of climate and beaver activity in Elk Island National Park in Alberta, Canada, Hood and Bayley (2008) estimate that beaver reoccupation of the park caused the total area of open water to increase from 365 hectares (in 1948) to 991 hectares (in 1996). In Acadia National Park in Maine, Cunningham et al. (2006) found that beaver contributed to an 89 percent increase in ponded wetlands from 1944 to 1997, by converting forested wetlands and riparian areas to open water and emergent wetlands and by converting forested upland habitat to forested wetlands and riparian areas. In Virginia, Syphard and Garcia (2001) found that, from 1953 to 1994, beaver activity in the Chickahominy River watershed accounted for only 1 percent of wetland gain, but the animal's activities accounted for 23 percent of the change in wetland types. In a region of northern Minnesota, Johnston and Naiman (1990a) found that the number of beaver ponds increased from 71 to 835 between 1940 and 1986 as beaver reoccupied the area.

Increased Groundwater Recharge

Beaver dams can play a critical role in replenishing alluvial aquifers by trapping and storing water, redirecting surface water onto adjacent floodplains, and forcing water into the streambed and banks. Overbank flooding is generally thought to be the main hydrologic mechanism for replenishing groundwater in riparian areas (Workman and Serrano 1999, Girard et al. 2003, Westbrook et al. 2006).

Subsurface flow patterns may also be affected by beaver impoundments. In two separate studies located in Rocky Mountain National Park (in Colorado) and in Central Oregon, Westbrook et al. (2006) and Lowry and Beschta (1994), respectively, observed groundwater flow moving laterally around the dams (i.e., perpendicular to the river) into floodplain soils, then downstream, and eventually back in toward the river channel. This "looping" pattern of groundwater flow does not always take place; its occurrence depends on topographic relief and beaver dam height, which affect the hydraulic gradient between river and riparian area (Westbrook et al. 2006). Groundwater flow may also be affected by the location of the beaver dam within the valley and the streams geomorphology. Furthermore, Westbrook et al. (2006) found that, in Rocky Mountain National Park, the main effects of beaver on hydrologic processes occurred downstream of beaver dams rather than being confined to the near-pond area. In semi-arid streams, the hydraulic head created by beaver dams can affect subsurface flows by increasing hyporheic interactions within and downstream of beaver dam complexes (Lautz et al. 2006).

During summer low-flow months, groundwater drawdown often can negatively affect riparian and floodplain plant communities, especially when rainfall and snowmelt flows have already diminished, as well as the frequency and duration of flooding events. In addition groundwater stored in the soil can be depleted by evapotranspiration. By attenuating the rate of water table drawdown during summer low-flow months, beaver dams can provide a constant supply of water to the riparian area, via surface and subsurface flow paths (Westbrook et al. 2006). This influence on the hydrological processes affects the development of the floodplain and riparian areas by maintaining high local water tables and deeper groundwater levels. Thus, beaver influence floodplain structure and function (Westbrook et al. 2006).

In addition to mitigating climate change-related decreases in stream flow, via surface water storage, beaver increase the amount of groundwater storage and aquifer recharge (Pollock et al. 2003, Westbrook et al. 2006). This ultimately may be the most important beaver-related factor in mitigating effects from climate change because groundwater is released more gradually than surface water and has no evaporative losses. In areas where groundwater is being depleted faster than it is being recharged naturally, beaver ponds may help to offset the aquifer depletion, especially when beaver activity is occurring at the reach or watershed scale. Furthermore, increased groundwater storage may help to offset rising stream temperatures associated with the increase in open-water surface area. Cold pockets of water have been found downstream of beaver dams, possibly from the upwelling of groundwater and an increase in hyporheic exchange (Pollock et al. 2007). This is particularly important for aquatic species that require cold water.

Water Quality

Beaver have the ability to improve the water quality of streams by reducing suspended sediments in the water column, moderating stream temperatures, improving nutrient cycling, and removing and storing contaminants. This section highlights how beaver dams can affect the water quality of streams in ways that often mimic common restoration project goals.

Sediment Retention

Beaver dams affect channel form by creating ponds that increase the local water depth, reduce flow velocities, and dissipate stream energy. This in turn promotes sediment deposition and channel aggradation upstream of the dams (Naiman et al. 1986, Butler and Malanson 1995, Pollock et al. 2007, Green and Westbrook 2009). The size of a pond (i.e., its surface area) is often the best predictor of the rates and volume of sedimentation (Naiman et al. 1986, Butler and Malanson 1995). By trapping sediment, beaver dams cause substantial changes to channel morphology. In contrast, removing beaver dams can transform intricate, multi-threaded channels to a simplified single channel and increase sediment loads. For example, in a study in the East Kootenay region of British Colombia, Green and Westbrook (2009) found that the removal of beaver and their dams from 1968 to 2004 simplified channel structure and resulted in an estimated fivefold increase in mean flow velocity and the release of an additional 848 cubic yards of sediment to downstream areas.

If suspended sediment is a water quality concern, beaver colonization may be an effective method for reducing the amount of sediment being conveyed through the system. Beaver dams can influence sediment transport rates in a watershed and act as long-term sinks for both suspended and bedload sediments (Green and Westbrook 2009). Sedimentation rates behind beaver dams vary widely and typically are a function of (1) sediment availability from upstream, and (2) flows capable of liberating and transporting this sediment (Pollock et al. 2014). Aggradation rates range from 1 inch to upwards of 1.6 feet per year, depending on the region and the interrelationships among flow, sediment characteristics, and pond geometry (Devito and Dillon 1993, Butler and Malanson 1995, Pollock et al. 2007). As beaver begin to reoccupy sites, they tend to choose dam locations that will pond large amounts of water (Duncan 1984) and have high sediment trapping capabilities (Ringer 1994). Allred (1980) found that 10 beaver ponds along the South Fork Snake River trapped 63 percent of the suspended sediment during peak flow. On Beaver Creek, Idaho, Reiner (1983) reported that four ponds trapped 78 tons of sediment in a single snowmelt period. Brayton (1984) reports that three years after beaver reintroduction, suspended sediment loads in Currant Creek, Wyoming, dropped by about 90 percent (from 33 tons per day to 3 tons per day). Pollock et al. (2007) found that beaver dams in Bridge Creek, Oregon, collected up to 1.5 feet of sediment behind them during the first year they were in place. This aggradation behind the dams (including dams up to 6 years in age) resulted in an average reduction in slope of 1.3 percent within beaver-modified reaches compared to upstream reaches with no beaver dams.

The total amount of sediment that can be stored behind beaver dams can be substantial. For example, 22 ponds in a 620-meter stretch of Mission Creek, Washington, stored 5,847 cubic yards of sediment, for an average of 266 cubic yards per pond (Scheffer 1938). In Quebec, Canada, Naiman et al. (1986) measured retained sediment volumes that ranged from 346 cubic yards to 8,502 cubic yards on second- to fourth-order streams. Butler and Malanson (2005) estimated that modern beaver ponds (i.e., after European settlement) are storing between 9.8×10^8 and 5.0×10^9 yd^3 of sediment.

The sediment retained behind beaver dams can remobilize and become available for transport if dams are intentionally removed, breach as a result of high flows, or are abandoned by beaver (see "How do beavers create their own habitat?" in Frequently Asked Questions). However, when dams breach on small streams, most of the sediment can remain in the pond area (Butler and Malanson 2005). This may be due to lack of erosive flows or because the dam breaches only partially (i.e., there is channel avulsion around the dam), leaving most of the dam in place. As the water table recedes, the remaining nutrient-rich sediment in the abandoned ponds becomes exposed and often is quickly colonized by herbaceous plants or shrubs, forming a beaver meadow (Ives 1942, Johnston and Naiman 1987, Westbrook et al. 2011).

Temperature Moderation

Land use changes and ecosystem degradation already have caused summer water temperatures in streams and rivers to frequently exceed levels suitable for aquatic life (Kaushal et al. 2010). Climate change models predict that in the near future, water temperatures will increase even further. Maximum summer temperatures are often the single most important factor limiting the distribution and presence of numerous fish species in rivers (McRae and Edwards 1994, Wenger et al. 2011). Many salmon habitat restoration efforts in rivers and streams focus on increasing shade by bolstering riparian areas to reduce summer peak temperatures. In many regions, beaver dams have the ability to lower stream temperatures through the creation of riparian and wetland habitat. Vegetation associated with these areas offers shade that helps to lower stream and pond temperatures.

A common concern about beaver dams is that they may warm streams by increasing surface water area and reducing the amount of shade (Reid 1952, Knudsen 1962, reviewed in Collen and Gibson 2000). Large ponds general do receive more solar radiation than flowing stream reaches and their surface waters can warm substantially in summer. However, large, deep ponds (greater than six feet deep) usually stratify, with cooler water near the bottom and a thin layer of warm water at the surface, separated by a sharp thermocline. The cool water in the depths of beaver ponds can provide a temperature refuge for fish during the warm parts of the day, and the fish can feed in the more productive surface layers during the night and early morning (Hoffman and Recht 2013). Cooling downstream of dams has been reported. Pollock et al. (2007) found that beaver dams in a stream in eastern Oregon created pockets of cool water downstream, presumably caused by hyporheic upwelling that resulted from the head differential created by the dam. The authors also found that the stream temperatures within the beaver dam complexes were cooler than both upstream and downstream reaches that lacked beaver dams (see also White and Rahel 2008). McRae and Edwards (1994) investigated how beaver dams in northern Wisconsin affected stream temperatures. They found slight warming downstream of beaver dams; however, large ponds tended to dampen temperature fluctuations. They also removed several dams to assess what effect dam removal would have on temperature. Dam removal did not generally reduce temperatures and in some cases actually increased warming rates. McRae and Edwards concluded that the disruptive effects of dam removal on the composition of fish and invertebrate communities may outweigh potential direct thermal benefits. Chesney et al. (2010) found that two beaver dams in the Shasta River in Northern California stabilized temperatures relative to upstream and downstream reaches that lacked beaver dams. Small beaver ponds may not have major temperature effects (Hoffman and Recht 2013).

Nutrient Cycling

Although beaver are less widespread and ecologically influential today than they were in the past, they continue to have substantial nutrient impacts on drainage networks throughout many areas of North America. As Naiman et al. (1994) states, "beaver feeding strategies and physical alteration of the stream environment affect the hydrologic regime as well as community composition (McDowell and Naiman 1986, Naiman et al. 1988b, Johnston and Naiman 1990a, b). In turn, these changes alter biogeochemical cycling and the accumulation of nutrients and ions in soils, sediments, and water."

Beaver ponds have the ability to trap and retain large amounts of material—woody and herbaceous vegetation and organic and inorganic soil particles—that would otherwise be transported downstream (Naiman et al. 1986, Naiman et al. 1994). This can easily be seen in the thick accumulation of material at the bottom of beaver ponds; sometimes these accumulations are up to 3 feet deep. Woody debris on pond floors can be important habitat for fish, amphibians, and aquatic invertebrates.

Woody debris reaches the pond floor through several mechanism, including upland surface flows and the active process of beaver cutting down woody material for food and construction material, transporting it to the pond, and depositing it in food caches, dams, and lodges. Debris also can consist of emergent vegetation produced within the pond, or forest vegetation that was drowned out during the original inundation of the forest by beaver. Depending on an individual beaver pond's age, its ecological maturity, the channel morphology, and other factors related to the maintenance of system properties, the pond can act as both a net sink for soil and woody debris and a source of elements that are transported downstream (Naiman et al. 1994).

When upland and in-situ vegetation becomes trapped in beaver ponds, it creates a deep organic sediment layer, generally within the first decade following pond creation (Naiman et al. 1994). Anaerobic conditions within the submerged sediment layers can lock nutrients in the pond sediments until high flows wash them downstream or the site is abandoned and drained, after which a meadow typically forms. When newly exposed sediments return to aerobic conditions, nutrients are released in a form that is available to vegetation, resulting in very productive soil conditions that catalyse rapid plant growth and diverse communities during initial successional stages (Naiman et al. 1994).

Contaminants

In Europe, beaver ponds have been shown to increase the self-purification capacity of small streams that have been polluted by communal sewage, cattle farms, and agricultural discharge (Balodis 1994). Müller-Schwarze and Sun (2003) used a computer model to estimate the retention time of water flowing through a system with and without beaver dams. The model suggested that water flowing through a 1-square-mile area (2.59 square kilometers) with no dams resides for only 3 to 4 hours, while the same area with a 5-foot-high leaky dam retains water for about 11 days. Non-leaky or tight dams hold water almost twice as long—for about 19 days. Retention times of 6 to 8 days are sufficient to remove excess nutrients and toxins such as nitrogen, phosphorus, and herbicides (e.g., atrazine) from the water column (Muller-Schwarze 2011). Removal processes include deposition, microbial decomposition, uptake by plants, and chemical transformation augmented by filtering. Additionally, beaver ponds can be sinks for fine particulate matter such as clay, which nitrogen and phosphorus can adsorb to. Thus, beaver ponds and associated wetlands created by dams can act as sinks for nutrients and toxins that would otherwise stimulate the growth of algae and other water plants and bacteria downstream. As one example, in the Lake Tahoe basin of California, Muskopf (2007) studied how removing beaver dams from Taylor Creek affected concentrations of phosphorus entering Lake Tahoe. The author reported that the mean total phosphorus concentrations downstream of the dams increased from 70.4 micrograms per liter (μg/l) (before dam removals) to 170.5 μg/l (after dam removals).

Geomorphology

The benefits of trapping and storing sediments behind beaver dams go beyond simply improving the water quality of streams. When beavers build dams on stream reaches, over long time periods the deposition of sediment behind the dams tends to raise the elevation of the streambed (Scheffer 1938, Butler and Malanson 1995, McCullough et al. 2005, Pollock et al. 2007) and increase stream channel complexity by expanding riparian area (Polvi and Wohl 2012). These changes may help prevent channel incision and maintain the hydraulic connection between streams and their floodplains. Channel incision—a widespread phenomenon in stream channels throughout the world—has caused extensive ecosystem degradation and is a common focus of river restoration projects. Incision can result from a number of different factors, including the widespread extirpation of beaver in the nineteenth century—as well as changes in climate, land use, grazing, etc (Naiman et al. 1988b, Pollock et al. 2014).

The effects of channel incision include lower stream bed elevations, disconnection of the stream from its floodplain, lower groundwater tables, loss of wetlands, decreased summer low flows, higher stream temperatures, less overall habitat diversity, loss of riparian areas, and population declines in fish and other aquatic organisms (Cluer and Thorne 2014, Pollock et al. 2014). Recovery of incised channels can happen naturally (see Cluer and Thorne 2014), but the process may require very long time scales.

Pollock et al. (2014) proposed an expanded view to Cluer and Thorne's (2014) stream evolution model, suggesting that the inclusion of beaver into incised streams may substantially reduce the recovery time, which typically ranges from decades to centuries (Figure 2). Whether beaver can not only stop the incision process but reverse it, creating a positive feedback loop, depends on the quantity of sediment entering the channel and the channel's ability to retain this sediment (Pollock et al. 2007) (Table 2). Beechie et al. (2008), studied channel incision on the Walla Walla and Tucannon River basins in eastern Washington and estimated recovery times of 60 to 270 years without beaver and assuming relatively low aggradation rates (approximately 1.2 inches per year). When low densities of beaver dams (2 km^{-1}) were included in their estimates and an estimated trapping of 224 cubic yards of sediment per year per dam, recovery time was reduced by 20 to 84 years—a decrease of up to 33 percent.

Table 2. Aggradation Rates behind Beaver Dams

Source	Location	Aggradation Rate (m/yr)
Butler and Malanson (1995)	Glacier National Park, MT	0.02-0.28
Meentemeyer and Butler (1999)	Glacier National Park, MT	≥ 0.06
Scheffer (1938)	Eastern Washington	0.55
McCullough et al. (2005)	Nebraska	0.04
Pollock et al. (2007)	Bridge Creek, OR	0.075 - 0.47

Beaver colonization in incised streams may be difficult because of the relatively deep, strong flow, which can breach or blow out beaver dams, especially during high-flow events (Pollock et al. 2012). For example, along incised reaches of Bridge Creek, Oregon, most beaver dams were extremely short-lived; many lasted less than a year before they were washed out by annual spring floods or summer flash floods (Demmer and Beschta 2008). Pollock et al. (2012) actively assisted beaver in the construction of dams by installing different types of

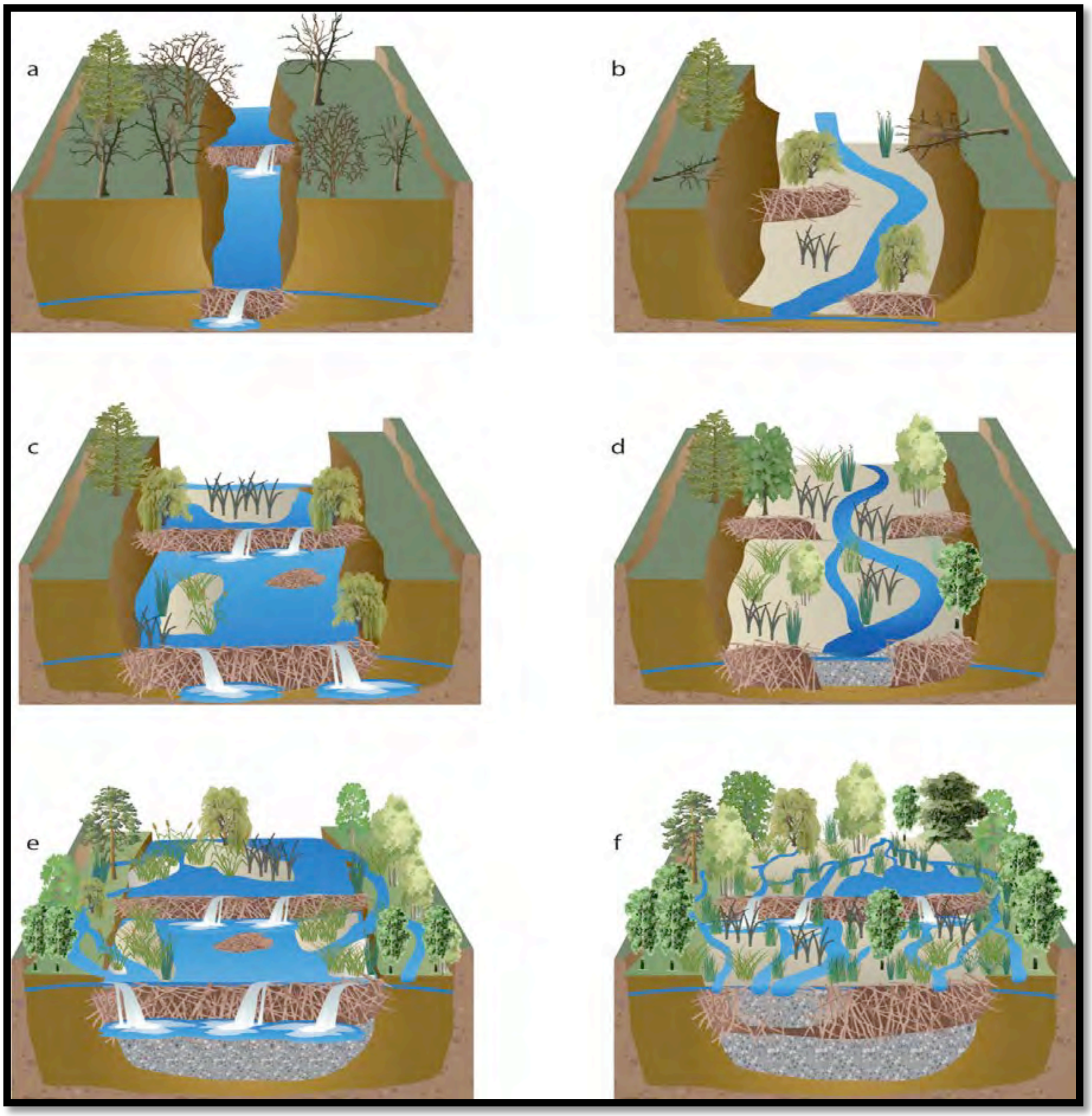

Figure 2: Conceptual model illustrating how beaver dams affect the development of incised streams; (a) beaver attempting to build dams within narrow incision trenches where high stream power often results in blowouts or end cuts that help to widen the incision trench, as illustrated in (b), allowing an inset floodplain to form. The widened incision trench results in lower stream power which enables

beaver to build wider, more stable dams (c). Because of high sediment loads, the beaver ponds rapidly fill up with sediment and are temporarily abandoned, but the accumulated sediment facilitates the growth of riparian vegetation (d). This process repeats itself until the beaver dams raise the water table sufficient to reconnect the stream to its former floodplain (e). Eventually (f), the stream ecosystem develops a high level of complexity as beaver dams, live vegetation and dead wood slow the flow of water and raise groundwater levels such that multithread channels are formed, often connected to offchannel wetlands such that the entire valley bottom is saturated, as described elsewhere (Sedell and Frogatt 1983, Walter and Merritts 2008). Figure from Pollock et al. 2014.

beaver dam analogues (BDAs) and dam support structures (i.e., starter dams, post lines with wicker weaves, and post lines—see "Beaver Dam Analogues" for more detail). Offering structural supports to possible dam sites, abandoned dams, breached dams, and existing dams increases the chance that these structures will withstand large flow events and remain intact for more than one year. A two-year life span for a beaver dam is critical for beaver colony viability because kits typcially remain with their parents for two years before they disperse from the colony. Once beavers have established themselves on incised reaches, the resulting stable beaver colonies cause the reaches to aggrade, resulting in measurable improvements in riparian and stream habitat conditions (Pollock et al. 2012, Woodruff unpublished data).

Reponse of Other Species to Beaver Dams

Beaver are a keystone species, meaning that they have a disproportionately large effect on their environment relative to their abundance. Beaver play a critical role in the watersheds of North America by maintaining the structure of the surrounding ecological community. Their presence in watersheds affects not only the types and numbers of many terrestrial and aquatic plant and animal species, but also maintains the change over time of channel form and the hydrology of watersheds. The subsections below highlight certain species that benefit from the habitat created by beaver.

Vegetation

How vegetation responds to habitat modifications by beaver depends on the type of vegetation and the region, but there are common general trends. Beaver ponds initially affect plants by increasing flooding. Typically, small plants within the footprint of the pond die as a result of the initial inundation, while trees are generally affected within the first year. As large trees and shrubs drown, the canopy opens, allowing more sunlight to reach the pond surface. Increased solar energy facilitates the growth of both emergent and riparian vegetation in the newly enlarged riparian area that has developed as a result of creation of the beaver pond and the expansion of the water surface area. Riparian and emergent vegetation begin to dominate where there used to be upland shrubs and trees. Overbank flooding associated with beaver dams may create surface flows onto floodplains, raising the local water table, which initiates succession toward wetland plant communities. Thus, beaver ponds can create aquatic habitat from many riparian, emergent, and wetland plant communities within and adjacent to ponds (Johnston and Naiman 1990a, Burchsted and Daniels 2014).

Increased riparian vegetation density results in the accelerated deposition of fine sediment on the floodplain—a result of greater flow resistance and lower velocities, as vegetation increases roughness and pulls energy out of the water flow, reducing erosion and transport power. Thus, beaver dams and beaver-assisted alterations in vegetation work in concert to increase sediment deposition.

The diversity and form of growth of riparian vegetation also are driven directly by beaver herbivory (Harrison and Stella 2010). Beavers consume their favorite plant species, leaving riparian areas dominated by non-preferred species, such as ninebark in western North America and red maple in eastern North America. In arid and shrub-steppe environments dominated by stands of willow, beaver herbivory tends to drive willow form from taller stands with less branching to shorter stands with more branching (Baker 2003).

Beaver dams create habitat while they are impounding water, but they continue to create habitat even after colonies are abandoned, often in the form of beaver meadows, particularly in more mesic climates (Ives 1942, Burchsted et al. 2010, Polvi and Wohl 2012). A large flow event can cause a dam to be breached, or it may be abandoned after a colony has depleted the resources in the surrounding area. After a breach some of the stored sediment is released downstream (Levine and Meyer 2014), but much of it is retained, depending on the local channel and valley form (Butler and Malanson 2005). As the water table drops in response to dam removal, the exposed substrate is usually colonized by vascular plants, including plants that germinate from the seed bank stored in the sediments (Wright et al. 2002). The resulting newly formed "meadow" usually is devoid of trees (because the former forest was drowned out by the beaver pond or removed by the beaver through herbivory). After a beaver meadow forms, it progresses through successional stages of young and wet to old and moist (Naiman et al. 1994, Wright et al. 2002). The meadow may then persist on the landscape for centuries (Wright et al. 2002).

Beaver meadows form distinct patches on a landscape (Johnston and Naiman 1987, Terwilliger and Pastor 1999). The meadows act as "islands" of wetland plant communities whose composition differs from that of adjacent, unmodified riparian zones and upland forest (Wright et al. 2002). The variability in plant species composition and richness of beaver meadows may contribute significantly to landscape-level heterogeneity.

Studies of the beaver-meadow complex have occurred almost entirely in mesic environments. Whether long-term beaver meadows form in more xeric regions (e.g. lower elevations in much of the American West) is a research question that should be pursued.

Primary Productivity and Aquatic Invertebrates

When beaver modify streams, they create excellent habitat for many aquatic insect populations by increasing the input and storage of organic material and sediment (reviewed in Collen and Gibson 2000) and increasing primary productivity. Beaver ponds boost primary productivity both by increasing the availability of organic nutrients (Francis et al. 1985) and by allowing sunlight to reach more water surface for photosynthesis. Primary producers such as periphyton, planktonic algae, and aquatic vascular plants take advantage of the increased solar radiation. This sets the stage for the secondary producers—micro- and macroinvertebrates—who, in turn, take advantage of the increase in detritus—i.e., the woody material, decaying leaves, and decaying in-situ vegetation produced in the pond. These microand macroinvertebrates form the base of the food web that juvenile salmon and steelhead rely on when rearing and overwintering in beaver ponds.

Beaver ponds harbor many lentic benthic invertebrates—i.e., invertebrates that prefer slow-water habitats. Riffle reaches between ponds primarily harbour invertebrates which prefer faster flowing water. In comparison to streams that have no beaver activity, beaver-modified streams influence the community structure of aquatic invertebrates by shifting from primarily lotic taxa to a larger presence of lentic taxa (McDowell and Naiman 1986). Overall, having multiple beaver ponds in an area tends to increase the biodiversity of aquatic insect communities by selecting for both lotic and lentic populations.

Fish

The pools and ponds created by beaver dams are excellent habitat for many fish species. More than 80 North American fishes have been documented in beaver ponds, with 48 species commonly using them (reviewed in Pollock et al. 2003). Because beaver ponds slow down stream flow and have very large edge-to-surface-area ratios, they provide considerable cover for fish and a productive environment for both vegetation and aquatic invertebrates that fish can use for food resources not found in unimpounded stream habitat (Hanson and Campbell 1963, Keast and Fox 1990, reviewed in Pollock et al. 2003). Additionally, fish expend less energy foraging in the slow, productive waters of beaver ponds and side channels than they do in the faster flowing main channel. This leads to increases in fish abundance and size (i.e., weight and length); fish found in stream reaches that have beaver dams are both larger and more numerous than fish found in streams lacking slow water habitat. (see Gard 1961, Hanson and Campbell 1963, Murphy et al. 1989, Leidholt Bruner et al. 1992, Schlosser 1995, reviewed in Pollock et al. 2003, Sigourney et al. 2006).

There has been extensive research on both the positive and negative effects of beaver modifications on fish species. Kemp et al. (2012) thoroughly reviewed the primary literature on this topic, focusing on North America, and completed a meta-analysis. They reported the most commonly cited positive and negative impacts to fish as shown in Table 3.

Table 3. Potential Impacts of Beaver Modifications on Fish Species

Potential Positive Impacts	Potential Negative Impacts
• Increased fish productivity/abundance • Increased habitat and habitat heterogeneity (which promotes biodiversity) (Smith and Mather 2013)) • Increased rearing and overwintering habitat • Enhanced growth rates • Providing flow refuge • Improved production of invertebrates	• Barriers to fish movement • Siltation of spawning habitat • Low oxygen levels in beaver ponds • Altered temperature regime

Kemp et al. noted that many of the positive effects cited (51.5 percent) were supported by data, while many more of the negative impacts (71.4 percent) were speculative and not supported by data collected in the field. Furthermore, the most commonly cited negative impact of beaver dams—as barriers to fish movement—was highly speculative, as 78.4 percent of the studies did not support this claim with data. The authors report that 49 North American and European experts consider beaver to have an overall positive impact on fish populations, through their influence on abundance and productivity.

Along the Pacific Coast of North America, interest in protecting beaver-modified habitat is growing because of the habitat's potential to benefit anadromous fish populations. Coho salmon (*Oncorhynchus kisutch*), for example, use various types of slow-water habitat (e.g., sloughs and perennial and seasonal wetlands, off-channel ponds, small lakes, side channels, alcoves, and backwaters) as juveniles (Solazzi et al. 2000, Bramblett et al. 2002, Pollock et al. 2004, Ebersole et al. 2006, Henning et al. 2006) and adults; they use fast water during adult migration and spawning (Reeves et al. 1989). The activities of beaver can create the type of slow-water habitat used by coho juveniles (Swales et al. 1988, Murphy et al. 1989).

During summer, beaver ponds are important rearing grounds for juvenile coho salmon (Leidholt-Bruner et al. 1992). For example, in the Fish Creek Basin of Northwest Oregon, Everest et al. (1986) found that the density of juvenile coho in beaver ponds (i.e., 1.43 per cubic meter) was four times higher than the density in side channels and 48 times higher than that in riffles. Beaver ponds constituted only 2.5% of the habitat at Fish Creek but produced 50.4 percent of the coho salmon smolts in 1986, more than in 1985 (reviewed in Müller-Schwarze 2011).

In addition to summer rearing grounds—and possibly more critical to coho populations— is the use of beaver ponds and slow-water habitat as overwintering grounds. For example, Pollock et al. (2004) found that in the Stillaguamish River basin in Washington, the decline in beaver populations and subsequent loss of their dams resulted in a 61 percent reduction of summer coho habitat capacity and an 86 percent reduction in overwintering capacity. The authors conclude that the production bottleneck of coho salmon in this watershed was from a lack of overwintering habitat and that increasing beaver populations could be a simple and effective means of mitigating this loss of productivity.

Nickelson et al. (1992) reported that, in coastal Oregon streams, beaver ponds and alcoves supported more juvenile coho salmon (about 1 fish per cubic meter) than did other stream habitats, such as backwater pools, trench pools, glides, riffles, and rapids. Beaver ponds and alcoves represented only about 9 percent of the habitat but accounted for 66 percent of the coho salmon found in the system. Likewise, Bustard and Narver (1975) showed that, on Vancouver Island, the overwintering survival rate for juvenile coho behind beaver dams ranged from 61 percent to 74 percent; this was higher than the average rate for the entire stream systems (i.e., 35 percent). Silloway and Beesley (2011) suggested that coho salmon populations in the Klamath River estuary in California were limited by the availability of juvenile overwintering sites such as coastal wetlands, beaver ponds, and alcove/slough habitats. Many other studies confirm the benefits of slow-water habitat on coho populations along the Pacific Coast (Bell et al. 2001, Brakensiek and Hankin 2007, Ransom 2007, Wallace and Allen 2007, Hillemeier et al. 2009, Chesney et al. 2010, Wallace 2010).

Most of the research on fish populations using beaver ponds and slow-water habitat along the Pacific Coast has been done on coho salmon; however, other fish species also benefit from this habitat. For example, juvenile Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) in British Columbia and Washington also use off-channel and floodplain habitats for overwintering (Swales et al. 1988, Cunjak 1996). Pollock et al. (unpublished data) found that juvenile steelhead in eastern Oregon had higher densities and survival rates in beaver ponds than did juveniles in similar reaches without dams. Juvenile steelhead in the upper Trinity River of California also preferred side-channels during winter (Macedo 1992). In the Sacramento River system of California, juvenile Chinook show more growth and higher survival in floodplain habitats than do fish in mainstem habitats (Sommer et al. 2001, Sommer et al. 2005). Similarly, Limm and Marchetti (2009) found high growth rates in juvenile Chinook salmon in off-channel ponds of the Sacramento River watershed. Salmon recovery plans along the Pacific Coast have recently identified beaver habitat as important for salmon and steelhead that must be protected to ensure future stocks of this important resource.

Amphibians

Beaver ponds provide important breeding habitat for some amphibians, including Northwestern salamanders, red-legged frogs, Pacific tree frogs, wood frogs, green frogs, cascades frogs, rough-skinned and red-spotted newts, and Western and American toads. By diversifying the landscape with different sizes and ages of ponds, beaver modified streams can significantly increase the biodiversity of amphibians (reviewed in Müller-Schwarze 2011).

Red-spotted newts (*Notophthalmus viridescens*) readily take advantage of the unique aquatic habitat created by beaver activity and may actually depend on beaver ponds for their survival. Because red-spotted newts respond to aquatic habitats that rapidly shift in time and space, they rapidly colonize new beaver ponds (Gill 1978). The newt's life history seems well-tuned to the shifting mosaic that typifies beaver-maintained habitat (Müller-Schwarze 2011).

The wood frog (*Rana sylvatica*), which breeds in beaver ponds, thrives in marginal ponds with little inflow or outflow; these habitats are primarily found in areas saturated with beaver populations that are not heavily managed. For example, in the central Adirondack region of the northeastern United States, wood frogs living in beaver ponds had higher survival rates of metamorphosed froglets and produced larger juvenile frogs than did wood frogs living in vernal (i.e., seasonal) pools (Karraker and Gibbs 2009). Stevens et al. (2006) suggested that older beaver ponds (older than 25 years) in boreal streams of west-central Alberta, Canada, supported more breeding wood frogs and had higher rates of juvenile growth and development than younger ponds (less than 10 years old). Canal networks created by beaver in the wetlands of Miquelon Lake in Alberta, Canada, may provide essential movement corridors for emigrating juvenile wood frogs (Anderson et al. 2014).

Along the West Coast, the Oregon spotted frog uses perennial wetland habitat—as well as pools, ponds, and small floodplain wetlands associated with permanent bodies of water—throughout its life history (Pearl and Hayes 2004, Cushman and Pearl 2007). Habitat loss has caused this species be become extirpated from possibly 70 to 90 percent of its historical range (Cushman and Pearl 2007). Its last refuge may be beaver-modified systems, which offer relatively favorable conditions for the Oregon spotted frog. Oregon spotted frog eggs survive and develop best in warm, shallow water where emergent vegetation already is established (Cushman and Pearl 2007). Beaver ponds' emergent vegetation and slightly warmer surface water (compared to upstream and downstream reaches) may provide critical habitat for this stage of the Oregon spotted frog life cycle. In addition, beaver dams increase the amount of surface water and retention times within their catchments, and this may reduce egg and hatchling larvae's susceptibility to desiccation.

For more information on beaver ponds and amphibians, see Russell et al. (1999), Skelly and Freidenburg (2000), Quail (2001), Crisafulli et al. (2005) and Stevens et al. (2007).

Reptiles

Beaver ponds provide important habitat to some reptiles, turtles being the most common. Painted turtles, western-painted turtles, western pond turtles and snapping turtles use beaver ponds. Other terrestrial reptiles that are found near ponds include snakes and lizards. Older beaver ponds seem to attract more reptiles than younger ponds, again highlighting the importance of the diversified landscape that beavers create over long time frames of occupation (Russell et al. 1999, Metts et al. 2001).

Birds

The water impounded behind beaver dams provides new habitat for waterfowl and many other bird species. This is not news to any avid bird watcher or waterfowl hunter who chooses to set up their blinds in areas colonized by beaver. Beaver-created wetlands and ponds produce numerous species of aquatic insects, which are essential food for hens and rearing broods of waterfowl. The cover offered by lush riparian vegetation— both tall trees and shrubs and emergent herbaceous vegetation—offers cover from predation by flying raptors and terrestrial hunters. Hens often choose beaver ponds to rear their broods because of the protection that ponds offer from predators and the large supply of protein- and calcium-rich aquatic insects. In addition, the habitat created by beaver dams is a refuge for many migratory birds species, providing rest and refuelling locations along their north-south routes. The dead snags created by beaver through girdling and flooding provide excellent nesting habitat for many birds, and attracts numerous woodpecker species.

The list of birds that actively use beaver ponds is long and varies by region. Most studies of beaver-modified habitat and its effect on bird populations have been on the East Coast of the United States. Beaver ponds in New York, for example, host American and hooded mergansers, Canada geese, mallards, pintails, buffleheads, wood ducks, horned and pie-billed grebes, great blue and green herons, kingfishers, woodpeckers, chickadees, tree swallows, eastern bluebirds, red-winged blackbirds, and numerous species of flycatchers and warblers. Surveys of birds at beaver ponds across New York show that active beaver sites support more species of birds than do vacant or potential sites (Lochmiller 1979) and the benefit to avifauna persists for decades after beaver are actively using the site (Alza 2014). In the southeastern U.S. state of Georgia, Lochmiller (1979) found that dead snags flooded or girdled by beaver attracted more than twice as many woodpeckers than did a tree stand without beaver. In Maine, the wetlands created by beaver contained flooded alder-willow thickets, herbaceous vegetation, and large water surfaces, all of which are essential brood-rearing habitat for the

American black duck (McCall et al. 1996). Protected beaver habitat in south-central Maine supported more mallards, hooded mergansers, and Canada geese than did areas where beaver trapping was allowed.

Beaver ponds in Wisconsin attract both waterfowl and other birds, including mallards, black ducks, blue-winged teals, ring-necked ducks, hooded mergansers, shorebirds, swallows, flycatchers, hawks, warblers, sparrows, kingfishers, osprey, and bald eagles (Knudsen 1962). Along the Continental Divide in the Rocky Mountains, birds such as the spotted sandpiper, Wilson's snipe, Brewer's blackbird, red-winged blackbirds, mallards, and green-winged teals all rely on beaver ponds (Brown et al. 1996).

The beaver's ability to create wetlands is especially important to waterfowl in the western United States, where riparian and wetland habitats make less than 2 percent of the landscape yet provide habitat for more than 80 percent of wildlife species (Hansen 1995). In addition, such beaver ponds may provide isolated breeding-pair ponds for waterfowl at a crucial time in their annual life cycle. After mating, these ponds offer the necessary protein- and calcium-rich invertebrates that sustain breeding pairs of birds during the egg-laying period. In a study of beaver-modified streams in Wyoming, McKinstry et al. (2001) found that the riparian width in streams with beaver ponds averaged 111 feet, in contrast to 35 feet in streams without beaver. This difference may have affected the waterfowl surveys: a total of 7.5 ducks were found per kilometer of stream in areas with beaver ponds, while similar areas that lacked beaver had only 0.1 duck per kilometer of stream. When McKinstry et al. (2001)reintroduced beaver to 14 streams throughout Wyoming, waterfowl quickly took advantage of the newly created wetlands and improved riparian areas.

Chapter 2—Frequently Asked Questions about Beaver

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Where do beaver live? How do they make their dams? Why do they slap their tails? This section answers some of the most common questions people have about beaver biology and ecology.

How many species of beaver are there?

There are two extant beaver species: the North American beaver (*Castor canadensis*) and the Eurasian beaver (*Castor fiber*). Habitat loss and trapping extirpated both species throughout most of their range. The Eurasian beaver, which closely resembles its North American cousin in both appearance and behavior, was extirpated from much of its former range by the beginning of the twentieth century (Halley et al. 2012), and the North American beaver soon followed suit. Estimates of the beaver population in North American before European settlement vary, but it is thought that around 55 million dam-building individuals were present (Pollock et al. 2003); Seton (1929) estimated the total population to be between 60 million and 400 million. Fur trapping, which began in the 1700s to support the European fashion for pelt hats (Bryce 1900), resulted in a massive decline in beaver populations.

Today beaver are making a comeback—in Europe, Russia, and North America. Reintroductions of the species began in the United States in the early twentieth century and continue today. Although population numbers have not reached historical levels (current rough estimates put them at only 6 million to 12 million individuals (Naiman et al. 1988b), beaver now occupy almost all of their former range in North America. They have been so successful that their burgeoning populations have migrated into human-occupied territory, sometimes causing localized flooding or loss of vegetation. This has contributed to people's negative perception of the species as a pest or nuisance animal.

Within both species of beaver, individuals manifest two very different but critically important behaviors: Some beavers build dams to impound water and some beavers do not. This has bearing on river restoration projects where habitat modification through dam construction by beavers is intended to produce the effects needed to meet specific goals. It is of critical importance to understand why beavers build dams, so that we can try to predict where and when dam-building activity may occur (see "Why do beavers build dams?" in Frequently Asked Questions). The effects of colonies that do not build dams on river systems are not well understood and not the focus of this document. Here, we highlight how beaver dams affect the landscape and how they can be useful in a wide range of restoration scenarios in North America.

In the past, numerous subspecies of North American beaver have been identified, but currently, the Integrated Taxonomic Information System (www.itis.gov) does not recognize any subspecies of *C. canadensis*. For a list of formerly recognized subspecies of C. *Canadensis*, see Table 1 in Appenix B.

What is the beaver's range?

The North American beaver occurs throughout most of Alaska, Canada, the continental United States and in portions of northern Mexico (Figure 1) (Pollock et al. 2003). The beaver's adaptability and ability to modify its environment to create suitable habitat has allowed it to thrive in a wide range of biomes. Novel evidence is challenging previously held assumptions about the historical range of beavers, pushing its territory to include high elevations in the Sierra Nevada Mountains (Lanman et al. 2012), parts of the California coast (Lanman et al. 2013), tidal wetlands in Washington State (Hood 2012), and peninsular Florida (Layne and Johns 1965). In North America, the only areas where beaver may be absent are the Arctic, the very far north of Canada and parts of Alaska, the dry Great Basin and desert country of Nevada and southern California (Jenkins 1979, Pollock et al. 2003). Otherwise, beavers are found throughout northern boreal forests, south to the deserts of northern Mexico, west to the Aleutian Islands, and all the way to the eastern seaboard.

What are important habitat elements for beaver?

Numerous studies describe detailed life history characteristics of beavers (Morgan 1868, Bradt 1938, Jenkins and Busher 1979a, Hill 1982a, Allred 1986, Hilfiker 1991, Novak 1999, Baker and Hill 2003, Muller-Schwarze 2011). The single most important feature of beaver habitat is the presence of water. Water is essential to the daily life of beavers and can be in the form of a stream, river, lake, or pond, as long as there is a year-round supply sufficient for access to food resources, protection of lodge and burrow entrances, and general safety from predators (Müller-Schwarze and Sun, 2003). Besides the presence of water, beaver need surrounding riparian areas that can provide food resources (see "What do beaver eat?"), construction materials, and places to build scent mounds (see "How do beavers communicate?").

