BEAVER MANAGEMENT ALONG ROADS AND WITHIN THE RIGHT-OF-WAY

Report and Recommendations for the Colorado Department of Transportation

COLORADO
Department of Transportation

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By Katherine Millman

Executive Summary

Beaver are an important keystone species and ecosystem engineer in North America providing habitat benefits and ecosystem services with their dam building activities. This report aims to cover the numerous ways in which beaver can be managed non-lethally. Cost effective coexistence tools create win-win scenarios preventing beaver from damaging infrastructure while allowing them to stay on the landscape providing ecological benefits. The information about beaver ecology, history, and non-lethal beaver management techniques was found using a combination of literature review and interview techniques.

Beaver build dam complexes for their own safety and survival. However, their dam building activities have often led them to be categorized as a nuisance species. Specifically, beaver can cause damage to human infrastructure and property by flooding areas, plugging culverts, felling trees, and becoming roadkill. Historically, transportation agencies and landowners have managed these beaver activities using lethal control and dam removal. The practice of lethal removal often becomes a revolving door situation where beaver are removed from an area and within a couple of years new beaver have colonized the site. At CDOT beaver were historically managed this way. Additionally, CDOT has used the live trapping and relocation method of beaver removal when possible. Currently CDOT continues to remove beaver dams from culverts and alongside roads in addition to holding contracts with Wildlife Services for beaver trapping and removal. However, CDOT has also begun studies and pilot projects with a few non-lethal beaver management techniques including flow devices on State Highway 9, a culvert fence on Highway 550, and a series of beaver dam analogs as part of the South I-25 Gap Project mitigation.

In terms of the management techniques found in this report, some are highly effective at managing beaver in certain situations, while others are not effective at all. Additionally, some effective strategies may be impractical due to their price point. Dam removal is an important tool for relieving flooding but should be used in conjunction with other management techniques as beaver can rebuild a dam overnight. Effective strategies for managing beaver flooding when dams are built across a stream running next to the road include pond levelers, raising the roadbed, and installing berms between the road and beaver pond. Effective techniques for preventing culvert plugging include culvert protective fence, fence and pipe systems, installation of oversized culverts or small bridges, starter dams, and beaver-proof culverts. Culvert extensions and culvert guards can prevent beaver plugging inside of culverts but should not be used as long-term culvert plugging solutions as they require frequent cleanings. Effective techniques for preventing tree felling and tree damage include abrasive tree paint, tree wrapping, and placement of straight fence around tree stands. Exclusion fence can help prevent animal roadkill although its efficacy for preventing beaver roadkill is not well-known. Additional techniques that were found in the research include: education, non-lethal trapping and relocation, beaver pipes, chemical repellents, culvert blocks,

culvert wing extensions, electric fence, frightening devices, logger's road crossings, partial dam breaching, piping, sterilization, supplemental food provision, t-culverts, and three-log drains.

Flow devices such as culvert fence and pond levelers need to be installed by experienced professionals using high quality materials in order to have a high likelihood of success. Contacts for experienced flow device contractors have been included in this report. In any situation where beaver activity is seen, whether or not that activity is likely to affect the roadway should be determined before any action is taken. If the beaver are present but not causing any problems, they can be left alone. In general, areas with beaver problems should be addressed using flow devices. If flow devices fail, then live-trapping and relocation may be used. Lethal beaver control should be used as a last resort. Issues with culverts should be addressed using a culvert protective fence or a fence and pipe system. Issues with flooding along the side of the road can be addressed using a pond leveler or a berm. Issues with tree felling should be addressed using either abrasive tree paint when aesthetics are the primary concern or tree wrapping when potential hazards of trees falling on the road are the primary concern. If there is an area with high beaver and/or reptile mortality, exclusion fencing can be installed. Additionally, maintenance staff should be given training on these techniques and why/where they should request a coexistence device be installed.

Overall, coexistence techniques can be a more cost effective and permanent solution to beaver problems than beaver removal and should be considered when encountering beaver along the roadway.

Introduction

Beaver are an important keystone species in the United States. The goal of this report is to create a comprehensive review of beaver management techniques for CDOT to use as a reference and tool when choosing how to effectively manage beaver around the roads it maintains. Beaver once numbered between 60 and 400 million individuals across North America [87] but were hunted/trapped nearly to extinction by the 19th century [42]. Since restrictions on trapping, a decrease in hunting, and protections have been put in place, beaver numbers are now increasing across the United States [30] [64] and number around 10-15 million in North America [31]. Beaver provide numerous ecological services and subsequently are ecologically and economically beneficial to have on the landscape. However, beaver do create many very real conflicts with humans and human infrastructure, which causes them to be labeled as a nuisance [28]. The two primary conflicts beaver create are flooding and tree felling, both of which can be mitigated using non-lethal techniques in many situations. Such techniques can be highly effective with only minimal maintenance. The field of beaver management is continually evolving over time and some beaver management techniques are outdated, as this report will cover.

Research Methodology and Overview

Literature Review

A literature review was conducted to locate papers discussing beaver management and ecosystem services of beaver. An initial set of papers was located using several methods. Most papers were found using

keyword searches in the search engines Google Scholar and Web of Science. Additional papers were found in the curated libraries on the Beaver Institute and Worth a Dam Websites, and a few papers were found by searching the keyword "beaver" in the National Technical report library. After the initial set of papers was obtained, additional papers were found using the references of papers from the initial set, and a few papers were provided by interviewees.