Are beaver just big rats?

Beavers certainly are big. They are the largest rodent in North America and second largest rodent in the world (after the capybara of South America) (Morgan 1868). Adult beaver typically weigh 35 to 71 pounds and can grow to a total length of 4 feet, including the tail (Jenkins and Buscher 1979, Baker and Hill 2003) (Figure 3). The tail alone is about 1.3 feet long, 6.3 inches wide, and 0.75 inch thick. The size and weight of an individual beaver depends on many variables, including the climate, availability and quality of food, extent and condition of habitat, and latitude. Mid-continent beavers, for example, can reach up to 110 pounds (Bailey and Balley 1927).

Figure 3: Photo of a North American Beaver from Southeast Alaska. Photograph courtesy of Bob Armstrong (Willson and Armstrong 2009).

Beaver have evolved to aquire unique features that make it well adapted for its role as both a keystone species and an ecosystem engineer. Baker and Hill (2003) describe the beaver's body as being drop shaped, thick and heavily muscled, and supported by a large skeleton that is massive in proportion to other mammals of similar length. The beaver's strong forelegs are shorter than its hind legs; this results in greater height at the hips than at the shoulders. The large head is supported by a short, thick neck almost continuous with the shoulders. The beaver's stout and powerful body is perfectly suited to manipulating the surrounding environment by gnawing on hardwoods and carrying branches, rocks, and mud with its forelimbs. The skull and mandible (Figure 4) are enormous and thick so that they can withstand the muscular force involved in chewing hardwoods such as oak and maple (Morgan 1868). The beaver uses its four chisel-like incisors to fell trees, cut branches, and peel bark from stems. These teeth grow continuously. The outer enamel layer appears yellow and is much thicker and denser than the white inner enamel. The chiselled edge is sharpened by grinding the upper and lower teeth together. The remaining molars—eight each in the upper and lower jaws—are used for grinding woody and herbaceous food (Müller-Schwarze and Sun 2003).

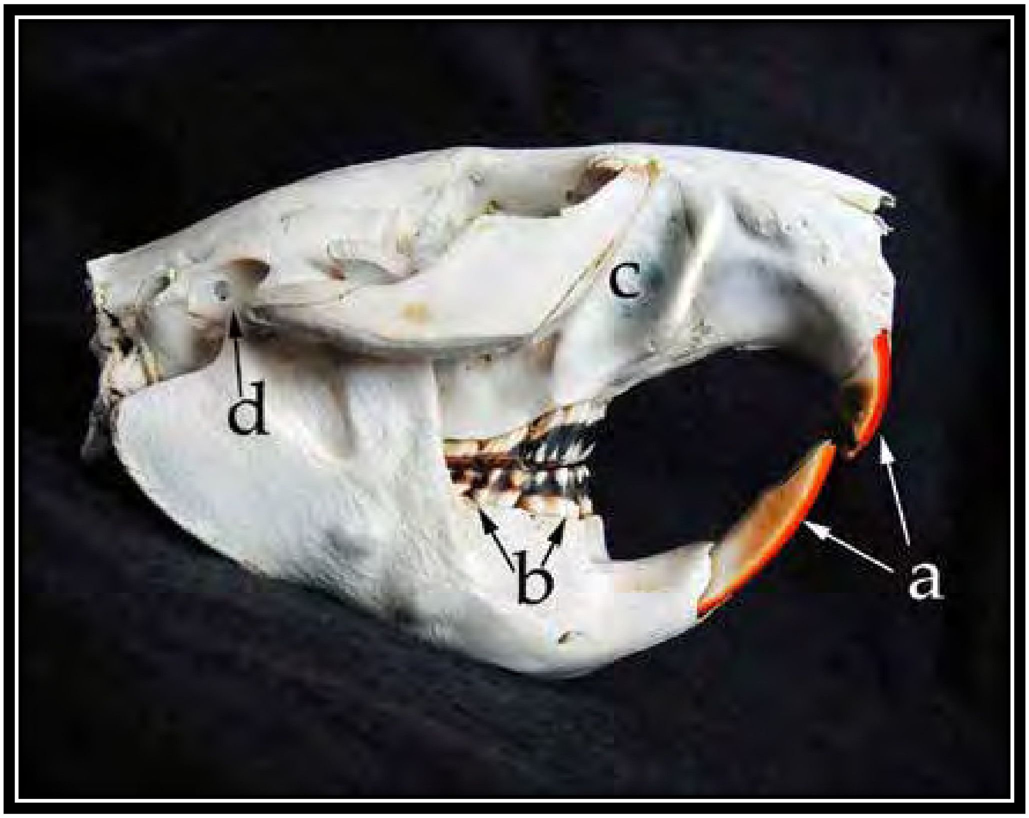

Figure 4: Beaver skull. Beavers have massive skulls that include large incisor teeth (a) with chisel-like cutting edges. The molars (b) are used to crush and grind plant material. The deep groove (c) houses a large muscle for closing the lower mandible. The jaw joint (d) is placed high on the skull, well above the tooth rows, which then can meet in parallel. Figure courtesy of Bob Armstrong (Willson and Armstrong 2009).

In adaptations to the beaver's semiaquatic lifestyle, small round eyes and ears sit atop the head. Beavers can close their nostrils and ears when submerged. They have a special membrane that protects their eyes while underwater, and fur-lined lips that can be closed behind the large incisors (Jenkins and Busher 1979). Beavers also have special adaptations to prevent water from entering their larynx and trachea (Müller-Schwarze and Sun 2003).

One of the beaver's most distinguishing and identifiable features is its broad, flat, scaly tail (Baker and Hill 2003)(Figure 16). This multipurpose appendage is used as (1) a prop when cutting trees and when walking on the hind legs while carrying construction materials with the forelimbs, (2) a rudder during swimming, (3) an alarm by slapping the water surface, (4) a fat reserve for lean winter months, and (5) a heat exchange organ to reduce heat losses from 25 percent in the summer to 2 percent in the winter (Marchand 1996).

Beaver have well-developed senses of hearing and smell but relatively weak eyesight (Morgan 1868, Novak, 1999). They are prey animals, so their eyes are widely spaced, to provide a large field of vision (Müller-Schwarze and Sun 2003). They use their acute sense of smell to detect predators, select palatable hardwoods, and locate other beaver via mud scent mounds (Müller-Schwarze and Sun 2003).

Can beavers walk on land?

The beaver's physiology is a product of its aquatic and terrestrial lifestyles. Beaver spend most of their life in water but may need to move overland when cutting woody vegetation for food or construction materials, or when dispersing from areas to find new territory. Because of its body form, a beaver tends to waddle awkwardly when moving overland, but the animal can gallop if frightened (Jenkins and Busher 1979). Adult beavers can walk on their hind legs, leaving their hand-like, dexterous front feet free to grasp and manipulate food, dig, and groom. The two inside toes of each hind foot have movable, split nails that serve as "combs" for preening the fur to keep it fluffy (Wilsson 1971). In the water, beaver are efficient swimmers who use their large webbed hind feet to propel them through the water.

Why was their fur so highly valued?

The high value placed on beaver fur pelts during the seventeenth, eighteenth, and nineteenth centuries is what led to the near extirpation of the animal from North America. Beaver pelts were used in winter clothing such as jackets and boots, but the primary use for pelts was in the construction of felted hats. From the 1600s through the 1800s, felt was made from the hairs of the under coat and shaped into a wide range of popular hat styles (Figure 5). Coloration of the pelt varies within and among populations, with reddish, chestnut, nearly black, and yellowish-brown specimens possible even within the same watershed (Baker and Hill 2003).

A beaver's fur consists of long, coarse guard hairs that are about 10 times the diameter of the soft, wavy, short underfur. The guard hairs are longest (2.0 to 2.4 inches) and most dense along the back, but the underfur also attains its greatest length (0.8 to 1.2 inch) on the back and can range from a dark grey to a light chestnut in color (Baker and Hill 2003). The extremely dense underfur keeps the body warm and dry. With approximately 12,000 to 23,000 hairs per square centimeter, beavers have more hair per skin area than the South American nutria (i.e. 8,000 to 3,000 hairs per square centimeter), but less than the river otter, which has 25,000 51,000 (Müller-Schwarze and Sun 2003). Beavers molt during the summer, so fur trappers prefer to harvest beaver pelts between December and March when the animals are considered to be in "prime condition" (Müller-Schwarze and Sun 2003).

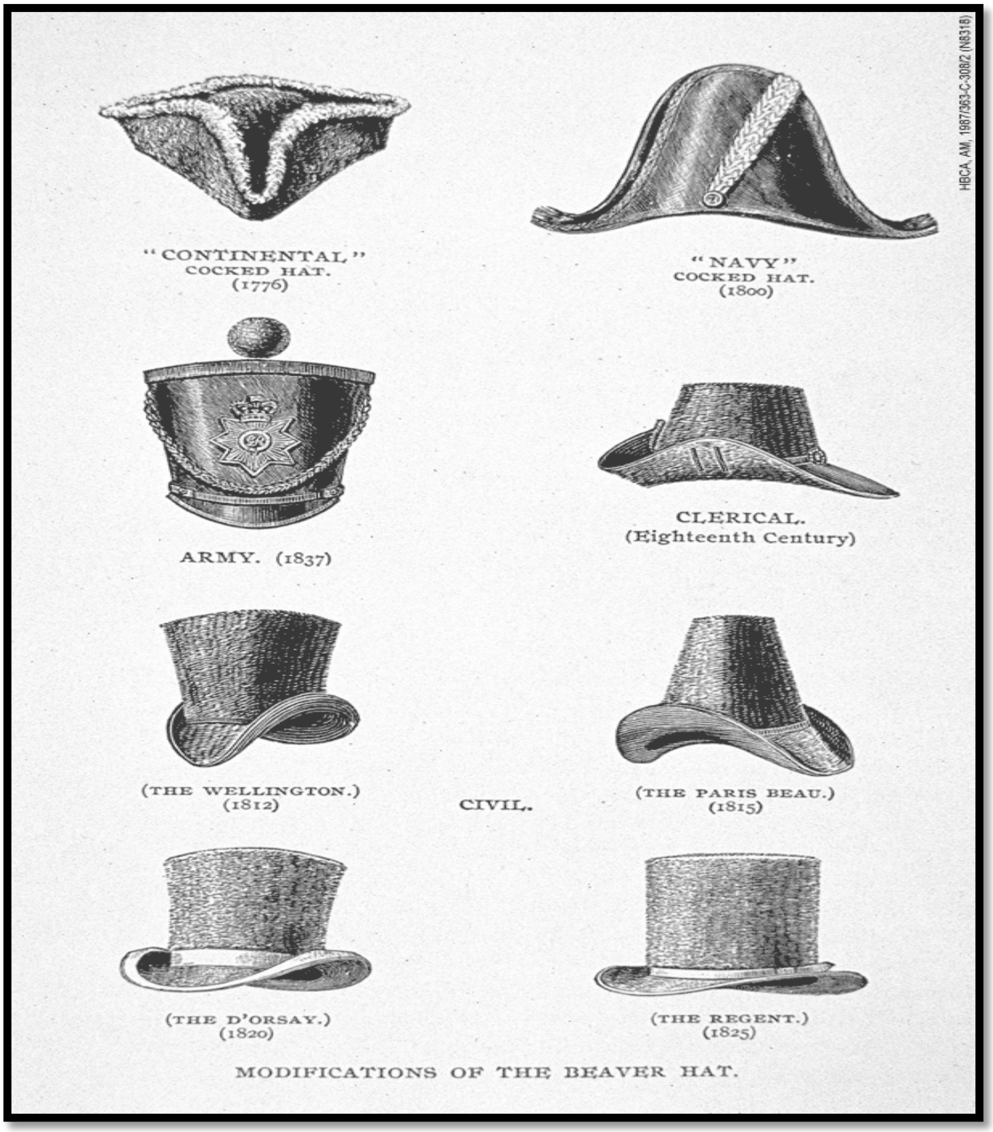

Figure 5: Different styles of hats made from beaver felt. Figure copywritten by batashoemuseum.ca.

What do beaver eat?

As herbivores, beaver consume a wide variety of plant species. They eat the leaves, twigs, and inner bark of most types of woody plants that grow near the water (Jenkins and Busher 1979). In addition, they eat many different kinds of herbaceous plants, including grasses, sedges, and aquatic species such as water lilies. Their diet appears to change seasonally. During the summer months they primarily consume nutritious herbaceous vegetation (Chabreck 1958, Jenkins 1975). During fall and winter, as deciduous leaves and other aquatic vegetation become scarce or unavailable, they switch to primarily the inner bark (i.e., cambium) of woody shrubs and trees. Their digestive tracts are adjusted to this diet high in plant fiber and, through the help of microbial action, are able to use much of the cellulose they consume (Clarke and Hoover

1972, Hill 1982b, Buech 1984). Estimates of the amount of woody material a beaver eats per day range from 1.0 to 5.5 pounds (reviewed by Novak 1999). On the East Coast, Brenner (1962) estimated that, during the spring and summer, individual beavers consumed about 12 ounces of herbaceous material per night (beaver are primarily nocturnal).

Beavers attempt to optimize their energy returns from herbivory by using a central place foraging strategy and choosing smaller trees and stems (i.e., less than 3.9 inches diameter at breast height [DBH]). In general, they seem to choose small trees over large ones of the same species (Aldous 1938, Stegeman 1954, Hall 1960, Jenkins 1979, 1980, Pinkowski 1983, Belovsky 1984). As distance from the pond increases, a beaver's choice in tree size seems to decrease (Jenkins 1980). Large trees (i.e., more than 3.9 inches DBH) are sometimes felled, debarked in place with only the smaller branches removed, and taken back to the pond (Jenkins and Busher 1979). This strategy may reduce the risk of predation by limiting the amount of time spent on land (smaller trees take less time to fell) and reduces the amount of energy spent transporting material back to the pond. Large trees may also be debarked around the base and left standing. Barking the base of a tree can result in only small pieces of bark removed, or most of the basal bark gnawed off. Varying the amount of barking may be a strategy to measure the relative nutrient value of different trees, which could explain why preferences for certain species of tree change from year to year (Jenkins 1979).

Beavers are able to colonize a large and diverse range of habitats throughout almost the entirety of North America because they can use a great number of woody and herbaceous species for food and construction material. (see Appendix A, see also Henker 2009 for a literature review of what beaver eat). Still, our understanding of beaver carrying capacity within a reach of stream based on food availability is somewhat primitive. Herbaceous vegetation taken by beaver is much harder to quantify than woody species (especially because beaver forage primarily at night), so scientists understand less about the impact that herbaceous species have on beavers' diet, both at the individual and population levels. Some studies have been done to try to answer this question. For example, Collins (1976), using fecal samples of beavers in Wyoming, found parts of 20 species of forbs and 24 species of graminoids (see also Chabreck 1958, Harper 1968, Jenkins 1975, Novak 1999, Parker et al. 2007).

Beaver need a reliable source of food, but they are choosy generalists (Harper 1969), consuming a wide variety of plant species. For example, Harper examined the stomach contents of beavers in Mississippi and found that they consumed 42 species of trees, 36 genera of herbaceous plants, four types of woody vines, and many species of grass (*Graminae*). Yet they are "choosy" because they prefer certain species over others and will take those first if available. Lists of preferred plant species vary by region, and most studies of beaver herbivory have taken place east of the Rocky Mountains. The focus of these studies is primarily woody species because it is easy to identify and count beaver-chewed stems. But beavers also eat a lot of herbaceous material, including sedges and other emergent vegetation and the tuberous roots of water lilies and cattails.

In most places generalities can be made as to the food preference of beaver. Woody species preferred by beaver are aspen and cottonwood (*Populus*) and willow (*Salix*). These trees grow fast, sprout rapidly, and have soft wood that is easy to fell and peel (Müller-Schwarze and Sun 2003). If beaver have occupied a site long enough to deplete their preferred food source, they will resort to less preferred species. Diets vary depending on what is available. For example, Müller-Schwarze and Sun (2003) report that in New York State, after aspen and willow, beavers' order of preference changes from birch, black cherry, beech, juneberry, and hornbeam to maples, hawthorn, and hemlock. The least preferred tree species were conifers, such as balsam fir, white pine, Scots pine, red pine, and Norway spruce. More recently, beaver have been known to take exotic species such as Japanese knotweed and kochia (*Kochia scoparia) and* salt cedar (tamarisk).

In freezing climates, what do beaver eat during the winter?

Where ponds or streams freeze during winter, beavers build food caches near their lodges or burrows (Jenkins and Busher 1979), which they access by swimming under the ice (Baker and Hill 2003). Because beaver do not hibernate or migrate during cold winter months, a reliable supply of food is necessary. Beavers may use the lower temperatures as a cue to start developing food caches during the fall, before freeze-up. Branches of deciduous species are gathered and embedded in the pond bottom or secured by structures such as large woody debris or boulders situated at the bottom. As the supply of woody vegetation accumulates in the cache, the material that is unsecured to the bottom becomes waterlogged and will sink. Generally, the majority of the cache will be submerged, with only a few sticks above and on the surface of the water where it may freeze in the surface ice. Interestingly, beaver may also initiate construction of the cache by selecting large branches of less palatable species and floating them near the lodge. Then selections of more favoured species are brought and placed under this "raft," which, over time, becomes water logged and sinks, pushing the cache down to the pond floor. The raft or "cap" often remains close to the surface and becomes locked in the ice, leaving access to the woody vegetation below to be consumed over the winter (Slough 1978). Beavers may also supplement their winter diet of woody vegetation with water lily tubers and rizomes, which can be accessed from beneath the ice of the pond, but this component of the beaver diet is not well understood.

Beavers remain in the lodge during most of the winter, emerging periodically to swim under the ice, cut branches from the cache, and take them back to the relative warmth and security of the lodge to eat. Beavers may build multiple food caches in a single colony and not consume the entire cache during the winter (Baker and Hill 2003). Without a large enough cache gathered before freeze-up to feed the entire colony for the duration of the winter, starvation may occur. When surface ice is not very thick, such as in late fall and early spring, beavers may break the ice near the lodge and dam to allow access to food on the shore (Jenkins and Busher 1979). They break the ice with their front paws, stand on it until it breaks, or butt it with head and shoulders (Wilson 2009). In climates where water bodies remain unfrozen, beaver typically do not construct food caches because they can forage year-round.

How do males and females differ?

Visually, male and female beavers are indistinguishable, and, because their sexual organs are located internally, determining a beaver's sex in the field can be challenging. There are a number of different ways to ascertain their sex. The easiest field method is to locate the four dorsal mammary glands on females; however, this method is of limited value because the glands are visible only during a brief lactation period in the summer (Müller-Schwarze and

Sun 2003) and non-breeding females do not develop conspicuous teats. DNA markers have been developed, so it is possible to identify gender by collecting hair samples (Goldberg et al. 2011). Two other methods are reliable ways to determine sex but require training and a sedated or constrained animal. These methods are (1) checking the color and consistency of anal gland secretions, and (2) palpating the baculum or penile bone (Schulte et al. 1995) (see the section on beaver sexing in "Relocating Beaver").

When do beaver begin to reproduce?

Beavers of both sexes usually reach sexual maturity and are able to produce their first litter by their second winter, at age 1.5 years (Larson 1967, Henry and Bookhout 1969). Regional variation of age at the first litter has been documented, but generally beaver can reproduce by 1.5 to 3 years of age, although puberty may be reached several months before first breeding (Baker and Hill 2003, Fischer et al. 2010). Adults form relatively long-term pair-bonds. Desertion of a mate is rare, and usually only the death of one of the pair will result in turnover of mates (Svendsen 1989). Breeding typically occurs in late winter and during the period of confinement to the winter lodge (in northern parts of the range) (Rutherford 1964). Mating occurs under water (Kowalski 1976) in bank dens or lodges (reviewed in Baker and Hill 2003). A gestation period of about 100 days is typical (Wilsson 1971), with births occurring in May through July ((Muller-Schwarze and Lixing 2003). Beaver produce one litter per year, giving birth to kits in the security of a lodge or bank den.

How many kits are in a litter?

The beaver litters can range in size from one to around nine kits, but the average is two to four (Wigley et al. 1983). Litter size varies by region, with beaver in the southeastern United States tending to have smaller litters than beavers in the North and West (Hill 1982a, Wigley et al. 1983). The variability in litter size may be due to the quality and quantity of habitat, severity of winter weather (Jenkins and Busher 1979a), or weight of the mother (Pearson 1960, Boyce 1974).

Beaver kits typically are born in late spring, fully mobile and furred (Figure 6) and weighing about 1.1 pounds (review by Hill 1982). Lancia and Hodgdon (1983) studied kits raised in captivity and found that they could swim at 4 days, dive underwater in response to alarm at 8 to 10 days, and dive and stay submerged at 2 months of age. The kits initiated tail slapping in response to alarm when they were 3 to 4 weeks old and bipedal walking at 1 month of age. They began carrying construction materials while walking on their hind legs at 90 days of age. The fur of kits is not water repellent at birth, but at 3 to 4 weeks of age they begin to spread secretions on their fur that, by 5 to 8 weeks, creates water repellency (Baker and Hill 2003). Kits slowly aquire adult behaviors, hence they need a long period of rearing within a family to develop and hone skills required for survival after dispersal (Bloomquist and Nielsen 2010).

Figure 6: Illustration of beaver kits in the lodge with their mother. Illustration courtesy of Katherine Hocker (Willson and Armstrong 2009).

How big is a typical beaver colony?

The basic social unit of beaver society is the family (Morgan 1868), often referred to as a colony. A beaver colony is defined as "a group of beaver occupying a pond or stretch of stream, using a common food supply and maintaining a common dam or dams" (Bradt 1938, cited in Hill 1982: 262). The number of individual beavers living in a colony varies depending on location, food abundance, habitat availability, population densities, predation pressure, and human activity. The average number of beavers observed living in a colony ranges from four in western New York (Muller-Schwarze 2011) and Alaska (Boyce 1981) to more than eight in Massachusetts (Brooks et al. 1980) and Nevada (Busher 1983)(Table 4).

The density of colonies varies with habitat quality and the degree to which colonization of an area has stabilized (Gurnell et al. 1998). It is typical for a colony on a high-quality site to have two kits of the year, two yearlings, and a breeding pair, making for a family of about six. However, a colony can range from a single individual up to about 10 members. Occasionally, 2-year-old adults will stay with a family for an additional year; this occurs more frequently in high-density populations where unoccupied habitat is limited. Kits generally stay with the colony for 2 years, and dispersal of 2-year-old subadult beavers is the primary mechanism of population expansion (Baker and Hill 2003). Dispersal of subadults often coincides with the birth of kits in the spring and/or high runoff, especially where ice in winter limits movements (Van Deelen and Pletscher 1996, Bloomquist and Nielsen 2010).

Table 4: Average Beaver Colony Sizes Reported in the Literature

Source	Location	Number of Individuals
(Nordstrom 1972)	New Brunswick	3.2
Boyce (1974)	Alaska	4.1
(Easter-Pilcher 1990)	Montana	4.1
(Hunt and Hodgdon 1953)	Maine	4.3
(Müller-Schwarze and Schulte 1999)	California	4.8
(Payne 1982)	Newfoundland	5.3
(Novak 1977)	Ontario	7.6
Busher et al. (1983)	Nevada	8.2
Hill,(1982)	North America	2.7 ± 6.2

How many beaver can live in one area?

The density of beaver populations varies both spatially and temporally, and often there are areas of unoccupied habitat between adjacent beaver family home ranges. Factors that contribute to variation in the density of beaver populations include human impacts (e.g. trapping), water quality, habitat suitability, area available for new colonization, length of habitation time relative to available resources, rapidly spreading diseases, local predation events, and territoriality (Baker 2003). Most important, perhaps, are abiotic factors that influence habitat quality, such as the stream gradient, stream size, and size of the valley bottom (Retzer et al. 1956, Beier and Barrett 1987b). For example, Pollock et al. (2004) studied 341 beaver ponds in the Stillaguamish watershed in Washington State and found that 90 percent of the ponds were in low-gradient streams in unconfined valleys. Similarly, (Suzuki and McComb 1998) studied 170 beaver dams in Oregon's Drift Creek basin and found that only 10 percent of the dams were on streams with gradients higher than 6 percent. After all the preferred habitat has been occupied, predation pressure can affect beaver population densities (see Boyce 1981).

Beaver density typically is calculated as the number of colonies per unit length of stream times the number of beavers in each colony (Table 5 and 6). Population estimates, on the other hand, can be derived using aerial counts of lodges or food caches multiplied by mean colony size (Hay 1958, Bergerud and Miller 1977, Peterson and Payne 1986). This method assumes spatial and temporal consistency of colony size; however, Swenson et al. (1983) found this assumption to be invalid, reporting that estimates did not correlate well with population size because mean colony size changed between years and across areas. Swenson et al. (1983) noted that the size and composition of colonies must be estimated periodically to provide the necessary information to detect temporal changes in beaver populations (McTaggart and Nelson 2003). Potential methods of assessing the size and composition of individual colonies include removal trapping, mark-and-release live trapping, and nocturnal censuses conducted using night-vision binoculars.

Table 5: Beaver Colony Densities Reported In The Literature.

Source	Location	Colony Density
McCall et al. (1996)	Maine	0.32 km^{-2}
(Boyce 1983)	Alaska	0.63 km^{-1}
Beier and Barrett (1987b)	California	0.74 km^{-1}
Howard and Larson (1985)	Massachusetts	0.83 km^{-1}
Collins (1976)	Wyoming	0.90 km^{-1}
Nordstrom (1972)	New Brunswick	1.25 km^{-1}
Johnston and Naiman (1987)	Minnesota	1.00 km^{-2}
Hill (1976)	Alabama	1.9 km^{-1}

How fast can colonies grow?

Beaver populations in areas at or near carrying capacity typically change relatively slowly over time. Conversely, in areas with unexploited preferred habitat, populations can rapidly increase and expand over the landscape. The size of an unexploited beaver population (meaning one with little to no predation pressure, including human trapping) is limited by the amount of suitable habitat and resources within that range.

For example, on the Kabetogama Peninsula of Voyageurs National Park in Minnesota, several studies have looked at the effects of an increasing beaver population on the landscape with few predators and excellent beaver habitat (Johnston and Naiman 1990b, a, Pastor et al. 1993). Using aerial photographs from 1940 to 1986 and beaver population data from 1958 to 1986 (Naiman et al. 1988b) showed that the number of beaver dams increased from 71 (many of which were abandoned) in 1940 to 835 by 1986. Beaver population rates remained fairly steady over that time, with approximately nine colonies added each year (Johnston and Naiman 1990a). This was an increase from near extirpation of beaver on this landscape to a density of about one colony per square kilometer in a little more than 4 decades.

Another example of expanding beaver populations is in Allegany State Park, New York. Here Müller-Schwarze and Sun (2003) note how a single pair of beaver was introduced to the park in 1937 after trappers had removed all the beavers by the start of the twentieth century. A year later two families were living within the park. By the 1950s beaver occupied all of the suitable habitat within the park, and by 1973 there were 34 beaver colonies in the park. Currently, 40 to 60 families occupy the park and the population seems to have stabilized, presumably because suitable habitat and food resources have become limiting.

Beaver populations undergo stages of growth and decline as populations increase, occupy more territory, and deplete resources in the area. (Busher 1987) studied a beaver population in California that illustrates this typical change over time. Originally, beaver occupied 20 percent of suitable stream habitat. Within 25 years, the population expanded to occupy 56 percent of the suitable habitat, increasing the number of beavers per kilometer of stream from 1.57 to 4.00. However, fluctuations in the beaver population occurred during this time of overall expansinon. Initially the population stabilized at around 3.38 individuals per kilometer and then declined. This was followed by two more population expansions, eventually reaching a high of four beavers per kilometer.

What are lodges?

Lodges are structures that beaver create protect themselves from predators and weather. As Morgan (1868) observed, beaver dig burrows and construct lodges, "both of which are indispensable to his security and happiness." Typically, lodges are composed primarily of sticks and branches piled into a large mound. Large rocks may be used as foundational or anchoring material, with herbaceous material used as sealant and filler. The top of the lodge generally is left unsealed to allow for ventilation (Novak 1999). If woody material is scarce, beavers may construct lodges primarily with non-woody material (Dennington and Johnson 1974)(Figure 7). The interior of the lodge typically contains a nesting area that is situated a few inches above the water line so that it remains dry (Grinnell et al. 1937) and often is lined with grasses or other herbaceous material (Morgan 1868). Well-built lodges can have considerable insulating capabilities. For example, Miller (1967) found that the lowest inside temperature for a water lodge in Alaska was 25 degrees Fahrenheit when the outside air temperature was -49 Fahrenheit. For more studies on lodge air temperatures see Stephenson (1969), and Novak and Cook (1972).

Figure 7: Beaver lodge constructed with primarily mud and herbaceous material in a site dominated by reed canary grass.

How many types of lodges do beavers build? What are bank burrows?

Lodges come in three general types: bank burrows, bank lodges, and water lodges. The entrances of all three types are continually submerged by water, to protect the beaver from predators.

Bank burrows are constructed in the bank of a river, lake, pond, or canal and are often dug under a large tree or shrub that provides support to the walls and roof of the den (Morgan 1868). The entrance is dug out below the water level, a nest area is created above the water line, and small holes are dug in the surface soil to ventilate the den (Gurnell 1998). Where beavers live exclusively in large rivers or deep lakes, bank dens typically are the only housing structures they build (Baker and Hill 2003). Even in areas where beaver eventually build dams and lodges, bank dens often are used while the lodge is being constructed and at times after its completion (Baker and Hill 2003). Beavers do not build bank burrows in areas where the substrate limits their construction (i.e., in very rocky soils or permafrost) or where the bank is not high enough to allow the nest chamber to remain above the water line (Gurnell 1998). In the latter case, beavers build intermediate structures between burrows and water lodges, called bank lodges (Gurnell 1998).

Bank lodges are essentially burrows where beaver have piled woody material and mud above the nest chamber on the bank and dug a hole through the soil surface to create a nest chamber (Gurnell 1998) (Figure 8). The nest chamber in a bank lodge may by located beneath the ground surface or on top of the hard ground, with sticks and mud piled above (Morgan 1868).

If dam height and water level increase, construction of the bank lodge may continue, sometimes for years (Baker and Hill 2003).

Figure 8: Bank lodge situated on the shores of a lake in Southeast Alaska. Photo courtesy of Bob Armstrong (Willson and Armstrong 2009).

Water lodges, which are situated in a lake or pond, are completely surrounded by water (Figure 9). Generally, lodges have two or more underwater entrances and a nest area situated above the water line (Grinnell et al. 1937). Fluctuating water levels can stimulate lodge-building activity (Novak 1999).

In many areas a combination of lodges and bank burrows are used by all or different members of the colony (Baker and Hill 2003). Looking at both species of beaver, researchers in Russia found that about 75 percent of beaver used water lodges and bank lodges, while the rest lived in bank burrows (Danilov and Kanshiev 1983).

Figure 9: Large beaver lodge completely surrounded by water in Southeast Alaska. Photo courtesy of Bob Armstrong (Willson and Armstrong 2009).

Why do beavers build dams?

Beavers build dams to raise water levels. Higher water levels provide the following benefits (among others):

- Allowing beavers to dive to safety from predators
- Increasing foraging area and providing safe and easy travel routes to and from feeding areas
- Allowing logs and branches to float within the pond
- Ensuring that the entrances to lodges and burrows remain underwater, so as to protect beaver from land-based predators such as coyotes, cougars,wolves and bears
- In colder climates, keeping ponds at a sufficient depth to maintain liquid water under a sheet of ice during the winter months

Without sufficiently deep water in their habitat, beaver may be more susceptible to predation and have to expend more energy to collect food resources by moving overland. To ensure a constant water level, beaver construct dams, with building activity being timed according to necessary adjustments in water level (Richard 1983). The sound of running water can stimulate beavers to initiate dam building or perform dam maintenance (Wilsson 1971). Sometimes several dams are constructed and maintained by the same colony to control ponded water in relation to lodge or burrow entrances (Gurnell 1998).

Typically beavers build multiple dams in succession over a relatively small reach of stream, creating a stair-step valley and stream profile (Morgan 1868). This series of dams, or beaver dam complex, consists of flat, ponded areas with abrupt gradient changes at each dam site (Pollock et al. 2003). Over long periods of time, beaver dams can accumulate significant sediment behind them, thus effectively changing the longitudinal profile of the valley slopes over long distances (Ives 1942, Westbrook et al. 2010, Polvi and Wohl 2012). Multiple dams in a series also help dissipate the energy of large flood events and may act as an insurance policy against dam failure: if one dam breaches, others are still in place. Furthermore, having multiple dams increases the amount of retained water, which increases the foraging area of the colony and encourages the growth of woody vegetation and herbaceous species used for both food and construction materials. Thus, beaver dam building activity can create a positive feedback loop.

How are beaver dams constructed?

Beavers are unique in their ability to construct impressively large structures located in dynamic aquatic systems where substantial amounts of water (Naiman et al. 1988b, Johnston and Naiman 1990a, Hood and Bayley 2008) and sediment can be impounded behind them (Butler and Malanson 1995, Pollock et al. 2003, Walter and Merritts 2008). Dam construction is initiated by pushing sediment, rocks, or sticks so that they form a ridge perpendicular to the flow of moving water, or by locating sites to take advantage of existing substrate (Lancia and Hodgdon 1983) or existing structures, such as abandoned breached dams or large woody debris (MacCracken et al. 2005). Structure is added by anchoring leafy branches, peeled branches, or other material to the substrate, which can be the stream bottom, stream banks, large rocks, or coarse woody debris. Branches in the bulk of the dam are intertwined perpendicular or parallel to the stream. In addition, branches are often placed on the downstream side of the dam, parallel to the stream, with the cut end placed into the substrate and the branched end pointed upstream; this adds structural support to the dam and helps prevent the development of a downstream scour pool.

Dam-building behavior has been well documented and described in the literature (Morgan 1868, Hilfiker 1991, Gurnell 1998). Baker and Hill (2003) reviewed this information and reported that dams typically consist of tree trunks, branches, twigs, bark, leaves, earth, mud, and sometimes stones (Gurnell 1998), but a wide range of material can be used. Dams can include conifers, sagebrush, tamarisk, aquatic plants, corncobs, cornstalks, plastic, metal, or other debris. Beavers sometimes peel and eat the bark of branches before adding the stems to the dam. When preferred woody food species are limited in the area, beavers will select less preferred species to use as construction material (Barnes and Mallik 1997a).

Once the woody material is in place, beavers seal the dam by adding mud and herbaceous material such as grass and leaves, especially on the upstream dam face. Mud is typically gathered from the stream bottom upstream of the dam and packed into the dam with their forelimbs. Typically, dams are maintained through repairs and additions (or removal of debris) to both the height and length to control water levels. In colder climates,dam construction activity is highest in the fall before freeze-up and in the spring to repair damage from high flows. In ice-free climates, construction activity may occur year round, with less activity during the summer months.

How big are the dams?

The size and number of dams in a colony and the amount of water retained in the ponds vary greatly, depending on factors such as duration of occupancy, topography, substrate, flow levels, and available vegetation (Gurnell 1998). Dams may begin as small structures that span the channel only partially but can evolve through time, progressively extending until they eventually span the entire channel. Dams range in size from small canal- or culvert-spanning structures approximately 20 inches long to an incredible 930 yards long in a recent example in Wood Buffalo National Park in Alberta, Canada. The height and width of beaver dams also vary in size. Dams range between 8 inches to 6 feet in height and 3 to 6 feet in width (Baker 1995).

As food sources are depleted or the water regime adjusts seasonally, additions to dams may extend further onto floodplains, until they eventually spans the entire valley width (Gurnell 1998). As water collects behind dams and spreads laterally from the primary channel, the beavers may build small check dams on the floodplain to further impound and direct the flow of water (Baker and Hill 2003). This illustrates how beavers may develop dams and ponds up on the floodplain, even though the width of the dammed channel is relatively small (Gurnell 1998). As the beaver colony grows in size, additional dams may be constructed throughout the colony's territory. The area of inundation generally increases over the first few years of occupation (Naiman et al. 1988, Johnston and Naiman 1990a). Over time dams eventually breach, possibly as a result of abandonment, high-flow events, or both. Breached dams often remain in place and may be used as a starting point for new dams when beavers attempt to reoccupy formerly used territory. Breached dams that remain in place, partially spanning the channel, can add heterogeneity and complexity to the stream system, providing additional areas of slow water, riffles, and riparian habitat (John and Klein 2004, Burchsted et al. 2010, Polvi and Wohl 2012, Pollock et al. 2014).

Do Beaver dams block fish passage?

A common concern regarding beaver-modified habitat is that their dams block the movement of fish, in particular salmon and steelhead. However, this claim is largely unsupported by the literature. Rather, the literature suggests that at most, beaver dams may act as temporary barriers to fish passage, typically during low-flow periods. As flows increase, dams typically become more easily passable by both juvenile and adult fish, with a diversity of flow paths over, through, under, and around these semi-permeable structures (Schlosser 1995, Pollock et al. 2014)(Lokteff et al. 2013). Moreover, these flow paths continually change with beaver maintenance, construction, and abandonment and with fluctuations in discharge (Lokteff et al. 2013).

Most recent research suggests that the increased complexity of habitat created by beaver dams is beneficial to many fish species (Collen and Gibson 2000, Schlosser and Kallemeyn 2000, Pollock et al. 2003, Pollock et al. 2004, Kemp et al. 2010, Kemp et al. 2012, Pollock et al. 2012). Dams might even provide a competitive advantage to certain native fish species relative to non-natives (Lokteff et al. 2013). This is reasonable because salmon, steelhead, and many other fish species are found throughout the range of the North American beaver and have cohabitated streams together with beaver since the last ice age. At times when low flows temporarily may inhibit non-native (e.g. bass) fish movement across beaver dams, species of native fish, most notably salmonids, are able to jump sufficient heights and lengths to clear the dams (Powers and Orsborn 1985). Although not well documented, observations suggest that, rather than leaping over dams, juvenile and adult species of salmon (i.e. coho, sockeye, and steelhead) pass beaver dams by swimming around the dam, either accessing the numerous small, low-velocity flow paths that are present in most dams or swimming over the wet portions of the dam face and into the upstream pool. Such behavior can also be inferred from observations of migrating juvenile coho salmon into upstream overwintering ponds, the movement of juvenile coho salmon between beaver ponds and downstream tributary habitat, and the spawning of adult coho salmon and other salmonids in stream reaches above beaver dams (Bryant 1983, Everest et al. 1986, Murphy et al. 1989, Olsen and Hubert 1994, Solazzi et al. 2000, Roni et al. 2006, Rosenfeld et al. 2008).

Lokteff et al. (2013) studied the effects of beaver dams on the movement of one native trout species (*Oncorhynchus clarkia*) and two non-native species (*Salmo trutta* and *Salvelinus fontinalis*) in two northern Utah streams. The authors found that all three species were able to pass through beaver dams, but the native trout passed dams more frequently than either of the non-native species. Spawn timing and the physical characteristics of the dams affected the passage of each species. In Bridge Creek—a tributary of the John Day River in Oregon—Pollock et al. (2012 and unpublished data) documented both juvenile and adult steelhead throughout four treatment reaches of a stream that had more than 100 beaver dam analogues (see "Beaver Dam Analogues") and reinforced beaver dams, including upstream of all the structures. Studies of the effects of beaver dams on Atlantic salmon also show that movement was affected by flow rates. In years with low flow, redd counts above dams were depressed, but with the return of high flows, access to upstream reaches and red counts generally increased (Mitchell and Cunjak 2007, Taylor et al. 2010). This suggests that any detrimental effects of beaver dams on the population as a whole were negligible.

Further research is needed to clarify this common misconception that beaver dams block fish passage. For example, Kemp et al. (2012) reviewed 108 studies evaluating the effects of beaver dams on fish and fish habitat. A total of 43 percent of the studies cited beaver dams as "barriers to fish movement." However, the authors found this negative effect of dams to be largely speculative, since 78 percent of those studies did not support this claim with data. Kemp et al. (2012) conclude that negative effects of beaver dams on fish movement at most are short-lived and localized, and have negligible long-term impacts.

Do beaver dams increase stream temperatures?

In some regions, high stream temperature can be detrimental to salmon and other aquatic species. Beaver dams may increase stream temperature by removing riparian shade and increasing water surface area and they may also lower stream temperatures by increasing groundwater (hyporheic) exchange, creating deep pools, and increasing shade from riparian vegetation (Pollock et al 2007). The effect of beaver dams on stream temperature largely depends on pre-existing conditions. For example, construction of a beaver dam in a shallow, wide stream is likely to reduce average water temperatures because the greater "thermal" mass of the larger water volume will dampen temperature fluctuations, while the decrease in the surface to volume ratio will reduce the amount of insolation per unit mass of water. While dam construction across the floodplain on a deep, narrow stream is likely to increase average temperatures because the surface area per unit volume will increase.

Similarly, where there is the potential for good hyporheic exchange, beaver dam construction can lower stream temperatures; this happens because water flowing through alluvium rapidly exchanges heat and equilibrates to the temperature of the substrate through which it is flowing. Conversely, during the winter, hyporheic exchange can warm water if the ground is warmer that the temperature of the stream surface water (e.g. see Chesney et al. 2010)

Beaver can both reduce and increase the amount of riparian vegetation and this can also affect stream temperature. When beaver initially occupy a site, they often cut down stream-adjacent trees and this can reduce shade and increase stream temperatures. Over time, emergent vegetation can grow and provide shade. In more arid environments, and particularly in incised streams where there is little to no riparian vegetation, beaver dams can raise water tables and expand the extent of riparian vegetation and this can increase the amount of shade relative to pre-dam conditions (e.g. see Pollock et al. 2007).

Whether changes in stream temperature are "good" or "bad" depends on the metabolic optimal temperature range of the species in question and, for fish such as salmon and steelhead, the availability of food resources. For example, warmer than average temperatures for the area combined with abundant food supplies can lead to rapid growth of certain cold-water species, such as steelhead and Chinook salmon. In northern latitudes such as in Alaska, a slight increase in water temperature such as that associated with beaver ponds (i.e., from 2 to 4 degrees) may increase the length and weight of rearing juvenile salmon (Willson and Armstrong 2009). Beaver modifications may increase thermal complexity due to the creation of deep-water habitats that stratify giving mobile fish more thermal options to choose from. Experimental removal of beaver dams to reduce temperature suggests that the physical habitat effects of dam removal are far more detrimental to aquatic habitat than the likely change in temperature (McRae and Edwards 1994).