Interviews

Interviews were conducted to determine what beaver management techniques are currently being used across the United States. All interviews were conducted between July 21, 2021 and February 25, 2022. In total 44 interviews were conducted with 53 people. The interviews included people from eleven states: Colorado, Idaho, Maine, Massachusetts, Montana, New Jersey, Ohio, Pennsylvania, Utah, Vermont, and Wyoming. Additionally, the interviews were conducted through a variety of mediums including three in person, 16 over video call (Zoom, Google Meets, and Microsoft Teams), ten by phone, and 15 over email. Of the interviewees, 39 were government employees (includes local, state, and federal governments) with eight being from CDOT, nine were consultants who install flow devices or other non-lethal beaver management tools, and five belonged to non-profit organizations.

In 22 of the interviews, at least one person stated that there were situations where they would prefer to use non-lethal management techniques in order to keep beaver on the landscape because of the ecological benefits they provide. Twenty-six of the interviews mentioned beaver repeatedly re-colonizing conflict sites after they were removed (using lethal control or relocation). Interviewees cited the typical return interval of new beaver re-colonizing a site after removal as anywhere from less than six months to approximately five years depending on the presence or absence of an active, reproducing beaver colony nearby. The most common techniques that interviewees mentioned they used to manage beaver were flow devices, lethal trapping, live trapping and relocation, and dam removal. Each of these techniques was mentioned in at least eleven interviews.

The following are examples of commonly asked interview questions. This list is not exclusive as follow-up and additional questions were also asked based on interviewee's responses and position. Additionally, not all questions were asked during every interview.

- What types of beaver problems have you encountered?
- What techniques have you used to manage beaver? Examples may include flow devices and trapping.
- How effective were the management methods that you used?
- In what percentage of cases were flow devices successful or effective at addressing your beaver problems?
- How much do the beaver management methods you use cost to install?
- How much maintenance does the beaver management method you use require in terms of time, labor, and materials?
- Have you experienced beaver returning to the same sites repeatedly over time?
- In areas where you allowed beaver to stay on the landscape, have you seen any ecological benefits from having beaver there?

Beaver Ecology

Beaver are large, nocturnal, semi-aquatic rodents that typically build dam complexes for their own safety and survival. Beaver weigh 16-32kg (35-70lbs) on average, but can get up to 40kg (88lbs) [1].

Beaver need a combination of food availability (trees & shrubs) and water (streams of varying sizes, irrigation canals, reservoirs, etc.) at a site for it to be suitable for beaver habitation. Beaver are "choosy generalists" [5] and will eat many plant species but preferentially eat certain species. The tree species that beaver prefer in Colorado are willow, aspen, and cottonwood. Beaver are most commonly found where these species are abundant [1]. Beaver will also eat alder, river birch, oak brush, and conifer when necessary [1]. The winter food cache beaver create consists of woody material. Beaver diet is more varied in the spring and summer when they eat more herbaceous plants [1] [42]. The majority of food that beaver eat is taken from within 100m of water [52].

Beaver are highly territorial [98] and upon colonizing a territory a colony will typically build a dam complex consisting of one or more dams, a lodge, and numerous bank dens and canals, all of which aid in the beaver's survival. However, it is important to note that not all beaver will build an entire dam complex, particularly in large river systems where there are sufficient water levels for beaver activities without the creation of a dam. In such systems beaver may only dig bank dens.

A beaver colony typically consists of a single beaver family unit including a mated pair of adults, the current year's kits, and the juveniles born in the prior year. In Colorado the average colony size is 5-7 individuals [1] although colonies have been known to reach 12 individuals in other states. At two years old, juvenile beaver will leave their natal colony in late winter/early spring, around the time a new litter is born, to disperse, find a mate, and establish their own territory [1]. Dispersing beaver may attempt to build dams in areas that are undesirable or unsuitable before they find an appropriate area to colonize.

A single beaver colony will maintain a complex of 1-25 dams, each with a pond behind it [22]. Beaver will often build dams at constrictions of streams and will often instinctively build or repair a dam when they can hear or feel running water. Beaver will build a dam using whatever materials are available, typically sticks, mud [1], and rocks [53]. Beaver will fell large diameter trees in order to strip off the limbs for use as food or damming material, and the trunk gets left behind [70]. However, beaver have also been documented using stolen posts [82], and even a prosthetic limb in a dam [42]. Beaver build a dam by placing a series of sticks parallel to the flow of water in a stream until the complete structure runs perpendicular to the stream. Beaver will stop increasing the height of a dam once the pond behind the dam is sufficiently deep for their needs. If a beaver dam has remained the same height for a year, the beaver are happy where it is and will not continue to increase the height of it [70]. Beaver will also stop increasing the height of the dam if the water level in the pond has stopped increasing despite the increased dam height. In some stream systems beaver dams may wash out during high flow events like spring runoff. When a beaver dam is removed, beaver can rebuild overnight as long as there are resources to do so [56]. Most beaver damming activity occurs in late spring after runoff and in the fall in preparation for the winter [1].

By flooding an area, beaver provide themselves with safety and reliable access to food. In Colorado an adult beaver has no predators while in the water [35], but many predators on land. Beaver kits may be taken by river otters while in the water. On land, beaver may be preyed upon by wolves, coyotes, bear, lynx, bobcat, and mountain lion [1]. This is due to the beaver's build. They are svelte and powerful in the water, but clumsy on land. Emily Fairfax compares beaver to "walking chicken nuggets" [35] that everything wants to eat when they are on land. Thus, beaver spend the majority of their time in the water or inside their lodge. The canals that beaver dig off the sides of their ponds allow access to trees that otherwise would have required walking across the land. By digging a canal next to a stand of trees, beaver can fell a tree into the water and swim it back to their lodge or den, with minimal time spent out of the water [70]. Additionally, beaver ponds provide year-round access to a food supply even in areas that freeze during the winter. Beaver will build a large cache of branches in the center of a dammed pond that acts as their winter food supply. If the pond is deep enough, the top of the pond will freeze over, but the lower portion, where the food cache is, remains unfrozen where beaver can access it from their lodge. Generally, beaver need a minimum pond depth of three feet for free-flowing water to remain under the ice in winter [22]. Food caches can reach up to 6m in diameter and 3.6m in height [1]. A beaver lodge is built in the middle of a pond using sticks and mud to form a structure with a raised internal platform and a protective outer shell. All entrances to the lodge are underwater so the majority of predators are unable to access the lodge. Additionally, beaver lodges that are built up with layers of frozen mud are extremely strong to the point that only grizzly bears and wolves have been able to dig into them. The inside of a beaver lodge will remain above freezing even when external temperatures are well below freezing. In the winter steam can be seen escaping the tops of active beaver dams [5].

Beaver will scent mark their territory using castor mounds [1], piles of mud scented using their castor glands, to warn away other beaver. If a new beaver attempts to enter an already occupied territory, they may be killed by the resident beaver.

Beaver require a constant flow of 0.5 cfs for a location to be attractive for them to dam [41]. Beaver also prefer to dam streams with a gradient less <3% [52]. Beaver dam at constrictions in streams where the sound or running water may be louder, and the water has a higher velocity [52]. And beaver are approximately 10% more likely to dam at road crossings, such as culverts, than elsewhere [3].

Beaver dams are less likely to breach, or blow out during a high flow event if they are retaining water behind them. Additionally, when you have a beaver complex with a series of dams, the uppermost dam is the most likely to breach during a high flow event, while the downstream dams remain intact preventing an out-burst flood event [114].

Beaver behavior is the same regardless of where you are in the world [4] [62].

Types of Beaver Conflicts

Flooding

Beaver cause flooding when they dam culverts or streams and create a pond. Flooding can cause damage to crops or roads. Road damage occurs primarily when prolonged flooding leads to roadbed saturation and

failure of the road surface. This can be especially pronounced in areas where the saturated roadbed prism can freeze in the winter causing frost heave and cracking of the road surface. Flooding may also become dangerous during extreme weather events should a beaver dam cause enough water to back up and create sheet flow or deep ponding on a road.

Culvert Plugging

When beaver plug culverts they cause flooding and other stormwater drainage problems. These plugs can cause issues if they ever blow out, and they are dangerous to remove as maintenance personnel may have to crawl inside of culverts to remove them.

Tree Damage/ Tree Felling

Beaver fell trees to build dams and for food. This leaves some trees damaged and others dead/removed. The trees that are damaged may be highly valuable, providing shade, fruit, or have historic significance in a community. Near roads there is also the risk that beaver will fell a tree in a direction that it will fall across the road and cause significant problems with traffic and even accidents before it can be cleared.

Roadkill

Beaver often cross roads rather than using culverts which makes them susceptible to road kill. Beaver are also slow moving on land, which makes them more likely to be struck by a vehicle should they cross the road at grade rather than using culverts to pass underneath it. Beaver are a large animal (~ 60lbs on average) and can cause a significant amount of vehicle damage if they are hit on the road by a vehicle with low clearance. Beaver on the road can also cause problems should people swerve to avoid hitting a beaver on the road and subsequently cause a crash.

Ecosystem Services Provided by Beaver: Ecological and Economic Benefits of Keeping Beaver on the Landscape

Beaver are ecosystem engineers [81], a keystone species that create wetland habitat through their dam building behaviors [37]. In Colorado, wetlands make up about 1-2% of the landscape. Historically, wetlands would have made up much more of the Colorado landscape, likely close to four times the current amount. And beaver are an important resource for increasing the amount of wetlands present on the landscape today [47]. It has been demonstrated that both wetlands and beaver ponds provide ecosystem services that can be economically and ecologically valuable [15]. Wetland habitat has an estimated ecosystem service value of $8,000/acre/yr [15].

Many Animals including bear, moose, wolves, and more will use beaver dams to cross streams and flooded areas [56]. And approximately 75-85% of all wildlife species in Colorado depend on wetlands and the types of habitats that beaver create for survival at some point in their life [30] [98]. Overall, beaver create a 'messy' heterogeneous landscape that allows many species to thrive [55]. Some notable species that depend on wetlands and beaver ponds include Preble's meadow jumping mouse (State and Federally Threatened) [85] [100], New Mexico meadow jumping mouse (Federally Endangered) [21], Eastern Black Rail (Federally Threatened) [77], Greenback cutthroat trout (State and Federally Threatened), other cutthroat trout species (State Special Concern) [117], and Boreal toad (State Endangered)[22]. The estimated value of habitat and biodiversity provision by beaver is $133/ha/yr [97].