What are beaver canals?

Once a dam is constructed and a pond develops behind it in a low-gradient area, the zone of floodplain that is accessible to the beavers can be further enlarged through the construction of canals (Gurnell 1998). The length and width of a beaver canal varies (i.e., 3 to 300 feet long and 14 to 40 inches wide), and typically they are more than 20 inches deep (Gurnell 1998). Beaver use canals as travel corridors to access new foraging habitat and also to transport woody vegetation to the beaver pond (Gurnell, 1998). As beaver collect and transport food and construction materials from the adjacent uplands back to the pond, they start to create surface trails or "slides." These trails make it easier to drag food and construction materials across the ground and extend their foraging areas (Baker and Hill 2003). Eventually, slides may be dug out, extending or converting them into canals and expanding the beavers' foraging range from the pond.

How do beaver communicate?

Beaver communicate through scent, vocal sounds, tail slapping and body movements. The highly social nature of beaver requires complex communication between family members within single colonies and between separate colonies within watersheds. These different types of communication are discussed below.

What is castoreum?

Communication by scent is facilitated through two functional scent organs: the castor sacs and anal glands (Walro 1980). Urine is concentrated in the castor sacs, where it becomes castoreum, a strong-smelling brown paste (Baker and Hill 2003). It is likely that, as the beavers' diet changes throughout the seasons, the castoreum changes in chemical composition and odor.

The scent of castoreum can elicit various behavioral responses from beavers, although territorial defense probably is the primary one. For example, Müller-Schwarze (2011) deposited castoreum chemical compounds within a beaver colony's territory. The resident beavers investigated these odors and often destroyed the marks and "overmarked" them. Butler and Butler (1979) proposed that castoreum is used by beaver to provide information about individuals and physiological status within a family. Svendsen (1980) proposed that, beyond simply being used as a territorial marker, castoreum deposited on scent mounds (see "What are scent mounds?") enhances the confidence of resident beavers and lowers that of intruders at the same time. Schulte (1998) showed how beaver can use castoreum to distinguish family members from non-members and neighbors from complete strangers. Although more research is needed to confirm these results and hypotheses, it is clear that beaver castoreum scent communicates more than just territorial occupancy.

What are scent mounds?

Both castoreum and anal gland secretions are used in scent marking and are actively deposited on "scent mounds" that consist of piles of mud and debris (Dugmore 1914, Hay 1958, Schramm 1968, Wilsson 1971, Butler and Butler 1979, Bollinger 1980, Müller-Schwarze and Heckman 1980, Walro 1980, Lancia and Hodgdon 1983, Muller-Schwarze et al. 1983). Most scent mounds are constructed by adult males who use their forelimbs to gather mud, sticks, leaves, and other materials from the bottom of the pond, carry the debris to a selected location in a bipedal fashion, and pile the debris into mounds near the shore (Figure 10). A mud pile can consist of a single "load" or measure up to 2.5 feet (80 centimeters) in diameter and 20 inches (50 centimeters) high (Müller-Schwarze 2011). The beaver deposits secretions on the scent mounds both during and after construction. Beavers of all ages anoint the mounds with scent, but the frequency of marking increases with age (Baker and Hill 2003, Müller-Schwarze 2011). Males of all ages place the most scent marks (Lancia and Hodgdon 1983) . Large numbers of scent mounds—more than 100—can be constructed within a territory, and they are usually placed on or near lodges, dams, and trails near the water's edge (Baker and Hill 2003). Beavers deposit scent marks on mounds to elevate the point of odor release. The moist mud helps intensify the odor, and the mound protects the raised odor beacon from becoming inundated as water levels fluctuate (Müller-Schwarze 2011).

Figure 10: Scent mounds piled near the shore of Dredge Creek in southeast Alaska near the Mendenhall glacier. Mary Willson pictured in the foreground. Photo courtesy of Chuck Caldwell.

Beavers build most of their scent mounds in the spring, as 2-year-olds disperse from their home colonies to colonize new areas (Hodgdon 1978, Svendsen 1980). Marking of the scent mounds sometimes continues year round in warmer, ice-free, climates, but generally it abates in the summer and fall, when invasion pressure has declined (Müller-Schwarze 2011). To maximize the efficacy of mounds, beavers place them in strategic locations, such as near the paths most likely used by invading beaver (Müller-Schwarze 2011).

Do beaver vocalize?

In addition to communicating by scent, beaver use a rich repertoire of vocalizations (Novakowski 1969, Pilleri 1983). Adult beaver have been known to produce burps, whines, hisses, and gnawing and chewing sounds. Hissing is probably the most common vocalization. Beavers hiss in defense when confronted with other animals or to defend their territory (Leighton 1932, 1933, Muller-Schwarze 2011). Young beaver are particularly vocal (Hodgdon 1978). They often produce a soft repetitive whine, apparently to solicit food from other beavers in the family, or when placed in uncomfortable situations such as being forcibly expelled from the lodge and into the water (Müller-Schwarze 2011).

Why do beaver slap their tails?

The best-known alarm signal of beavers is the tail slap. In response to any disturbance at or near the pond, beavers first attempt to investigate the source. If they are sufficiently startled, they immediately slap their tail on the water surface with a powerful stroke, creating a loud "slap" sound, and dive away (Müller-Schwarze 2011). Tail slapping may serve as a warning signal to family members, who typically respond by returning to the pond (if foraging on land), diving away, or returning to the lodge (especially kits). Tail slapping also may be used to drive away predators or ungulates looking to forage on the beaver's food cache, and to elicit a response from the source of disturbance (Brady and Svendsen 1981, Lancia and Hodgdon 1983).

Beaver seem to discriminate among tail slaps from different individuals. Tail slaps by adults—most notably adult females—elicit the most response by all age classes and sexes (Lancia and Hodgdon 1983). In contrast, older beaver often ignore tail slaps by juveniles, whose slaps sound different because of the size and shape of their tail (Müller-Schwarze 2011). It may be that young beavers learn the "social rules" of appropriate use of the tail slap over time.

How do beaver create their own habitat?

Beavers are ecological engineers that create and maintain habitat to better suit their needs for survival. They do this primarily through their unique behavior of constructing dams on the landscape. Beaver dams can dramatically increase the amount of impounded water (Johnston and Naiman 1990a) and sediment behind them (Naiman et al. 1986, Butler and Malanson 2005, Green and Westbrook 2009), increase riparian vegetation (Pollock et al. 2007), expand wetlands (Hood and Bayley 2008), increase floodplain connectivity (Naiman et al. 1988, Pollock et al. 2003, Westbrook et al. 2006), and change and enhance biological diversity (Schlosser and Kallemeyn 2000, Muller-Schwarze 2011). At the landscape scale, beaver can alter the hydrology, geomorphology and plant and animal community structures of watersheds (see Naiman et al. 1988, Pollock et al. 2003, Müller-Schwarze 2011, Pollock et al. 2014).

These aquatic habitat modifications are a successional process on the landscape, varying both temporally and spatially, that creates a shifting mosaic of environmental conditions (Johnston and Naiman 1987, Naiman et al. 1988b, Johnston and Naiman 1990a, Pastor et al. 1993, Johnston 1995, Snodgrass 1997, Schlosser 1998, Schlosser et al. 1998, Snodgrass and Meffe 1998). Beavers create dynamic patches on the landscape that change over time as stream reaches are colonized, flooded, and eventually abandoned (Schlosser and Kallemeyn 2000). The dynamics of these changes result in a mosaic of aquatic patches that vary in age across the landscape; types of patches include ponds, collapsed ponds, streams, and beaver meadows (Naiman et al. 1988b, Wright et al. 2004).

Once beavers are established in an area, population expansion may cause their food supplies to become limited. As beaver impound water, it expands onto the floodplain, increases local aquifer recharge, and raises water tables. The increase in saturated soils creates larger areas of wetlands and riparian zones, which facilitate the growth of emergent vegetation and herbaceous vascular plants used for food. The increase in deep water facilitates beaver's access to woody vegetation that can be also used as construction material to build more dams. With more food resources and suitable habitat increasing, the number of beavers that a given area can support also increases. Thus, once established, beaver tend to create a positive feedback loop that improves their own food supply, enabling more dams to be constructed and further increasing food availability (Pollock et al. 2007, 2014).

Chapter 3—Beaver Myth Busters

Greg Lewallen

Today we know a lot about beavers. Yet people still repeat a number of poorly substantiated assertions (i.e., myths) about beaver and beaver dams. In this section we discuss, and dispel myths and rumors surrounding this storied creature.

Myth: Beaver always live in streams.

Headwater and low-gradient streams are well-known beaver habitat, but beavers are opportunistic and commonly use a wide variety of available habitat, including lakes, side channels, estuaries, large rivers, and tidal channels (Hood 2012) (Figure 8), as well as artificial features such as ditches, canals, ponds, and reservoirs. As long as there is a food supply and either the existence of—or the ability to build—deep, slow-water habitat that reduces predation and keeps lodge entrances submerged, there is potential for beaver occupation (Müller-Schwarze 2011) (Figure 7).

Myth: Beaver eat fish.

Beavers have never been observed eating live fish. Beavers are considered choosy generalist herbivores (Harper 1969) (see “What do beavers eat?” in Frequently Asked Questions). Beavers are morphologically and physiologically adapted to feeding on woody and herbaceous material; for example, they have unique microflora in their digestive tract that allow them to digest cellulose (Jenkins and Busher, 1979, Novak 1987). Unlike the river otter, which eat primarily fish, beaver do not have the speed, maneuverability, sharp teeth, or claws necessary to catch fish. Beaver ponds can be excellent habitat for fish, especially summer and winter rearing grounds for juvenile salmonids. Although they directly increase the quantity and quality of fish habitat, beaver themselves do not prey on fish.

Gleason et al. (2005) reported observing three beaver feeding on Chinook salmon carcasses that had been discarded after being filleted by anglers along a relatively deep-water pool of Montana Creek in Alaska’s Susitna River drainage. The authors hypothesized that beaver in Alaska, and presumably elsewhere in the Pacific Northwest, engage in this feeding behavior to take advantage of the readily available and predictable source of protein and fat, at least on a seasonal basis.

Myth: Beaver ponds are a source of fine sediment.

Beaver ponds have the ability to retain significant amounts of fine sediments. However, sedimentation rates behind beaver dams vary widely (Pollock et al. 2003). Naiman et al. (1986) found that beaver dams in a boreal forest ecosystem stored between 46 and 8,502 cubic yards of sediment. Butler and Malanson (1995) studied sediment deposition behind beaver dams in Montana and found that younger ponds averaged 73 cubic yards of sediment, while older ponds averaged 266 cubic yards. Butler and Manlanson (2005) estimate the total amount of sediment stored behind beaver dams in pre-European settlement of North America from 9.81

billion cubic yards to an astounding 163.5 billion cubic yards of sediment. Factors that influence sedimentation rates include the growth rates of the emergent vegetation found in the ponds, upstream sediment loads, the number of beaver dams upstream, and the frequency of dam failures (Pollock et al. 2003). For more information on sedimentation accumulation behind beaver dams, see "Sediment Retention" and "Geomorphology" in Section 2.

The sediment stored behind beaver dams has the potential to be a source of fine sediment for downstream reaches of streams and rivers after dams are abandoned or breached. However, the amount of sediment evacuated downstream beyond a breached dam is typically small (Butler and Malanson 2005), and dam breaching generally occurs during high-flow events. Much of the sediment stored by beaver dams is retained by emergent vegetation that colonizes the bare surfaces of the accumulated sediment, although Butler and Malanson (2005) do present rare examples of catastrophic events resulting from beaver dam failure.

Myth: Beaver always build dams.

Beavers do not always build dams. They construct dams to impound water in low-gradient areas and to create ponds when needed. The pond is used to dive to safety from predators, increase their foraging area, transport food resources, and control water levels so that burrow and lodge entrances remain submerged at all times. In northern latitudes and at high elevations where streams freeze, the pond must be deep enough to remain ice free below the surface, so that beaver can access food resources stored under the ice in caches.

In areas where these conditions are already met, such as lakes or large rivers, beaver do not build dams. Instead, they dig bank burrows, bank lodges, or lodges for habitation. They may also build canals to increase their foraging area. Mixed populations of beaver, some of which build dams and some of which do not, have been observed in smaller streams, suggesting that the non-dam building strategy may be more common than previously thought. Furthermore, when beaver do not build dams, they are less conspicuous and thus more easily overlooked (Petro et al. 2015).

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Section II - Beaver Restoration and Management

Photo Credit: Michael Pollock

Chapter 4—Watershed Planning for Beaver Restoration Projects

Michael M. Pollock and Kent Woodruff

Encouraging beaver to build dams and create ponds is an affordable and effective habitat restoration technique. In broad terms, there are three general beaver restoration approaches:

- Passive actions such as trapping restrictions or changes in grazing regimes
- Active habitat manipulation to entice beaver to build dams and establish colonies
- Actively relocating beaver to areas with the intent that they will establish colonies

Frequently there is considerable synergy among the three approaches. Reintroduction efforts, in particular, often are synchronized with trapping restrictions and habitat improvement efforts.

We view beaver as a watershed-scale restoration "tool." Beaver can be used to restore conditions at an individual site, but any beaver colony is part of a larger population, and the population dynamics of beaver are such that colonies form and disappear at different rates across the landscape. This means that any particular location that is suitable for beaver may not always be occupied. Furthermore, successful site-specific beaver restoration results in the production of beaver that disperse and contribute to the larger population, so even a site-specific beaver restoration effort will have watershed-level implications. Nonetheless, all restoration actions ultimately take place at a site, and many techniques are available to encourage beaver to occupy or remain at a specific site for longer periods than would occur under natural conditions.

We discuss specific restoration and management techniques for encouraging beaver to establish dam-building colonies but do not focus on establishing bank beaver colonies. Not all beaver build dams or wood lodges, instead, some so-called "bank" beaver establish reproducing colonies by building lodges in banks. Bank beaver have not been particularly well-studied, but observations suggest that they can exist in the same streams as dam-building beaver, that dam-building behavior can be triggered in bank beaver, and that dam-building beaver can stop building or maintaining dams and adopt a bank beaver lifestyle. In this manual, we focus on restoring dam-building beaver behavior because beaver dams and the water they impound create multiple ecosystem benefits, whereas the benefits of bank beaver are more limited (although evidence is growing that even the slow-water habitat created by the slides, burrows, and tunnels of bank beaver can be extensively used by juvenile salmon) (M. Pollock, K. Woodruff, personal observations).

Planning and Implementation Framework

To induce dam-building at a specific location, beaver are needed at the site. But where do the requisite beaver come from? There are several options:

(1) beaver can be reintroduced from an offsite location,

(2) beaver from a nearby colony can be triggered to recolonize the site, or

(3) dam-building behavior at the site can be triggered in an existing population of bank beaver.

In each case, many of the steps in the restoration process are similar. Figure 11 provides a flow chart to follow in making decisions about beaver restoration actions.

We use Figure 11 as a collaborative, watershed-scale framework for discussing specific actions to induce the establishment of dam-building beaver colonies. We approach beaver restoration from a watershed scale because that is the scale that is most likely to lead to successful colony establishment and a stable population. However, the approach described here can be adapted to a site-specific scale, as long as there is awareness of the larger watershed context within which the site-specific restoration actions occur. Below we provide an overview of previous efforts to establish beaver colonies, followed by a discussion of each of the steps in the restoration process outlined in Figure 11.

Goals, strategies, and objectives

Developing project goals and objectives, as well as a strategy for reaching the goals are key to any successful project. For the purposes of this document, goals, strategies, objectives, and tactics are defined as follows:

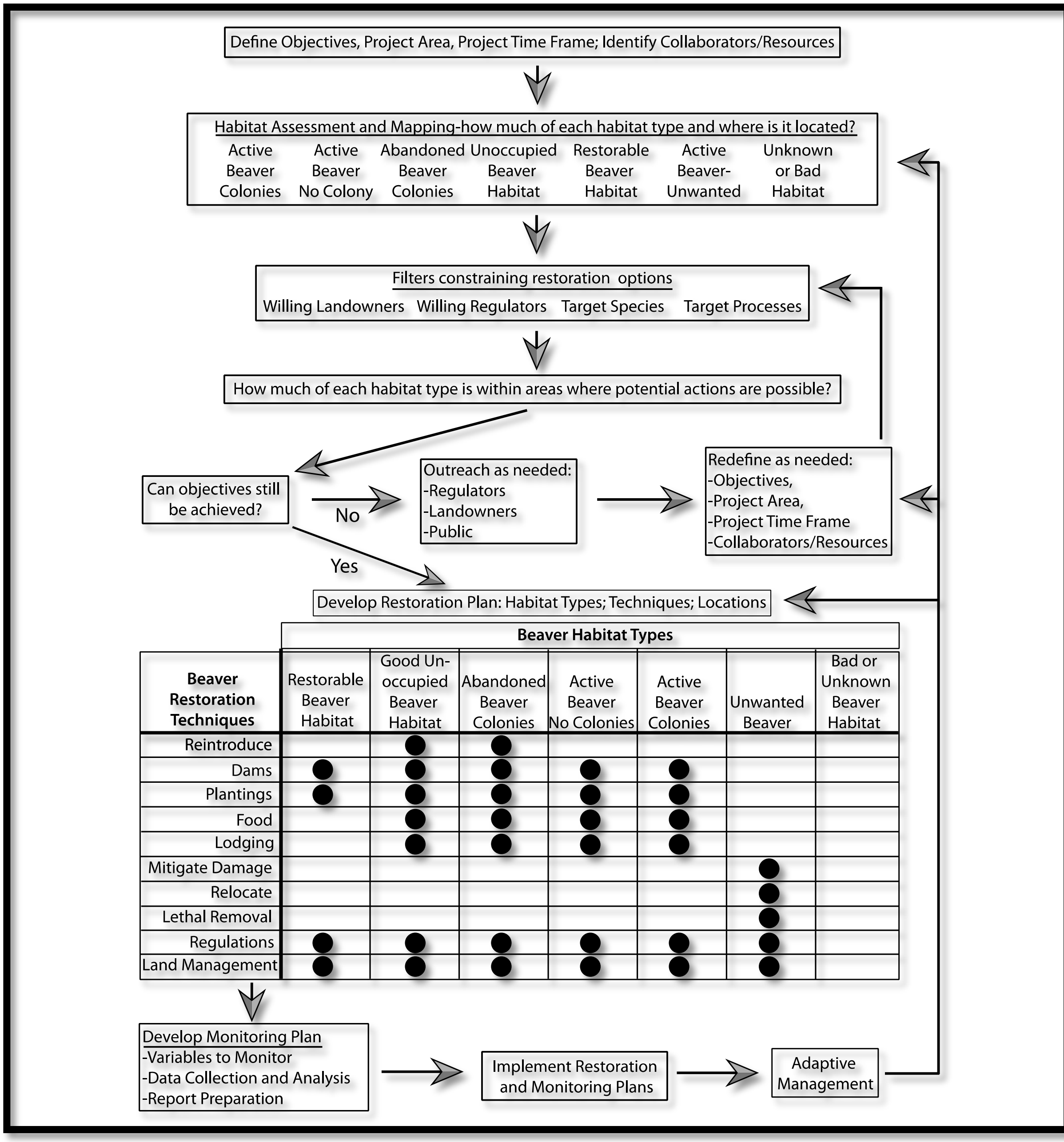
- A goal is a broad, primary desired outcome.
- A strategy is the approach you take to achieve a goal.
- An objective is a measurable step you take to achieve a goal, consistent with the strategy.
- A tactic is a tool you use in pursuing an objective associated with a strategy.

Identifying the project goals is an essential first step, after which strategies, objectives and tactics can be developed that will best achieve the goals.

Goals

A beaver restoration project could have any of a number of goals:

- Address nuisance beaver problems via non-lethal methods
- Restore beaver populations
- Increase water storage or raise water tables
- Restore wetland habitat
- Restore habitat for a particular species (e.g. salmon, Cascade frog, or willow flycatcher)
- Restore mountain (i.e., wet) meadow habitat
- Restore riparian habitat
- Increase floodplain connectivity
- Restore incised streams



	Beaver Habitat Types						
Beaver Restoration Techniques	Restorable Beaver Habitat	Good Un-occupied Beaver Habitat	Abandoned Beaver Colonies	Active Beaver No Colonies	Active Beaver Colonies	Unwanted Beaver	Bad or Unknown Beaver Habitat
Reintroduce		●	●				
Dams	●	●	●	●	●		
Plantings	●	●	●	●	●		
Food		●	●	●	●		
Lodging		●	●	●	●		
Mitigate Damage						●	
Relocate						●	
Lethal Removal						●	
Regulations	●	●	●	●	●	●	
Land Management	●	●	●	●	●	●	

Figure 11: Flow chart for data acquisition and decision-making process in beaver restoration projects.

Strategies

Developing a strategy is the next step. A strategic assessment identifies both potential routes for moving forward to achieve the desired goals as well as the likely obstacles. Many of the goals above can be achieved through multiple approaches that don't necessarily involve beaver or beaver dam analogues (BDAs), but for the purposes of this document, we assume that a broad strategic decision has already been made to use these beaver restoration tools. However, if at some point it becomes apparent that the chosen beaver restoration strategy is not likely to be effective, it is important to remember that other restoration strategies exist and can be employed in conjunction with or separately from beaver restoration strategies.

Strategic considerations are many and could include any of the following, among others:

- Where is there support for the project with landowners/land managers, the regulators and the general public?
- To what extent will educational components be needed for landowners/land managers, regulators, and the general public?
- What is the regulatory environment? Are any regulatory changes needed?
- How extensive is the willing landowner base? Can it be expanded if necessary?
- How can the effects of nuisance beaver be mitigated?
- What is the size of the project area?
- How much pre-project habitat assessment is needed?
- What is the timeframe for project completion?
- What is the project funding strategy? (Although of key importance, this topic is not discussed in this document.)

Objectives

Objectives can serve as benchmarks or targets that are helpful in determining whether the overall goal is being achieved. Examples of objectives might be to install a set number of BDAs, relocate a specific number of beaver, mitigate problems created by an identified number of nuisance beaver, or establish a certain number of new beaver colonies. Related objectives might be to increase the amount of slow-water habitat by a proscribed amount, institute a specific regulatory change, or provide a certain number of educational interactions. It is helpful if objectives are quantifiable. Good monitoring programs quantitatively assess whether the objectives are being achieved.

Goals, strategies and objectives should all be dynamic and included as part of the adaptive management feedback loop. If monitoring suggests that project objectives are not being realized, then the project's strategies or goals may need to be revisited.

Project Area

The project area includes the area where the restoration is intended to occur, and, if relocating beaver is part of the strategy, the population source area. The restoration area should include both the restoration and/or release sites, and, if the project is likely to increase beaver populations, a larger area that includes where beaver might be likely to emigrate. If the emigration area includes landowners who are opposed to having beaver on their property, a strategic decision needs to be made as to whether to offer to mitigate for or relocate beaver that become established in areas where they are unwanted.

Time Frame

Good project development requires an estimate of the number of years or decades needed to achieve project goals. When working with beaver to restore streams, it is helpful to take the long view, and to put in the effort needed to develop lasting relationships with people, beaver, and streams.

Beaver restoration projects tend to take longer than many other types of restoration projects because it is often necessary to change the way people think about managing both streams and beaver, and this takes time. In addition, because beaver are a living creature, they cannot be engineered to create habitat the way say, a piece of large wood might be engineered to provide a pool. It takes time for beaver to establish a colony in a new location and for the habitat benefits of the colony to be realized, as hydrologic, geomorphologic, and biological changes occur in response to beaver dams. Ideally, a beaver restoration project should have a minimum time frame of at least 5 years. It may be designed to extend for decades or longer, particularly if the goal is to initiate process-based changes to the physical condition of streams and riparian areas over large spatial scales.

Potential Collaborators and Resource Assessment

Because of the watershed scale at which beaver populations are maintained, and the multiple physical and biological processes that are affected by beaver dams, beaver restoration efforts usually require a collaborative effort by multiple organizations. Creating a cooperative relationship among organizations also helps diversify implementation of the tasks at hand. Some partners may have access to solutions that others don't. For example state wildlife agencies may have the most expertise at handling beavers. Typically they are trained, equipped, and permitted to trap and move beavers, whereas other organizations might face logistical or regulatory hurdles. Other agencies or non-governmental organizations may have ready access to geographical information system (GIS) data.

Identifying which permits are needed for the project may guide you to potential collaborators. Developing positive, collaborative relationships with agencies from which you will need permits is always a good strategy. In addition to permit facilitation, people from other organizations may have access to labor, expertise, and funds. Perhaps most important of all, they may have already established relationships with the managers or owners of the land where you would like to engage in restoration actions.

Identifying available collaborators and incorporating them and the resources they bring into the restoration effort is an ongoing and dynamic process that may require you to modify the initial project goals. Clarifying roles and commitments is an important part of any collaborative process, and developing written cooperative agreements and funding instruments is essential for projects to function over the long-term.

There is a long and ongoing history in the development of methods for predicting where existing or potential beaver habitat exists (see Table 6). This fact in and of itself suggests that consensus is lacking as to what constitutes good beaver habitat, and that there is no one tool appropriate for assessing a watershed in terms of beaver habitat suitability.

Table 6: Physical and Biological Parameters of Stream Reaches Used to Estimate Suitability as Beaver Habitat. Studies are arranged chronologically, left to right, from oldest to youngest. Locations are all U.S. states, except as follows: RM = Rocky Mountains, US = United States, ON =Ontario, Canada.

Location	RM	US	MA	CA	SD	OR	KS	ON	ON	OR	WA	IL	WV	UT	WA
Physical Variables															
Stream slope		X	X	X		X				X	X	X	X	X	X
Stream depth or width			X	X		X				X					X
Stream power (Q*S)	X								X		X			X	
Valley bottom width	X									X		X			X
Stream length		X													
Stream substrate						X	X								X
Bank slope	X														
Water quality							X								
Water fluctuations		X													
Basin size			X					X			X				
Biological Variables															
Habitat area		X													
Vegetation	X	X	X		X	X		X	X	X		X	X	X	
Land use / development		X					X					X			
Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

References: 1= Retzer et al. = 1956; 2= Allen 1983; 3 = Howard & Larson 1985; 4 = Beier & Barrett 1987; 5 = Dieter and McCabe 1989; 6 = McComb et al. 1990; 7 = Robel et al. 1993; 8 = Barnes and Mallik 1997; 9 = Slough and Sadleir 1997; 10 = Suzuki and McComb 1998; 11 = Pollock et al. 2004; 12 = Cox and Nelson 2008; 13 = Anderson and Bonner 2014; 14 = MacFarlane and Wheaton 2014; 15 = Dittenmeier et al.unpublished data.

Additionally, experimental relocation efforts that have used habitat suitability models to find good release sites have universally observed a high rate of emigration by the released beaver (McKinstry and Anderson 2002, Babik and Meyer 2013, Methow-Beaver-Project 2014).This suggests that existing models may need refinement. Nonetheless, there are some basic physical constraints on where beaver can establish dam-building colonies within a stream network, and potential beaver habitat can often be described by three physical variables; stream gradient, stream width, and valley bottom width, while a fourth, biological variable—vegetative condition—is also often used to predict where suitable beaver habitat exists (Table 6).

Years of data collection by numerous observers suggests that most dam-building colonies are established on small to medium-sized, low-gradient streams that are unconstrained within a valley bottom (Table 6). Large rivers, high-gradient streams, and confined channels tend not to support beaver colonies, but there are always exceptions, particularly when beaver are abundant and all the high-quality habitat is already occupied. What is often surprising is how little water beaver need to build dams. Small ephemeral streams, springs, and seeps can be dammed by beaver to create perennial ponds. Some beaver seem to have an uncanny ability to identify hydrologic conditions that are suitable for pond formation, including locations that habitat suitability indices may not identify because these areas have drainage areas so small that they are not even recognized as streams (let alone perennial streams) on GIS data layers. In addition, stream layers are often missing side channels on large rivers, yet beaver frequently dam such channels. Using GIS analysis tools to identify these areas can be challenging, and thus they are often overlooked or ignored as potential beaver habitat.

Ideally a beaver habitat assessment is performed at the watershed scale and includes some basic coarse-scale categories of beaver habitat suitability (see Figure 12). At the broadest scale, stream networks can be divided into stream reaches that have no, low, medium, or high intrinsic potential as beaver habitat. Streams with high intrinsic potential can further be divided into areas with and without active colonies. Reaches with medium to high intrinsic potential without active colonies can be further divided into reaches with beaver activity but no dam-building colonies, reaches with abandoned colonies, reaches without beaver that have existing high-quality habitat, and areas that could have existing high-quality habitat but are in need of restoration. Thus a stream network can be divided into six basic categories in terms of beaver habitat suitability (see Figure 11):

- Low/no/unknown intrinsic potential
- High/medium intrinsic potential
    - Active dam-building colonies
    - Abandoned dam-building colonies
    - Beaver activity but no dam-building colonies
    - No beaver, but habitat suitable for colonization by dam-building beaver
    - Potentially good beaver habitat but needs restoration

Each category requires different restoration tools to achieve the desired outcomes.

With the increasing availability of remote sensing tools such as GIS mapping software and Google Earth, many indices or approximations of the three variables of stream slope, stream width, and valley width can be estimated mathematically and applied over large spatial scales, so as to create maps of beaver intrinsic potential or habitat suitability (Figure 12). Other calculated physical variables that have been used in GIS to estimate beaver habitat quality include drainage area, stream power, and bankfull discharge (Table 6).

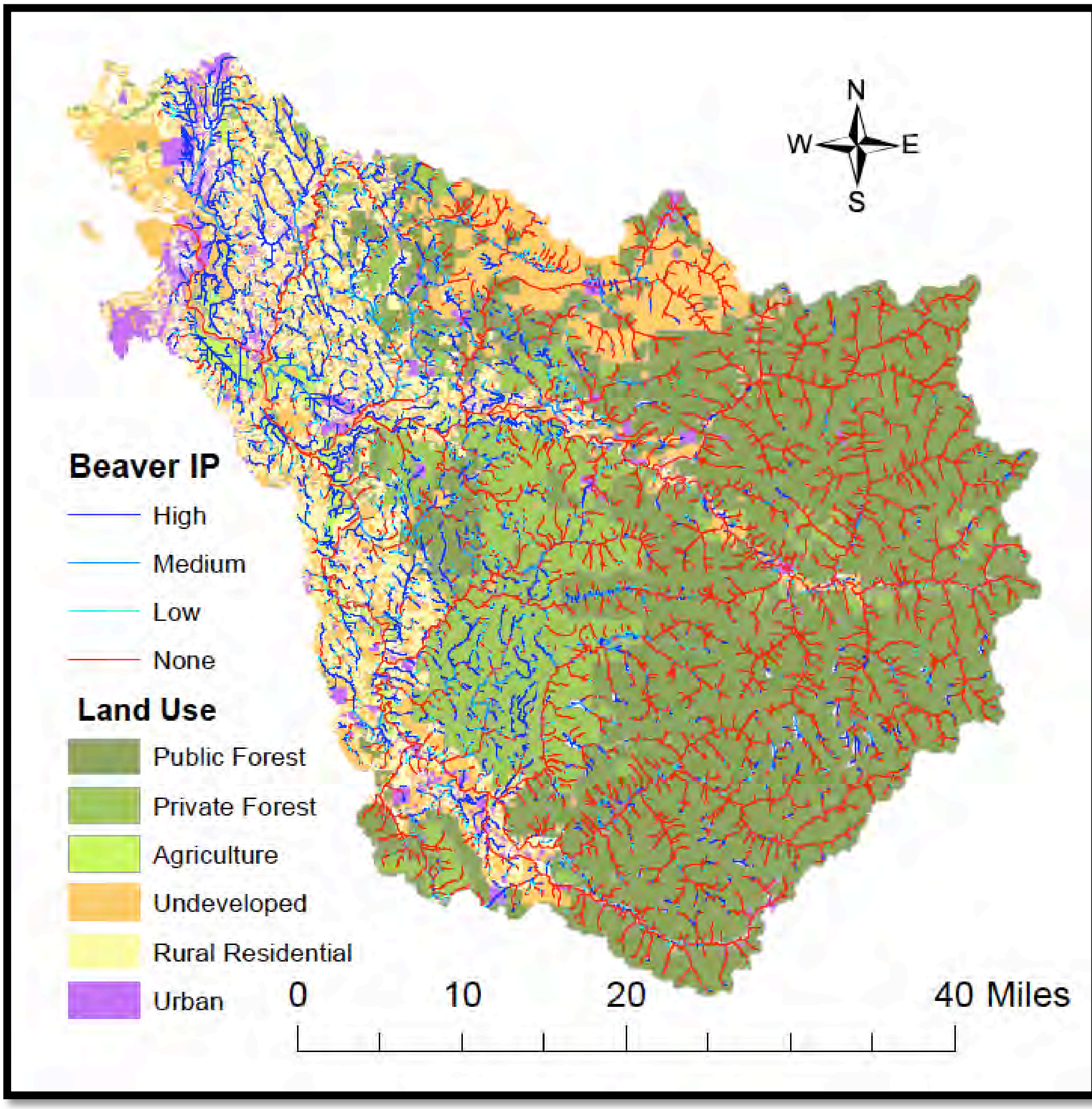


Figure 12: Beaver Habitat Intrinsic Potential map for the Snohomish River basin, Washington. Note that most of the potentially high-quality beaver habitat is found in agricultural, urban, and rural residential areas, which are concentrated in the low-gradient lands to the west, while the steep, mountainous headwaters on public forest lands to the east contain very little quality beaver habitat.

Analyzing stream networks within a watershed enables identification (with a certain amount of error) of stream reaches that could potentially support beaver colonies. Remote sensing tools can be used to categorize stream reaches as either not suitable for beaver (this is the case for most of the stream network), potentially suitable for beaver, or unknown. When aerial photography (e.g., Google Earth) is used to locate beaver ponds, potentially suitable habitat can be further divided into occupied versus unoccupied. Aerial photography can also be used to identify, to a certain extent, recently abandoned sites, particularly if there are time series of high-quality aerial photographs. This is increasingly the case (Johnston and Naiman 1990b). Additionally, aerial photography can be used in making initial assessments of vegetative condition, and distinguishing unoccupied sites that currently are in good condition from those that need restoration. Thus, remote sensing tools can be used to create an initial watershed map of the stream network that divides it into the five of the six categories in the second box of Figure 11: unsuitable beaver habitat, active colonies, abandoned colonies, good unoccupied habitat, and potentially good habitat that needs restoration.

GIS tools also can be used to further filter the landscape by identifying the property boundaries of cooperating and non-cooperating landowners, jurisdictional boundaries where beaver management regulations may vary, habitat distribution maps for other species that may be the target of the restoration efforts (e.g. salmon), habitat types that may be the focus of restoration efforts (e.g., mountain meadows), and locations where there may be beaver-infrastructure conflicts (e.g., road and stream crossings).

Once a GIS-based map has been created, the beaver habitat categories need to be ground truthed. Ground truthing is the only means of identifying the sixth category of beaver habitat suitability: locations where beaver are present but not part of an active dam-building colony. Figure 13 is an example of a beaver habitat scoring sheet, developed by the Methow Beaver Project, that has been used by several projects to evaluate the quality of beaver habitat on the ground; this aids in identifying areas where beaver can be relocated. Such a scoring system is useful in assessing and improving the accuracy of the habitat classification derived from remote sensing but also in helping to further refine the relative quality of good beaver habitat and identify the sites where beaver reintroductions are most likely be successful. Key on-the-ground variables the scoring system uses include riparian condition, beaver activity, food availability, substrate and geomorphic parameters such as stream gradient and width, floodplain width, and the general size of the available habitat. The scoring system does not identify areas that could be good habitat if they were restored, or what is needed to restore such streams and riparian areas.

Filters (External Constraints)

Landowner Assessment

A key external factor that affects the success of beaver projects is the spatial distribution of land where beaver are wanted (or tolerated). Property boundary maps are available for most jurisdictions. Managers of public land are generally (but not always) supportive of beaver restoration efforts, but beaver do prefer low-gradient areas in valley bottoms, and such areas often are privately owned (see Figure 12). However, a growing number of private landowners are recognizing the benefits of beaver dams, and support for allowing beaver on private lands is growing. In many places, identifying and developing a network of private landowners who support beaver restoration efforts is an essential early step.

Potential infrastructure conflicts should be identified and mapped. Examples of instream infrastructure that has the potential to create conflicts with beaver restoration efforts include culverts, stream gages, outfalls irrigation/diversions ditches, weirs, and fish screens. On floodplains near stream channels, flooding from beaver dams can cause conflicts related to human infrastructure such as buildings, roads, and commercial crops. In addition, beaver use Some commercial crops, such as *Populus* plantations, alfalfa fields, and even watermelon, as a food source to varying degrees if the crop is growing near a stream (see Appendix A).

Methow Beaver Project Release Site Score Card (2015 update) Date_________________

Site ID_______________________________ Observer______________________________

GPS Coordinates_UTM (NAD 83)___________________________ Subwatershed__________________________

Lat x Long______________________________ Location Description ___________________________________

_______ **Gradient of the assessed stream habitat unit** **10**. ≤3% **0**. 4-6% **-10**. 7-9% **-30.** ≥9%

Stream Flow _______ Max (spring) / Min (fall)

	garden hose	fire hose	10″culvert	30″ culvert
Fire hose	1			
10″ culvert	3	4		
30″culvert	4	5	10	
un-wadeable	1	3	2	1

NOTE – Stream flow above or below these parameters limits beaver dam viability

_______ **Habitat Unit Size** (linear stream measure) **5.** Extensive stretch of the stream **1.** Small isolated pocket

Woody Food (select the highest number possible in each line – then multiply lines**)**

a. **3.** Aspen, willow **2**. Alder **1.** Other hardwoods

b. **3**. Within 10 meters **2**. Within 30 meters **1**. Within 100 meters

c. **2**. Large amount (hundreds of stems) **1.** Some (dozens of stems)

_______ **Woody food score = multiply a x b x c**

_______ **Herbaceous Food** **10**. Grasses and forbs (aquatic and terr.) abundant **5.** No Grass/Forbs Present

_______ **Floodplain Width** **5.** Wide stream bottom **0.** Narrow 'V' Channel

Dominant Stream Substrate

________ **5.** Silt/Clay/Mud **2.** Sand **1.** Gravel **0**. Cobble **-1**. Boulders **-3**. Bedrock

Historical Beaver use

________ **15.** Old structures present **0.** No indication of previous occupancy

Lodge and dam building materials

________ **5**. abundant 1-6″ diameter woody vegetation available **-20.** no building material present

Browsing / Grazing impacts

________ **5.** No Impact or obvious presence of browsers / grazers **-10.** Heavy browsing / grazing

_______ **Ease of access** **2.** Easy travel to deliver beavers and monitor. **-5** Long hike

________ **Existing aquatic escape cover** **10**. Multiple deep pools (>1 meter deep) present. **-10.** No pools

________ **Total Score** (100 points maximum)

Release site viability requires securing adjacent landowner support and careful mitigation of human infrastructure conflicts in the vicinity.

Narrative description of site and notes/ Photo ID #s / sketch on back

Figure 13: Methow Beaver Project Potential Release Site Score Card.

Project Goals Assessment

Project goals usually constrain the potential extent of the project. For example, if a beaver restoration project focuses on a target species, habitat type, or habitat condition, the potential project area will be limited to places where those species or habitat types could occur. Examples of taxa for which beaver can improve habitat include salmon and steelhead, waterfowl, amphibians, and certain songbirds, such as the willow flycatcher. Examples of habitat types or conditions that beaver can help restore include mountain meadows, incised streams, off-channel habitat, wetlands, and riparian vegetation.

Jurisdictional Assessment

Federal, tribal, and state governments all have a certain amount of jurisdictional authority over the management of beaver. Which agency has regulatory authority over which lands is a matter of debate. In general, state legislatures and state fish and wildlife departments set the rules for beaver management across the state, but Indian nations and federal agencies that own or manage land within a particular state's boundaries sometimes develop their own beaver management or other natural resource management guidelines, as when, for example, the National Parks Service sets fishing regulations within the boundaries of its parks.

Further complicating matters is that some state agencies have developed specific beaver management guidelines that are tied to restoration funding and that may not necessarily be consistent with state laws or fish and wildlife department rules. The state of Oregon is particularly complex, with state laws, Oregon Department of Fish and Wildlife (ODFW) regulations, ODFW guidelines, and even an Oregon Department of Justice legal opinion, all guiding the management of beaver within the state. Finally, the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service, the two Federal agencies that oversee the recovery of species listed under the U.S. Endangered Species Act (ESA), both recognize the importance of beaver-created habitat to the recovery of some endangered species, such as coho salmon. Thus using beaver or beaver dam analogues within the range of endangered species such as salmon usually requires consultation with these agencies. The coordination of jurisdictional authority of beaver, beaver dams, and beaver dam analogues among and between state, Federal, and tribal authorities is an ongoing, fluid, and dynamic effort.

Permit Assessment

Key to any successful restoration effort is acquisition of the necessary permits. Identifying and obtaining the necessary local, state, Federal and tribal permissions can often be the most time-consuming and confusing aspect of a restoration project. It can take agencies months to years to process permit applications, so it is best to begin identifying the necessary permits early on in the project. This is especially true for beaver restoration permits because many agencies have not yet figured out how to process various restoration projects that involve beaver, beaver dams, and beaver dam analogues.

The following are some common regulatory issues concerning beaver:

- Movement of reintroduced beaver to offsite locations where they are unwanted
- Fish passage over beaver dams or beaver dam analogues

- Turbidity
- Increased stream temperatures
- Flood damage to private property
- Flood damage to public infrastructure
- Downstream effects of dam failures
- Bank erosion
- Loss of riparian vegetation
- Loss of agricultural crops
- Loss of ornamental vegetation
- Habitat changes upon colony abandonment
- Degradation of habitat important to state or Federal ESA-listed species
- Assignment of liability associated with any of these perceived negative effects

Although many of these concerns are not well-founded for most situations, some may have to be addressed in the permitting process. Furthermore, individuals within regulatory agencies are not necessarily well-versed in the ecosystem benefits of beaver dams and may be more concerned about avoiding negative effects than creating positive outcomes. For a beaver restoration project to be successful, the concerns of the individuals within regulatory agencies who are responsible for issuing permits must be understood and addressed. It is essential to be able to convey the benefits of beaver restoration so that regulators can weigh potential risks against potential rewards and reach a determination that the project will provide an overall beneficial outcome.

State and Federal permits fall into the following broad categories, among others:

State:

- State Environmental Policy/Quality Act review
- Instream work permits
- Trapping and release permits
- Wild animal husbandry permits
- Archaeological/historical preservation permits
- Water Board permits

Federal:

- National Environmental Policy Act (NEPA) review (for Federal lands)
- Consultation with USFWS and National Oceanic and Atmospheric Administration (NOAA) Fisheries if ESA-listed species are in the area
- U.S. Army Corps of Engineers permits for instream work

Depending on the location of the restoration project, many of these permits may already be addressed under programmatic permits that cover specific types of actions over a specific geographic area, or a specific agency may have a programmatic permit from another agency. For example, the Aquatic Resources Biological Opinion (NMFS 2013) provides ESA coverage for the construction of beaver dam analogues on U.S. Forest Service (USFS) and Bureau of Land Management (BLM) lands in Oregon and Washington, while the Malheur National Forest in eastern Oregon has adopted a memorandum of understanding for managing beaver on its lands (Malheur-National-Forest 2007) and the U.S. Army Corps of Engineers has created a nationwide permit (NWP 27) which allows for a wide range of stream restoration actions consistent with Section 404(e) of the Clean Water Act. Developing collaborative relationships with agencies or organizations who already hold permits needed for beaver restoration and may be familiar with the current regulatory environment can aid in successfully navigating the permitting process.

Community Assessment

Most watersheds exist within a community of people, and it is important to gauge the level of local community support for beaver restoration activities before proceeding with a project. Community opposition can stop a project, while community support can ensure its success. Spending time building support for beaver restoration in your local community can help facilitate long-term success. In particular, many regulators are reluctant to approve beaver relocation projects because of the perception that most landowners do not want beaver on their property, although this perception seems to be a bit dated (Needham and Morzillo 2011).Although beaver can be established at specific locations without community support, if the goal is to create or expand a sustainable population of beaver within a watershed, a certain amount of educational effort will be needed so that people better understand that the benefits of beaver far outweigh the problems they may create, and that most of the problems can be addressed with proper management. Community support can also be helpful when regulators are considering whether to issue permits.

Evaluate options

As outlined in Figure 11, there are five tools that can be used to encourage or simulate dam-building behavior in beaver:

- Reintroducing beaver
- Building dams
- Providing food
- Providing lodging
- Planting riparian vegetation

There are also tools for addressing problems caused by beaver:

- Education
- Mitigation
    - Caging vegetation
    - Protecting culverts
    - Water level controls
- Relocation
- Termination (i.e., lethal removal)

Additional indirect tools that are useful in long-term beaver restoration efforts are:

- Working on regulatory changes
- Working on land management changes, particularly for public lands

Each of these tools has a role to play in beaver restoration projects, with the appropriate set of tools being determined by the project's goals and the risks and rewards associated with each project option. The next sections discuss these restoration tools, with an emphasis on the mostly commonly used of these tools: reintroduction efforts and construction of beaver dam analogues.

We also discuss the use of a Beaver Dam Viability Matrix (Figure 45), which is intended to assist project managers in quickly assessing the likelihood that a beaver dam will persist over at least two seasons—the time necessary for a mating pair of beaver to successfully rear their offspring. Depending on where a project site plots on the matrix, appropriate restoration techniques and tools can be selected or an alternative site pursued.

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Chapter 5—Relocating Beaver

Kent Woodruff and Michael M. Pollock

Overview of Relocation Efforts

In North America, there is a relatively long history of reintroducing beaver to areas from which they have been extirpated, primarily in the hopes that they would build dams and create ponds. In the United States, beaver reintroductions began in the early twentieth century across the continent from New York to California (Radford 1907, Tappe 1942). Most reintroduction programs were successful to the point that trapping bans were lifted so that populations could be controlled.

Early reintroduction programs were not concerned with maintaining genetically distinct populations, and many reintroductions used beaver from distant locations. As a result, there has been an unknown amount of genetic mixing. For example, reintroduction efforts in California used beaver from Idaho, Oregon, and California (Lynn 1949). Although numerous subspecies of the North American beaver, *Castor canadensis*, have been proposed in the past (Baker and Hill 2003), the Integrated Taxonomic Information System (ITIS.gov) currently recognizes *C. canadensis* as a single species and does not consider any of the many proposed subspecies "valid" (Appendix B). The International Union for the Conservation of Nature Red List (IUCNredlist.org) rates *C. canadensis* as "least concern," which is the lowest level of concern for a species in terms of its likelihood of becoming extinct. The IUCN considers the population of North American beaver stable and widespread throughout its range. These findings suggest that taxonomists and conservationists do not recognize distinct genetic populations of *C. canadensis*, and that unwanted genetic mixing between potentially distinct populations is not a high-priority concern. Much more effort should be focused on understanding beaver population genetics and identifying genetically distinct population segments, as well as linking specific life-history or behavioral characteristics with genetically distinct populations.

Beaver restoration efforts in the early to mid-twentieth century in the western United States generally did not focus on quantitative measures of success. Some efforts appear to have been successful, while for others, the success rate is unknown. For example, in 1948, Heter (1950) released 76 beaver (by parachute) on Forest Service lands in Idaho. One year later surveys indicated that the airborne transplants were successful, but the number of release sites was not stated. Lynn (1949) documented California transplant efforts in the 1930s and 1940s, when 1,208 beaver were released at 274 sites. The success rate was not stated. Hibbard (1958) reported the transplant of 466 beaver in North Dakota. Again, no success rate was documented. In Washington, Sheffer (Scheffer 1938) successfully transplanted beaver for the purpose of building dams to control sediment in Mission Creek. The project was largely successful, with 22 dams being built and more than 3,924 cubic yards of sediment being stored behind beaver impoundments. Also in Washington, in Okanogan County, in the 1930s a total of 76 beavers were released at 40 sites. Eighteen of these resulted in successful establishment (Okanogan Wenatchee National Forest unpublished records).

Today, beaver relocations are often proposed as a non-lethal means of dealing with so-called "nuisance" beaver that are in conflict with humans, usually because they are either flooding property that landowners do not want flooded, damming culverts, affecting irrigation ditches, or cutting down trees (e.g., see Revised Code of Washington [RCW] 77.36.160). Yet other landowners recognize and value beaver dams' numerous hydrological and ecological effects and want to have the animals on their property (e.g., see RCW 77.32.585).

Recent studies suggest that re-establishing beaver colonies by relocating beaver to areas where they are not currently found can be challenging, and that mortality rates for the relocated beaver can be high (McKinstry and Anderson 2002). At the same time, a number of beaver habitat suitability models have been developed that relate beaver dam or colony abundance to physical and biological habitat characteristics and use of such models should help reduce mortality (see Table 1).

These models vary in their utility for identifying sites where relocated beaver are likely to successfully become established. Why relocated beaver do or do not become successfully established at or near release sites is not entirely clear, although recent studies provide some insights.

In Wyoming, McKinstry and Anderson (2002) relocated 234 beaver to 14 sites over a 6-year period. They radio-tagged 114 beaver and found that mortality rate was 30 percent and the emigration rate (i.e., moving more than 6.2 miles from the release site) was 51 percent, inclusive of transmitter failures. They estimated a survival rate of 49 percent after six months and 43 percent after a year. Animals less than 2 years old had a mortality or emigration rate of 100 percent after 6 months. The high overall mortality was attributed to abundant predators (coyote, black bear, grizzly bear, mountain lions, and humans) and limited cover. The release sites contained shallow water, with no ponds and little protection. No food, lodging, or dams were provided. However, 13 of the sites had evidence of old beaver activity, indicating good habitat potential, and all sites had abundant riparian vegetation. Because the release sites were a long distance from the capture sites the beaver were temporarily retained and transported as groups on a weekly basis; however, it was not clear whether individuals from a trapped colony were released at the same site. Releases occurred primarily in the fall because that is typically when beaver construct new dams and lodges. Some beaver were successfully released in the spring at sites where flow tended to be ephemeral, but the relative survival rates for spring versus fall releases were not compared. Despite the high mortality and emigration rates, beaver were successfully established at 13 of 14 sites (beaver were removed from one site because of conflicts with agriculture). Twenty-three beavers (i.e., 19 percent) lived more than 6 months and eventually built dams and lodges near the area where they were released. Another 10 were found in dams and lodges within 1.86 miles of the release sites. On average, 17 beaver were transplanted to each release site before the successful establishment of dams and lodges.

In the Methow Valley in north-central Washington, Woodruff (2015) has an ongoing beaver restoration project that has relocated 240 beaver to 51 sites from 2008 to 2014, for an average of

4.7 beavers per site. As of November 2014, there was activity on 17 sites (34 percent), and 31 (61 percent) had established dam-building colonies. The 31 successful sites average 0.46 acres of surface water. Fifteen well-established sites average 0.89 acre of surface water, with an average of five ponds per site. In 2014, 38 beaver were released to 13 sites (an average of 2.9 per site), and eight of those sites (62 percent) saw successful establishment the first year.

Unlike many relocation projects, the Methow Beaver Project is providing considerable assistance at the release sites; it is likely that this is contributing to project success. Prior to releasing beaver, the project team constructs artificial lodges and provides an initial source of food (aspen—*Populus tremuloides*). Furthermore, many release sites contain deep pool cover (i.e., more than 1 meter deep).

Quantifying the long-term success of the Methow Beaver Project has been somewhat challenging because reintroduced beaver have occupied sites one year, only to abandon them and move elsewhere the next. In some instances, based on passive tagging information, beaver that were introduced to a site immediately went elsewhere. In three cases, when another group of beaver were introduced to the same site they elected to stay and build dams. The project illustrates the difficulty of predicting the behavior of any individual beaver or group of beaver, in particular when and where they will establish a colony. In general the project results suggest that carefully planned beaver reintroductions can increase the density of dam-building colonies on the landscape, but the precise location where colonies will be established cannot always be predicted.

In the Yakima River basin in Washington, another collaborative beaver restoration effort has met with considerable success by adopting and modifying the Methow Valley methodology (Babik and Meyer 2013). The Yakima Beaver Project has been managing beaver complaints in the Yakima Valley through a combination of education, mitigation, and relocation. From 2011 to 2014 they received 134 nuisance beaver complaints, primarily in the agricultural lowlands and near urban areas, and have relocated 130 beaver to Forest Service lands in the high-elevation headwaters of the Yakima River. Of these relocated beaver, 81 (62 percent) have moved to unknown locations or died. Thirteen were monitored moving to a different area, with the greatest movement being more than 40 miles in 47 days. Of the remaining 49 beavers, two died and 47 (36 percent) were successfully established in 17 colonies within a year of being released. The number of beaver relocated per known successful colony was 7.6, but subsequent field surveys of streams near the release sites have found additional recently established colonies, suggesting that some of the beaver that dispersed from the release sites successfully established colonies elsewhere. The Yakima Beaver Project enticed beaver to stay at the release sites by providing lodges and food and releasing them in areas with deep pools. The project team used the same scoring system as the Methow Beaver Project (see Figure 13) to identify good beaver habitat, but even with these incentives, many beaver dispersed to other areas. In some cases the dispersing beaver established colonies elsewhere, indicating again that it is difficult to predict where translocated beaver will establish a colony but also that the success of a project can extend well beyond the initial treatment areas.

Petro (2013) studied the survival of 38 radio-tagged beaver released into nine sites in coastal Oregon. After 16 weeks, the survival rate was 47 percent, with predation by mountain lions the greatest source of mortality and with most of the mortality occurring within 1 week of release. Only one released pair engaged in dam building. They built six small dams in two locations, but the dams were ephemeral because of high winter flows. The suitability of the release sites was determined by using a beaver habitat suitability model for western Oregon (Suzuki and McComb 1998). The beaver received no assistance at the release sites such as a dam, den, or food. In addition, instead of being temporarily retained at a holding facility, they were released individually and immediately after capture, such that individuals from intact colonies were released to new sites over a period of about one to four days.

Jackson and others (unpublished report) used nine physical and biological characteristics of sites with naturally occurring beaver dams to identify unoccupied sites with similar characteristics that they thought would be good relocation sites. From May to August of 2009, they captured, radio-tagged, and released 37 animals at 13 sites in Oregon's Umpqua River basin. When the last transmitter quit working after more than 500 days, about 26 percent of the beaver had survived. Some beaver moved very little from the release site, some beaver moved around a bit and then returned to the release site, and some travelled a considerable distance—up to 8 miles. The animals were released without being provided a dam, den, or food and were released during summer low-flow conditions.

In summary, multiple projects have successfully relocated beaver across a wide range of habitat. At the same time, most projects have documented many instances where beaver have failed to establish at a target location. The reasons for establishment failure are varied and often the reasons are not clear. Below we describe a relocation methodology that incorporates many of the lessons learned from the efforts cited above as well as incorporating lessons learned from other efforts that we did not describe. The methodology we present is the most comprehensive description of how to relocate beaver of which we are aware.

Relocation Methodology

Most recent relocation efforts have benefitted from the experience of prior activities. For example, the Methow Beaver Project in Washington relied on knowledge accrued by Mark McKinstry and others in Wyoming (e.g., McKinstry and Anderson 2002), the publication of results and techniques by John Vore in Montana (Vore 1993), guidelines developed for stream habitat restoration in the state of Washington (Washington Department of Fish and Wildlife 2004), and advice from Lew Pence in Idaho, who has years of beaver relocation experience (Woodruff 2015).

Current relocation projects in the western United States often include the following key steps:

1. Identify suitable habitat (often using remote sensing).
2. Assess current beaver population status and distribution.
3. Evaluate individual release locations.
4. Pursue acquisition of beavers.
5. Collect information about beavers captured (or re-captured).
6. Care for beavers temporarily and ensure that beavers are grouped as families or compatible units with both males and females.
7. Prioritize and prepare release locations.
8. Deliver beavers to selected sites.

9. Conduct follow-up monitoring and provide support.

Identifying and Prioritizing Suitable Habitat for Releasing Beaver

The Methow Beaver Project developed and employed a GIS model for evaluating the 1,800-square-mile target watershed that emphasized stream gradient and stream discharge as the key features for habitat suitability. This exercise identified approximately 160 highly likely reaches for beaver establishment. Additionally, known beaver occupancy from multiple stream survey efforts was mapped and compared with predicted suitable habitat. This allowed model inputs to be validated and adjusted.

A habitat assessment scorecard was created that was based on all available literature, consultation with people experienced in beaver management, and the local knowledge of Methow beaver crews (Figure 13). The scorecard allows individual sites to be ranked based on multiple factors, including many that are listed as risk factors in the Beaver Dam Viability Matrix (see Section 10). The scorecard should be modified for individual circumstances, as it has been over the years for the Methow Project. Factors evaluated include the availability of woody food and building material, stream gradient and flow, availability of existing aquatic escape cover, presence of herbaceous food, stream bottom character, potential for conflict with existing human activities, and past beaver presence.

Sources of Live Beaver

Often when beaver restoration is pursued, the beavers themselves come from areas where landowners or land managers have concerns about human/beaver conflicts. Common concerns include orchard damage, culvert blockage, damage from flooding, trees fallen along roadways, fallen trees affecting buildings or vehicles, impacts to irrigation canals, beavers feeding in agricultural fields (e.g., alfalfa), and loss of ornamental or landscaping trees. Where it is not practical to mitigate beaver damage onsite (see section 9), removal can be initiated through live trapping, ideally using licensed trappers or others who are familiar with trapping and handling beaver.

Landowner Contact

Positive landowner relations are essential to the success of beaver relocation. Respecting landowner wishes is critical. Communication with landowners should include an assessment of the potential conflict situations and messages about the value of beaver in enhancing watersheds. This communication serves as an important foundation for gaining community acceptance of beaver restoration as a practice. It is helpful to clarify that beavers are not villains that always need to be removed, but that they have much to offer, especially as watershed function is more heavily emphasized throughout much of the western United States and elsewhere.

Live Trapping—Techniques and Equipment

Each state has specific guidelines, rules, and regulations for managing, capturing, handling, and relocating beavers that must be followed. Coordination with local biologists and enforcement agents is important.

Although capturing beaver is not difficult and can be learned through trial and error, relevant knowledge and experience can significantly improve the likelihood of success. Gaining tips, ideas, and tricks from experienced trappers is helpful and will substantially lower the slope of the learning curve. Because each beaver represents a substantial contribution to habitat improvement, enhanced stream function, and water storage, it is prudent, ethical, and respectful to limit injuries and impacts associated with trapping and transport.

Hancock-style "suitcase" beaver traps (Figure 14) are a common method of capture, but other box and suitcase trap configurations have been employed successfully . Snares with "deer stops" are also used for live capture but require special authorization and training.

Baiting traps placed on the edge of water bodies with scent lures and food, or placing passive traps on trails and near centers of heavy use, is common practice. Beavers like to investigate uncommon smells, especially those of unfamiliar beavers. Castoreum-based lures are available commercially or can be easily made using castor glands and oil glands from dead beavers. Breaching dams is another way to draw beavers to traps, as beavers are drawn to the sound of running water.

Traps should be set and then checked frequently. Beaver activity usually commences late in the day and goes through most of the night. Near-freezing temperatures and holding beavers in traps for an extended time can add stress, which can possibly affect the success of re-introduction. If temperatures are high and beavers are away from water, that too could be stressful. Conversely, if placed to close or far into the water beaver can drown in traps. Finally beavers can be exposed to predators while in traps. Frequent trap checks are important.

Beaver Holding Facilities—Assessment and Care

Temporarily housing beaver has the potential to substantially improve successful reintroduction rates. Some recent beaver relocation projects have employed very simple to very elaborate holding facilities (Babik and Meyer 2013, Methow-Beaver-Project 2013),while others have not held beavers at all following capture (Hoffman and Recht 2013, Petro et al. 2015).However, allowing time for an entire group to be united before release (this can take several nights of trapping) seems to be an important part of successful reintroductions.

In some cases success has been accomplished with immediate release. However, given the easy mobility of beavers in watersheds and the social, gregarious nature of this animal, it is unlikely that individual beavers would wait for others to arrive over succeeding days in an unfamiliar location—and that they could avoid detection and predation long enough to become established at the new location. It is also possible that the social factors of site selection are a cooperative decision for a group of beavers and that the decision is made based on the perceived capacity of the connected group. This is an area where more studies are needed.

Techniques and Equipment

Once beavers have been successfully captured, data should be collected on their age, weight, sex, and condition, and whether they have been encountered before. On long-term projects, it is helpful to mark captured beavers in some way so that individuals can be identified in the future. Marking with techniques that allow for ongoing movement monitoring is challenging.

Standard VHF or satellite telemetry has yielded limited results. PIT tag marking with readers in streams has also provided some movement data.

Holding beavers in a temporary facility appears to contribute to the likelihood that the groups released will become established and create the desired watershed improvements, as long as the holding facility allows beavers to:

- Be away from "the scene of the crime" for a while and disassociate with their original territory and the behavior that contributed to beaver/human conflicts
- Have time away from predation risk
- Become accustomed to other captured beavers and possibly form new bonds of affection within self-selected pairs and groups
- Have abundant food resources to improve body condition before release
- Be monitored for health and condition

Group size is determined largely by the trapping situation. A minimum of a male-female pair is needed.

Intake Processing Procedures (Methow Beaver Project)

The techniques described below are those used by the Methow Beaver Project to process and handle beavers at the project's beaver holding facility. Not every project will have such an ideal holding facility. Adjustments can be made based on available resources.

Animal Safety

Some basic practices can go a long way in protecting the health of the beavers, which is important. For example, working quietly and calmly can reduce stress to the animal, and keeping beavers properly restrained helps protect them—they may need protection from each other. It is important to properly sterilize your tools and injection sites. Also, if an animal appears to be suffering from great stress, it is appropriate to postpone the intake until later.

Beaver Handling Precautions

Like most wild animals, beavers do not like to be handled and could bite if threatened. Also beavers can carry a variety of diseases. Caution is warranted when handling beavers to keep human contact as safe as possible. Be aware of the potential to be bitten during all transport and handling. A restraint bag is a good tool to keep beavers and humans safe during handling, tagging, and examinations. If you are bitten while working with beavers, clean the wound carefully and immediately notify your supervisor. Additional wound management may be necessary.

- Wear exam gloves during all beaver evaluations, PIT tagging, ear tagging, and sexing.
- When tagging, prep skin on tails and ears with alcohol to reduce bacterial infection.

- Always wear personal protective equipment (PPE) (i.e., waders) in raceways.
- Limit the exposure of wounds on hands and arms to water in the raceways.
- Don't eat, drink, smoke, or touch your eyes, nose, or mouth after handling beavers, their traps, or working in their environment **until you have thoroughly washed your hands.**
- If you become ill (fever, aches, swollen glands) during or after the project, report to your supervisor, see your physician, and inform them that you have been working with beavers and that bacterial infection could be the cause of your discomfort.
- If a beaver appears injured or sick, it should be placed by itself and watched carefully. Do not tag or sex any beaver unless it seems well. Beavers that seem unwell should not be used in a reintroduction project. Instead, consider (1) attempting to support the beaver's recovery in an isolated raceway for a few days, or (2) euthanizing the animal for humane reasons and to protect captive and wild beavers.
- Avoid dissection or necropsy. Necropsies need to be conducted by qualified veterinarians at appropriate facilities.
- Regularly disinfect vehicles, traps, and gear—especially after handing sick beavers. Rinse traps, boots, tools, and food bowls with Virkon ™ every week. This is a disinfection best management practice.
- Dry and expose raceways and houses to sunlight between occupancy.
- Work with state wildlife veterinarians to identify potential beaver disease issues. This includes shipping recently deceased beavers or tissues.

Assigning a Unique Identification Number

The first step in processing captured beaver is to assign a unique identification number (ID) to each individual. The Methow Beaver Project also inserts PIT tags into all captured beaver, so the first step is to determine whether the animal is a recapture by carefully scanning its tail with a PIT tag reader. This can usually be done while the beaver is still in the trap, when it arrives at the holding facility.

The beaver ID is a combination of several items together. First is the two-digit year of capture (i.e., "13" for beavers captured in 2013). The second is the four-digit capture location. All beavers captured at a particular location will have the same location ID. For example, beavers captured at Pearrygin Lake have the code "PEAR." If you are trapping at a new location, try to pick a four-digit ID that will make sense in the future. Often this is the landowner's name abbreviated. The last part of the ID is the sequential number of capture, which increases by one every time a capture occurs. For example, a beaver captured at Pearrygin Lake in 2013 following beaver number 212 would be 13PEAR213.

Special Notes on Recaptured Beavers

Recapturing beavers is not uncommon. The Methow Beaver Project recaptures several beavers each year, often many kilometres from their previous capture site. If a beaver has a PIT tag or ear tags, it is a recapture. The PIT tag number can be used to identify the beaver with the help of the PIT tag spreadsheet, computer records, or a printed copy of capture records (in the intake log). Once a beaver has been assigned an ID, that number stays with the beaver for life.

The Methow Beaver Project typically keeps the intake forms from previous years on file in its office to reduce clutter in the field and protect the forms. For this reason, a new processing form should be filled out for a recapture. This also allows anything that may have changed, such as weight or tail damage, to be noted. The back of the intake form has a table to keep track of recaptures and observations of PIT tags by the instream fish PIT tag arrays. Any new capture information should be added to this table on the old form in the office. The paperwork should ultimately be stapled and filed together.

Weighing Beavers

After an ID has been assigned, the beaver is weighed. The beaver should be kept in the trap as it is hung on the scale at the holding facility. Keep hands off the trap and weigh it several times, until a consistent number is reached. Subtract the trap weight and record the number. Snared beavers will have to be weighed by the difference in an appropriate enclosed container, probably the transport cage.

Collecting Beaver Hair Samples

The Methow Beaver Project takes a hair sample from every beaver captured. This usually is done at the same time as ear tagging. Hair samples originally were collected to verify sex using mitochondrial DNA, but now the sample is taken because it is useful for future studies. The hair sample should be taken in such a way as to prevent cross contamination with human DNA or any other contaminants. While the beaver is in the Hancock trap, grasp a lock of hair with pliers and quickly tug it out. You want to get both guard hair AND underfur, to ensure that you collect hair follicles with the sample. Place the hair sample into a small manila (coin) envelope with the pliers. Do not mash the hair around with the pliers or stick your fingers into the envelope. Staple the envelope and write the beaver ID and date on the envelope. Between samples wipe the pliers thoroughly with a 95 percent ethanol solution to avoid cross contamination. The Methow Beaver Project stores hair samples in a clearly labeled Ziploc bag in a freezer until they are delivered to the U.S. Forest Service Wildlife Genetics Laboratory in Missoula, Montana. Many western beaver project DNA samples are being collected and catalogued there for future study.

Ear Tags for Beavers

Ear tags (the Methow Beaver Project employs Floy tags) are used to quickly and easily identify captive beavers in the holding facility (Figure 14). They are not designed as a permanent marker because they do fall out naturally and get pulled out by beavers. They are color coded to correspond with the beaver ID capture number.

Figure 14: Floy tag being attached to a beaver held in a Hancock "suitcase" style trap. Photo credit: Methow Beaver Project.

Beaver Bags

Once the beaver has been weighed and ear tagged and a hair sample has been collected, everything else is done from the posterior of the beaver, with the animal restrained in a "beaver bag." If you cannot obtain a beaver bag, you can sew a large bag out of a 45°-45°-90° triangle of Cordura cloth. Sew the bag so that it remains open on one end adjacent to the 90° corner with a small breathing hole in the opposite 45° corner.

To get the beaver into the bag, place the beaver in its trap into a dry raceway to prevent escape during transfer. Prepare all materials you will need to finish processing before transferring beaver to the bag. Open the Hancock trap and place the beaver bag over the open end of the trap. Lower the trap to its side and lay the bag out so the beaver can crawl into it. Laying the trap folded-frame-side down is awkward but allows the beaver to "step up" out of the trap; this can be useful, especially with larger animals. Extend the bag so that the beaver can see the breathing hole—"the light at the end of the tunnel." Minimize any rustling of the bag's Cordura material because this is a frightening sound to many beavers. As the beaver enters the bag, use your hands outside the bag to guide the animal into the end and prevent it from turning around. The beaver will squeeze down into the end. An assistant can hold the beaver in the bag while you work (Figure 15).

Figure 15: Workers transferring a beaver from the Hancock trap to a beaver bag. Photo credit: Methow Beaver Project.

Photographing Beaver Tails

Move the bag away from the tail and take a digital photo of the dorsal side of the tail. Record the picture number on the intake sheet. This may be useful data and help with future identification (Figure 16).

Figure 16: Photograph of a beaver tail, showing distinctive markings that are useful in identification. Photo credit: Methow Beaver Project.

PIT Tagging Beaver

PIT stands for Passive Integrated Transponder. The Methow Beaver Project injects PIT tags internally under the skin on the dorsal side of beaver tails. Although other projects tag elsewhere on beaver bodies, the Methow Beaver Project chose the tail to increase the chances that the PIT tag will be read by in-stream readers.

About the size of a grain of rice, the PIT tag consists of inert wire, a chip, and a capacitor encased in glass. When a scanner is passed over the site where the PIT tag was injected, the radio frequency of the scanner will excite the PIT tag, which in turn will reflect the radio waves back to the scanner. In this way, the scanner can detect the unique alphanumeric code of the PIT tag. The main benefit of using PIT tags for marking beavers is that the tag is permanent (although some loss of PIT tags can occur). Additionally, detection arrays are located in waterways throughout the Columbia Basin, and all data are shared in the PTAGIS database online, from all agencies that maintain readers. This allows an organization or agency to search for PIT tags from its beavers anywhere in the Columbia Basin. It is critical that the tags be placed carefully, and that the number be recorded accurately.

The PIT tag procedure is not necessarily difficult but it can be challenging to master. Use sharps safety, and consider practicing ahead of time on an orange. However, be aware that a beaver tail is quite tough (especially if the beaver is large) and that nothing will quite replicate the controlled force required to properly inject a PIT tag into a beaver tail (Figure 17).

Figure 17: PIT tagging a beaver. Photo credit: Methow Beaver Project.

Beaver Sexing

Sexing beavers is a key part of successful beaver restoration. Accurately sexing beavers helps with the following:

- Reducing peer-induced conflicts and death in captivity
- Raising the chances that breeding colonies will become established
- Predicting whether beavers will remain at a trapping location
- Inferring the demographics of beavers in the watershed

Sexing of lactating or reproductively receptive females can be done by simply checking for enlarged teats, but it is recommended that the sex be confirmed by examining anal gland secretions as well.

Sexing beavers is done while the beavers are restrained in the beaver bag, by manipulating the cloacal area and examining anal gland secretions (Figure 18). Schulte and others (1995) originally published this technique, which Dr. Lixing Sun demonstrated at the Methow Beaver Project facility in 2011. A beaver's two anal glands are located inside the cloaca on the left and right, slightly anterior of the vent. They need to be manually pressed out of the vent and "milked" gently to yield secretions for examination. This is a tricky, slippery, and somewhat messy process—one that gets easier with practice.

Figure 18: Sexing beaver. Squeezing a beaver for oil gland secretions (male). Photo credit: Methow Beaver Project.

You and your assistant should wear gloves for this procedure. Have your assistant cradle and restrain the beaver on its back, in the bag. Beavers do not like to be on their back and will thrash around if you let them. Cradling, as with an infant, can be effective. You may be able to kneel on the ground and position the beaver on its back with its tail away from you and its body resting on your thighs. The cradling method is by far the safest for most animals.

Once you have clear, stable, and unimpeded access to the cloaca, press your fingers GENTLY along the exterior of the vent, just anterior to and to the side of the vent. You should feel a lump. Pressing too far forward may cause castor oil—a thin, brown strong-smelling liquid—to be expressed. (If this incidentally occurs, you may wish to save it on cotton balls to use as a trapping lure). In addition, force applied in the wrong area—i.e., too far forward or too centrally—may cause the beaver to excrete feces or gas. Obviously this procedure should be done with your face a reasonable distance from the cloaca, with your mouth shut. You may also want to wear safety glasses.

When you feel one of the anal glands (either one is fine) you can direct it to emerge from the cloaca for manipulation. The gland looks like a swollen bulb with a pointed tip. It usually is quite slippery and has a few hairs at the tip. Continue to use one hand to maintain the same steady, gentle pressure you have used so far. Use your other hand to massage the gland to get the secretion from the tip. Steady, firm, and gentle pressure may work, or perhaps a milking motion. You will need to vary your technique to find what works best for you, and some animals will be easier to work with than others. Be patient and gentle; the animal under your care needs to be protected. It may happen that the anal gland withdraws and you will need to start over multiple times. Once some of the secretion has been emitted, wipe it onto a clean finger on your glove for inspection and compare to the chart in Table 7.

Table 7: Indicators for Determining the Sex of a Beaver (from Lixing Sun, unpublished)

	Male	Female
Color	Yellowish brown	Whitish
Viscosity	Thicker,	Thinner,
Odor	Smells like petroleum (motor) oil	Smells like funky cheese

Use a combination of the indicators in Table 7 to make your determination as to the sex of the animal. Relying on just one indicator increases the chance of a mistake. Remember that these are general guidelines, and that individual animals can differ, although the color and odor are quite distinct and probably the best indicators.

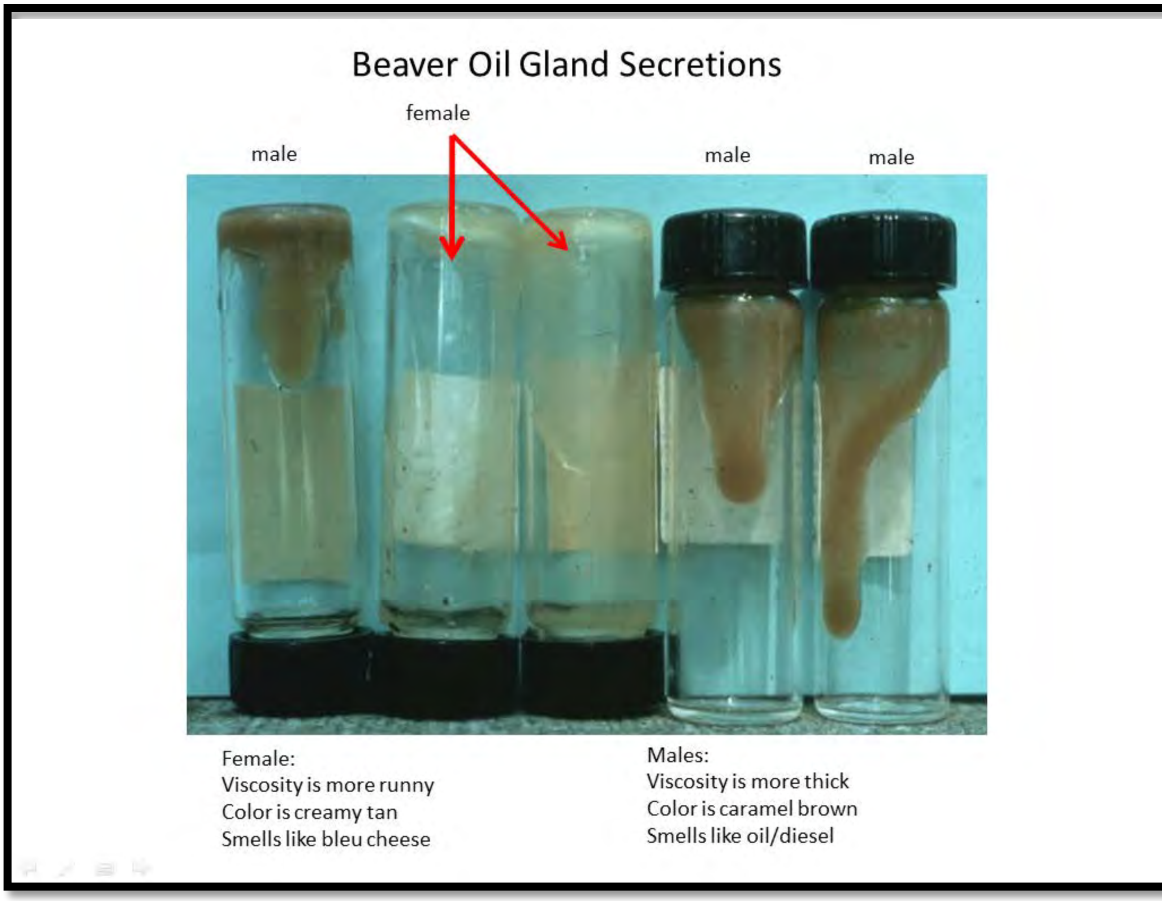


Figure 19: Differentiation of oil gland secretions between the sexes. Photographs courtesy of Dr. Lixing Sun.

The sexing process may need to be repeated for a good sample to be obtained. Have your assistant evaluate the sample as well. The two of you should make independent decisions about the sex of the animal before comparing answers. It is better to admit that you cannot tell than it is to make unsure decisions. Try again, later if necessary. This technique, when done correctly, can give you an unmistakable sex identification (see Figure 19).

Releasing Beaver at the Holding Facility

Putting the beaver into a detention area at the holding facility is the next step. First though, double check your intake sheet, because now is the time to catch omissions and errors, not after the release. The person already holding the beaver can bring the animal to the water and let it go, or hand it off carefully to someone else. Place the beaver bag into the water and pull it off the animal carefully. If necessary grasp the beaver by the base of the tail to pull it out of the bag. Do not drop the beaver from any height into the water. Always place the animal gently.

When the Methow Beaver Project builds beaver groups in the holding facility for release, every situation is a bit different. Which beaver to release with which is important, as is monitoring the beavers immediately after release. Here are some general guidelines for successful beaver "matchmaking":

- Consider keeping family groups intact. This usually is a good way to go, but family groups still should be observed.
- Keep an eye on the beavers' initial meetings and subsequent interactions until you are confident that they are friendly with each other.
- Position yourself in the water where you can act quickly to physically separate beavers—safely—if necessary.
- Release beavers into the water, so that any victims of aggression can flee quickly.
- Give stressed beavers time to calm down; this may be necessary before their true reactions can be observed.
- Protect kits from aggression, including from their parents. Kits are especially vulnerable to attack.
- Remove the aggressor, not the victim.
- Use caution when placing unrelated males together.
- Have multiple houses available for the first night or two, so that if a beaver is rejected from a lodge it has another place to sleep.
- Observe whether beavers that arrived at the holding facility at different times are lodging together.
- Take good notes on unusual interactions.
- Make sure you know who is who before releasing.

Feeding Beavers While They Are Being Housed

Because captured beavers likely have been without food (and water) for some time, the Methow Beaver Project provides food right away. Food for beavers is delivered daily, at the end of the day (i.e., the beginning of the day for beavers). The Methow Beaver Project uses Mazuri Rodent Pellets because this product is high in protein and nutrients, is easy to acquire at the local feed store, and is one of the best foods beaver can receive (according to professional beaver keepers at Northwest Trek in Puyallup, Washington). The Methow Beaver Project also feeds beaver small amounts of apple and carrot. Apples are high in glucose therefore too sugary to serve as a main food for beavers, but supplementing with apples is a good way to get beaver to reach into the food bowl where the pellets are. Beaver should be given as many aspen and willow branches as they want. Fresh-cut green alfalfa is a good herbaceous supplement.

Ravens and crows like the rodent pellets (and other food), so late evening delivery helps ensure that it is the beavers that get the food. Ideally, food amounts are such that most of the food is gone by morning (this can take some adjustment) which avoids waste. It is essential that any wet food be cleaned from the bowl regularly.

Condition Notes for Each Beaver

Condition notes are a good way to keep track of the health, behavior, and location of each beaver. Condition notes should be made in a binder that stays at the holding facility at all times. Notes should describe diet (i.e., whether, when, and what the beavers are eating), behavior, and any injuries.

Keeping track of each beaver's health is critical. Individual beavers tend to behave differently from each other, so it's important to get to know each of them so that you can recognize when they aren't acting normally. Condition notes are especially helpful for weekend feedings, when you are observing. Communicating with your crew any concerns you may have about a beaver's health is extremely important.

The binder should be used to make good notes when you are moving beavers from raceway to raceway. To make sure you are moving the correct beaver, double check the ear tags and pit tag. The binder also is a place to record how well individual beavers are getting along (e.g., are they sleeping in the same house?). This information is important in figuring out whether specific beavers are going to do well together when they are released.

The Beaver Whiteboard

The Methow Beaver Project uses a whiteboard to keep track of which beavers are in each raceway. The whiteboard shows the four raceways and each beaver's ID, sex, and ear tag color. The whiteboard is helpful as long as it is kept up to date.

Beaver Release Site Preparation

Predation has been documented as a key impact on reintroduction success (McKinstry and Anderson 2002, Petro 2013). Finding ways to reduce exposure to predation losses is a reasonable objective for many restoration projects aiming to improve their results.

The Methow Beaver Project has attempted to provide an initial period of security and calming for beavers immediately after they are delivered to sites by constructing temporary housing from downed material adjacent to the release stream (e.g., see Vore 1993)(Figure 20). The concept in the Methow has been to provide a dark, quiet space covered with sticks and logs about the size and volume of an overturned bathtub, next to the water, and in contact with the soil. Additionally, it can create a sense of familiarity if a deep layer of wood chips and sticks, bedding from the holding facility, is placed within the hollow area, so that the space has the odor of the beaver's recent home, along with a small amount of the commercial food the beavers have been eating recently (large amounts may attract unwanted animals). These types of site preparations may encourage the beavers to give their release site a second look.

Figure 20: Construction of an artificial beaver lodge in the Methow Valley, Washington. The lodge opening faces the water and is about 10 feet away from the water's edge.

Another method the Methow Beaver Project has explored is to build an "awning" of sticks over the water connected to the structure that provides beavers overhead cover while in the water adjacent to the artificial lodge.

A key habitat feature at release sites is the availability of water deeper than 1 meter. Beavers need this for security and to eliminate body waste. Enhancing pools could substantially improve the likelihood that the released beaver will establish a colony. Where feasible, using beaver dam analogues (see Section 7) to create pools where none previously existed could substantially enhance the attractiveness of release sites and thus increase the number of reaches where beaver restoration can be considered.

Transportation and Release of Beaver

There is much to learn about enhancing establishment success by modifying release methods. Some literature recommends releasing beavers in the fall, when site construction is urgent (Vore 1993, Cramer 2012); however, the Methow Beaver Project, the Yakima Beaver Project (William Meyer and Melissa Babik personal communication), the Skykomish Beaver Restoration Project (Jason Schilling and Ben Dittbrenner personal communication), the Grand Canyon Trust Beaver project (Christensen personal communication), Wildlife 2000 (Sherri Tippie personal communication), the Colville Beaver Project (Desautel personal communication), and others have experienced successful establishment in all months of the year during which releases have occurred. All have also experienced abandonment during the same months. This suggests that other factors are more important to eventual success than the timing of the day, season, distance travelled, weather on the release day, food provided the day before release, etc.

More significant may be the controllable site factors such as protection from substantial livestock overgrazing and trampling, proximity to roads and human infrastructure, beaver removal by recreational trappers, and unwelcome conflicts with adjacent landowners. Exposure to stochastic events such as fire, flood, and predation may also influence the success of beaver relocation efforts (Figure 6, transporting a beaver).

Delivery in metal transportation cages (Figure 20), wooden boxes, burlap sacks, and pet kennels (Figure 22-left photo)—by vehicle, game cart, backpack, horseback, ATV, and even crates thrown from aircraft (Heter 1950)—all have proved successful delivery methods for beavers.

Figure 21: Transporting a pair of beavers to a new release site in the upper Methow River watershed, Washington. 2009. Photo credit: Methow Beaver Project.

Perhaps the bottom-line take-home message from the last 80 years of beaver relocation efforts is that beavers are flexible, productive, tolerant animals that can adapt to new situations and locations and respond to a variety of situations to set up a colony and thrive—as long as basic woody building material and food, herbaceous food, and constant clean water are available and population limitation pressures of disease, human interactions, and predation are not extreme.

Follow-up Beaver Monitoring and Support

Visiting the release sites frequently and providing appropriate follow-up support can encourage beavers to remain at the site, but this, too, is an area for further investigation. It is very difficult for humans to evaluate or monitor the exposure of release groups to predation pressure at a particular site. For example, although augmenting the existing sources of building material and food can be beneficial, there is also the risk that doing so will attract unwanted animals or draw beavers to places where they are more exposed to predation.

If you do decide to provide follow-up support, aspen or another local favored woody food is least likely to attract bears and can be used both as food and for construction of lodges and dams (Figure 22). It is easy to tell at the next visit whether the supplementary material has been moved or chewed, which would indicate ongoing beaver activity. If there is no indication of activity, the site can be supplemented with additional beavers.