Beaver ponds store and slow water on the landscape. This can help mitigate some of the impacts of climate change experienced in the arid West [6]. Beaver dams help with groundwater recharge as the weight of the water in the pond forces water into the ground in surrounding areas, raising the water table [35]. Also, beaver dams are 'leaky' structures, meaning that they allow some water to continue flowing through the dam at all times [70]. By allowing some water to flow from the beaver pond into the stream below the dam, beaver change the hydrograph in flashy mountain streams from having a large peak during spring runoff and very little water for the rest of the year, to having a smaller peak during spring runoff and a more consistent trickle throughout the rest of the year. This means that farmers, ranchers, and other water users have that water available for use much longer than they would without beaver, even if the same amount of water flows over the course of the year [6]. The value of having water available year-round was also well known to Native American Plains Peoples who refused to hunt beaver due to their ecological value [42]. The estimated value of water supply from beaver is $77/ha/yr [97].

By slowing and stilling the water in streams and behind beaver dams, beaver help to prevent erosion and capture sediment [15] [30]. Beaver complexes can also slow stormwater and storm flood surges [47]. The estimated value for the moderation of extreme events by beaver is $124/ha/yr [97]. In areas where beaver have been removed, the sediment they would have captured has ended up in reservoirs, reducing their water storage capacity [30]. The ability of beaver ponds to store sediment has been estimated to be worth $2 per cubic yard [15]. By storing sediment, beaver also help increase stream aggradation, causing streams to become less channelized across the landscape [78]. By removing sediment from the water, beaver help improve water quality, as the sediment they store contains pollutants previously suspended in the water. Some pollutants, like nitrogen, that are captured by beaver ponds are processed by microorganisms in addition to being stored [15]. The sediment in beaver ponds may contain many pollutants associated with agricultural run-off such as nitrogen and phosphates [15]. Additionally, beaver ponds have been shown to reduce acidity by removing sulfates from streams [15]. Beaver complexes have also been shown to reduce metal concentrations (including heavy metals) downstream of mine drainage [90]. The estimated value of water purification by beaver is $108/ha/yr [97].

Beaver complexes also serve an important role in wildfire mitigation. During and immediately after fire beaver complexes can be seen in aerial imagery as 'ribbons of green' across the landscape. These are areas that do not burn even when nearby areas are burnt severely. By wetting the landscape and raising the water table, beaver ponds have allowed nearby plants to remain green and unburned during fire. This provides a refugia for many species on the landscape that would otherwise not survive the fire. If an animal can make it to a beaver pond, they are likely to survive a fire they otherwise would not have. Those surviving individuals, both plant and animal, can then become source populations to return the

species to the landscape where they may have been locally eradicated otherwise [36]. In some cases, beaver ponds can also act as firebreaks [47].

Finally, beaver ponds provide value as areas for recreation and tourism including activities such as birding, fishing, and canoeing [15] [47]. The estimated value of recreational hunting and fishing created by beaver is $6.1/ha/yr [97]. The estimated value of non-consumptive recreation provided by beaver is $167/ha/yr [97]. Beaver ponds also provide an aesthetic value on the landscape [15].

Because of all of the ecosystem services and ecological benefits beaver provide, beaver restoration has been increasing in popularity in recent years, and is being conducted more frequently [30] [32] [59] [70].

Historic Beaver Management

Beaver once numbered between 60 and 400 million individuals across North America [87], or approximately 1 beaver per kilometer of habitable stream in the United States [55]. However, beaver were hunted and trapped nearly to extinction by the mid-19th century [42]. Beaver fur was highly prized for its ability to make felt hats fueling part of the trapping frenzy at the time [42]. The Hudson Bay Company was granted a monopoly by the English government and deliberately trapped/killed everything to create a "fur desert" to discourage colonization of the Western US [55]. Additionally, Europeans attempted to eradicate species such as beaver and bison upon which many Native American peoples depended [42]. This removal of beaver from the landscape altered every stream in the inland west [55]. Because of this history, people are unfamiliar with how streams are supposed to look and behave on the landscape [42]. Around the time beaver were nearly extirpated from North America, beaver hats fell out of fashion as silk hats gained popularity [2]. With the change in fashions, trapping pressures eased and beaver slowly recolonized the landscape. Beaver populations on the East coast had begun to recover by the early 20th century. However, the beaver were not coming back to the landscape they left, instead they returned to a landscape full of humans and human infrastructure. This was when beaver began to be considered a nuisance [42]. Now beaver in North America number approximately 10-15 million [31].

As beaver populations expanded into areas populated with humans, they began to create conflicts just by following their instincts and creating dams that impacted human infrastructure [30]. Farmers and other landowners then began to manage beaver lethally using many different methods (kill trapping, snares, shooting, poison, and more) in order to prevent property damage by beaver [30] [63]. This creates a cycle, or revolving door, of trapping and dam removal where landowners remove the beaver and new beaver re-colonize the area within a couple of years depending on how close the nearest source population is, and how likely the beaver are to be killed between the source population and the area of concern [22]. If only the beaver dam is removed, beaver continue to rebuild it overnight after it is removed [30] [49] [56] [113]. Many transportation agencies, including CDOT, have been using, and in some cases still use, this method of removing the beaver and their dams any time a conflict comes up, as it is the only management strategy they know [22] [29] [30]. Cleaning inside of an unprotected, beaver-clogged culvert can be dangerous if someone must enter the culvert to clear it, or may damage the culvert, shortening the culvert lifespan, if heavy machinery is used.

Beaver populations across North America are now increasing [30] [64]. However, areas that are stuck in the trapping revolving door can still become an ecological "black hole" where any beaver that passes through is killed, thus preventing beaver from expanding into areas where they would be ecologically beneficial [55].