Figure 22: (left) Releasing beaver, and (right) bringing a long-term food supply for relocated beaver in the BLM Green River Ranger District, Wyoming. Photographs courtesy of Kevin Spence.

Risks Associated with Beaver Relocation Projects

Project Failure

Most beaver relocation projects have establishment success rates that generally don't exceed 50% (McKinstry and Anderson 2002, Babik and Meyer 2013, Hoffman and Recht 2013, Petro 2013, Methow-Beaver-Project 2014)which means that many release attempts will not be successful and that repeated attempts may be needed for beaver to colonize a site. This is normal. Additional cautions include the fact that beavers are very mobile. They can move offsite and completely disappear, or they may show up and build dams where they are not wanted. Identifying the precise factors that cause beavers to "stick" continues to be difficult. Projects that have had success emphasize the value of persistence and patience.

Additional Risks: Parasites and Disease

Like other wild animals, beavers as a group carry parasite and disease loads that are part of their ecology. Some aspects of beaver parasites and diseases have been studied, but there is much to learn about how relocation efforts influence these factors for beaver populations.

Tularemia, yersinia, rabies, and leptospirosis are some of the diseases noted in wild beaver populations. In 8 years of sampling and monitoring, the Methow Beaver Project has encountered two cases of tularemia and one case of yersinia infection in captured beavers (K. Woodruff, personal observation). The subject beavers died in captivity and were necropsied at the Washington Animal Disease Diagnostic Laboratory; subsequent testing was conducted at the National Wildlife Health Laboratory. In discussions with Washington State health officials, they acknowledged that these diseases are naturally present in most wild animal populations, not just beaver (K. Woodruff personal communication).

Giardiasis is a chronic, intestinal protozoan infection seen worldwide in most domestic and wild mammals, many birds, and people. Although most people associate *Giardia lamblia* intestinal infection with beavers, the protozoa is commonly found in most waterways in North America and occurs in a percentage of most wild and domestic animals and humans across the globe.

Beaver can carry the rabies virus, and, although rare, attacks on humans by rabid beaver do occur. Beavers acting aggressively or erratically should be avoided.

Wild beaver may also carry ectoparasites, such as the beaver beetle (*Platypsullus castoris*), the North American beaver beetle (*Leptinillus validus*), and several species of beaver mites belonging to the genus *Schizocarpus*. None of these ectoparasites presents a risk to humans or beavers.

In summary, precautions against infection are necessary for everyone who handles beavers. Any beaver relocation project should implement safe handling and sterilization policies to protect crew members and limit the potential spread of disease.

Chapter 6—Beaver Dam Analogues (BDAs)

Michael M. Pollock, Nick Weber and Greg Lewallen

Beaver dam analogues (BDAs) are channel-spanning structures that mimic or reinforce natural beaver dams (Figure 23). As such, they are semi-porous to water, sediment, fish and other water-borne materials. Like natural beaver dams, BDAs are biodegradable, temporary features on the landscape with functions that change in response to the effects of flowing water, sediment, and beaver activity (Pollock 2012). Also like natural beaver dams, BDAs function best when constructed in sequence, such that the structures work in concert with each other.

Beaver dam analogues are constructed with material that is similar to what beaver use to build their dams. Depending on what type of BDA is constructed, this may includes sediment ranging in size from cobbles, gravel, sand, silt and clay, vegetation such as the stalks of emergent vegetation, the branches and stems of decidous trees and shrubs (usually willow or cottonwood) and wood posts made from the boles of conifers (Figure 24). A complete construction sequence for a BDA would be to first install a line of posts using a hydraulic or pneumatic post pounder (Figure 25), followed by weaving branches in between the posts. An upstream face is then constructed first using cobble and other large material placed at the upstream base to prevent underscour, followed by successive layers of vegetation and finer-grained material until the structure has achieved the desired level of flow permeability and upstream pool depth.

Background

Beaver dam analogues are the latest iteration in a long history of constructing channel-spanning structures for the purposes of restoring stream habitat. Past efforts include construction of wire cages filled with rocks, rock dams, rock dams with mortar, boulder weirs, and channel-spanning logs and log steps (Slaney and Zaldokas 1997, Flosi et al. 2010, Cramer 2012). Key to the successful application of any of these techniques is understanding how they affect the transport of sediment and water, and how such effects vary depending on where they are placed within a watershed. Thus, understanding the hydrogeomorphologic context within which such structures are placed will have a tremendous effect on project success. In the case of BDAs, success will be determined largely by the selection of a suitable location for the structure, and less so on the relatively simple construction techniques. Chapter 5 describes the planning framework for identifying suitable locations within a watershed.

The addition of BDAs to a fluvial ecosystem with beaver should increase both the abundance and life span of natural dams, which in turn should promote reconnection of floodplain surfaces and an overall increase in both instream and riparian habitat heterogeneity and quality. Such longer lived, less transient dams should become building blocks for resilient and dynamic beaver dam complexes that support thriving colonies of beaver.

Although resilience and dynamism may seem at odds with each other, it is natural for activity in beaver dam complexes to ebb and flow (Naiman et al. 1988b, Pastor et al. 1993, Burchsted et al.

2010). Individual dams within a dam complex may be washed out or abandoned, but the importance of individual dams is not as critical as the combination of multiple dams within a broader dam complex. Individual dams can serve different functional purposes or be at different stages in their trajectories. The significance of the failure of an individual dam in a dam complex is much less than that of an isolated beaver dam. The resilience of a dam complex lies in its ability to maintain a healthy and stable system state (i.e., population) despite disturbances or external forcings. If other suitable locations are available, a colony may also be able to retain resiliency by shifting to a new location and abandoning a dam complex when its functionality decreases (Naiman et al. 1988b, Burchsted et al. 2010). This leads to a dynamic, shifting habitat mosaic in time and space (Tockner and Stanford 2002) that should promote habitat complexity and resilience for beaver and species that benefit from the beaver dam complexes.

Figure 23: Examples of beaver dam analogues in Oregon and California.

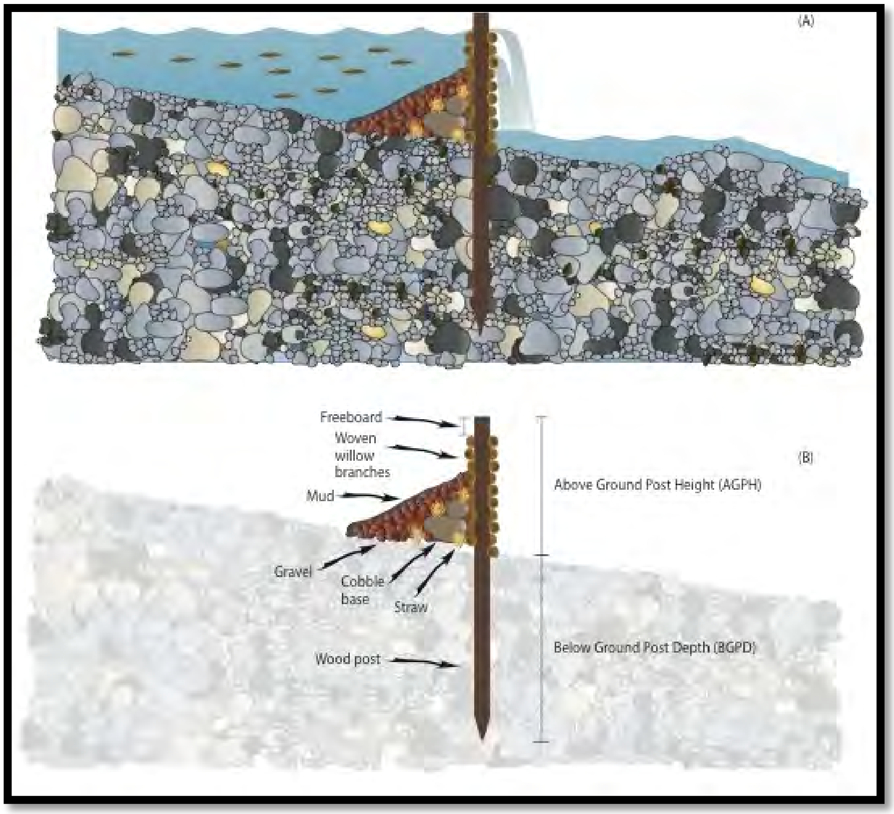


Figure 24: Diagram of a starter dam, showing design detail and the necessary material needed for construction. (top) side view (bottom) plan view.

Figure 25: Hydraulic post pounder options. Options include, clockwise, starting from upper left: (a) a hand-held pounder attached to hydraulic power pack, (b) a post pounder attached to bulldozers, (c) a handheld pneumatic post pounder attached to an excavator and (d) a modified excavator with a vibrating pad. Options (a) and (b) take approximately 5 to 10 minutes per post, depending on substrate, and it can be difficult to get to the desired depth. Option (d) takes less than 1 minute per post and can drive posts as deep as needed. All pounders have a metal cylindrical cap that holds the post in place while pounding. Each option has pros and cons to consider, including cost, maximum depth the posts can be pounded, substrate type, operator strength and expertise, and the amount of likely riparian and instream disturbance. Photo credits: (a) Nick Weber, Ecological Research, (b) Mark Cookson, USFWS, (c) Peter Thamer, Siskiyou County Resource Conservation District, and (d) Julie Ashmore, Okanogan Highlands Alliance.

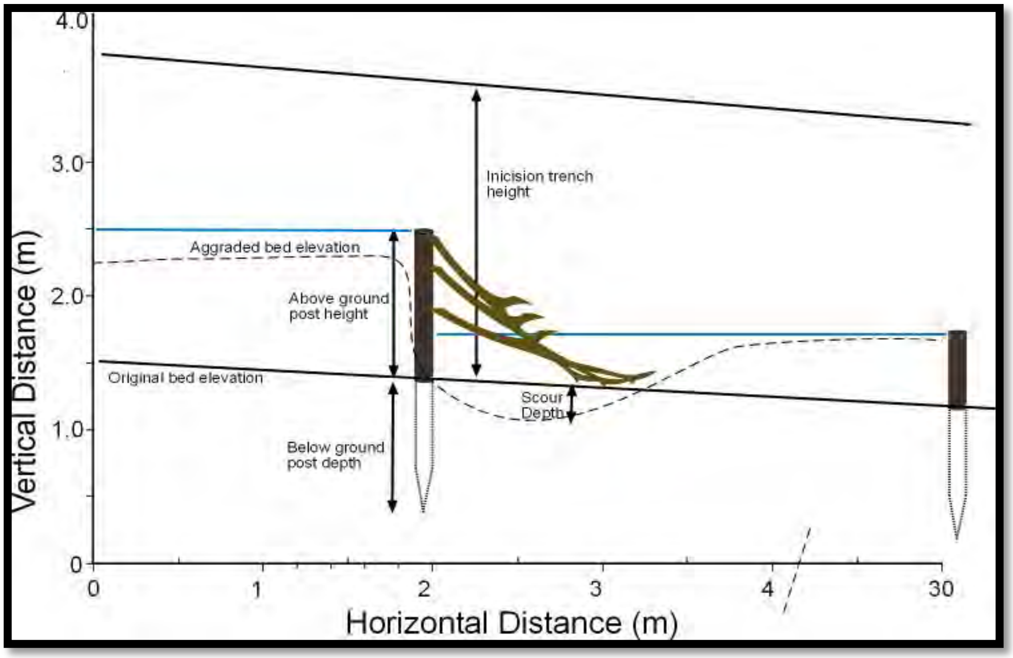
Typical Successional Trajectories and Outcomes for BDAs

Because BDAs are designed to mimic natural beaver dams, some key considerations need to be incorporated into their design. Like pools caused by natural beaver, pools upstream of BDAs go through a sequence of changing habitat types, with the rate of change and successional trajectory depending largely on stochastic processes, such as flooding, sediment transport, and beaver activity, as well as the hydrogeomorphic setting.

In general, like natural beaver dams, BDAs that remain intact form a pool upstream that fills with sediment over time. As the sediment accumulates, it is colonized by emergent and riparian vegetation and transitions from an open pool to an emergent wetland and eventually to a wet meadow that may or may not contain a definable stream channel. At each step in a successional trajectory, both natural beaver dams and BDAs can fail, altering the successional trajectory and creating different successional trajectories depending on the failure mechanism. Failed dams can also be repaired, creating additional successional trajectories. Thus there are multiple successional trajectories that BDAs can take, which are not predictable in a deterministic sense because of the stochastic nature of the mechanisms that can trigger alternative pathways.

Because BDAs are intended to mimic beaver dams, they require ongoing maintenance and repair, similar to beaver dams. The amount and type of maintenance needed depends on project objectives. Typical maintenance includes extending the length of the structure as a result of end cutting, replacing sections that have been damaged (often from underscour), and raising the height of a structure, typically by constructing a new BDA on top of the sediment wedge that has accumulated upstream of an existing BDA (Figure 26).

By providing some short-term (i.e., less than 10-year) structural complexity in stream systems that generally lack structure, BDAs should set in motion natural processes by which the stream restores its natural dynamics. This is often the expected outcome of projects that use BDAs. BDAs should facilitate fluvial geomorphic changes that include sediment retention, streambed aggradation, increased stream sinuosity, pool formation, increased stream length, reduced stream slope, reduced bed shear stress, and a shift in the bed composition from coarser to finer sediment (Pollock et al. 2007, Demmer and Beschta 2008). Similar to beaver dams, BDAs should also raise water tables in the alluvial aquifer, thus helping to greatly expand the amount of riparian forest and reduce stream temperatures (Lowry 1993, Westbrook et al. 2006, Pollock et al. 2007). Previous research has shown that these are reasonable outcomes to expect from the presence of stable beaver dams, particularly in streams with high sediment loads (Scheffer 1938, Pollock et al. 2003, McCullough et al. 2005, Westbrook et al. 2011).



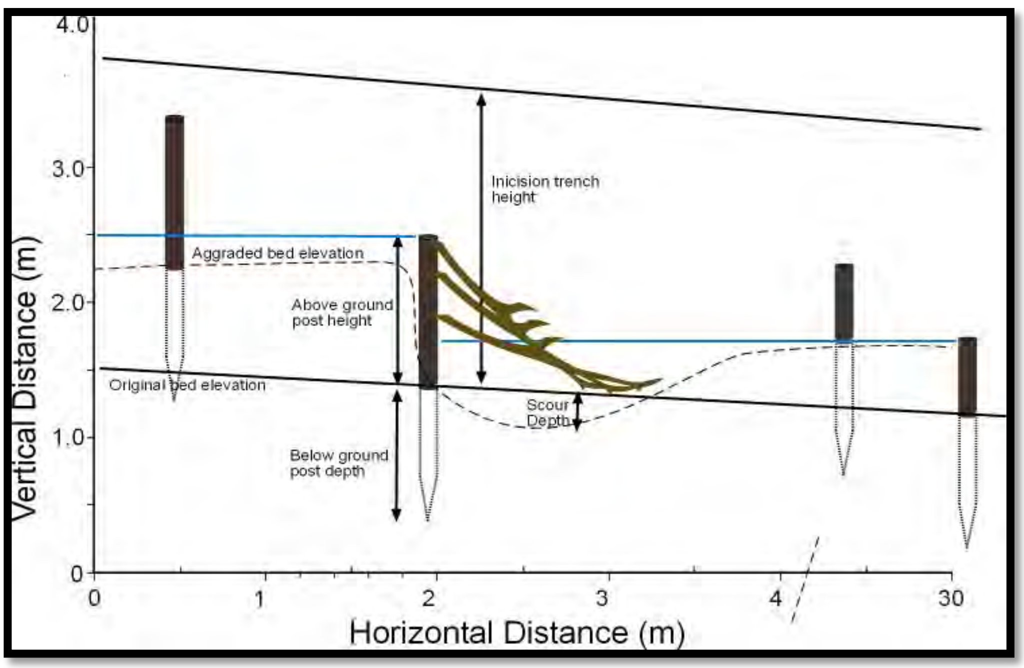


Figure 26: Side view of beaver dam analogues designed to aggrade a bed within an incision trench. (top) Year one placement. The downstream BDA backs up water to the upstream BDA, forming a water "pillow" that helps prevent overtopping scour below the upstream structure. Willow branches can be placed parallel to the stream flow on the downstream side of a BDA to help reduce scour. The post should be placed deep enough in the ground to prevent structure failure as a result of downstream scour, although multiple posts woven together with willows can hold some scoured posts in place. (bottom) After sediment accumulates and aggradation occurs upstream of the BDAs, another round of BDAs is placed upstream of the existing BDAs, on the aggraded bed. Placement should be upstream such that the downstream sediment scoured is deposited against the BDAs installed in Year One; this helps to reinforce and strengthen the BDAs. The process can be repeated until the stream bed has aggraded sufficiently to reconnect it to its former floodplain.

Uses for BDAs

Beaver dam analogues have several advantages over natural beaver dams. For example, because they are constructed using posts pounded into the stream bed, they are less susceptible to failure from overtopping flow than are natural beaver dams (overtopping flow is a common failure mechanism for natural dams). Thus they can be placed in incised streams and other locations where the stream power per unit width is higher than what natural beaver dams would be able to tolerate. Another advantage of BDAs is that they can be placed at a specific location and designed to increase the likelihood of a specific outcome. Structure width and height can be controlled, and adjustments can be made as needed to facilitate restoration objectives.

BDAs can be used to do the following:

- Create pool habitat (upstream and downstream)
- Improve floodplain connectivity
- Expand riparian vegetation
- Increase stream sinuosity
- Create multi-threaded channels
- Nourish streams with sediment
- Reduce bank erosion
- Establish beaver colonies
- Provide protection for relocated beaver

BDAs may be especially useful in incised streams where the steep banks confine the stream, thus concentrating stream power during floods. When placed in narrow, incised reaches, BDAs are often sufficient to reduce stream velocities, increase sediment deposition, and initiate aggradation. They can also be designed to direct concentrated flow to erode resistant banks, widen the incised channel, and enhance the sediment supply to downstream reaches (Pollock et al., 2014).

Similar to the multiple dams found in beaver colonies, placement of multiple BDAs is critical (Figure 27). Multiple placements will increase the overall effectiveness of the system and decrease the likelihood of failure during a large flood. With multiple structures, if one fails, the remaining BDAs still dissipate stream energy. As with natural beaver dams, when a BDA fails, it often produces more heterogeneous habitat (Denmer and Beschta 2008, Pollock et al., 2014).

Types of BDAs

BDAs are intended to mimic the functions of natural beaver dams. There are several ways of constructing beaver dam analogues: (1) constructing starter dams using vertical posts with willow woven between the posts (wicker weave) and fill material (such as cobble, vegetation and mud) placed upstream to create a water-retaining structure, and (2) installing just post lines with wicker weaves, which are highly permeable and may or may not initially retain water, depending on stream discharge; and (3) simply reinforcing existing natural beaver dams with vertical posts, These common designs are discussed below.

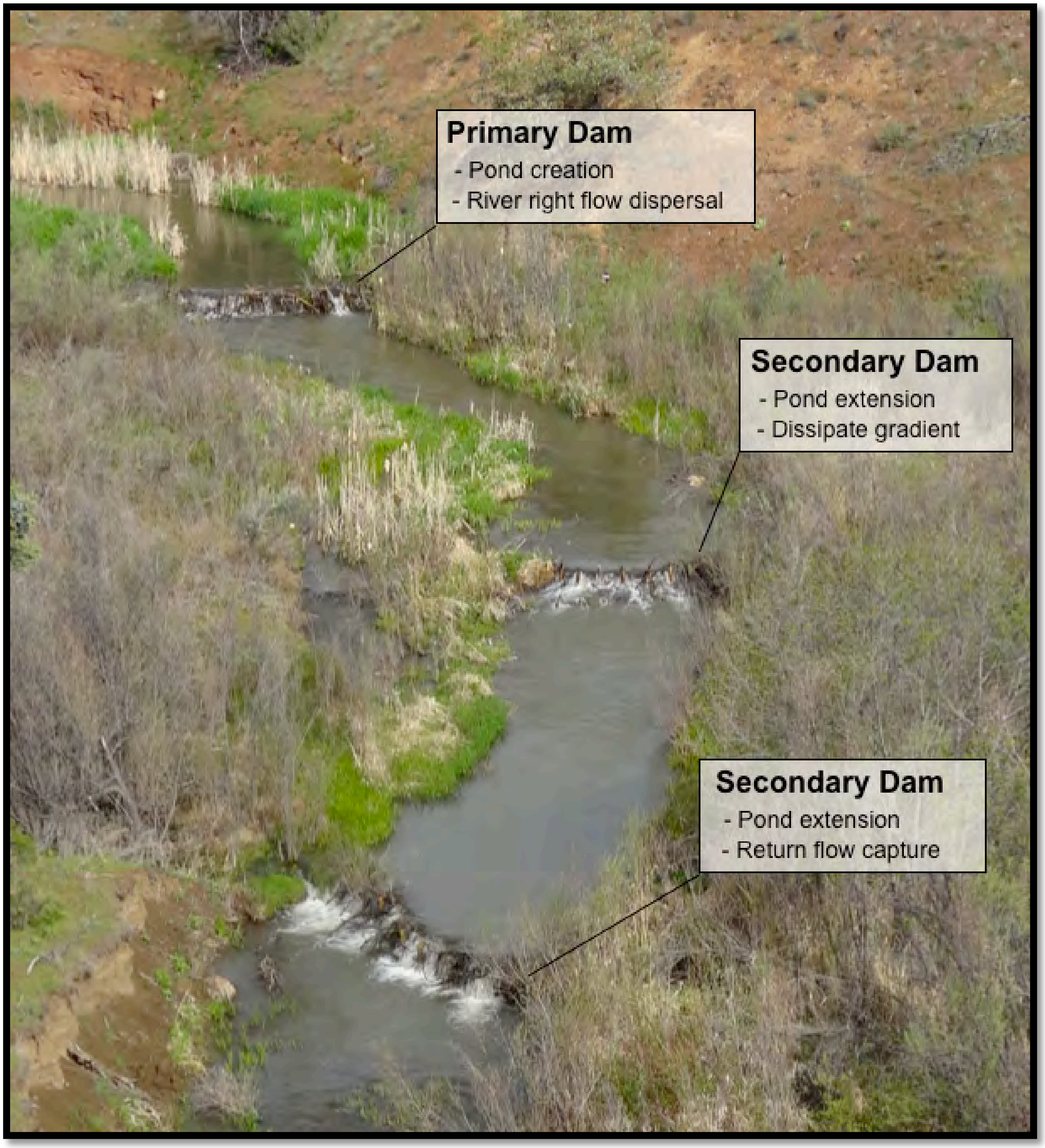


Figure 27: Example of a sequence of beaver dam analogues on Bridge Creek, in Oregon. The primary dam is a reinforced existing dam originally built by beaver, while the secondary dams are post lines with wicker weaves that self-sealed with sediment and organic material. The primary dam has remained stable for more than 5 years and has created extensive flooded wetlands on river right. The secondary dams create pool habitat, dissipate energy, capture return flow, and raise water levels, which reduce the potential for headcutting on return flow side channels, while also increasing the floodplain inundation period. (Photograph and graphics by N. Weber).

Starter Dams

Starter dams utilize all the elements of BDA design, and are designed to immediately pool water upstream upon completion. They are constructed of vertical wooden posts that are pounded into the stream bed using a hydraulic post pounder (Figure 24) and typically spaced about half a meter apart. The posts then are interwoven with fresh branches or stems, usually willow (Figure 23). This creates a highly permeable dam that often does not restrain flow sufficiently to form a pool, at least in the short-term. When an upstream pool is immediately desired (e.g., if beaver are going to be released at the site, or there are beaver in the area and you are trying to entice them to establish a colony), permeability can be reduced by placing cobble, sand, silt, and vegetation on the upstream side of the starter dam, sufficient to form a pool of the desired depth (usually 1 meter or more).

Starter dams are generally not as thick as natural beaver dams, particularly on the downstream side, and thus they are more prone to forming downstream scour pools that can lead to underflow failure (Figure 28). To minimize the potential for underscour failure, posts should be pounded into the substrate as deeply as possible, and sufficient material placed on the upstream side of the post line to prevent the upstream bed from mobilizing (Figure 24). On the downstream side, branches can be placed at an angle, perpendicular to the stream flow (similar to how beaver place branches), which also helps to minimize downstream scour from overtopping. For a given stream size, highly mobile beds (e.g., those containing limited amounts of cohesive, fine-grained material) will be more prone to underscour and require more material to prevent underscour from occurring (Figure 28).

Scour failure can also be reduced by constructing structures such that they are connected to wide floodplains, at least during high flows. A well-constructed beaver dam will disperse flow evenly across its width, sufficient to reduce stream power per unit width so that flow is not concentrated and scour is minimized. This is a dam construction feature at which beaver excel, even compared to humans, and it illustrates why it is important to consider beaver as collaborators in restoration efforts. If beaver can be enticed to come to or remain at a project site, they will do a much better job than people will of maintaining structures, such that flow is more evenly dispersed across the entire width of the dam. Even if beaver are not (immediately) present, building structures that disperse flow across the floodplain helps to keep the structures from failing by creating multiple smaller “side” channels that lack the erosive power of a single larger channel.

Floodplain connectivity is also important in ensuring that fish can pass beaver dams. Observations suggest that most fish cross beaver dams by swimming through or over the dam where water is flowing, or by swimming around the dam using side channels. Fish rarely pass over a beaver dam by jumping over in a single leap. The use of side channels and dam interstices explains how fish are able to regularly pass beaver dams that may rise as much as 6 feet above the stream bed and may be 6 to 12 feet wide at the base (Figure 29).

Starter dams can fail when flow removes erodible bank material such that there is an “end cut” around the dam (Figure 28). The potential for end-cut erosion can be reduced by extending the structure by wrapping the upstream banks using posts and wicker weave (Figure 27). These bank wraps are typically higher than the main portion of the structure so that flow remains in the main channel or is dispersed across floodplain side channels, without being concentrated on erodible bank materials.

Post Lines with Wicker Weaves

Post lines with wicker weaves (PLWW) are constructed similar to starter dams but are left unsealed so that they are quite permeable to flow, at least initially (Figure 23). Ideally, PLWWs naturally become less permeable over time as sediment and organic material transported from upstream sources accumulates, or because beaver occupy and maintain the structure. The advantage of PLWWs is that they require much less effort to build than starter dams do, so many more of them can be built for the same cost. They are particularly useful in streams where fine sediment loads are high (e.g., incised streams with cohesive fine-grained banks) and there is a reasonable expectation that they will self-seal as upstream sediment and organic material accumulate.

Both starter dams and PLWWs work well when enough of them are placed near each other that the ponding from a downstream structure provides a “water pillow” below the upstream structure; this reduces the potential for scour and subsequent structural failure (Figure 25). Placing several structures near each other thus provides stability, similar to how multiple beaver dams in a colony function together. If one structure fails, other structures may still hold and, overall, important ecosystem functions within the treated reach can be maintained.

Reinforced Existing Dams

The simplest type of BDA is simply to reinforce an existing beaver dam if it is in a desirable location. Existing beaverdams are reinforced by pounding posts vertically into the dam on the downstream side, 1/2 meter to 1 meter apart, and inserting them into the steam bed as deeply as possible— preferably 1 meter deep or more, although shallower depths can still be quite effective.

Reinforced existing dams are usually more stable structures than BDAs that are primarily constructed by humans. This is because beaver generally use more material during dam construction than humans and beaver also create wider dams that are less prone to underscour. Also, if beaver are present, they will maintain reinforced dams, further ensuring stability. Common causes of failure of reinforced existing dams are side scour of erodible banks and failure from underscour or overtopping erosion.

Not all existing dams should be reinforced. The decision to reinforce an existing natural dam usually is made when it is likely that the dam will fail sooner than desired, given the project objectives, or when the consequences of failure—even if unlikely—would be undesirable. For example, a existing beaver dam upstream of a culvert might be reinforced so that it won’t blow out and block the culvert with debris.

Like natural beaver dams, starter dams can fail during high flows, and they need to be inspected, maintained, and repaired if necessary. If beaver are present, they may do much of the repair work. It takes a certain amount of judgment to know whether and when to repair a damaged structure. Damaged structures may still function, or they may have already achieved their desired purpose, or they may no longer be needed because their function has been subsumed by another structure. Natural dams fail but still function to increase habitat complexity, and this is also the case for failed BDAs. Thus it is inaccurate to consider a "failed" dam a "failure."

When placed within incision trenches, BDAs often end cut because stream power cannot be sufficiently dispersed. In these situations, it is reasonable to expect to repair such structures annually by extending them across the end-cut channel, either until sufficient aggradation has occurred upstream that flows are dispersed across a reconnected floodplain or until the incision width is sufficiently to create a stable dam in the inset floodplain.

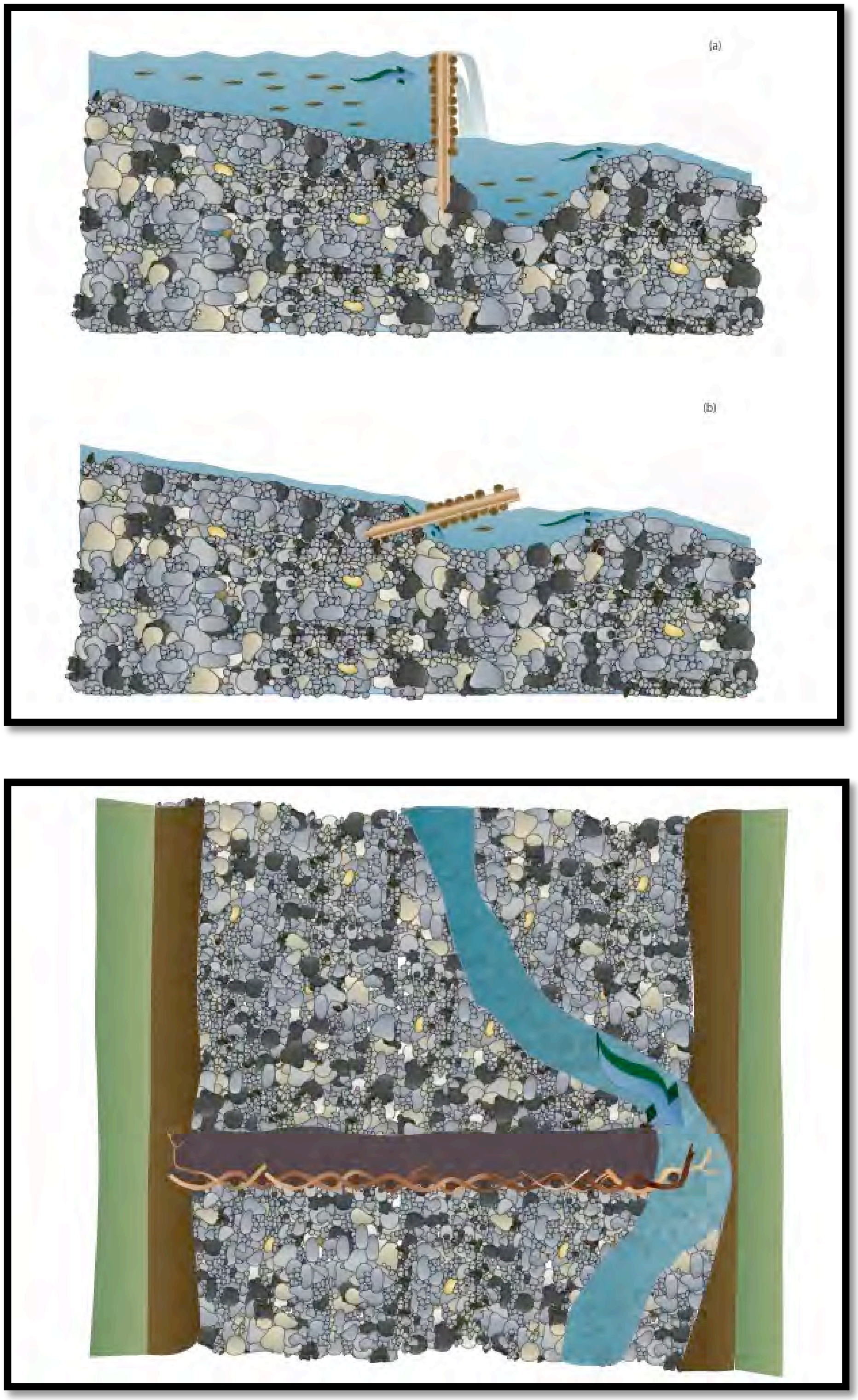


Figure 28: Examples of beaver dam analogue failure mechanisms: (top) overtopping downstream scour followed by underscour; posts that are not pounded deeply enough into the bed deep can be undermined by overtopping downstream scour, and (bottom) lateral scour of an erodible bank results in an end cut.

Figure 29: At nearly 2 meters height, this natural beaver dam on Bridge Creek, Oregon, substantially exceeded most fish passage guidelines for instream structures, which generally call for a maximum "jump" elevation of 15-20 cm between the upstream and downstream water elevations of a structure. Nonetheless, adults and juveniles of steelhead trout were able to pass the structure, as documented by PIT tag data, and there is a well-distributed population of steelhead upstream of this dam and the dozens of other dams further downstream. (Julie Maenhout is in foreground, photographer, unknown).

Effects of BDAs

The primary effect of BDAs is to reduce stream power per unit width by dispersing flow over a wider cross-section and through localized lowering of the slope; this greatly increases stream width and creates a hydraulically complex channel-spanning structure that causes turbulence, thus dissipating energy. As with natural beaver dams, the resulting benefits can be many and varied:

- Trapping of sediment
- Aggradation of incised channels
- Floodplain connectivity and creation
- Elevation of the water table
- Groundwater recharge
- Increased surface area for riparian colonization
- Increased aquatic habitat diversity

- increased avian habitat
- Increased wetland area
- Localized water temperature buffering

Some of the effects of BDAs can be more pronounced than those of natural beaver dams. For example, because BDAs are reinforced with posts, they tend to fail by end-cutting rather than overtopping erosion (Demmer and Beschta 2008). This means that, if they are strategically placed and designed, they have the potential to increase erosion in specific areas by concentrating flow toward erodible banks. This may be desirable in channels in the initial stages of incision, where there is little or no development of an inset floodplain. Placing BDAs to direct and concentrate flows in specific areas can help erode resistant banks and widen the active channel. Development of an inset floodplain, or widening the active channel, increases the amount of potential riparian habitat, lowers the unit stream power, and reduces active incision. Additional BDAs placed in the inset floodplain can cause the streambed to begin to aggrade, thus providing more suitable habitat for beaver.

Because BDAs tend not to be as wide as natural beaver dams, they also tend to create deep scour pools downstream of the structure. If posts can be inserted into the bed deeply enough that they are not undermined, these scour pools can be maintained and will provide deep pools with complex cover that are preferred by many fish species, particularly salmon and steelhead. In addition, the scouring action sorts and deposits sediment further downstream, creating transverse gravel bars that can be used for spawning. This may be particularly important in streams where the bed is armored with coarse substrate and there is limited bed mobility or sediment sorting.

Risks in Using BDAs

Risks in using BDAs for stream restoration are limited. BDAs are inexpensive, so there is less chance of wasting large sums of money on ineffectual restoration efforts than with more standard—and more expensive—restoration approaches. Also, because BDAs are small in size and use material similar to that in natural beaver dams, if the BDA fails there is less risk to downstream habitat or infrastructure than there is with other types of restoration projects, such as large wood placement.

There is some risk that a series of ponds created by BDAs could increase stream temperatures enough to degrade habitat for fish, or that a series of structures could block the movement of fish enough to have a negative population-level effect. However, these risks need to be weighed against the likely benefits of BDAs in terms of the ecosystem functions targeted by the restoration project. For example, a beaver pond may have high temperatures in the summer and thus avoided by salmon and steelhead, but in the winter it provides critical juvenile overwintering habitat and holding pools for migrating adults.

In incised streams, BDAs can initiate the process of restoration, but ultimate success often hinges on active colonization by both vegetation and beaver. Although artificial structures can cause rapid aggradation, vegetation is still needed to increase bank strength and surfaces and to provide shade, and beaver are needed to maintain and expand the BDAs. It also is necessary to identify and eliminate the stressors that caused the initial incision to occur (e.g., livestock grazing in the riparian zone or extirpation of beaver) (Pollock et al., 2014).

Finally, as with natural beaver dams, BDAs are meant to be temporary features on the landscape and may breach or fail completely during high-flow events and contribute to flood peaks. On the other hand, using posts to reinforce existing beaver dams can reduce the potential for failure of dams in vulnerable sites, where failure could have severe consequences to downstream infrastructure. Also, the risk of downstream flooding is reduced when multiple BDAs are constructed in series.

Both BDAs and natural beaver dams will increase the amount of surface water at a site in the form of pools, ponds, overbank flows, and side channels. This increase in surface water may flood areas that rarely flooded in the recent past. However, flooding of infrastructure, agricultural fields, or private property in low-gradient areas, floodplains, or on adjacent properties may not be a desirable outcome of the restoration action. In addition, riparian restoration and management can increase the hydraulic roughness of the stream bank and floodplain, thereby raising floodwater elevations (Kauffman et al., 1997).

Careful placement and monitoring of BDAs will reduce the risk of inadvertent flooding and other beaver/human conflicts. In areas where inadvertent flooding is likely, restoration projects should be designed for continuity of flow and sediment. Such projects will necessarily provide less value to river ecosystems, but they will decrease the potential for damage to infrastructure that that is located on floodplains or in channels.

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Chapter 7—Comparison of BDAs with Other, Similar Instream Structures

Elijah Portugal and Michael M. Pollock

(See Figures 31-37. To be completed in a future version)

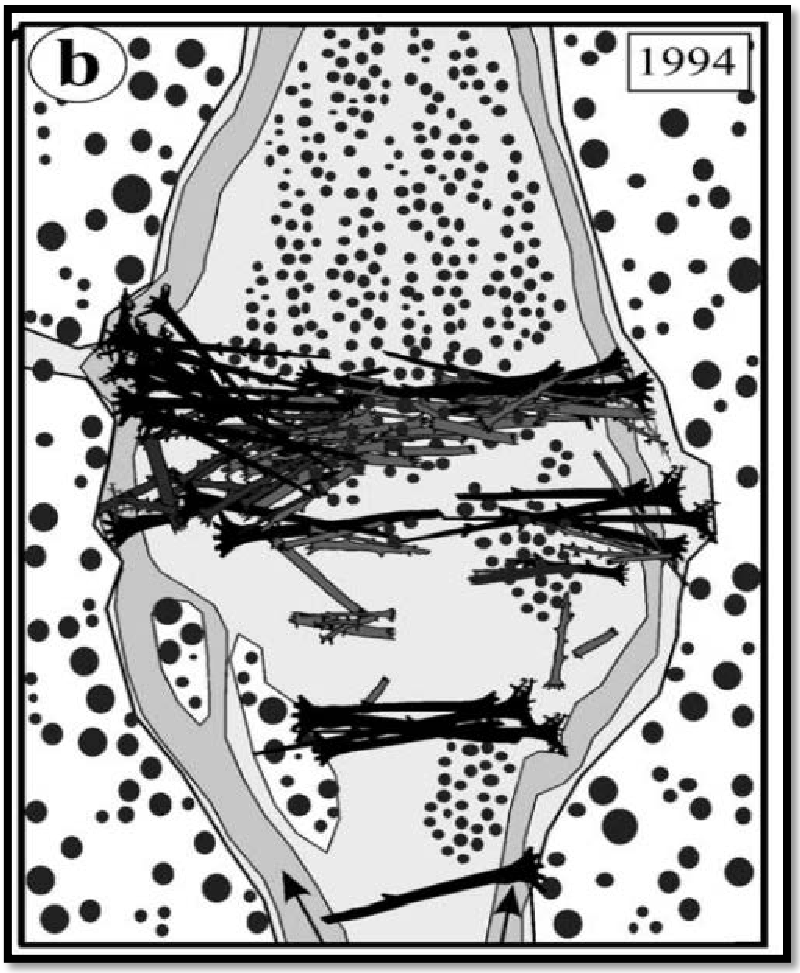


Figure 31: Channel-spanning log jams. Log jams occur naturally in many river systems and historically were much more widespread, before the extensive removal of wood from most streams. Channel-spanning log jams retain sediment, create channels with multiple threats, and can even convert bedrock reaches into alluvial reaches. In many aspects the benefits of stable channel-spanning log jams can equal or exceed those of beaver dams, but we are not aware of any restoration projects that have intentionally constructed channel-spanning log jams. (Abbe 2000).

Figure 32: Examples of rock and gravel dams that are called “artificial beaver dams” in Oregon House Bill 3217, which would exempt these structures from normal environmental review by designating this area as a pilot project. These instream structures look similar to road crossings and are substantially different from beaver dams. It is thought that these structures were placed in an incised ephemeral stream that lacked fish, but there has been no onsite verification, fish passage over gravel dams is a concern, as is the potential loss of riparian vegetation as a result of flooding. This example is from the Silvies Valley Ranch in eastern Oregon. (From Google Earth; GPS coordinates: 44.052364 -119.004789).

Figure 33: Log steps on the Mattole River, California, designed to raise water tables and create pool habitat for threatened coho salmon. (From McKee, unpublished).

Figure 34: Channel-spanning logs. Channel-spanning logs can provide many of the hydrologic benefits of beaver dams, but the simplified hydraulics can create fish passage issues. (From USFS).