In 1996 the State of Colorado passed Amendment 14 to the Colorado constitution, which banned the use of cable, body gripping, and leg hold traps in the state [28]. These traps were considered inhumane as they do not kill immediately and in the case of beaver they often led to death by drowning. Now beaver take is limited to shooting beaver or trapping beaver using live traps and then immediately euthanizing them. Live traps must be checked once a day [28]. However, "Landowners, and others authorized by statute, may be eligible for a 30-day trapping permit where certain body grip devices, cable device traps, foothold traps, etc. can be used in order to protect commercial livestock and/or commercial crop production." [28] These permits may also be issued when there is a significant human health and safety risk. Beaver are regulated by the state as a furbearer with a hunting and trapping season [116]. However, in Colorado "if wildlife [beaver] is causing damage to crops, real or personal property, or livestock - a person (or any employee or agent of the landowner) may hunt, trap, or take the following wildlife on lands owned or leased by the person without securing a license to do so." [28] Pelts may only be sold if the person performing the take of beaver has a valid furbearer license [28].

Current costs for lethal nuisance beaver trapping include $70 an hour by USDA Wildlife Services [34] which typically adds up to $1,000-$3,000 to trap a whole colony [64], $600 for 8 days of nuisance trapping by a private trapper [42], $150 set up fee plus $50 per beaver trapped [84], and $500 per beaver trapped by a nuisance beaver trapper [98]. Having USDA Wildlife Services use thermal imaging to shoot a newly established pair of beaver in an area near a Wildlife Services office can cost as little as $300-$400 [64]. Currently a beaver pelt sells for less than $15 so there is no economic incentive to trap for furs [55].

Examples of Beaver Management Practices Utilized by CDOT

Beaver Trapping and Dam Removal in CDOT Region 5, Maintenance Section 7

Ongoing

Several patrols in CDOT Region 5, Maintenance Section 7 have experienced reoccurring problems with beaver plugging culverts and causing flood risks. They deal with these problems through a combination of trapping and dam removal. Trapping is done by USDA Wildlife Services and includes both lethal control and live trapping and relocation. Historically maintaining the section of U.S. Highway 160 from mileposts 270-275 cost CDOT $10,000 a year. However, since that point Wildlife Services has required the entire section to submit a single purchase order. Currently the entire maintenance section is paying $6,000-$9,000 a year for trapping done by Wildlife Services. New beaver move into the areas where

beaver were trapped out approximately every 6 months – 3 years. In addition to having beaver trapped out in conflict areas, the maintenance technicians also remove beaver dams from plugged culverts and nearby streams where there is a risk of flooding and subsequent road damage. Dam removal is done both by hand and using a backhoe. In areas where beaver are damming a culvert regularly, a maintenance team must clean the culvert daily to prevent debris build up. Each cleaning takes about 20 minutes. If the culvert is not cleaned regularly and becomes completely plugged, dam removal can take several days to complete [49] [57] [76].

Beaver Dam Analog Research as a Part of the South I-25 Gap Project

Installed in 2021, research ongoing

In 2018 CDOT began the South I-25 Gap Project to improve 18 miles of Interstate 25 between Denver and Colorado Springs. The project's impacts included a reduction in Preble's meadow jumping mouse, a state and federally listed species. The Preble's meadow jumping mouse relies heavily on healthy riparian habitat for survival. As mitigation for the impacts of the I-25 South Gap Project, CDOT installed a series of beaver dam analogs on Carpenter Creek and East Plum Creek, which cross or run adjacent to the I-25 Project area. Approximately 14 beaver dam analogs were installed across both streams at a cost of $50.89 per linear foot, or approximately $500-$1,500 per beaver dam analog ranging from approximately 10-30 ft. The beaver dam analogs are intended to aid the restoration of the riparian areas surrounding the creeks. In addition to the beaver dam analog installation, the Colorado Natural Heritage Program will be working with CDOT to conduct a three-year study of Preble's meadow jumping mouse in the area to monitor the impact of beaver dam analogs on Preble's meadow jumping mouse habitat and habitat use. The aim of the research is to determine if beaver dam analogs are an effective mitigation tool for jumping mice species. The research is estimated to cost a total of $85,000 [86] [100].

Culvert Fence Project in CDOT Region 5, U.S. Highway 550 Near Red Mountain Pass

Installed in 2021

Photo Credit: Tim Funk, Colorado Department of Transportation

Photo Credit: Rory Cowie, Alpine Water Resources LLC

The 24-inch culvert where an unnamed tributary to Mill Creek crosses under U.S. Highway 550 north of Silverton has experienced problems with beaver for years. Because the culvert was continually plugged with beaver debris, the maintenance staff out of Silverton placed a metal screen guard in front of the culvert entrance, which made the culvert easier to clean but did not stop the problem. With the guard in place, the culvert required an average of 1 hour of maintenance each week including cleaning and travel time. In 2020 Tim Funk organized a conference call presentation to explain coexistence techniques to region 5 maintenance staff. The presentation was given by Malcom Macleod and focused primarily on culvert fencing. After the presentation, the maintenance staff from Silverton approached Tim Funk about the Mill Creek tributary culvert. Tim Funk then contacted Rory Cowie, who completed the culvert fence

installation for $2,800, inclusive of materials, labor, and follow-up monitoring, in the fall of 2021. The fence is currently working well and requires much less maintenance than the culvert guard [40].