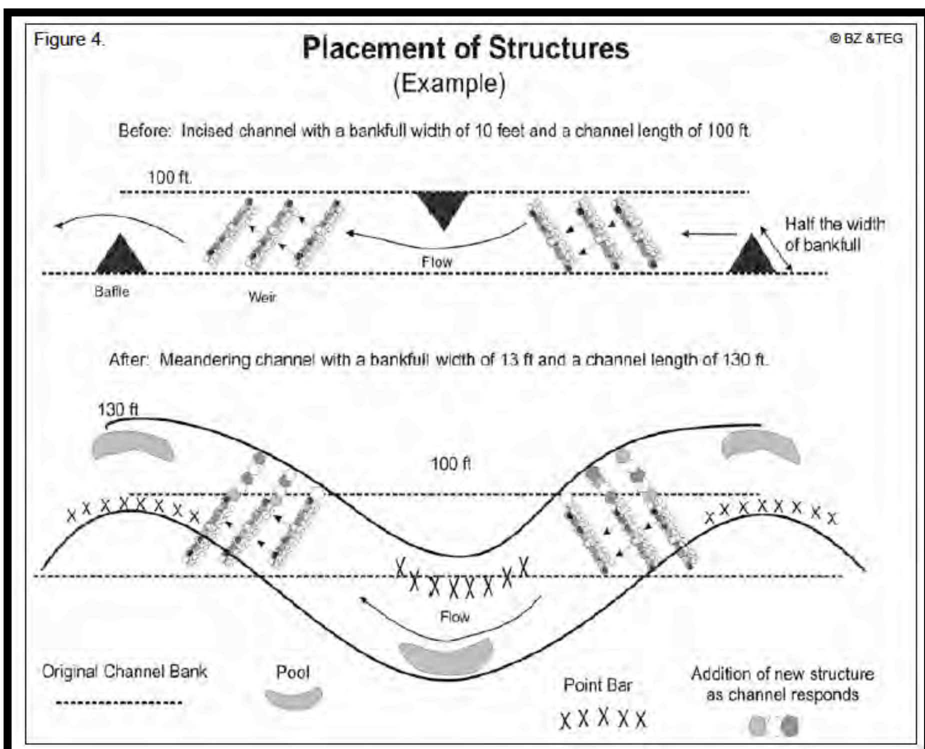


Figure 35: Induced meanders intended to increase sinuosity in linear streams. Induced meanders are not channel spanning structures. (From Zeedyk 2009).

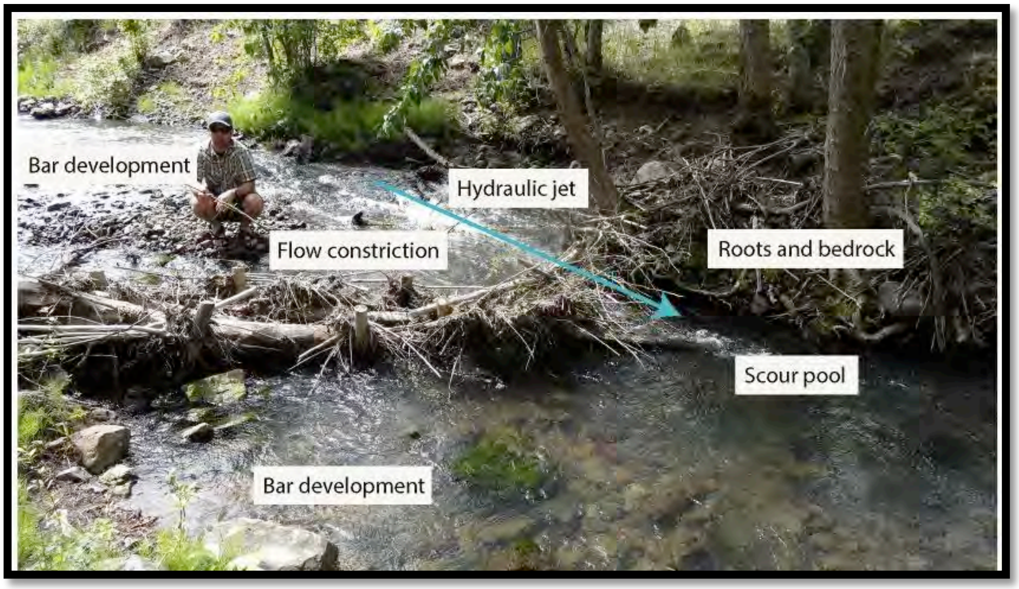


Figure 36: Constriction dam. Constriction dams are non-channel spanning structures intended to constrict flow, creating a high velocity hydraulic jet. Constriction dams can be used to increase bed and bank erosion to create scour pools. Such structures often span most of the channel, and in many ways behave like beaver dams with end cut failures. Construction is similar to beaver dam analogues, with posts pounded into the stream bed and woven with willow or other organic material. (From E. Portugal, unpublished).

Figure 37: Flow-choke structures. These slow the movement of high-flow waters, increasing upstream flooding and creating temporary ponding, but during low flows they provide little functionality that is similar to a beaver dam. (From Devries et al. 2012).

Chapter 8—Managing Habitat for Beaver

Michael M. Pollock and Greg Lewallen

Habitat that is intrinsically suitable for beaver may not contain beaver because of active land management that selects for other values. Where desired, land management strategies can be shifted to encourage beaver colonization. There are three components to management strategies intended to support beaver: reducing competition from other herbivores for beaver food resources, increasing the abundance of beaver food resources, and reducing beaver predation rates, especially from humans.

Reducing Herbivore Competition

In the western United States, elk and deer are the native animals that most frequently compete with beaver for food resources, while cows are the most common non-native competitor for food. A growing literature exists on methods for keeping cows away from stream corridors so that riparian vegetation can recover, primarily through alternative grazing regimes (e.g., rest-rotation) and riparian fencing (see Figure 38). Competition from elk can also be reduced with robust riparian fencing, or the construction of exclosures. Starkey Experimental Forest and Range near La Grande, Oregon is running a long-term experiment to assess the effects of different grazing and fencing strategies on grazing by elk, deer, and cattle in riparian areas. Research in Yellowstone National Park suggests that riparian grazing pressures from elk can be reduced by increasing the abundance of elk predators, specifically wolves. In the presence of wolves, elk change their behavior, spending less time resting and grazing in riparian areas and more time on the move, so that their location is less predictable to wolves. There has been a related increase in the abundance of both woody riparian vegetation and beaver. Because wolves also prey on beaver it might seem counterintuitive that introducing such a predator would increase the beaver population, but this in fact appears to be the case.

Increasing Beaver Food Sources

Areas that lack woody riparian vegetation can be improved by planting easy-to-grow species that are preferred by beaver, such as willow and cottonwood. Such species can be propagated from planted stakes. A reliable water supply is needed for successful propagation. If beaver are already present, it is necessary to protect the newly planted stakes to avoid premature harvest. It also can be helpful to estimate the extent of flooding that is likely to be caused by beaver dams, so that vegetation can be planted in areas that are not likely to be immediately flooded. For more on methods for successfully propagating (and protecting) willow and cottonwood, see Hall et al. (2014).

Reducing Beaver Predation Rates

Humans are beavers' primary predators, but black bears, coyotes, mountain lions, grizzly bears, and wolves can also affect beaver populations. Trapping restrictions are the most effective means of reducing beaver mortality from predators. State fish and wildlife agencies have administrative procedures for responding to requests that areas be closed to trapping. Working with such agencies may be the best avenue for reducing trapping-related beaver mortality in specific areas, such as where beaver restoration efforts are taking place, but the declining value of beaver pelts has been more effective in reducing trapping-related beaver mortality rates. At the Federal level, land agencies such as the U.S. Forest Service and Bureau of Land Management adopt land management policies that include beaver management, and these policies often provide more protection for beaver than do policies at the state level. For example, the Malheur National Forest in Oregon has an ongoing commitment to integrate beaver into its aquatic restoration management strategies and seeks to expand beaver populations where possible (Malheur-National-Forest 2007).

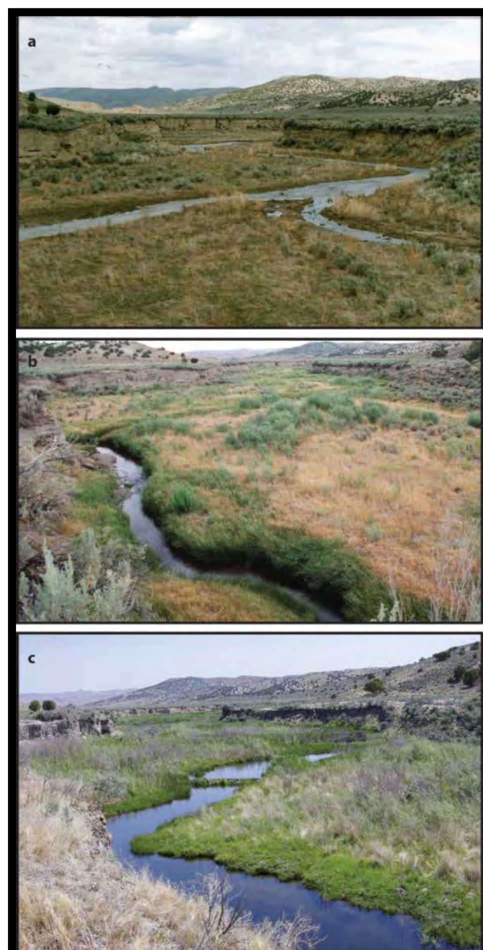


Figure 38: Recovery sequence of an incised stream ecosystem over a 20-year period. In 1993, (a) the stream was open to annual summer grazing by cattle. After 1999, (b) grazing was limited to cow–calf pairs during spring and fall. By 2012, (c) beaver had established a persistent colony for several years. The size of riparian vegetation had substantially increased, and vegetation now extended across the entire width of the incision trench, because beaver dams had elevated the water table. Upstream of the dams, the channel is (for now) wide and deep. Dams and the density of riparian vegetation further increase flow resistance and reduce stream power, creating conditions ideal for the retention of sediment, but the trench width will make aggradation rates low. (Photographs: Carol Evans, Bureau of Land Management, from Pollock et al., 2014).

Chapter 9—Non-lethal Options for Mitigating the Unwanted Effects of Beaver

Michael M. Pollock and Greg Lewallen

Beaver activities that conflict with human interests generally fall into two categories:—tree cutting and dam building—and potentially problematic dams can be further divided into dams that block culverts or irrigation canals and dams that do not. Historically, in many states and provinces throughout North America, lethal removal of beaver has been the method of choice for solving such beaver/human conflicts, but more interest in non-lethal approaches has been growing.

Non-lethal approaches have gained popularity for a number or reasons, including the following:

- Non-lethal management is more effective and less costly than lethal removal (Callahan 2005, Simon 2006, Boyles and Savitzky 2008).
- The public is becoming increasingly dissatisfied with lethal removal, in part because of concerns that trapping and drowning or bludgeoning beaver is not humane (IAFWA 1997, AVMA 2000, Hadidian 2003).
- There is growing demand for live beaver, because of organizations' and agencies' renewed interest in re-introducing beaver to locations where they can provide environmental benefits (Apple 1985, Boyle and Owens 2007, Pollock 2012) (Olsen and Hubert 1994, McKinstry et al. 2001).

Non-lethal approaches to solving the major sources of human-beaver conflict are summarized below.

Tree Cutting

Beaver can travel up to 328 feet (100 meters) from a water body to cut and harvest trees, but the probability of harvest decreases exponentially with distance from water (Rutherford 1955, Allen 1983, Gallant et al. 2004). Although beaver generally prefer species in the genera *Populus* or *Salix* (cottonwood, aspen, and willow), they will harvest a wide range of trees and shrubs (reviewed in Boyle and Olsen 2007 and Baker and Hill 2003). Beaver also use the base of large trees of both palatable and unpalatable species as gnawing stations; gnawing can lead to the tree's ultimate demise. As in all burrowing rodents, beaver teeth grow continuously and thus need to be continually worn down, which is done primarily by gnawing on wood.

Solution: Wire Mesh Cages

There is little in the way of peer-reviewed literature on non-lethal methods for preventing beaver from cutting trees, but an extensive review of technical information from various government and private organization websites suggests that surrounding trees with a cylindrical wire mesh cage is the simplest, most effective means of preventing a beaver from cutting down a tree (Figure 39) (e.g. beaversolutions.com, APNM.org, beaversww.org, martinezbeavers.org, www.kingcounty.gov/environment/animalsAndPlants/beavers). Cage specifications vary slightly, but recommendations generally are as follows:

- Wire mesh gauge should be reasonably heavy (e.g., 6 gauge) to prevent beaver from chewing through it. Chicken wire is not recommended.
- Mesh size should be 6 x 6 inches or smaller.
- The cage should be 1 to 2 feet in diameter larger than the tree trunk.
- The cage should extend 3 to 4 feet above the ground or, in colder climates, above the anticipated snow line.
- Wire fencing can be used to encircle multiple trees.

One of this guidebook's authors (Pollock) has noted the effectiveness of exclosure cages using these specifications at various field sites. Not all cages were 100 percent effective. In some cases beaver managed to harvest trees inside of exclosures, presumably by climbing the cages.

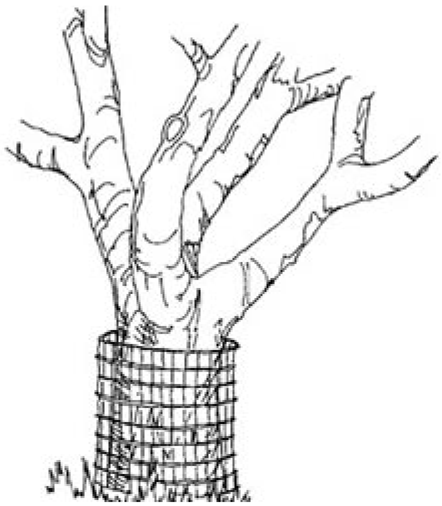
Solution: Paint Mixed with Sand

A number of websites and bulletins also suggest that paint mixed with sand is effective, although repeated application is required. For example, beaversww.org recommends a mixture of 8 ounces (227 grams) of fine sand (30-mil, 70-mil, or masonry sand) mixed with 1 quart (0.94 liter) of oil or latex paint, matched to the color of the tree trunk and painted to 4 feet above ground. Placement of 3- to 4-foot-high fences between streams and the trees that need protecting has also been suggested, presuming that beaver won't travel long distances on the upland side of the fence because they are exposed to predation. Electric fences strung 4 to 6 inches above the ground have also been suggested. We could find no data assessing the effectiveness of these approaches.

Other Approaches

Techniques such as chemical deterrents were considered to be marginally effective because they work only for a few months at most and repeat application is needed. Techniques such as noise and flashing lights appear to deter beaver for a few days at most (Nolte et al. 2003, Kimball and Perry 2008).

(a)



(b)

(c)

Figure 39a-c: Illustrations of a wire cage for protecting trees against beaver. Note that all three examples show caging that is too close to the trunk of the tree, with (c) showing the inevitable result of such a miscalculation.

Flooding Problems

Solution: Flexible Pond Levelers

Where beaver dams raise water levels enough to cause unwanted flooding, a large-diameter flexible pipe inserted horizontally through the dam in combination with a vertical cylindrical wire cage to protect the upstream pipe end from being dammed has also proven highly effective in permanently lowering water levels behind a beaver dam (Figures 40 and 41). Such devices are generically referred to as "flexible pond levelers," "flex levelers," "pond levelers," or "water level control devices." Callahan (2003) examined the effectiveness of 116 flexible pond levelers on free-standing dams that were causing conflicts with humans but that were not associated with human infrastructure such as culverts. He found that installation of flexible pond levelers resolved human-beaver conflicts 83 percent of the time.

Figure 40: Flexible pond levelers with cylindrical wire cages on the upstream pipe end. Clockwise from upper left (a) and (b) are examples during the construction phase, while (c) is an example just after completion but before dam repair. (b) is a downstream view of a pond leveler after beaver have repaired the dam. Photographs from Boyle (2006).

When the conflict was not resolved, the failure most commonly was attributed to the beaver constructing dams downstream of the installation site; this was the case in 75 percent of the sites where the conflict was not resolved. The few remaining failures were due to vandalism or insufficient pipe capacity.

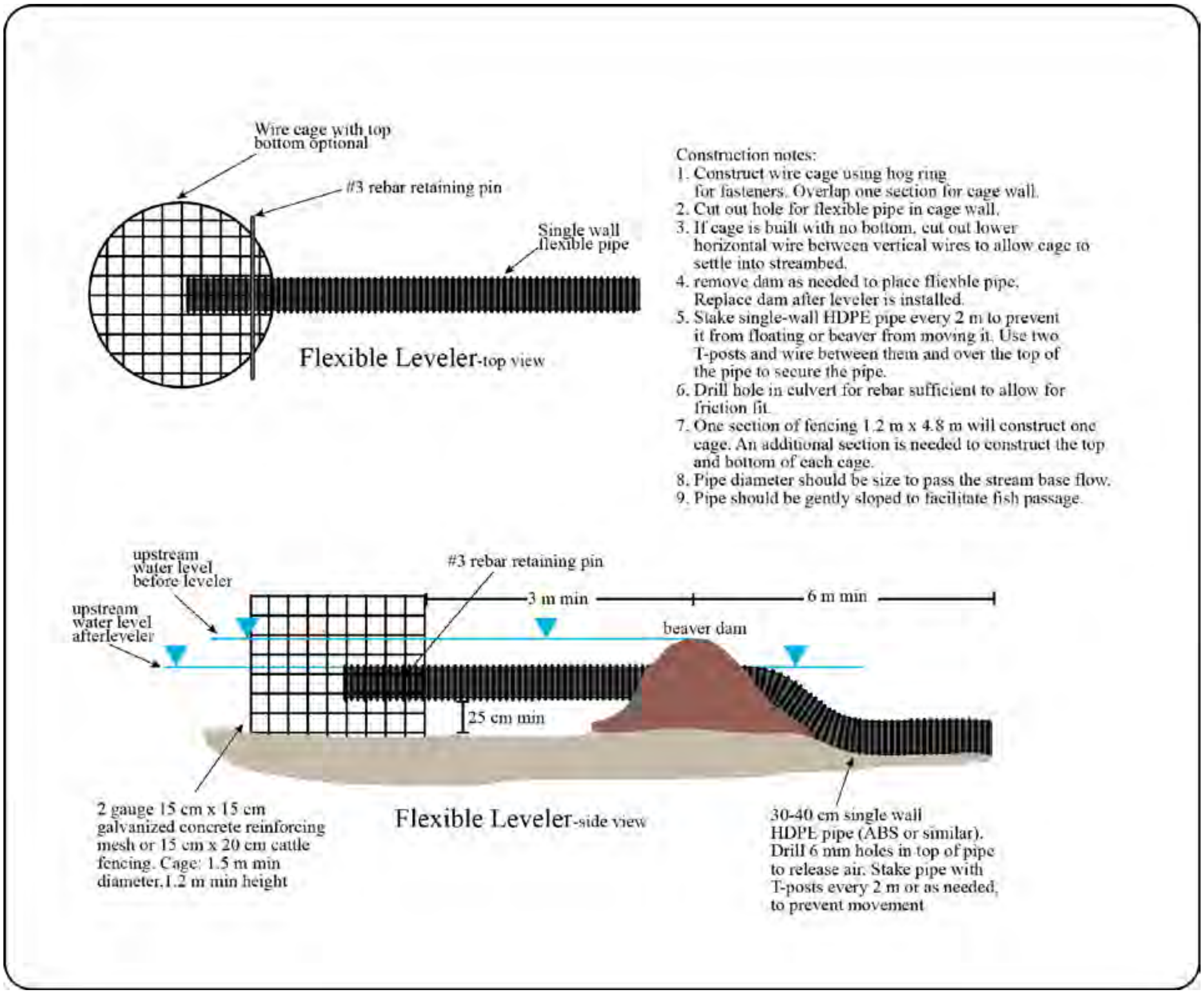


Figure 41: Design specifications for a flexible pond leveler that is used to adjust beaver pond water levels to an acceptable level when there is unwanted flooding. The design allows some pond habitat to remain and is passable to adult salmon. Figure adapted from a design provided by Jake Jacobsen, Snohomish County, Washington Public Works Department, Jacobsen (2010).

Solution: Clemson Leveler

Another popular method of controlling beaver pond levels and preventing culvert plugging is known as a "Clemson leveler." This is a perforated polyvinyl chloride (PVC) pipe whose upstream end is wrapped in wire mesh fencing; the pipe is then inserted horizontally through the dam (see Figure 42). Reported success rates with the Clemson leveler are only about 50 percent (Nolte et al. 2000).

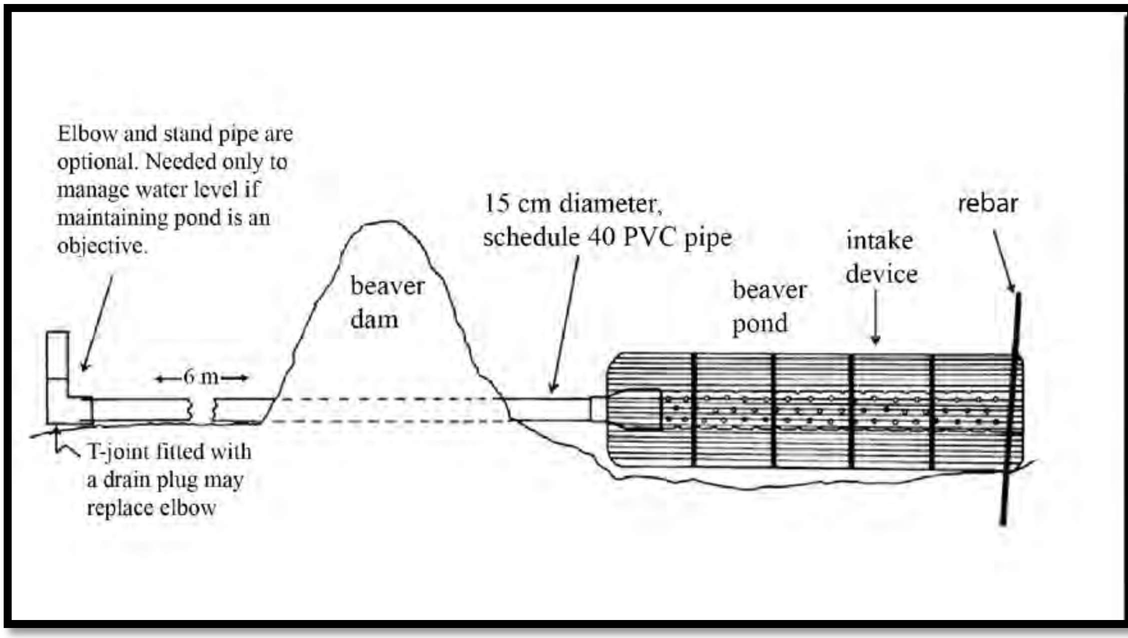


Figure 42: A Clemson leveler-style device is not fish-friendly. The small mesh size, the pipe perforations, an end cap at the upstream end of the pipe, and an elbow on the downstream end are all features that make it challenging for fish to move upstream or downstream. Adapted from Wood et al. (1994).

Other Approaches

More extreme measures, such as the use of heavy equipment or dynamite to remove problem beaver dams have produced mixed results (Dyer and Rowell 1985). Enthusiasm for such approaches seems to be on the decline, presumably because of associated environmental impacts to fish, wildlife, and water resources.

Culvert Blocking

Solution: Culvert-Protective Fencing

Considerable research has gone into the development of non-lethal solutions to the widespread problem of beaver damming culvert inlets and flooding roads. Several studies have evaluated a range of options and found a highly cost-effective solution to be heavy-duty (i.e., 2- to 6-gauge) cattle panel wire mesh fencing installed in a rectangular or trapezoidal configuration upstream of the culvert (see Figure 43) (Jensen et al. 1999, Jensen et al. 2001, Callahan 2003, Boyles 2006, Simon 2006, Boyles and Savitzky 2008).

In Virginia, Boyles (2006) compared the cost of installing and maintaining fencing upstream of culverts with the cost of removing beaver and conducting associated road maintenance and repairs. Boyles found that before fencing was installed, the average annual cost for 14 road maintenance sites with beaver activity was $21,500, compared to $3,200 after culvert fencing was installed. Callahan (2003) extensively examined the effectiveness of culvert protection fences in New England. Out of 131 sites, 126 (96 percent) effectively prevented beaver from damming the culverts. Two sites failed because the entire fence was dammed by beaver, two others failed because proper maintenance was not performed, and another site was considered a failure because a new dam was constructed downstream. Callahan estimated that the average cost of the culvert-protective fences was $654, with an expected life span of 10 years and an average maintenance time of 1 hour per year for an annualized cost of $190 per year (in 2003 dollars). Both of these studies included culverts with protective-fences and pond levelers because of concerns that the fencing, if partially dammed, would provide insufficient flow capacity.

Similarly, in the Pacific Northwest, some observations suggest that culvert-protective fencing alone accumulated enough debris during floods to raise concerns about adult salmon passage, although no data were collected (Jake Jacobsen, Snohomish County Public Works, personal communication). Therefore, pond levelers were installed at some culverts—in conjunction with fencing—to alleviate fish passage concerns.

Simon (2006) expanded upon Callahan's study, examining the effectiveness of various beaver management strategies at 482 sites. Simon found that culvert-protective fences, some of which included pond levelers, were effective 97 percent of the time (at 220 out of 227 sites). Pond levelers not associated with roads were successful 87 percent of the time, cylindrical fences attached to the inlet of culverts were successful 60 percent of the time, and lethal removal by trapping was successful just 16 percent of the time because other beaver quickly occupied the site. Simon found the 10-year annualized installation and maintenance costs of culvert fences, culvert fences with pond levelers, and pond levelers to be $275, $290, and $200, respectively.

Figure 43: Examples of culvert-protective fences. From left to right: (a) and (b) are stand-alone culvert-protective fences, while (c) is a stand-alone fence combined with a flexible pond leveler pipe (underwater and not visible) and a cylindrical wire mesh cage, which provides extra protection against obstruction. Figures from Boyle (2006).

Solution: Right-Sizing Culverts

The right-sizing of culverts is another approach that has been advocated to reduce beaver/road conflicts. Many culverts are undersized or contain design elements that are attractive to beaver. Jensen and Curtis (1999) comprehensively examined factors correlated with beaver damming culverts on streams in New York. On streams with a 3 percent gradient or less they found that the frequency of culvert plugging by beaver decreased exponentially as the culvert inlet opening increased in size, and that size was the most important predictor of culvert plugging (Figure 44). Culverts with an 8.6-square-feet inlet area (i.e., 3.3 feet in diameter) had a 73 percent chance of being plugged by beaver, whereas culverts with a 113 square-foot opening (i.e., 12 feet in diameter) had a 7 percent chance of being plugged.

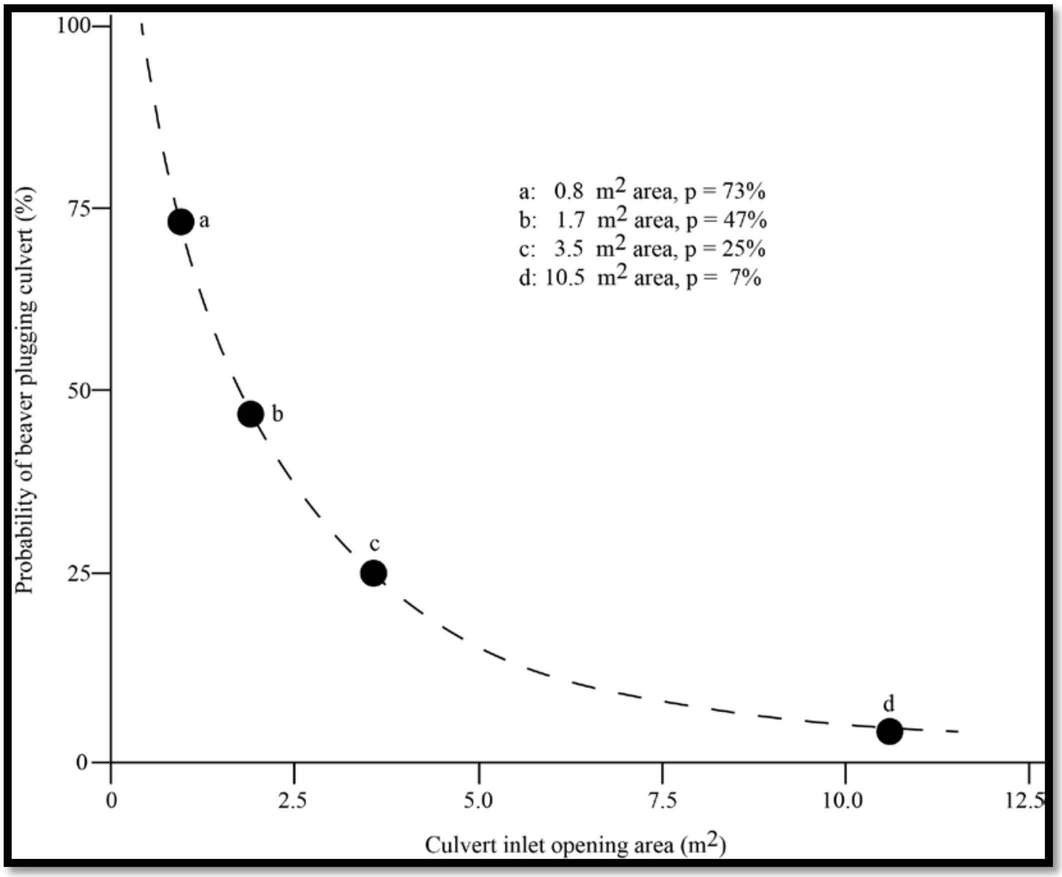


Figure 44: Relationship between the size of a culvert opening and the probability that beaver will plug the culvert, for streams < 3% gradient in New York (adapted from Jensen and Curtis 1999). For reference, the areas of the culvert openings for a, b, c and d approximately correspond to circular culverts with diameters of 3 ft, 5 ft, 7 ft and 12 ft, respectively.

Jensen and Curtis (1999) also found that pipe arch culverts that maintain the stream width are less likely than round culverts to be plugged by beaver. They speculated that round culverts are more attractive to beaver in part because they channel water and reduce stream width; Jensen and Curtis found that, on average, stream width at plugged culverts was twice the width of the culvert inlet opening. Jensen and Curtis thought that round culverts may also generate flow noise that attracts beaver but found that the frequency of plugging did not differ between smooth-walled and corrugated pipes. They further found that culverts that extended beyond the road prism were no more likely to be plugged than culverts that were flush with the road prism. Jensen and Curtis also examined the annualized costs of replacing small culverts with larger ones and found that annualized costs for various pipe arch and box culverts with 10.5-square-meter openings ranged from $881 to $1,717 (1999 dollars), about three to six times the annualized costs estimated by Simon (2006) for culvert-protective fences with pond levelers. There are other potential benefits to using large culverts (with natural streambed bottoms) that should be considered, including improved passage of fish, wildlife, sediment, and organic matter, as well as increased stream habitat.

Fish Passage through Culvert-Protective Fences and Pond Levelers

There is little published research on how pond levelers or culvert-protective fences affect fish passage. A fence with a small mesh size will impede migrating adult salmon. The only study we could find that mentioned mesh size in the context of fish passage was Hall et al. (2005). In their study on the Skagit River, Washington, Hall et al. found that numerous chum salmon (*O. keta*) were able to volitionally pass through a flexible horizontal pipe that had a vertical cylindrical wire cage with 10 x 15-centimeter meshing attached to the upper end. In Snohomish County, just north of Seattle, the Public Works Department built more than 50 flexible levelers using 10 x 15-centimeter mesh or 15 cm x 20-centimeter mesh, which they considered “fish friendly.” Although they did not do a formal study, repeated site visits during the fall when adult salmon migrate never revealed a fish blockage problem and spawning fish were observed upstream of many sites (Jake Jacobsen, Snohomish County Public Works, personal communication).

The mesh size of Clemson levelers is typically too small to pass adult salmon. Mesh sizes ranging from 1 x 2 inches to 2 x 4 iches have been recommended (Wood et al. 1994, Langlois and Decker 1997, Brown 2001, MDNR 2001). Typical pipe diameters for Clemson-style levelers are 7.9 to 9.85 inches, and the levelers may be 20 feet long or longer, which can present an obstacle to the upstream movement of large fish such as adult salmon, particularly if the pipe is capped as is often suggested (Wood et al. 1994, Langlois and Decker 1997, Brown 2001, MDNR 2001). Close (2003) was able to modify a Clemson-style pond leveler on a stream in Minnesota to allow passage of 10 brook trout ranging in length from 6 to 8.6 iches, a size still much smaller than most adult salmon.

Numerous pond levelers and other devices designed to mitigate human-beaver conflicts are described in Gerich (2004). However, many of these devices, such as beaver exclusion fencing with perforated pipes, array piping, pond drain pipes, and wire mesh culverts, appear impassable to fish. Also included are a number of designs for various fencing and pond leveler combinations that appear to be passable to fish.

The movement of both adult and juvenile fish across pond levelers may also be impeded by the placement of the downstream end of the pipe. A number of pond leveler diagrams (particularly for Clemson-type levelers with rigid pipe), have the pipe perched above the streambed on the downstream end. This presents a clear passage obstacle for fish. The location of flexible leveler pipes can also present problems if the outlet is placed in a riffle rather than a pool, or if the outlet is too far downstream of the dam and migrating fish are unable to find the opening. Placing the outlet of a flexible leveler in a pool, with the outlet close to the face of the dam, minimizes fish passage problems.

Chapter 10—Beaver Dam Viability Matrix: A User's Guide

Janine Castro

Background

The Beaver Dam Viability Matrix is an outgrowth of the Project Screening Risk Matrix—one of several tools generated by the River Restoration Analysis Tool Project (RiverRAT), a broad Federal effort to more efficiently and effectively evaluate stream management proposals. For additional information on the RiverRAT Project, see https://www.webapps.nwfsc.noaa.gov/apex/f?p=275:1:.

The purpose of the Beaver Dam Viability Matrix is to assist project managers in quickly assessing the likelihood that a beaver dam will persist over at least two seasons—the time needed for a mating pair of beaver to successfully rear their offspring. Depending on where a project site plots on the matrix, appropriate restoration techniques and tools can be selected or an alternative site pursued.

Explanation of the Axes

The matrix has two axes that transition from the highest dam viability in the lower left corner (green), to the lowest viability in the upper right corner (red). Green indicates a higher likelihood that a beaver dam will persist naturally or that it will not be removed through management actions.

The x-axis represents decreasing beaver dam viability. Decreased viability may be due to natural conditions, such as those caused by a flood or drought, or human-induced conditions, such as channelization or urbanization. The x-axis, therefore, uses attributes such as stream slope, valley form, channel incision, the presence of vegetation and beaver, and flow regime to assess overall dam viability. Because dam viability is associated with inherent stream properties, risk along this axis cannot be reduced unless the project site is relocated or significant restoration work, such as levee removal or floodplain reconnection, is undertaken.

The y-axis represents the increasing negative impact potential. This axis uses indicators such as project context and scale, land use, infrastructure, and monitoring to assess overall risk if the proposed project were implemented (e.g., how likely is it that a dam will be removed). Reducing risk on the y-axis is often feasible through project redesign, implementation of best management practices (BMPs), public outreach and education, and increased monitoring and adaptive management.

Explanation of the Factors

X-axis: Decreasing Beaver Dam Viability

Stream Slope Categories:

<1%

1 - 3%

> 3%

To persist over years, beaver dams must withstand forces (i.e., stream power) from ongoing flowing water. Because stream power is a product of the density of water, gravity, stream discharge, and channel slope, slope is a key element in determining dam viability. Beaver also require riparian vegetation for food and building materials, and riparian areas are most extensive when there is a floodplain. Floodplains become intermittent to non-existent at stream slopes greater than about 4 percent.

Valley Form Categories:

Wide floodplain

Narrow floodplain

Confined channel

Gross valley form controls the habitat potential for beaver because the animal relies on riparian vegetation. A channel that is confined by valley walls has low potential for floodplain creation or reconnection over time. If a channel is incised into a wide floodplain, there is still the potential to reconnect the floodplain. The "valley form" factor evaluates the intrinsic geomorphic potential for beaver dam viability.

Channel Incision Categories:

Yearly out-of-bank flow

Occasional out-of-bank flow

No out-of-bank flow

If a channel is connected to its floodplain, water will flow out onto the floodplain in most years except in the case of drought. In disconnected floodplains, flooding may only occur only every 5 or 10 years, while in extreme conditions, flow may never access the disconnected floodplain. Floodplains provide significant energy dissipation, and when they are disconnected from the stream all of the energy is concentrated in the channel. For this reason, unit stream power is much higher in incised channels than in their unincised counterparts, for a given discharge.

Riparian Corridor Categories:

Continuous/wide

Semi-continuous/wide

Discontinuous/narrow

Urbanized or levee confined

Riparian vegetation provides essential building materials and food supplies for beaver, but vegetation also increases the capacity of the stream to absorb disturbances. The probability that the stream may be adversely affected increases when the riparian corridor is narrow or discontinuous. Riparian vegetation both reduces velocity and increases soil strength. Risk increases in urban and levee-confined streams that lack the space necessary to dissipate stream energy, and thus beaver dam viability is also reduced.

Beaver Presence Categories:

Established, thriving colony

Evidence of past occupation

No evidence of past occupation

Determining beaver intrinsic potential is an inexact science. Even with a thorough understanding of beaver life history and habitat preferences, it is still challenging to predict where beaver will establish a colony. Field indicators of past or present beaver use are excellent indicators of potential future use. If there is no indication in the historical or geomorphic record of beaver occupation, the likelihood of colonization is very low.

Dominant Hydrologic Regime Categories:

Spring-fed

Snowmelt

Rain

Rain-on-snow

Convective

Thunderstorm

Flow characteristics are a function of watershed hydrology. Whether the flow is dominated by spring-fed or rain-on-snow events profoundly affects the relative channel stability and potential for stream response. For example, spring-fed stream systems have low flow variability and thus are highly stable and predictable. In contrast, convective thunderstorm-driven hydrology results in streams with high variability, so flows in these streams are often unstable and unpredictable. The "flashier" the hydrology, the lower the dam viability becomes. In higher variability systems, dams in side channels or a cascade of dams may be more viable than dams in the main channel.

Y-axis: Increasing Negative Impact Potential

Planning Context and Scale Categories:

Coordinated watershed plan

Stand-alone project

Multi-reach scale

Reach scale

Site scale

All stream management and beaver restoration projects should be developed within a watershed framework; this is especially important when identifying the underlying causes of a problem. The "planning context and scale categories" risk factor uses watershed plans as a surrogate for project prioritization and context. It is assumed that if the project is identified as part of a larger plan that some level of technical analysis has been performed to justify the need and appropriateness of the proposed project.

The multi-reach, reach, and site-scale factors acknowledge that beaver will use resources within an area until they are depleted and then move to adjacent areas with suitable habitat. If a site is too small or isolated, the beaver will not have the space necessary to sustain a colony over time.

Adjacent Land Use Categories:

Open space

Agricultural

Rural/suburban

Urban/industrial

Beaver/human conflicts increase when available habitat is limited, there is human encroachment on habitat, and the land value in the area is high. Adequate space for beaver, combined with land uses that are not vulnerable to increased flooding and saturation, results in a lower potential for beaver dam removal.

Infrastructure Categories:

None

Bridges

Culverts

Intakes/outlets

Flooding is addressed in the "land use" factor, above. The "infrastructure" factor is specifically about water management concerns and the impact of beaver. Bridges are a relatively low risk because their openings are large and generally do not result in increased beaver activity; however, culverts (especially undersized culverts) attract beavers because of the ease with which they can block a culvert entrance and create a pond. This behavior is further encouraged because beaver respond to the sound of flowing water, which is amplified when a culvert is perched. Beaver ponds can also cause significant problems if there are water intakes or outlets, where specific water levels are required.

Monitoring Plan Categories:

Adaptive management

Monitoring only

None

Because all projects have some unanticipated outcomes, monitoring is needed to determine the extent of any negative impacts (along with the expected benefits). Although monitoring will detect changes and help to identify problems, adaptive management will allow for correction of these problems.

For higher risk projects or new project types, an adaptive management plan can help to significantly reduce the overall risk over the long term and improve future projects.

Using the Matrix to Screen Projects

Once the factors have been assessed, projects risks can be combined and analyzed in at least three different ways:

- Assume that all factors are critical to achieve beaver dam viability. In this case, the overall risk category is defined by the highest risk factor on each of the x- and y-axes. A good example of this precautionary principle is a levee-confined channel, which would always receive a high risk rating for low beaver dam viability.

- Consider none of the factors to be individually critical to success. In this case, the overall risk category is defined by the average of the risk factors on each of the x- and y-axes. There is a balance between factors.

- Deem some of the factors to be more important than others, with no single factor dominating. In this case, the overall category is the defined by weighting the factors on each of the x- and y-axes.

There is no "cookbook" solution to deciding how to select the overall category because each project and stream presents different challenges and risks. What is required is consistent critical thinking and transparent, evidence-based decision making. The level of risk is often reduced when more data are available, or when the reviewer is familiar with the site.

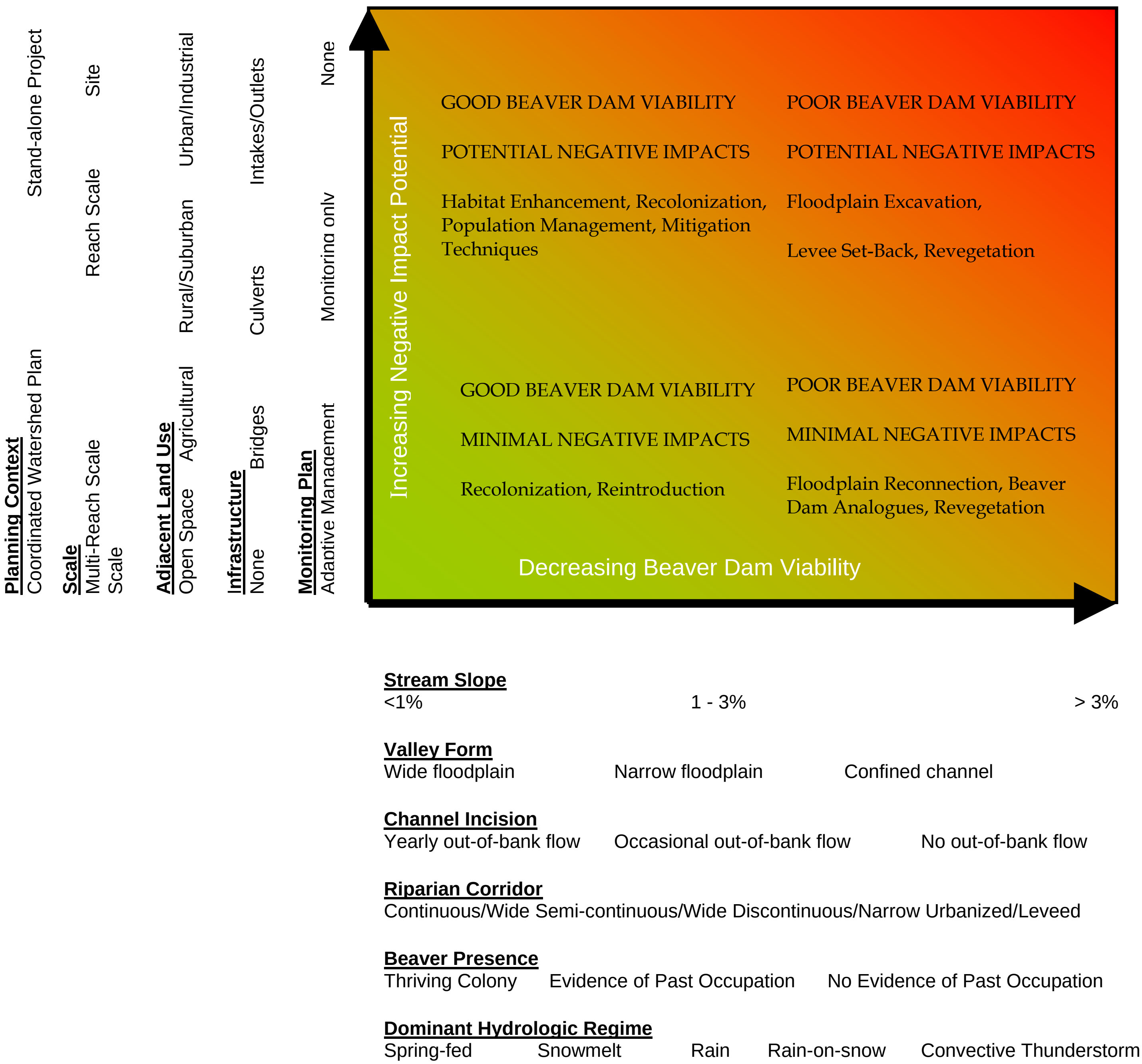


Figure 45: Beaver Dam Viability Matrix

Chapter 11—Beaver Restoration Case Studies

Greg Lewallen, Mark Beardsley, Daniel Armichardy, Scott Jay Bailey, Bob Hassmiller, Sean Bistoff, David Helzer, Kendra Smith, Susan Firor, Janet Hohle, Scott Reid, Jessica Doran, Brad Johnson, Mike Claffey, Matt Weaver, David Kliegman, Julie Ashmore, Lauren Rich and Cathryn Wild

In this chapter we provide examples of restoration projects that have either incorporated beaver and/or beaver dam analogues into the restoration design and plans, or accommodated for beaver recolonization of the site after completion of the project. These examples provide a spectrum of ideas and approaches for using beaver and beaver dams for stream restoration projects. We will continue to expand this chapter as we gather more case studies. Currently, we describe nine case studies from five western states:

(1) Miami Wetlands Restoration Project, Oregon—Helping an existing beaver population.

(2) Camp Creek, Oregon--Log Weir Removal And Large Wood Placement Project, with an unexpected colonization by beaver

(3) Mason Flats Wetland Enhancement Project, Oregon—Helping an existing beaver population.

(4) Tualatin Basin, Oregon— Healthy Streams Plan Implementation—Helping an existing beaver population.

(5) Wet Meadow Restoration, Latah County, Idaho—Beaver relocation and Beaver Dam Analogues.

(6) Cucumber Gulch Preserve, Colorado—Encouraging beaver recolonization using Beaver Dam Analogues.

(7) Myers Creek, Washington Habitat Restoration Project-Beaver Dam Analogues and large wood.

(8) Hansen Creek, Washington Floodplain Restoration Project—Encouraging beaver recolonization

(9) Eastern New Mexico –Beaver Dam Analogues and beaver reintroduction

We recognize that there are numerous other ongoing beaver restoration efforts, including the Martinez project in California, the Elko project in Nevada, the San Rafael River project in Utah, the Pine Creek and Bridge Creek projects in eastern Oregon, the Scott Valley, Boise Creek and Child's meadow projects in northern California, the Methow Valley,Yakima, Wenas Creek and Lands Council projects, all in eastern Washington, the Tulalip project in western Washington and many others which we have not described. We will be including descriptions of more of these projects in future versions of the Beaver Restoration Guide, along with a map showing the approximate locations. If you are interested in sharing your beaver restoration story, and the lessons you have learned, please contact Gregory Lewallan at glew2@pdx.edu.

(1) Miami Wetlands Restoration Project, Oregon

Tillamook Estuaries Partnership, Scott Jay Bailey, Project Manager

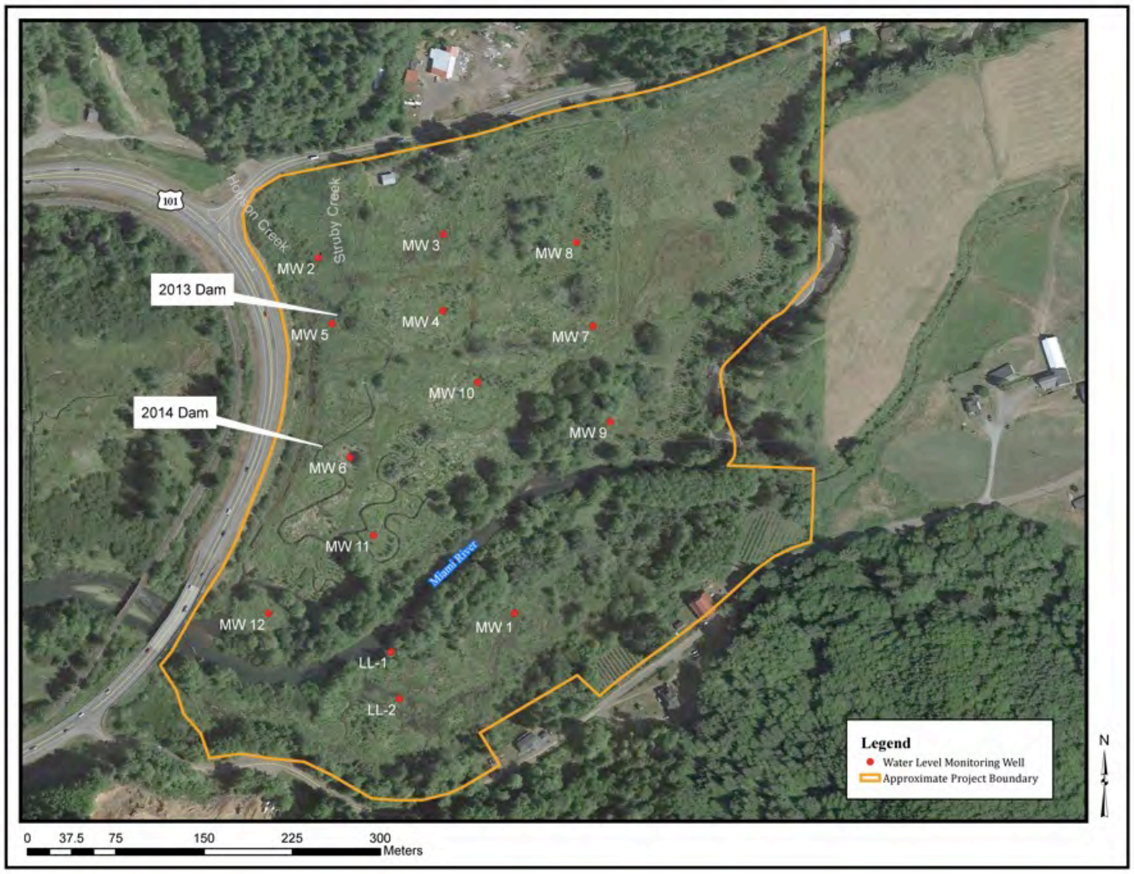


Figure 46: 2014 aerial photo of the site showing locations of monitoring wells and two beaver dams

Location and Description

The Miami Wetlands Restoration Project is located along the Pacific Coast in Tillamook County, Oregon. The approximately 58-acre wetland straddles the Miami River near its mouth at Tillamook Bay. The site is located well below head-of-tide and elevations within the wetland portion of the site range from approximately 6 to 12 feet above sea level. The site is isolated from a downstream tidal wetland at the river mouth due to U.S. Highway 101 and, although elevations within the site are within the range of tidal amplitude, water quality monitoring indicates that fresh water predominates. Water levels are influenced by precipitation, beaver activities and tidal fluctuations.

Restoration Goals

- Improve connectivity between on-site wetlands and the mainstem Miami River
- Increase the quantity and quality of on-site aquatic habitats

- Restore the historical character of on-site vegetation
- Restore Hobson and Struby creeks to a more natural configuration, further away from the U.S. Highway 101 corridor
- Enhance riparian vegetation along the Miami River to increase shading and provide a source of wood for future in-channel large wood recruitment

Construction began in 2010 and concluded in 2011, and returned the function of the on-site wetlands through reconnection of the tidally influenced hydrology to the mainstem Miami River and improving conditions in a freshwater stream channel running through the site. This was accomplished by filling drainage ditches and creating a series of new channels throughout the site, including a meandering stream channel and several tidally-influenced channels. Planting followed construction activities and incorporated a variety of native trees, shrubs, graminoids and forbs. The plant palette included beaver-preferred species such as willows (*Salix* spp.) and black cottonwood (*Populus trichocarpa*).

Beaver were present on the site before the project started and occupied all pre-construction channels. A few dams were present pre-construction, but beaver activity increased post-construction apparently as willow distribution and abundance expanded due to planting of pole cuttings. As a result, the number of beaver impoundments has increased substantially. The project plan did not specifically involve beaver, but the expectation was that they would remain after construction was completed and continue to modify the site. No beaver were removed from or transplanted to the site. Almost all the tree plantings were protected from beaver herbivory by 4-foot high chicken wire cages. Pole cuttings, shrubs, graminoids and forbs were not protected. While protected trees have remained relatively undisturbed by beaver, herbivory of other plantings (especially pole cuttings) has been very common. However, because the planting strategy incorporated large numbers of plants, beaver herbivory has not driven plant survival to unacceptably low levels.

In June of 2013, beaver rapidly built a bank-high, channel-spanning dam at the confluence of two small stream channels that created a large pond and lateral overbank flooding (Figure 46). This dam has raised the local water table and moderated fluctuations between precipitation events as compared with pre-project conditions (Figure 47). Beavers quickly developed small channels extending outward from the pond to increase their forage area. During summer 2014, another channel-spanning dam was built (Figure 46), which has also included lateral channel development and resulted in over-bank flooding, pushing water laterally and increasing the area of soil saturation, and moderating water level fluctuations (Figure 48). Most channel-spanning dams seem to be situated at or near the confluence of streams and side channels, and most construction activity has been associated with the stream channel and not the tidal channels. Beavers have also built small check dams to control the new overland flows that resulted from these larger dams. Beaver are actively consuming herbaceous vegetation, willows and alders at the site, with primary dam construction material of willow branches with leaves, mud, and reed canary grass used as fill and sealant.

Monitoring indicates that dam-building activity has substantially increased the amount of surface and subsurface water present on the site. Fish surveys show increased numbers of cutthroat trout and coho salmon, especially in the beaver ponds and around constructed large wood structures. Water temperature monitoring indicates that surface and subsurface water temperatures at the site are consistently below Oregon Department of Environmental Quality maximum temperature standards for salmon and trout spawning and rearing/migration periods (Oregon Administrative Rules 340-041-0028).

Predicting where beavers would build dams is very difficult. As a result, some of the plantings (primarily shrubs and conifer trees) were indirectly killed by beaver from the inundation following dam construction. However, the benefits from the increased surface and subsurface water, fish habitat, and complexity that can be attributed to the dam-building activity outweighs the loss of the small percentage of plantings from flooding. To compensate for these losses, mortality replacement planting in these areas has incorporated plant species compatible with long-term inundation. As with beaver herbivory, this indirect mortality has not driven plant survival to unacceptably low levels.

Overall, the managers consider the project to be a success and the beaver activity a welcome complement to the project.

For more information regarding this project including baseline and interim monitoring reports, Miami River Watershed Assessment (2001), and other reports go to:

http://www.tbnep.org/habitat-enhancement-and-restoration.php

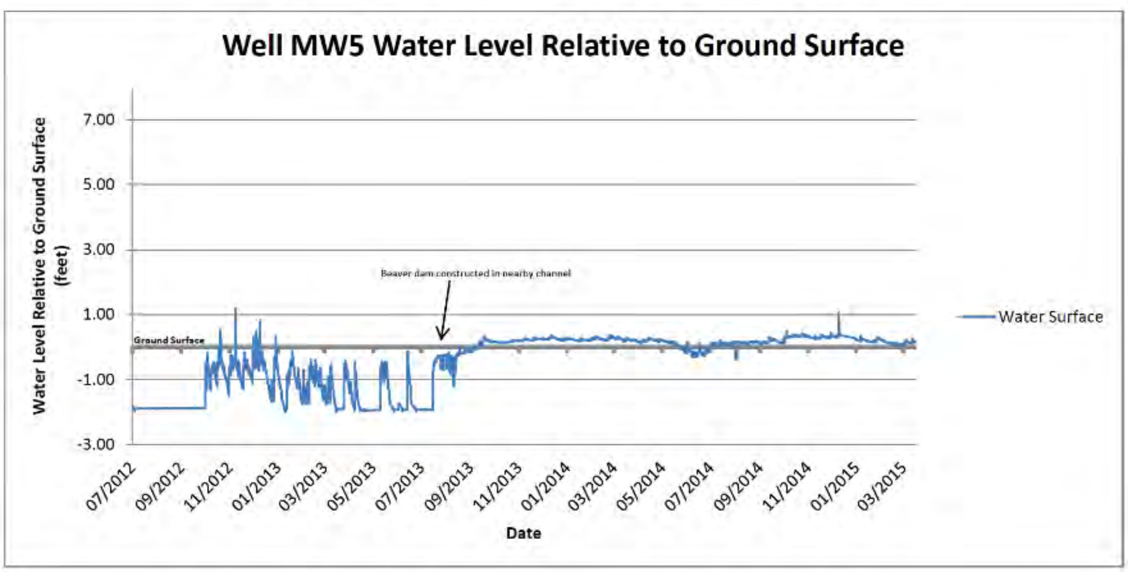


Figure 47: Data from monitoring well #5 showing a moderation of the water table following the construction of a beaver dam in the nearby channel

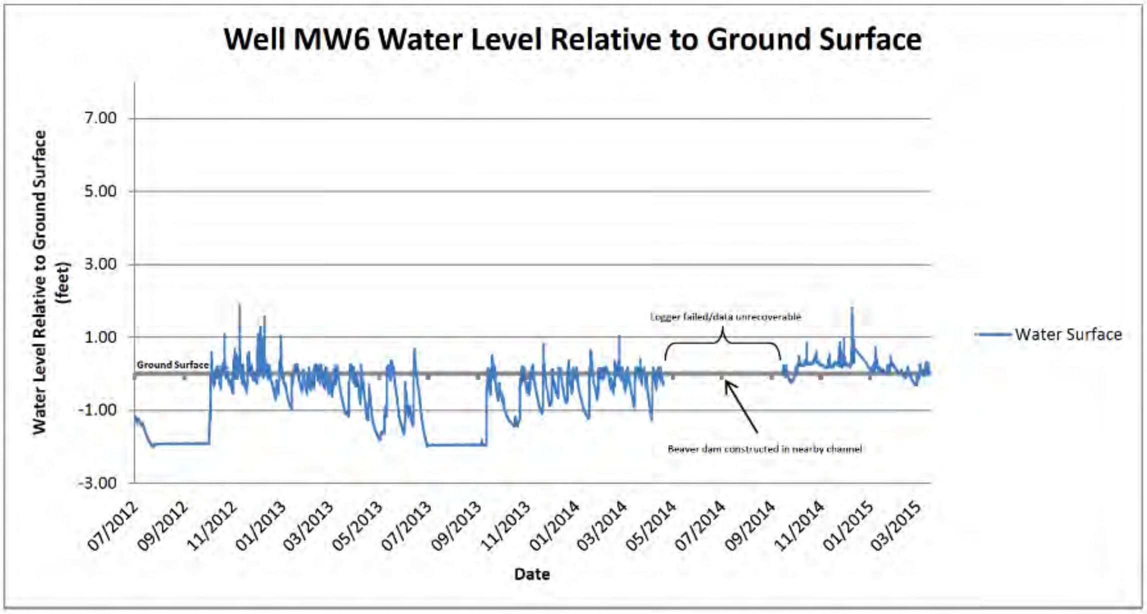


Figure 48: Data from monitoring well #6 showing a rise in the local water table following construction of a beaver dam in the nearby channel

(2) Camp Creek Log Weir Removal And Large Wood Placement Project (2011-2014)

Malheur National Forest, Blue Mountain Ranger District, Bob Hassmiller, Zone Hydrologist. Case study prepared by Dan Armichardy, United States Forest Service

Location and Description

Camp Creek is a 6th order creek that drains into the John Day River Basin. The John Day River Basin is considered the "most biologically diverse river system and a globally important stronghold of wild salmon" because the John Day River is the longest free-flowing river in the Columbia basin, and is mostly devoid of hatchery influences. The Camp Creek watershed has been rated as high priority for habitat protection and restoration within the subbasin by the Mid-Columbia River Steelhead Conservation and Recovery Plan. This Plan identified limiting factors that impact steelhead production and ecohydrological processes and functions in the Camp Creek watershed: degraded riparian communities, floodplain connectivity and function, channel structure and complexity, water quality (stream temperature), and altered hydrology and sediment routing, all of which are integrally related and play critical roles in the creation and maintenance of quality fish habitat. Past practices of beaver trapping, heavy livestock grazing, riparian logging and associated railroad grade construction in the valley bottoms are the dominant actions that disrupted process and functions and led to the listed limiting factors. Camp Creek is considered the highest priority watershed by The John Day Subbasin Revised Draft Plan. In response to these designations a 2008 Watershed Restoration Action Plan (WRAP) was developed as a road map to complete high priority restoration projects. These projects have been planned with the intent to meet the desired conditions stated in the WRAP. Threatened Mid-Columbia River summer steelhead and spring Chinook salmon, take up residence in Camp Creek and its tributaries during various life stages. Summer steelhead adults use Camp Creek and its tributaries as crucial spawning grounds from April through June. The fry emerge by mid-July, and the juveniles reside in Camp Creek and tributaries for 1 to 3 years, migrate to the ocean, and return as adults to spawn. Spring Chinook adults spawn in the lower reaches of Camp and Lick Creeks. Juveniles use the habitat for 1 to 2 years, and then make their way to the Pacific Ocean. Chinook juveniles hatched in the Middle Fork John Day River use Camp Creek as thermal refuge during the hot summer months when the Middle Fork John Day River temperatures rise.

One of the primary goals identified within the Camp Creek WRAP included the removal of approximately 238 log weirs within Camp Creek watershed. Large wood structures and trees with rootwads were placed in Camp Creek within the same vicinity of log weir removal in 2011 (see Figure 49). 123 log weirs were removed or modified during this work in the lower sections of Camp Creek.

Restoration Objectives:

- Reduce the width of the active channel
- Increase floodplain connectivity
- Increase roughness to induce gravel deposition

- Increase area of quality pool habitat

Stream channels within the reaches where log weirs were located have narrowed and vegetation has colonized exposed stream banks. The majority of pools created through excavation have been maintained by instream wood. Gravel sorting is evident throughout the reaches that were predominantly plane bed with an armor layer of cobble that functioned as a transport reach (slope 0.017). Based on this evidence the project continues to improve Mid-Columbia River Steelhead habitat deficiencies identified within the Camp Creek WRAP.

Unforeseen Benefits

In 2014, beaver moved into a portion of Camp Creek where log weirs were removed, pools were excavated, and wood was added (see Figures 53 and 54). While historical beaver evidence was present within Camp Creek, transient beaver activity and dams have been noted but no prior large dams, such as those observed in 2014, were documented within lower Camp Creek. Many of the dams that appeared in 2014 were keyed into placed wood or boulders for added stability and persistence (Figures 50-52). Additionally the beaver dams backwatered the placed wood structures and the excavated pools increased the depth upstream of the dam to over 5 feet in places. Observations indicate beaver are using the wood structure locations as dens and the deep excavated pools as food caches for over wintering. During the spring of 2015, several smaller dams were breached leaving large gravel patches (built by beaver for dam construction). Several steelhead were observed constructing redds in these breached areas. This provides an example of combined salmon/beaver because the same limiting factors affecting salmonids may also be limiting beaver—the two are not exclusive, but share a common beneficiary relationship. Dams anchored to large wood tended to be taller, had more internal stability and had a larger hydrologic zone of influence (see Figures 50 and 52).

Figure 49: Log Weir Removal from Reach 4 of Camp Creek before (top left), immediately after (top right), and 3 years later (bottom)

Figure 50: Medium size (< 12 inch) diameter ponderosa pine placed in mid-channel in 2011 following log weir removal. Beaver dam has incorporated rootwad into center of dam (6/15/2014).

Figure 51: Existing rock placed mid-channel during log weir removal 2011 has been incorporated into beaver dam (6/15/2014)

Figure 52: Beaver dam with rootwad incorporated (12/15/14)

Figure 53: Smaller beaver dam built at pool tail out without wood (12/15/14).

Figure 54. Valley bottom being inundated with moderate flood because of beaver dam influence (12/22/14). Same dam as Figure 52.

(3) Mason Flats Wetland Enhancement Project

Sean Bistoff, Capital Project Manager, City of Portland Environmental Services

Figure 55: 2015 aerial photo of the site showing locations of old, reconstructed, and newly constructed beaver dams. Figure courtesy of City of Portland, Environmental Services.

Location

NE Mason and Airport Way in the Big Four Corners Natural Area of an industrial neighbourhood, Portland, Oregon.

Restoration Goals

- Improve Columbia Slough water quality through stormwater treatment and temperature reduction of runoff and effluent entering the wetland restoration site
- Improve habitat for native species (e.g. willow flycatcher, western painted turtle, red legged frog)
- Increase floodplain function and floodwater storage
- Increase native vegetation
- Protect and enhance wetland habitat

Site Description

The project site is a 27-acre marsh and scrub wetland, which discharges to the Columbia Slough in an industrial area in Northeast Portland. The site consisted of a drained and abandoned agricultural field of reed canary grass adjacent to a partially functioning wetland mitigation site. The project directs water back onto the drained field, increasing the water retention on site. Two sets of weirs and a network of engineered swales and vegetated channels were constructed to divert spring flow and treated stormwater onto the field. During design, several existing beaver dams were observed in the project area (Figure 55). Rather than designing a system that would be at odds with beaver activity, and since all of the project goals are in align with the effects beaver dams, a flexible design was developed to allow modification and enhancement by beaver.

Data collected by the Bureau of Environmental Services show that beaver activity has increased since project completion, and has improved the overall project effectiveness. For example, beaver dams have remedied a site grading problem that might have otherwise required additional work, and a complex of new dams has increased the overall wetted area and detention time on the site. In addition, beaver have forced overland flow onto an existing willow glade directly adjacent to the restored site that is slightly higher in elevation. This has allowed access to important food and construction materials leaving the newly planted, and exposed, willows and other native plantings relatively unbrowsed by the beaver, thus giving them time to mature. Since the site is inherently difficult to access with equipment, had past beaver occupancy, and is suitable habitat for many different species supported by beaver modification, it has been successfully designed to be flexible and to allow continued beaver modification without intensive maintenance or management. Furthermore, located in an industrial area of a major metropolitan city, this site is a great example of how beaver can be utilized in restoration projects where perceived risks of human-beaver conflict may seem high. Utilization of an adaptive management plan, post-project monitoring, and ensuring that adjacent properties are safe from beaver modifications and inundation from dams have contributed to this projects success.

(4) Tualatin Basin, Oregon—Healthy Streams Plan Implementation

Kendra Smith, Restoration Ecologist

Location

The Tualatin Basin in northwest Oregon drains 712 square miles from the forests of Oregon's Coast Range, Tualatin Mountains and Chehalem Mountains, to the valley floor dominated by agricultural lands to the west and densely populated areas to the east, including the cities of Hillsboro, Tigard, Tualatin, Beaverton and portions of southwest Portland. Protection and restoration of the surface waters of Tualatin Basin began in the 1970s, with upgrades to wastewater treatment plants. In the late 1990's efforts to improve the quality and connectivity of the steam network were initiated.

Enhancement Goals

Large-scale watershed enhancement, to advance water quality, water quantity, and habitat goals were guided by the Healthy Streams Plan (Clean Water Services, 2000-2005) and other watershed planning efforts developed in 1995 to 2000. Enhancement projects were designed and implemented to support recovery of stream processes and function, including:

- Restoring degraded riparian areas by removing invasive plants and revegetating with native plant communities
- Improving stream function by remeandering straightened and incised streams and placing large wood
- Reconnecting floodplains and the streams by encouraging overbank flows, reconnecting side channels, and removing fish barriers
- Engaging with local maintenance staff and USDA's Animal and Plant Health Inspection Service (APHIS) to aggressively remove nutria, while allowing native beaver to persist in the system

Projects started in 1996 and are ongoing, as part of Clean Water Services watershed management program. A majority of the streams treated in the Tualatin basin had highly degraded riparian areas dominated by non-native species. Several reaches were highly incised resulting in increased stream power, channel erosion, and floodplain disconnect. Beaver activity and summer water levels were low throughout the watershed; only 25 reaches out of 506 assessed (representing 338 miles of streams) in 2000 had documented evidence of beaver use (4.9% of the reaches)(Watersheds 2000 Dataset, Clean Water Services, 2000).

Riparian restoration, barrier removals, channel remeanders and large woody debris placement were the focus through the first 8 years of the program. But in 2005, an informal agreement was negotiated between Clean Water Services, member cities, Washington County and APHIS, to redirect trapping activity to non-native species (nutria) and, stop the trapping of beaver in the urban reaches of the Tualatin basin. By 2010, the evidence of the release of trapping pressure on beaver were already being seen and increases in riparian vegetation seemed to be supporting the beaver activity (i.e. dam and lodge building) in the urban areas

(Figure 56). By 2014 there was a substantial difference in the amount of native riparian vegetation, in-stream water, and over-bank flooding onto the floodplains in the urban areas versus the rural areas. The Willamette Riparian Revegetation Effectiveness Study (BEF, 2015) completed a sub-study of 40 sites within the original 509 reaches, confirmed beaver use at 25 sites (62.5% of those assessed), and a local park district documented another 26 sites in 2012 that were not occupied in the 2000 assessment. At one urban site, a pond leveler was installed where beavers have constructed channel and floodplain spanning dams that pond enough water to inundate both the floodplain and a bike path. The pond leveler helps reduce the flooding of infrastructure by regulating the amount of impounded water.

Figure 56: Photo of urban reaches (within the yellow lines) showing limited beaver activity in 2005 (above) and increased beaver activity in 2015 once trapping pressure was removed (below). Figures courtesy of Kendra Smith.

Lethal removal of beaver through trapping and hunting continues in rural areas where beaver activity is not well documented in the Tualatin Basin, except at enhancement sites. Sites with limited food sources and water withdrawals during summer low surface flows, are less than ideal locations for beaver to occupy and may be a limiting factor in addition to trapping activities.

Utilizing beaver to help restore streams in urban areas requires a thoughtful, adaptive management approach. Regular site monitoring, open communication and collaboration with all interested parties can reduce the risk of human-beaver conflicts (i.e. flooding of property/infrastructure). This project is great example of how beaver can be used to help restore streams in urban and suburban settings.

(5) Wet Meadow Restoration, Idaho

Susan Firor, Principal Restoration Engineer, TerraGraphics Environmental Engineering, Inc.; Trish Heekin, Resource Conservation Planner, Latah Soil and Water Conservation District; and Janet Hohle, Project Manager, Clearwater Focus Program, Idaho Office of Species Conservation

Location

Latah County, Idaho

Restoration Goals

- Reconnect streams to wet meadows
- Improve/increase summer rearing habitat for steelhead
- Aggrade incised stream reaches
- Redirect flow into historical channels and out of old borrow ditches formed during construction of railroad berms in late 19th – early 20th centuries
- Increase local aquifer recharge
- Raise groundwater elevations
- Transform ephemeral streams to intermittent or perennial flow where possible
- Restore beaver habitat

The restoration site consists of approximately four stream miles on several forks of a tributary to the Potlatch River. The site is primarily on private land owned by a single landowner. Many of the existing beaver meadows have become hydrologically disconnected from their stream systems due to lack of beaver dams and large wood impoundments, incision of streambeds, and channel diversions into old borrow ditches. There are signs of historical beaver activity in this region as well as recent beaver activity; however, the beaver population appears to be very low, with some reaches lacking any recent beaver activity. Anecdotally, the beaver seem to abandon areas within a year or two, either moving to new areas or being trapped out. Although some lodges have been built in this area, most beaver appear to be bank dwellers. Riparian vegetation for both food and construction material is available in many reaches; however, some meadow reaches are completely devoid of woody vegetation. Beaver trapping was prohibited in this watershed for a 10-year period but was reopened to trapping in 2011. Although most of the project is on private land, which is posted no trespassing, the landowner believes there is still significant trapping pressure.

Currently, the Idaho Fish and Game Department authorizes kill trapping of nuisance beavers, but they will refer affected landowners to a small group of people who live trap and then release the “nuisance” beavers in suitable habitat. To date, the group has live trapped two beaver families (11 beavers total) from nearby sites and released them within the subject restoration property.

Restoration at this site has included installation of two types of beaver dam analogues (BDAs) (see Figures 57 and 58). Earthen BDAs are used to divert flow back into historical channels and to develop wetland cells along the degraded channel (Figure 1). Other BDAs consist of cedar stakes 3–6 feet tall, driven halfway into the ground and woven with willow cuttings and other brush materials (Figure 58). Beaver have not modified or maintained any of these structures yet. However, the BDAs are functioning as anticipated by slowing and impounding water and sediment, which has increased the area of saturated soils during spring runoff. To date, FBDs have been placed in small seasonal side channels and along potential avulsion pathways. Placement was determined primarily in response to hydraulic needs to protect the in-stream BDAs. Future BDA installations are planned for main channel locations where they slow flow velocities, pool water, and trap sediment, ultimately prolonging saturation of the wet meadows well into the dry summer season.

Monitoring is underway in five meadows within this watershed to determine whether the meadow restoration projects are, as anticipated, raising the local water table and retaining water for longer duration than prior to implementation.

The project organizers believe that utilizing beaver to restore wet meadow habitat is gaining widespread interest across the western United States. Often, however, the desired effects of beaver dams can be outweighed by negative perceptions from landowners and managers. This project provides an example of how BDAs can be utilized to achieve landscape improvements similar to those resulting from natural beaver activities in areas where trapping pressure keeps populations low. Installing BDAs initiates long-term restoration of the site, promoting aggradation of sediments, increased water table, saturated soils, and better survival of woody riparian plants. These conditions could attract beaver by providing food and cover, or support beavers reintroduced to the project area. In addition, this project’s positive effects on the landscape and available livestock forage have helped to assuage cattle operator concerns about potential flooding.

Figure 57. Earthen BDA and Wetland Cell in second growing season after construction.

Figure 58. BDAs after peak flow constructed with posts driven into the streambed and woven with wicker weaves.

(6) Cucumber Gulch Preserve, Colorado

Scott Reid, Town of Breckenridge; Mark Beardsley and Jessica Doran, EcoMetrics; Brad Johnson, Johnson Environmental Consulting; Mike Claffey, Claffey Ecological; Matt Weaver, Five Rivers; Breckenridge Ski Area

Location and Description

Cucumber Gulch Preserve is located near the town of Breckenridge, Colorado at the base of the Breckenridge Ski Area (Figure 59). It is a first order headwaters wetland system at about 10,000 feet elevation. The wetland area is designated an Aquatic Resource of National Importance (ARNI) by the US EPA because it supports unusually high biodiversity for the area. It is managed as a wildlife preserve.

Figure 59: Location of Cucumber Gulch Preserve in Summit County, Colorado

Problem

The contributing watershed for the wetland is entirely within the Breckenridge Ski Area (Figure 60). Ski area developments include base area developments, imported water (snowmaking), clear cuts (ski runs), miles of service roads, and a highly modified drainage system. Runoff from the watershed is collected from a system of ditches and drains into a central point where it is routed under road fill to the Cucumber Gulch wetlands through a single 60 inch diameter culvert known as Boreas Creek. The combined effect of these stressors is an altered hydrology that is both augmented (more water) and flashier (higher magnitude and shorter peaks) and a severely increased sediment supply to the wetland.

Figure 60: The contributing watershed (blue) to the Cucumber Gulch Preserve (purple) is entirely within the Breckenridge Ski Area and severely modified to meet that purpose

Sediment routed from the ski area to the wetland through the pipe eventually filled beaver ponds with as much as four feet of deposition (Figure 61) and beavers were unable to raise the height of dams fast enough to keep up. Beavers eventually abandoned the site and were completely absent by the early 2000s. Though mostly full of sediment, the beaver dams continued to function for some years, spreading water among a system of tiny distributary channels. But without the daily maintenance by beavers, the ancient dams began failing after 2007 as nick points formed and eventually head cut through the dams. Head cuts migrated rapidly upstream through deposition in the ponds and wetland forming a deeply incised channel (Figure 62). This effectively cut off the water supply to the wetland, and the wetland began shrinking. By 2011 all of the ponds in this portion of the preserve were dry, Boreas Creek had become a deep incised gully, and the wetland was a fraction of its original size and still shrinking (Figure 63).

The community would like to maintain the Preserve in as natural condition as possible to support the greatest number of native plants and animals, so a restoration project was conceived in 2012. The guiding image for restoration is to restore the wetland habitat of Upper Cucumber Gulch to its previous extent and condition by mitigating external stressors (hydrology and sediment), repairing the incised channel, and restoring beavers.

Figure 61: A beaver pond that is completely full of sediment that was routed into the wetland from the contributing watershed prior to restoration. The accelerated rate of sediment accumulation in ponds exceeded the ability of beavers to keep up, so they abandoned the site

Figure 62: Once dams failed, a channel formed and immediately began head cutting. These photos show the Boreas Creek channel in different stages of incision, initial channel formation (left) and advanced incision (right)

Restoration Goals

The overarching goal for this project is to restore the former extent and condition of wetland habitat. Specific goals describe the means to that end:

- Mitigate hydrologic impacts from contributing watershed
- Mitigate allochthanous sediment supply from contributing watershed
- Restore the incised Boreas Creek channel to a native anastomosed condition
- Restore a self-sustaining beaver population

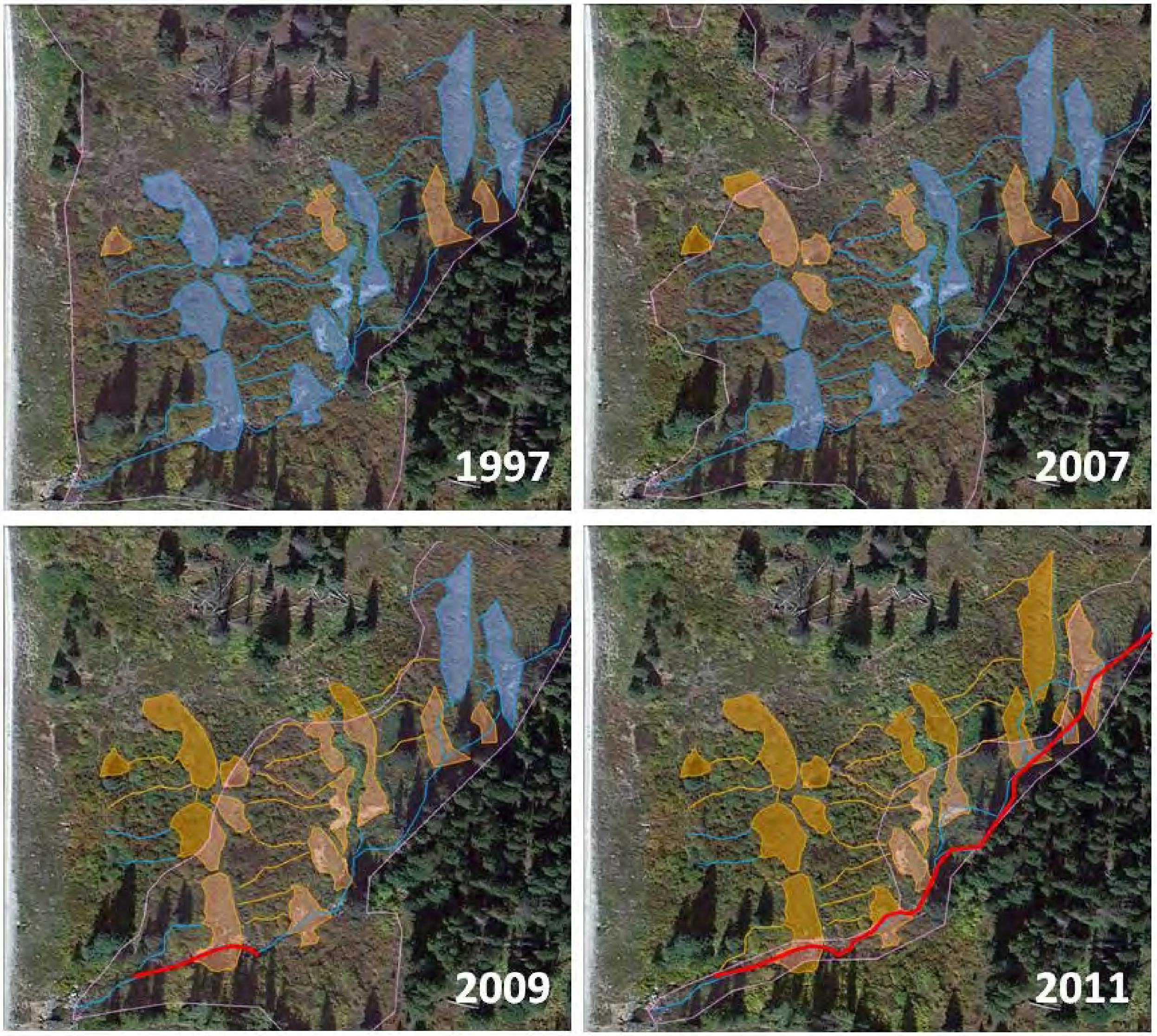


Figure 63: This photo series shows the sequence of wetland degradation after beaver abandoned the site in the early 2000s. Full ponds and active channels are depicted in blue. Dry ponds and channels are shown in orange. Pink shading depicts the extent of wetlands based on Army Corps of Engineers delineation criteria. The red line shows the extent of the newly formed incised Boreas Creek channel. The background imagery is from 2011.

Strategy

It is clear that beavers were the primary agent that formed and maintained the stream and wetland in Cucumber Gulch, so the strategy is focused on recovering a self-sustaining population of beavers. The first step towards beaver recovery is restoring suitable habitat. The wetlands were just recently dried, so most of the hydric vegetation was still in place, including a sufficient supply of woody vegetation for beaver food and building material. The limiting habitat factor was deep water cover, and restoring deep water to the site was a two-part process involving the removal of accumulated sediment from the ponds and repairing the breached dams.

Figure 67: Breached dams were "plugged" with soil lifts wrapped in coir fabric and sod interwoven with live willow stems

Removing allochthanous sediment was acieved by excavation to haul several hundred cubic yards of material, but the strategy for repairing the dams required an approach a bit different from traditional BDAs. The dams on this site are so ancient that their cores have mostly decomposed into mineral and organic soil, so the dam breaches were patched with coir-wrapped soil lifts interwoven with live willow stems (Figure 67). On one dam, a PLWW was constructed across the top of the dam to fortify a nick point in the repaired dam to (hopefully) entice beaver to take over maintenance (Figure 68). These treatments were implemented in the fall of 2012.

Figure 68: A PLWW was constructed on one repaired dam to temporarily fortify a nick point while we were waiter for beaver to reoccupy the site

Secondary goals of the project involve mitigating external stressors, particularly the altered hydrologic and sediment regimes caused by land use in the contributing watershed (which is a ski area). Addressing these issues is paramount for long term success since these impacts are likely responsible for the original collapse of the system and will continue to impact restoration efforts if they are not alleviated or mitigated. Alleviation of these stressors at the source is not a feasible option, so both problems were simply mitigated to the greatest extent possible at the head of the wetland. The first beaver ponds in the system are being used to spread flows across the wetland area and to capture incoming sediment. Maintenance staff is on call to remove sediment that accumulates as a delta at the inlet to the first pond as needed, before it starts filling the pond proper. The first clean-out is scheduled for spring, 2015 to remove about 40-50 cubic yards of sediment.

Several treatments were applied to the incised Boreas Creek channel in 2013 including two BDAs, but the ultimate strategy is to rely on beavers to complete the restoration. Since most of the incoming flow is now spread across the wetland and no longer consolidated within the incised channel, we suspect that beavers will easily be able to build dams. If this proves not to be the case, additional BDAs will be constructed.

The initial strategy for restoring a beaver population was to rely on natural immigration of beavers to the site from nearby locations, but we were able to take advantage a fortuitous opportunity to host a recently captured nuisance beaver (Figure 69). We named him Franklin and released him to one of the recently restored ponds in summer 2013, where he took advantage of a supply of aspen that was set out for him and fortunately decided to stay. In a matter of days, Franklin had begun packing mud and sticks on the dam face, apparently having taken residence in an old abandoned bank lodge. Later that season several additional beavers returned to the site, and most of the dams on the site were being fully maintained by beavers before winter of that year

Figure 69: The project relied on natural beaver immigration to the site, but one trapped beaver was released at the site in 2013

Monitoring and Results

The functional condition of the wetland was rated as severely impaired in 2011 using the Functional Assessment of Colorado Wetlands (FACWet) version 2.0, and a delineation at that time showed that wetland extent was severely reduced. Quantitative hydrology, soils, and vegetation data confirmed these results. Beaver population surveys showed no indication of beaver activity on the site in 2011 or 2012. To develop a quantitative monitoring plan, we predicted what the change in FACWet variable scores would be if the treatments were successfully implemented and beavers returned to the site. Prognosticated scores provided a benchmark for setting specific objectives, targets, and success criteria by which the effectiveness of wetland restoration could be judged (Table 8), and an array of monitoring points was established across the site to track changes in hydrology, soil, and vegetation parameters (Figure 70).

Table 8: A monitoring plan was developed to track the effectiveness of restoring functional condition of the wetland based on FACWet variable scores. Pre-project and target scores are shown, along with a description of success criteria and monitoring activities.