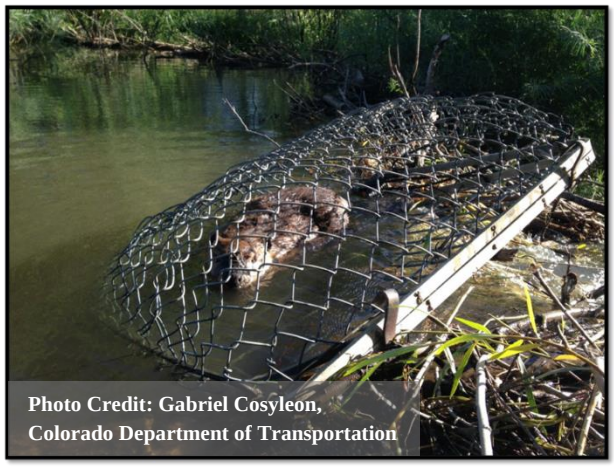
Flow Device Installation by Summit County Open Space in CDOT Regions 2/3, State Highway 9 Near Hoosier Pass

Installed in 2016 and 2017

The culvert at State Highway 9 milepost 78.7 between Breckenridge and Hoosier Pass has repeatedly experienced problems with beaver plugging it and causing flooding. As a result of beaver plugging the culvert, the beaver were removed sometime between 2006 and 2011. After several years of beaver absence, beaver returned to the area in 2013 and began causing problems with the culvert again. At that time, Summit County was unwilling to let CDOT trap the beaver, as they were beneficial to a nearby wetland mitigation area owned by the County. As such, CDOT attempted to place fencing in front of the culvert. However, the beaver dammed the fence and flooding of the road was still an issue. Then in 2016 Summit County Open Space installed their first round of flow devices in coordination with CDOT. Just prior to the flow device installation, CDOT repaired the damaged road and cleaned the culvert using a backhoe and high-pressure water. The flow devices installed consisted of two pond levelers that were placed through the fence in front of the culvert, creating a fence and pipe system. In 2017, Summit County Open Space installed a second set of flow devices, two pond levelers placed through dams upstream of the culvert. These devices were designed and installed by Summit County Open Space staff who had no prior experience with flow devices. As such, the devices required several rounds of tweaking including changing fencing size and pipe diameters. While the devices were being tweaked, they required significant cleaning and maintenance. However, once the devices were positioned so that both the beaver and the humans could be happy with the pond and dam height, the devices required very little maintenance. The pond levelers upstream of the culvert have continued functioning with no maintenance having been conducted on them. In total, CDOT has spent $15,000 on this location between 2006 and 2021, with the majority being spent between 2013 when the beaver returned and 2016 when Summit County Open Space took over the site [29] [56] [59].

Live Trapping and Explosive Dam Removal in CDOT Region 2, State Highway 12 Near La Veta

Occurred in 2014



In 2014, Gabriel Cosyleon, an ecologist for CDOT Region 2, was contacted by CDOT maintenance about a beaver complex near the bridge over the Cuchara River located at State Highway 12, mile post 4. The beaver were redirecting water flow into one of the bridge abutments and causing a scour concern. Gabriel then contacted Colorado Parks and Wildlife and USDA Wildlife Services. Wildlife Services live trapped the beaver and CDOT then gave them to Colorado Parks and Wildlife for relocation on private land. After the beaver were removed the beaver dams were detonated, as detonation was deemed to be the option with the least impact on surrounding riparian vegetation and did not require additional property easements for CDOT staff. The operation cost approximately $3,000 [29].

Non-Lethal Beaver Management Techniques

Key:

Technique Name

Synonymous Terms, Trademark Names, and Sub-Category Technique Names

Images When Available

About the Technique

Cost: $-$$$ based on a single project installation or use

Maintenance Requirements

Effectiveness and Reasons for Failure

Resources and Construction Instructions

References

Notes:

$ indicates a technique that cost less that $2,000 for a single use of the technique.

$$ indicates a technique that costs between $2,000 and $100,000 for a single use of the technique.

$$$ indicated a technique that costs greater than $100,000 for a single use of the technique.

Estimated Materials Price = $XX Indicates an estimated raw materials cost for the technique from a list of materials and the prices of those materials listed on the websites of several retail stores. These estimates do not include labor costs.

To learn more and get more in-depth information about any of the beaver management techniques see the papers listed in the references for the technique.

Recommended and Widely Used Non-Lethal Beaver Management Techniques

Flow Devices

Flow devices are successful at managing beaver problems at between 75% to 95% of sites when installed by a trained professional. The rest of the time another approach, such as live trapping and relocating the beaver, may be required [13] [20] [83]. Flow devices can always be installed with the beaver in place. The goal of a flow device is to allow beaver to stay where they are without causing damage to human

infrastructure. Additionally, if there are beaver in an area, new ones won't move in. Thus, trapping should not be conducted in conjunction with flow devices [98]. The majority of flow device research has been conducted on the East coast where beaver are more abundant. However, flow devices have been used effectively in Colorado [30] [41] [47] [62] [98] [99].

Flow devices should be installed by experienced professionals. The two primary reasons that flow devices fail are that they are constructed using low-quality materials or they are constructed by someone who does not understand beaver biology or stream dynamics, who may even use the wrong tool for the problem they are trying to address [4] [47] [62].

If you use high-quality materials, flow device lifespans can be up to 50 years. In general, the expected life span of flow devices is between 6 and 50 years, with the most common estimate being a 10-year lifespan. Note that these estimates are primarily from the eastern United States where the water is acidic. Devices may last longer in Colorado where the water is not as acidic [17] [18] [46] [62].