FACWet Variable #	Variable Description	Pre-project score	Target score	Success Criterion	Monitoring
1/2	Connectivity	C	C	N/A	N/A
3	Buffer Capacity	D	D	N/A	N/A
4	Water Source	D	B	1. Incoming water from Boreas Cr. is spread laterally in a full "spreader pond" that feeds multiple distributary channels across the width of the complex.	1. Observation, photos, streamflow monitoring
5	Water Distribution	D-	B	1. Historic extent and depth of pond habitat restored to abandoned ponds. 2. Water table elevations throughout historic wetland area meet criteria for wetland hydrology.	1. Observation, photos. 2. Water table depth monitoring at 14 test sites within Upper CG.
6	Water Outflow	D	B	1. Water out flow distributed through multiple channels and groundwater.	1. Observation, photos
7	Geo-morphology	D	B	1. Breached dams repaired and functional. 2. Beavers present and actively maintaining dams. 3. Soil profiles indicate hydric soil throughout historic wetland area. 4. Boreas Creek channel is no longer enlarging or becoming further incised	1. Observation, photos. 2. Observation, photos, wildlife cameras. 3. Soil profiles 4. Channel surveys.
8	Chemical Environment	D	B	1. Restoration of the characteristic soil redox environment via reestablishment of the natural saturation regime. 2. Maintain existing water quality	1. Observation, photos, redox monitoring at test sites 2. Evaluate ongoing WQ monitoring
9	Vegetation Structure and Complexity	C	B	Wetland vegetation is present throughout historic wetland area. Vegetation composition and structure is similar to unimpacted reference condition.	Observation, photos, sampling Vegetation plots at test sites, weed surveys, ongoing vegetation monitoring

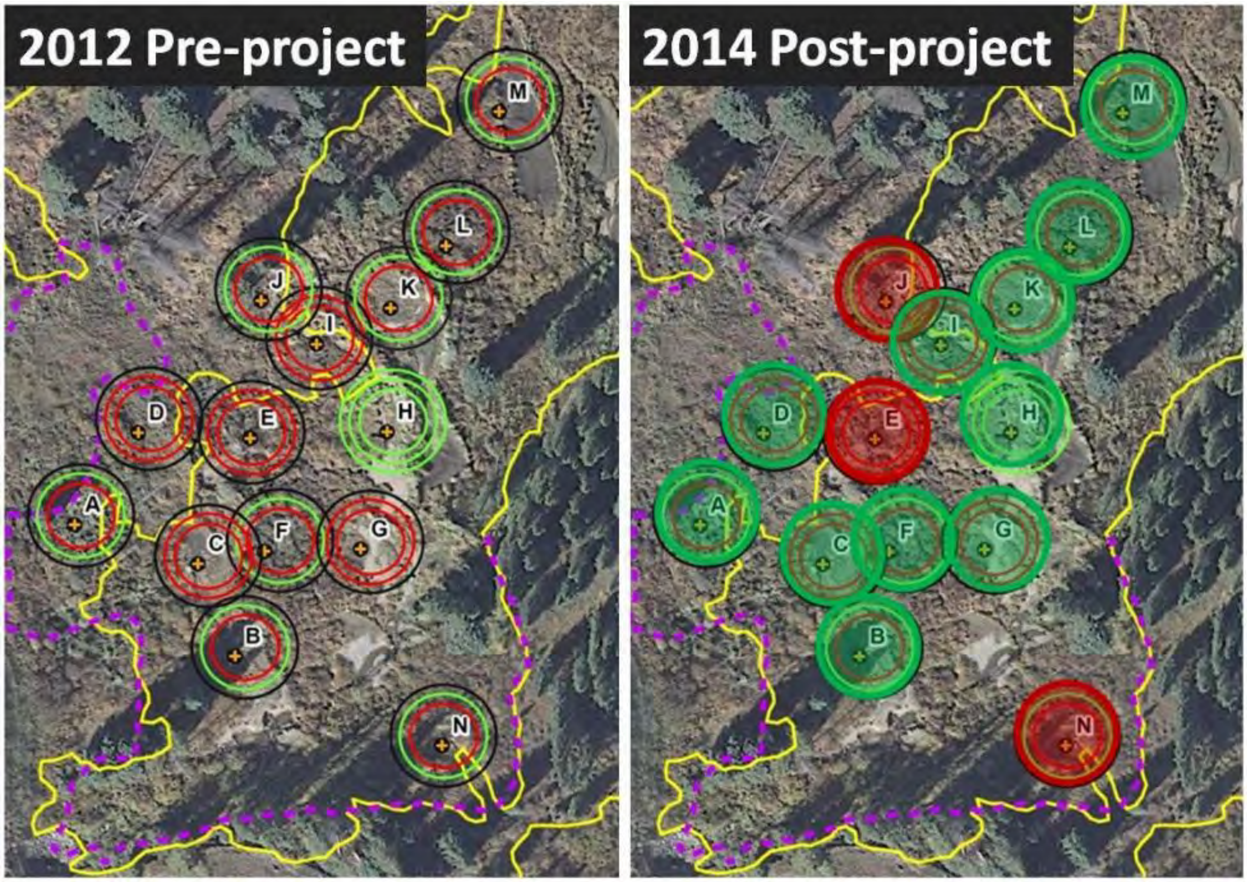


Figure 70: An array of 14 test points were set up across the project area to track wetland conditions. Each point is equipped with a data-logging groundwater monitoring well, soil redox probes, and vegetation plots. The left photo shows results for the pre-project condition. The concentric circles at each test site indicate wetlands status based on hydrology (inner circle), vegetation (middle circle), and soils (outer circle). Green indicates the presence of a wetland indicator, red indicates the absence of a wetland indicator, and grey indicates the presence of relict hydric soils. The right photo shows post-project condition in 2014. Sites shaded green are positive for all three wetland indicators, those shaded in red are still lacking hydrology. The lines are delineations that reflect estimated wetland extent for 2007 (pink) and 2009 (yellow).

The reduced wetland condition prior to restoration is reflected in hydrology and soil redox data. Only one of the test points was positive for wetland hydrology and anaerobic soil chemistry in 2012, though relict hydric soil indicators were still present on all sites (indicating a recently dried wetland soil) and hydric vegetation prevalence indices were still positive on all but three sites (Table 9). This pattern is indicative of a recently dried wetland since it is common for hydric soil indicators to persist for years after a wetland is dried and for persistent species of hydric vegetation to "hang on" for several years after drying. The pattern also indicates an ideal wetland restoration scenario, since neither soils nor vegetation had been seriously impaired yet.

Post project hydrology, vegetation, and soil chemistry monitoring documented an immediate recovery of wetland conditions across most of the site (Figure 70 and Table2. Pond and channel mapping indicates a recovery of most of these native aquatic features (Figure 71).

Table 9: Three tables summarizing critical wetland parameters. Sites shaded green or blue had positive wetland indicators (green are terrestrial wetland and blue are ponds). Sites that are negative for wetland indicators are shown in red. The upper table shows results for hydrology monitoring. THD stands for Total Hydric Days and CHD stands for Consecutive Hydric days, where a hydric day is defined as one in which the mean static water table is less than 1.0 ft deep. Only one point had positive wetland hydrology prior to restoration in 2012, but 2 years after treatment all but three points were positive. The lower left table shows similar results for soil chemistry, using reduction potential as an indicator of anaerobic conditions. The lower right table shows results for wetland vegetation monitoring. A prevalence index less of 3.00 or less is considered wetland vegetation.

Site	2012 THD	2012 CHD	2012 Wetland hydrology (by hydrograph)	2013 THD	2013 CHD	2013 Wetland hydrology (by hydrograph)	2014 THD	2014 CHD	2014 Wetland hydrology (by hydrograph)
A	0	0	Negative	99	98	Positive	106	105	Positive
B	0	0	Negative	150	150	Positive	140	140	Positive
C	0	0	Negative	150	150	Positive	140	140	Positive
D	0	0	Negative	150	150	Positive	140	140	Positive
E	0	0	Negative	45	45	Positive	0	0	Negative
F	0	0	Negative	N/A	N/A	Negative	62	47	Positive
G	2.5	2	Negative	150	150	Positive	140	140	Positive
H	N/A	N/A	Positive	150	150	Positive	140	140	Positive
I	0	0	Negative	150	150	Positive	140	140	Positive
J	0	0	Negative	0	0	Negative	0	0	Negative
K	N/A	N/A	Negative	150	150	Positive	140	140	Positive
L	0	0	Negative	150	150	Positive	140	140	Positive
M	5.5	2	Negative	150	150	Positive	140	140	Positive
N	0	0	Negative	0	0	Negative	0	0	Negative

Site	Redox patterns indicative of anaerobic soil chemistry		
	2012	2013	2014
A	negative	positive	positive
B	negative	pond	pond
C	negative	pond	pond
D	negative	pond	pond
E	negative	negative	negative
F	negative	negative	positive
G	negative	positive	pond
H	positive	pond	pond
I	negative	pond	pond
J	negative	negative	negative
K	negative	positive	pond
L	negative	positive	positive
M	negative	positive	positive
N	negative	negative	negative

Site	Prevalence Index	
	2012 (pre)	2014 (post)
A	2.17	1.90
B	2.65	pond
C	3.03	pond
D	3.00	pond
E	1.81	1.39
F	1.46	1.26
G	3.22	pond
H	1.67	pond
I	3.17	pond
J	2.89	2.49
K	2.61	pond
L	2.85	2.18
M	2.15	1.84
N	2.40	0.93

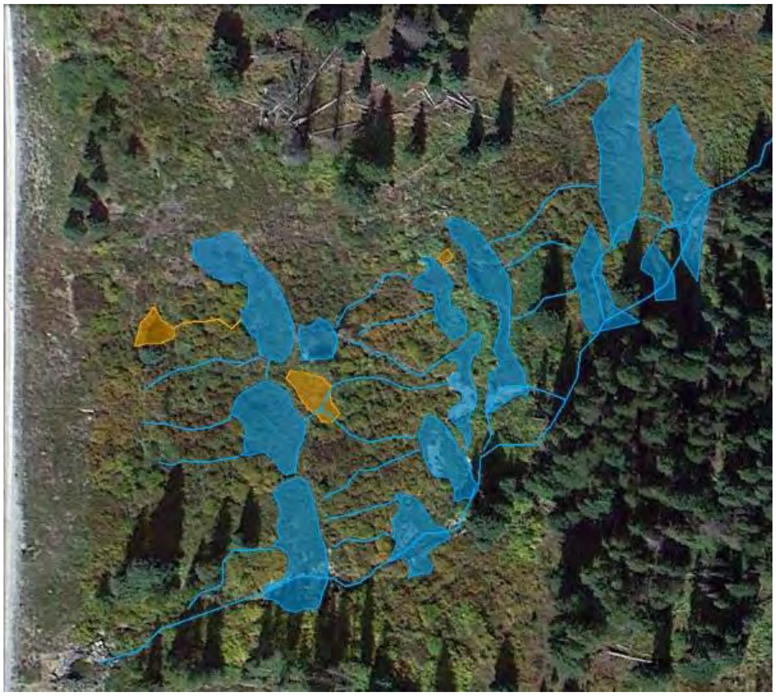


Figure 71: Condition of ponds and channels in 2014. Most of the native ponds and channels are now active

While these results are encouraging, the initial positive response is more a direct effect of the mechanical treatments than an effect brought about by beaver. Wetland restoration success over the long term, however, depends on the recovery of a viable and active beaver population. At this point, the prognosis looks good. The one transplanted beaver was joined by several other "voluntary" beaver immigrants in 2013. In 2014, we observed two separate beaver families on the site including several new kits (Figure 72). All but two of the dams in the project area were actively maintained by beavers through 2014. These results suggest that habitat conditions are once again suitable for beaver, and we are optimistic that they will remain here and continue to expand.

Figure 72: This pair of beaver kits was captured by a motion-trigger camera near lodge in the project area in 2014, confirming suspicions that the beaver colonies on site were reproducing

In 2014, beavers had not yet constructed dams on the remaining incised segments of Boreas Creek, but signs of dam building were observed on the channel in spring of 2015. If beavers do not voluntarily build dams on this segment in 2015, we may consider constructing several additional BDAs to speed the recovery of the incised channel.

Photos

Photo documentation is perhaps the most powerful monitoring tool for showing the habitat conversion from dry upland to a functioning beaver-mediated wetland complex at the Cucumber Gulch Preserve. Taking photos from specific locations several times per year is a good way to track progress via time-lapse. Several time lapse photo series are provided here as an example (Figures 73-76).

Figure 73: The left photo shows a repaired beaver dam and pond just after construction in 2012 with a single "spillway." Beaver dammed the spillway in 2013 and continued to raise the height of the dam in 2014 (right photo).

Figure 74: Sediment-filled ponds prior to treatment in 2012 (upper photo) and after they were treated and occupied by beavers in 2014 (lower photo). Ongoing maintenance will be required to capture incoming sediment at the head of the wetland to prevent ponds filling in the future.

Figure 75: This series of photos shows a time lapse of one restored pond The small green "island" is a beaver lodge. Starting at the top, the photos are from (a) 2011 before the dam breached (note that the sediment plume extends to the lodge attaching it to the shoreline), (b) 2012 as the dam began breaching but before the channel incised, (c) 2013 after treatment but before beavers returned, and (d) 2014 after beavers returned. The returning beavers reoccupied the old lodge.

Figure 76: This series of photos shows a time lapse overview of a portion of the project area. Starting at the top, the photos are from (a) 2012 before the project, (b) 2013 after construction but before beavers arrived, (c) spring 2014 during runoff, and (d) summer 2014 after beavers significantly raised the height of dams.

(7) Myers Creek, Washington Habitat Restoration Project

Okanogan Highlands Alliance (OHA), David Kliegman, Executive Director; Julie Ashmore, Conservation Coordinator

Location

Myers Creek, situated in Northeast Okanogan County in northern Washington State, near the Canadian Border.

Restoration Goals

- Improve stream habitat
- Increase instream sediment retention to cause aggradation of the streambed over time
- Incrementally raise the water table through placement of LWD and BDAs that have the ability to adjust and adapt to dynamic stream conditions, and encourage natural habitat-forming processes
- Raise the local water table to facilitate the growth of native vegetation on the historical floodplain, providing resources to encourage beavers to recolonize the area and further modify and maintain the site
- Ultimately, re-establish a thriving, dispersing beaver colony onsite

Figure 77: Myers Creek restoration site showing locations of LWD and BDA placement

The Myers Creek Restoration site is owned by Kinross/Crown Resources, a gold mining company, and is a mitigation site for wetland impacts on Buckhorn Mountain. Traditionally, this area supported freshwater emergent wetland and freshwater forested/shrub wetland. Numerous Washington Department of Fish and Wildlife priority species have all been confirmed onsite, including rainbow trout, Columbia spotted frog and great blue heron. Prior to restoration activities, historic aerials indicate that LW was intentionally removed to facilitate grazing, which resulted in the loss of native riparian plant communities. Invasive Reed canarygrass began to dominate the riparian vegetation. Removal of beaver, combined with the loss of adequate food and construction resources, have substantially reduced the ability of the site to support dam-building beaver.

Project implementation began in September of 2014, with the installation of the LW and BDAs to initiate habitat-forming processes. The BDAs were placed using three primary criteria: 1) locations downstream of areas producing high sediment loads from rapid bank erosion that would capture the most sediment; 2) where naturally occurring wood and debris piles had formed; and 3) where the structure would facilitate flooding onto a mid-level terrace that developed within the incision trench in certain parts of the reach. Large wood with root wads attached were placed at numerous locations within the channel, including BDAs (Figure 78), and BDAs were placed at five locations along the reach (Figure 77). The BDAs consisted of pilings sharpened at one end and driven four feet into the channel substrate with a pneumatic post driver. Almost all of the BDAs were channel spanning, with some extending up onto the bank (Figure 78). Only BDAs placed at naturally occurring debris piles were partially channel spanning (Figure 79). Pilings were woven with live red osier dogwood to encourage resprouting after placement. Some of the horizontal, woven red osier dogwood was planted directly into the side of the bank, especially at undercuts, to encourage growth and provide increased resistance of the bank (Figure 80). Other red osier clumps were planted vertically into the bank near the BDAs. Cobbles and grass were added to the upstream base of some of the structures to prevent scour, and brush mattresses were added to the downstream side of some BDAs to prevent development of a downstream scour pool, mimicking features found in natural beaver dams.

Figure 78: BDA—Two pilings extending onto the bank with LWD placed through the structure

Figure 79: Partially channel spanning BDAs and LWD additions to a naturally occurring log and debris jam

Figure 80: Pilings woven with live red oiser dogwood, some of which was planted directly into the exposed bank to facilitate resprouting

Following installation, the BDAs immediately collected small wood and impounded water (see Figures 81 and 82). Two weeks after installation, water depth behind some of the structures had increased by up to 8 inches, completely submerging some of the LW. Six months later, some of the pilings were completely submerged, with the water level being much higher, and the wetted width continuing to increase. One of the BDAs, located in a narrow incision trench, developed a side cut from bank scour (Figure 83). This structure is still partially functioning in terms of water and sediment impoundment, and facilitating the widening of the incision trench at this location by directing the flow of water around the structure, increasing sheer stress on the bank and causing lateral migration of the channel. This structure is not deemed a failure by the project team as it is adding complexity and habitat to the channel in the form of slow water habitat and development of an inset floodplain directly downstream. Before the next construction season, this structure will be reassessed, and adaptive management may be implemented to extend the post line and weave to fill the gap, wrapping it up the bank 5 to 10 feet. Additional BDAs may be installed downstream to help capture the sediment resources being released as the channel widens.

This project integrates adaptive management in order to facilitate natural habitat forming processes, has been deemed successful, and is being used as a pilot project for a larger restoration site upstream on Myers Creek, utilizing BDAs on a bigger scale. Monitoring will continue to evaluate the project and adaptive management will provide opportunities for community involvement, and eventually allow for beaver recolonization. The site will be placed under a perpetual conservation easement.

Figure 81: Before installation of a BDA and placement of LWD (see figure 82)

Figure 82: 12 days following installation of a BDA (same location as figure 81) and placement of LWD and other debris showing water pooling upstream

Figure 83: Breach of BDA 1 showing water flowing around the structure, eroding the left bank. This BDA is still functioning as grade control through water impoundment upstream as well as facilitating the widening of the incision trench. Notice the development of an inset flood plain directly downstream along the right bank

(8) Hansen Creek, Washington Floodplain Restoration Project

Skagit County and Upper Skagit Tribe, Lauren Rich

Location

Northern State Recreation Area Park on Hansen Creek, tributary to the Skagit River, in northwest Washington State.

Restoration Goals

- Reconnect 140 acres of alluvial fan, floodplain, and riverine wetlands to Hansen Creek
- Reduce flooding for downstream agricultural areas
- Increase complexity and habitat, especially for anadromous fish populations
- Increase native vegetation and reduce invasive vegetation (i.e. reed canary grass) below 15% total cover
- Increase amount of large wood on site
- Construct set-back levees to protect upland areas from flooding
- Increase ground and surface water levels
- Decrease stream temperatures
- Eliminate need for dredging through reductions in sediment loads
- Allow for beaver recolonization following construction completion

This project restored 140 acres and 17,000 lineal feet of stream, riparian, and floodplain habitat within the 726 acre recreation park. Most of the reed canary grass, which dominated the site (see Figure 84), was removed (Figure 85), side channels were excavated, 270 large wood structures were installed, and 90,500 trees, shrubs, live stakes, and wetland emergent plugs were planted. While the project design targeted restoration of salmon habitat, beavers were present in the vicinity prior to project implementation and the design was created with the assumption that they might return, colonize, and modify the site after construction was completed. The revegetation plan included a diverse array of native plant species including several species palatable to beavers. Though the project elements were designed specifically for salmon, the colonization by beavers is synergistically supporting salmon habitat.

This site is well-suited to accommodate beaver colonization and modification due to its very large size and owner (Skagit County) that desire a return to natural floodplain function. Adjacent infrastructure and private land is protected from flooding by set-back levees and dikes, allowing for the construction and expansion of beaver dams and their subsequent impoundment of water. Construction on the site was largely completed by 2009. In August of 2013, beavers started constructing dams and a lodge in the riverine wetland habitat, which they have since greatly expanded (>600 lineal feet of dams providing 11 acres of summer low-flow inundated area)(Figure 86). This beaver activity has increased summer low flow wetted area and increased pool habitat in the wetland area, improving rearing habitat for coho salmon and steelhead trout and improving stream/groundwater interactions. This project also provides an educational opportunity because the park land allows numerous visitors easy access due to the construction of an additional 1.5 miles of trail traversing through the restoration site.

Figure 84: Photo taken on 06/30/2009 of the restoration site pre-project initiation showing invasive reed canarygrass as the dominant vegetation present

Figure 85: Photo of the restoration site during construction after removal of invasive reed canarygrass

Figure 86: Photo taken on 06/04/2013 of the site four years following completion of construction. Beavers built a lodge in the restored wetland and numerous dams, which they continue to add to and maintain

(9) Beaver Reintroduction on Private Property, New Mexico

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PO Box 31698
Santa Fe NM 87594
www.seventh-generation.org

Project Partners

The landowners, USFWS Partners for Fish and Wildlife , Integral Ecology, The Biophilia Foundation, Patagonia, Inc., The Norcross Wildlife Foundation, New Mexico Department of Game and Fish, ESRI Conservation Program, Individual donors and volunteers

Location

Eastern New Mexico, Private Ranch, on a perennial, but spatially intermittent stream.

Restoration Goals and Objectives

Improve riparian function and resilience (restoration [repairing the past] and climate change adaptation [preparing for the future]: specifically,

- downcutting will not exceed current levels
- existing incision and the water table will be elevated at least until the stream can reconnect to the original floodplain and over bank flooding occurs
- Double the width of riparian area vegetation, double the quantity and complexity (multi-storied) of riparian and buffer zone vegetation , use the project as a model project to demonstrate the effectiveness of beaver, specifically, the compatibility of beavers and ranching
- Double the productivity of forage within the area
- increase the amount of water held on the site in the stream system
- communicate successes/results to other ranchers.
- hold workshops, provide other outreach events, publish, and present

Site Description

The stream is located in eastern New Mexico on a very large, working family ranch. Surrounded by steep banks with rocky substrate, the stream is located in a high, arid desert region with short grass prairie habitat. The water regime is highly variable, fluctuating between drought and severe flash flooding due to summer monsoons. Flow is perennial with spatially intermittent reaches. In the early 1900's, the stream was straightened by the previous generation of owners. Following intense rainfall and flooding events in the 1940's, the stream started actively incising. Currently, incision in some reaches is up to 25 feet resulting in very high stream power during high flow events, degraded riparian zones, and disconnection from the floodplains with no overbank flooding in most reaches. Large wood or any other impoundments are lacking in the stream channel. No beavers have been present on this stretch of river or the surrounding areas up and downstream for decades. The site has been fairly heavily grazed in the past. The current generation of owners, which is deeply committed to restoring land and stream health, is utilizing holistic grazing practices by controlling the timing and intensity of grazing of certain areas with exclusion fencing. Riparian vegetation is primarily cottonwood and sedges with lesser amounts of willow. Salt cedar and Russian olive had been removed prior to initiation of project activities.

Seventh-Generation is a non-profit organization based out of Santa Fe, New Mexico. They are using adaptive management techniques to reintroduce beaver to this stretch of stream in eastern New Mexico located on a private ranch. The project started 3-4 years ago and has involved terrific collaboration with the ranch family from the outset including huge amounts of labor, ideas, and funds. Beaver dam analogues were placed in several places to encourage upstream pooling and ponding, and sediment deposition. The BDAs consist of reused juniper fence posts, driven into the streambed to resist high-flow events that would typically blow out natural beaver dams. Cut cottonwood saplings were placed in between the posts parallel to the stream flow with cut stems facing upstream, and additional cottonwood saplings were interwoven between the posts perpendicular to stream flow and tamped down to tighten up all the branches. This design was copied from the first edition of the Salmonid Habitat Restoration written in 1991 by Gary Flosi and Forrest Reynolds. Due to severe flash floods, downstream scour behind the beaver dams was a concern. The saplings placed parallel to the flow with cut ends upstream and small branching down steam directly on the stream bed was intended to act as a "brushwood mattress" that would be more resilient to scour underneath the dam (Figure 87). This mimics features found in natural beaver dams that reduce the development of downstream scour pools. Since installation, the starter dams have survived major flooding events and accumulated substantial amounts of sediment.

Figure 87: BDA interwoven with cottonwood branches parallel and perpendicular to the stream flow. The perpendicular, downstream (left to right) branches are placed to limit the development of a downstream scour pool during high-flow events, which could compromise the integrity of the structure. Photo courtesy of Seventh-Generation Institute.

Four beavers were translocated and reintroduced to the stream (Figure 88), two of which were fitted with tail mounted radio transmitters by a veterinarian (protocol followed Arjo et al. 2008). Temporary lodges were provided at one release site (Figure 89) to provide cover after release, which can reduce stress, the risk of predation and the probability of beaver leaving the release site. The four beavers, two males and two females, one pair of which were siblings, were released in a site with an existing pond, robust cottonwood and willow trees along the shoreline, and installed BDAs. All but one beaver (a female) left the release area, presumably moving downstream. The female was using a bank burrow at the release site. One male has moved downstream to an area with much less standing water and riparian vegetation. He unsuccessfully attempted to build a dam while living in a bank burrow. All radio transmitters failed, but beaver are still being tracked by sign. Risk of predation by mountain lion and coyote in the area is very high and, unfortunately, only one beaver is currently believed to have survived. To date, there has been no attempt by the reintroduced beaver to add or maintain any of the faux dams. Food supplementation was provided during the winter months and consisted of cottonwood saplings placed on the shoreline. Beaver readily took advantage of this resource presumably adding to a food cache in the pond. Exclusion fencing was placed around large cottonwoods to prevent herbivory by beaver ensuring that a significant amount of overstory remained for wildlife.

Figure 88: Beaver release site with deep-water habitat provided by placement of BDA (out of photo). Notice the pile of cottonwood branches placed on the bank to provide food resources to the reintroduced beavers and encourage them to remain at the release site. Photo courtesy of Seventh-Generation Institute.

Figure 89: Release of beaver into a temporary lodge placed on the bank of the stream. Photo courtesy of The Seventh-Generation Institute.

This is a great example of utilizing several techniques offered in this guidebook: utilization of BDAs (called faux dams in this project), temporary lodges during reintroductions, exclusion fencing to protect vegetation from herbivory of both beaver and ungulates, and the reintroduction of beaver. Highly incised streams often prevent beaver from being able to build long-lasting dams (at least two years) or provide enough resources in the form of developed riparian and/or floodplain plant communities. Using BDAs to create ponds and deep water habitat, and initiate natural habitat-forming processes may increase the probability that the reintroduced beaver will stay at the release site, survive, and eventually start building and maintaining dams.

Lessons Learned to Date

This project truly illustrates the contribution of luck and timing in restoration outcomes, at least as much as specific methods. This project encountered numerous challenges, including a drought of the most severe category, "exceptional," almost immediately after initiation of the project activities. This was punctuated with record breaking convective precipitation that produced severe flash flooding. This combination reduced the statewide supply of beavers available to translocate, reduced food supplies for beaver, increased predation pressure, and forced the land owners to divert time to unexpected tasks. In addition, project partners encountered significant health and family issues during this project, including the death of one of the land owners. This too, profoundly affected the project activities.

These climate conditions are a repeat of the historic conditions found in this area during the Dust Bowl, or alternatively may be viewed as conditions expected under an altered climate several decades hence. While the project was designed to help protect against altered climate, arrival of such severe conditions decades earlier than expected has not allowed the project to gain a foot hold. Although the drought has eased slightly, the area remains in drought after approximately 5 years. Statewide beaver populations are starting to recover, as is vegetation. Conditions over the next few years will continue to influence outcomes. This illustrates how narrow the resilience building window of time is in the Southwest.

This project also illustrates some of the obstacles found in restoration work, where textbook-based project selection criteria never quite jive with reality. Not all land, water flows, or other conditions are under control of the partners. Pros and cons of a project must be carefully weighed - is this project worth investing time, effort and funds?

Project partners knew that this project would be very challenging, even before the severe drought conditions arrived. A few specific factors that contributed to the challenge were: 1) the remoteness of the site, which made labor and materials more scarce and expensive; 2) lack of control over conditions of the upper watershed, which is also private land, but believed to be in poor condition, resulting in large runoff events; 3) location of the project on private land, with a limited supply of funders willing to fund projects that benefit private lands; 4) high potential predation rates on translocated beaver, from a very healthy population of coyotes, mountain lions and others. In sum, none of the project partners were clear that the project would be a "success" if success were defined as immediate or short term completion of all activities and results.

In contrast, the large scale of the site, support of the land owners and specifically, their willingness to experiment with various techniques, enabled us to push the “beaver-assisted restoration envelope” on this project and try to discover if beaver and BDAs could, over longer periods of time and under extreme conditions, still restore important processes to this stream system and build resilience. The decision was made to try, and at a minimum, learn some lessons.

Translocation techniques, tree wrapping, riparian fencing, grazing management changes, supplemental feeding and monitoring have all worked well. Attachment of radio transmitters was successful to the extent that no animals were ill or lost in the attachment procedure. The failure of the radio transmitters to perform over long periods of time in the field was not unexpected, but still a disappointment.

All project partners were very pleased with the performance of the initial set of BDAs. They withstood very large flows – estimated at 50-75 feet wide, 6-8 feet high - without scouring. However, the intensity of the flash flooding meant that the BDAs filled with sediment much faster than anticipated – one flash flood completely filled the dams with sediment. This is a positive outcome overall, in the sense that they served the restoration goals. But the beaver never had a chance to use them. Ideally, crews would have rapidly built additional BDAs. But at this point, funding was exhausted, “crews” were not available due to labor shortages in the area, and several project partners were coping with the family and health issues mentioned previously. Additional project activities have had to be postponed. In sum, the jury is still out on the eventual restoration results of this project. Unquestionably, the goal of learning has been and will continue to be met.

Next Steps

Drought and other conditions are being monitored in hopes of an improved restoration window. Next steps in the project will be to significantly expand the project area and the scope of all project activities, with the expectation that an expanded scope will push the project area over a tipping point and initiate a new positive feedback cycle.

Section III – Additional Information and Resources

Beaver Resources

The following websites provided useful information regarding beaver, with the first two sources mentioned being particularly notable for their wealth of information:

- Worth a Dam
  http://www.MartinezBeavers.org
  Contact: Heidi Perryman

- Beavers: Wetlands and Wildlife
  http://www.beaversww.org
  Contact: Sharon Brown

- Beaver Solutions
  http://www.beaversolutions.com
  Contact: Mike Callahan

- Animal Protection of New Mexico
  http://www.apnm.org/campaigns/beavers/

- Washington Department of Fish and Wildlife 2012 Stream Habitat Restoration Guidelines and general information on living with beaver
  http://wdfw.wa.gov/publications/01374/
  http://wdfw.wa.gov/living/beavers.html

- The Occidental Arts and Ecology Center WATER Institute
  http://www.oaec.org/beaver
  Contact: Kate Lundquist and Brock Dolman

- The Seventh Generation Institute
  http://www.seventh-generation.org/
  Contact: Cathryn Wild

- King County
  http://www.kingcounty.gov/environment/animalsAndPlants/beavers.aspx

- The Beaver Solution
  http://www.landscouncil.org/beaversolution/
  Contact: Joe Cannon

- The Grand Canyon Trust
  http://www.grandcanyontrust.org/
  Contact: Mary O'Brien

Many others deserve recognition as well, but the listed organizations and websites are good starting places that contain numerous links to myriad beaver-related resources, news, trivia, entertainment, people, and information.

For those who would like to read some classic books on the beaver, we can recommend several:

- *The American Beaver and His Works*, by Lewis Henry Morgan (1868)
- *In Beaver World*, by Enos Mills (1913)
- *Three Against the Wilderness, by Eric Collier (1959)*
- *Beaversprite: My Years Building an Animal Sanctuary*, by Dorothy Richards (1984)
- *Lily Pond: Four Years With A Family of Beavers*, by Hope Ryden (1989)
- *The Beaver: Natural History of a Wetlands Engineer*, by Dietland Müller-Schwarze and Lixing Sun (2003; updated 2011)

Acronyms and Abbreviations

BDAs	beaver dam analogues
BLM	Bureau of Land Management
BMPs	best management practices
DBH	diameter at breast height
ESA	Endangered Species Act
GIS	geographical information system
GNIS	Geographic Names Information Systems
ID	identification number
ITIS	Integrated Taxonomic Information System
IUCN	International Union for the Conservation of Nature
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Department of Fish and Wildlife
PIT	Passive Integrated Transponder
PLWW	post lines with wicker weaves
PPE	personal protective equipment
PVC	polyvinyl chloride
RCW	Revised Code of Washington
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
μg/l	micrograms per liter

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Appendix A. Plant Species Eaten by North American Beaver

Species of Woody, Herbaceous, and Common Foods Known to Be Eaten by Beaver

Woody Species

Common Name	Species	Location	Source
loblolly pine	*Pinus taeda*	SE USA	1
sweet gum	*Liquidambar styraciflua*	SE USA	1
southern sweetbay	*Magnolia virginiana*	SE USA	1
spruce pine	*Pinus glabra*	SE USA	1
willow	*Salix species*	NE USA	1
maple	*Acer species*	NE USA	1
oak	*Quercus species*	NE USA	1
alder	*Alnus species*	NE USA	1
gray birch	*Betula populifolia*	NE USA	1
white pine	*Pinus strobus*	NE USA	1
quaking aspen	*Populus tremuloides*	NE USA	1
willow	*Salix species*	Western USA	1
cottonwood	*Populous Species*	Western USA	1
trembling aspen	*Populus tremuloides*	Western USA	1
ash	*Fraxinus Species*	Western USA	1
choke cherry	*Prunus virginiana*	Western USA	1
bog birch	*betula glandulosa*	Western USA	1
mountain alder	*Alnus incana*	Western USA	1

chaparral	*Various species*	Western USA	1
currants	*Ribes species*	Western USA	1
silverberry	*Elaeagnus commatata*	Western USA	1
russet buffaloberry	*Shepherdia Canadensis*	Western USA	1
lodgepole pine	*Pinus contorta*	Western USA	1
white fir	*Abies concolor*	Western USA	1
blue spruce	*Pinus pungens*	Western USA	1
black hawthorn	*Crataegus douglasii*	Western USA	1
willow	*Salix species*	New York	2
apple	*Pyrus malus*	New York	2
juneberry or shadbush	*Amelanchier species*	New York	2
black cherry	*Prunus serotina*	New York	2
quaking aspen	*Populus tremuloides*	New York	2
American beech	*Fagus grandifolia*	New York	2
musclewood	*Carpinus caroliniana*	New York	2
hop hornbeam	*Ostrya virginiana*	New York	2
sugar maple	*Acer saccharum*	New York	2
red pine	*Pinus resinosa*	New York	2
Eastern hemlock	*Tsuga canadensis*	New York	2
yellow birch	*Betula alleghaniensis*	New York	2
Norway spruce	*Picea abies*	New York	2
red maple	*Pinus sylvestris*	New York	2
ash	*Fraxinus Species*	New York	2
maple	*Acer species*	New York	2
witch-hazel	*Hamamelis virginiana*	New York	2

hawthorn	*Crataegus species*	New York	2
white pine	*Pinus strobus*	New York	2
willow	*Salix species*	Oregon	3
red alder	*Alnus rubrus*	Oregon	3
vine maple	*Acer circinatum*	Oregon	3
cottonwood	*Populus species*	Oregon	3
salmon berry	*Rubus spectabilis*	Oregon	3
big-leaf maple	*Acer macrophylum*	Oregon	3
sitka spruce	*Picea sitchensis*	Oregon	3
western hemlock	*Tsuga heterophylla*	Oregon	3
elderberry	*Sambucus species*	Oregon	3
thimbleberry	*Rubus parviflorus*	Oregon	3
salal	*Gaultheria shallon*	Oregon	3
western red cedar	*Thuja plicata*	Oregon	3
Douglas fir	*Pseudotsuga menziesii*	Oregon	3
willow	*Salix species*	NW Terr., CA	4
poplar	*Polulus balsamifera*	NW Terr., CA	4
alder	*Alnus crispa*	NW Terr., CA	4
white Oak	*Quercus alba*	Massachusetts	5
northern red oak	*Quercus rubra*	Massachusetts	5
black oak	*Quercus velutina*	Massachusetts	5
grey birch	*Betula populifolia*	Massachusetts	5
yellow birch	*Betula lutea*	Massachusetts	5
eastern white pine	*Pinus strobus*	Massachusetts	5
red pine	*Pinus resinosa*	Massachusetts	5

red maple	*Acer rubrum*	Massachusetts	5
sugar maple	*Acer saccharum*	Massachusetts	5
whitch hazel	*Hamamelis virginiana*	Massachusetts	5
iron wood	*Carpinus caroliniana*	Massachusetts	5
black cherry	*Prunus serotina*	Massachusetts	5
eastern hemlock	*Tsuga canadensis*	Massachusetts	5
holly	*Ilex species*	Massachusetts	5
blueberry	*Vaccinium corymbosum*	Massachusetts	5
white ash	*Fraxinus americana*	Massachusetts	5
hawthorn	*Crataegus Species*	Massachusetts	5
hornbeam	*Ostrya virginiana*	Massachusetts	5
american chestnut	*Castanea dentata*	Massachusetts	5
spruce	*Picea species*	Massachusetts	5
red maple	*Acer rubrum*	Michigan	6
sugar maple	*Acer saccharum*	Michigan	6
mountain maple	*Acer spicatum*	Michigan	6
speckled Alder	*Alnus rugosa*	Michigan	6
yellow birch	*Betula alleghaniensis*	Michigan	6
paper birch	*Betula papyrifera*	Michigan	6
red osier dogwood	*Cornus stolonifera*	Michigan	6
beaked hazel	*Corylus cornuta*	Michigan	6
american mountain ash	*Sorbus americana*	Michigan	6
eastern cottonwood	*Populus deltoides*	Texas	7
bur oak	*Quercus macrocarpa*	Texas	7

mulberry	*Moru Alba*	Texas	7
mexican buckeye	*Ungnadia speciosa*	Texas	7
buttonbush	*Cephalanthus occidentalis*	Texas	7
dogwood	*Cornus species*	Texas	7
texas ash	*Fraxinus texensis*	Texas	7
red buckeye	*Aesculus pavia*	Texas	7
bald cypress	*Taxodium distichum*	Texas	7
boxelder	*Acer negundo*	Texas	7
hackberry	*Celtis species*	Texas	7
pecan	*Carya illinoinensis*	Texas	7
cedar elm	*Ulmus crassifolia*	Texas	7
chinaberry	*melia azedarach*	Texas	7
privet	*Ligustrum vulgare*	Texas	7
black willow	*Salix nigra*	Texas	7
sycamore	*Plantanus occidentalis*	Texas	7
american elm	*Ulmus americana*	Texas	7

Herbaceous Species

Common Name	Species	Location	Source
rice cutgrass	*Leersia oryzoides*	SE USA	8
golden club	*Orontium aquaticum*	SE USA	8
switchgrass	*Arundinaria tecta*	SE USA	8
poison ivy	*Toxicodendron radicans*	SE USA	8
pondweed	*Potamogeton species*	SE USA	8
grasses	*Gramineae*	NE USA	8

queen-of-the-meadow	*Filipendula ulmaria*	NE USA	8
evergreen Christmas fern	*Polystichum acrostichoides*	NE USA	8
field fern	*?*	NE USA	8
sedge	*Carex*	NE USA	8
waterweed	*Elodea species*	NE USA	8
white water lily	*Nymphaea adorata*	NE USA	8
yellow pond lilly	*Nuphar advena*	NE USA	8
water-shield	*Brasenia schreberi*	NE USA	8
water arum	*calla palustris*	NE USA	8
sedges	*Carex Species*	Western USA	8
grasses	*Graminae*	Western USA	8
mountain pond lilies	*Nuphar polysepalum*	Western USA	8
horsetail	*Equisetum species*	Western USA	8
cattail	*Typha species*	Western USA	8
Bur-reed	*Sparganium americanum*	Georgia	9
lizard's tail	*Saururus cemuus*	Georgia	9
marsh seedbox	*Ludwigia palustris*	Georgia	9
smartweed	*Polygonum densiflorum*	Georgia	9
milfoil	*Myriophyllum aquaticum*	Georgia	9
water lily	*Nuphar variegatum*	NW Terr., CA	4

Cultivated or manufactured Foods

Common Name	Species	Location	Source
commercial rodent pellets	*n/a*	Washington	10
apples	*Malus species*	Washington	10
alfalfa	*Medicago sativa*	Washington	10
acorns	*Quercus species*	NE USA	1
corn	*Zea mays*	New York	2
soybean	*Glycine max*	SE USA	8

Sources:

1 = Novak (1999)

2 = Müller-Schwarze (2011)

3 = Bruner (1989)

4 = Aleksiuk (1970)

5 = Jenkins (1979)

6 = Belovsky (1984)

7 = Baccus et al. (2007)

8 = Novak (1999)

9 = Parker et al. 2007

10 = Kent Woodruff, Methow Valley Beaver Project, personal communication

For more information on beaver eating habits see "*What do Beaver Eat?*", a literature review prepared for the Grand Canyon Trust (Henker 2009).

Appendix B. Subspecies of *C. canadensis* Considered “Invalid” by ITIS

All Subspecies of the North American Beaver are Recognized as "Invalid" by the Integrated Taxonomic Information System (ITIS.gov)

Castor canadensis Kuhl, 1820 – valid – American Beaver

Castor canadensis acadicus Bailey and Doutt, 1942 – invalid

Castor canadensis baileyi Nelson, 1927 – invalid

Castor canadensis belugae Taylor, 1916 – invalid

Castor canadensis caecator Bangs, 1913 – invalid

Castor canadensis canadensis Kuhl, 1820 – invalid

Castor canadensis carolinensis Rhoads, 1898 – invalid

Castor canadensis concisor Warren and Hall, 1939 – invalid

Castor canadensis duchesnei Durrant and Crane, 1948 – invalid

Castor canadensis frondator Mearns, 1897 – invalid

Castor canadensis idoneus Jewett and Hall, 1940 – invalid

Castor canadensis labradorensis Bailey and Doutt, 1942 – invalid

Castor canadensis leucodontus Gray, 1869 – invalid

Castor canadensis mexicanus Bailey, 1913 – invalid

Castor canadensis michiganensis Bailey, 1913 – invalid

Castor canadensis missouriensis Bailey, 1919 – invalid

Castor canadensis pallidus Durrant and Crane, 1948 – invalid

Castor canadensis phaeus Heller, 1909 – invalid

Castor canadensis repentinus Goldman, 1932 – invalid

Castor canadensis rostralis Durrant and Crane, 1948 – invalid

Castor canadensis sagittatus Benson, 1933 – invalid

Castor canadensis taylori Davis, 1939 – invalid

Castor canadensis texensis Bailey, 1905 – invalid

Castor subauratus Taylor, 1912 – invalid

Castor subauratus shastensis Taylor, 1916 - invalid