Most flow devices require some tweaking after they are first installed. Tweaking may include changing pipe or fence size, moving the device around, or adding an additional pipe. Most flow device professionals will include some tweaking as part of their maintenance plan on the device, although additional materials may make the device cost slightly more. Any person seeking to have a flow device installed should be aware of this and not be discouraged if there are a few issues initially. Once the device is adjusted properly to the beaver's needs at a site, it will often work for long periods of time with minimal maintenance. Additionally, if you allow continued tweaking of the device, there are almost no sites where a flow device won't work to solve the problem [63] [29] [56] [62].

In some areas it can make sense to remove part or all of a flow device during periods of high flow. Typically, just the fence panels on the ends of the device will be removed. This allows passage of debris and prevents damage to the device caused by debris clogging the device and causing it to collapse [47] [117].

In some cases, the price of flow devices can be reduced by using excess materials that a transportation agency has lying around after other large projects, rather than buying all of the materials new [60].

Note: The term Beaver Deceiver™ has commonly been used as an umbrella term to refer to all flow devices, however that is inaccurate as Beaver Deceiver™ is a trademark referring exclusively to the fence devices built by Skip Lisle. The term should not be used to refer to any other device types [62].

Note: The prices of flow devices have gone up in the past two years as material and supply chain issues have made it difficult to find some materials, such as epoxy coated concrete reinforcing panel and piping. Additionally, prices of those materials have increased two- three times. Any price estimates for devices before 2020 are likely to underestimate the current price [22] [30] [56] [62].

Basic Components of Flow Devices

All flow devices are composed of the same three base components which can be combined in several different ways. These components are described below. Also note that most flow devices require some adjustments to their designs after they are first installed and thus may require more maintenance during the initial time after installation.

Fence: Heavy, 4- or 6-gauge, galvanized steel fence panel [46] or epoxy coated steel panel [62] with 4x4 or 6x6 inch openings. Typically, fence panels are combined to create larger structures and longer fence lines by using galvanized hog rings and 9-gauge wire for joining panels and either heavy duty metal t-posts or pressure treated wood posts as the supports. Fence panels used in flow devices should not have openings smaller than the 4x4 inch size as they will clog more easily with debris, requiring frequent maintenance, or even encourage beaver to dam on the fence. 6x6 inch openings are sufficient for most projects as adult beaver cannot fit through it. However, 4x4 inch may be required at sites where beaver have figured out how to send their kits through the fence with damming materials [46] [99].

Pipe: Double-walled polyethylene (HDPE pipes) in a large diameter, typically 8-12in with holes cut through the outer wall to allow the pipe to be submerged and prevent floating (flexible pond leveler and fence and pipe designs) [99]. OR 12in diameter rigid wall polyethylene pipe [13] [24] [66].

Filter: A device made of cage and/or pipe designed to prevent debris from entering a pipe and disperse the water entering the pipe over a greater area, so the feel of running water is less noticeable. Typically, a cage made out of fence, described above, in the form of a short cylinder with a hole cut out of the rounded edge sized for a pipe to be inserted. In some cases, a fence may also act as a filter.

Note: Filters may also be called beaver baffles, fence filters, and intake devices

Note: Filters cannot be used as a stand-alone device. They should be used as a part of a pipe and fence system or pond leveler device.

Note: The filters trademarked by skip Lisle are called Round Fences™

Filter references: [13] [61] [68] [94] [99] [112]

Culvert Protective Fence

Barrier fencing, Beaver Deceiver™, beaver exclusion fencing, beaver fencing, beaver stop, complex fencing, CulverClear™, culvert fence, culvert protection fence, culvert protection structure, culvert protective device, culvert protector, deep water fence, diversionary fencing, fence system, Keystone Fence™, pre-dam, trapezoid culvert protective fence, trapezoidal beaver fence, trapezoidal fence system, wire mesh fence

Photo Credit: Rory Cowie,
Alpine Water Resources LLC

Photo Credit: Paul Planer, RangeWorks LLC
and Alli Del Gizzi, Arable Earth LLC

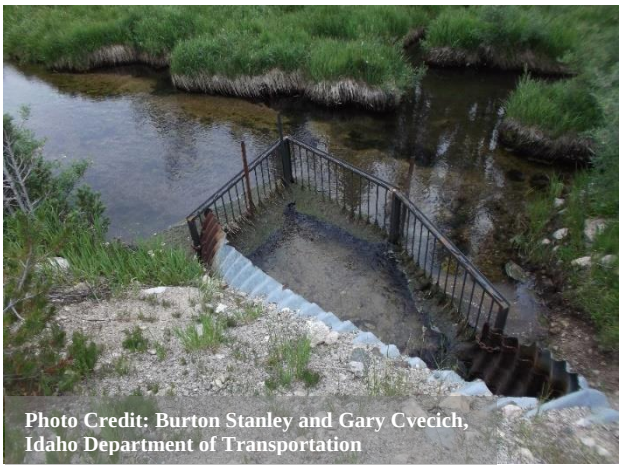


Photo Credit: Burton Stanley and Gary Cvecich,
Idaho Department of Transportation

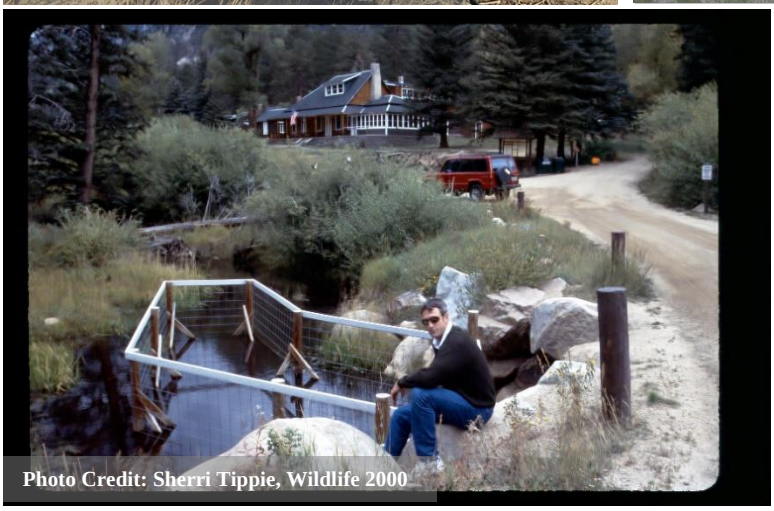


Photo Credit: Sherri Tippie, Wildlife 2000

Culvert protective fence is designed to prevent beaver from damming or plugging a culvert. Many designs have been used for culvert fence including circular, crescent, rectangular, triangular, and diamond shapes. Some shapes, such as triangular, have been abandoned because they were ineffective. However, the most common, effective, design for culvert fence is the 40 to 120ft trapezoidal fence (length increases with

stream and culvert size) where the fence is formed in a trapezoid that extends in front of a beaver-affected culvert, with the culvert entrance constituting the short edge of the trapezoid. The fence is typically placed only on the inlet of the culvert, but certain cases may require fencing on both ends if beaver move to dam the culvert outlet. Other shapes than a trapezoid may be used depending on the shape of the drainage being protected. If the stream approaches the culvert at an angle rather than straight on, it is likely to need a unique fence configuration, as the trapezoidal shape can be ineffective in such situations. Often the fence will be lined along the bottom to prevent beaver from digging underneath the fence to continue plugging the culvert. The heavy gauge (4 or 6 gauge) fence panel is typically supported using either t-posts or a wooden frame. The fence openings are 4x4, 6x6, or 6x 8inch because that is the span of the beaver's webbed hind foot. The webbed hind foot is the biggest span on the beaver, and they won't push through anything that will get their feet caught. Additionally, the large openings in the fence allow some debris to flow through the culvert fence while still preventing beaver access to the culvert.

Culvert fence protects the culvert because beaver are inclined to dam streams where there is a restriction, and to dam the streams perpendicular to water flow with the sticks that comprise the dam lying parallel to the water flow. Thus, the fence pushes beaver back to an area where the stream is no longer constricted, lengthens the area they would need to successfully dam, and includes a length where they would need to dam at an unnatural angle. Thus, beaver are unlikely to choose fenced areas to dam and will likely move upstream or downstream to an area that may be more acceptable to land managers.

Culvert protective fence can be easily modified to allow for animal passage through the culvert while still preventing beaver damming. The modification consists of a section of fence that extends perpendicular from one of the corners of the culvert fence that would be at the culvert inlet. The fence section then runs parallel to the road for ~ 10ft. A gap is left between the fence and the culvert so that animals must walk around the extension to enter the culvert, but they still have access to it. This works because beaver do not get out of the water while carrying sticks. So, they may leave the water and walk around the fence to go through the culvert (wildlife passage) but will not do so while carrying damming material.

Culvert fences work best in low flow areas where there is little risk of severe flow events. Additionally, the culvert fence should not block the entirety of the stream channel or beaver will use it to create a dam. However, Culvert fences can still continue to work at partial capacity even if they become completely clogged with debris as water can still flow over the top of the fence and through the culvert. Culvert fences should be cleaned after high flow events to prevent flooding and beaver damming activity.

The typical culvert fence has an estimated 6-year life span, but that is based on areas in the eastern United States that have acidic water. Culvert fence life spans are likely much longer in Colorado. If you use very high-quality materials, flow device lifespans can be up to 50 years.

T-posts should be heavy duty. Streams with really mucky bottoms will require longer t-posts than those with hard rocky bottoms.

Cost: $-$$

- $2800 quote from a proposal for a recent installation along highway 550
- $2000 including materials and personnel [46]
- $140 in materials plus Labor for 2-5 people for 2-4 hours [63]
- $500-$1,200 on average [70]

- $1,500-$2,500 installation cost, plus $350 a year for maintenance on a Mike Callahan installation [83]
- Lower end of $2,000-$6,000 [47]
- Estimated Materials Price = $80 per galvanized fence panel (typically 5 are necessary for a single fence), plus $4 a bag for galvanized hog rings, plus $10 for a roll of galvanized steel wire, plus $4 a t-post (number depends on fence size and configuration)

Maintenance Requirements: Culvert fence must be periodically cleaned of any debris. They should be cleaned any time there is build-up of debris or if plants have grown up around the base of the fence. Debris typically consists of leaves and sticks, although some drainages may also have significant amounts of human trash. Cleaning a culvert fence can typically be done in under an hour by maintenance personnel wearing waders. Cleaning a culvert fence is also much safer than cleaning an unprotected culvert as there is no risk of large volumes of dammed water being released unexpectedly during the cleaning process. The number of times a culvert fence must be cleaned of any debris can vary widely depending on the amount of debris and the flow regime of a given system. Some systems have survived for nearly 20 years with no maintenance, while others may require cleaning multiple times each year. On average most flow devices should be checked twice a year, depending on the flow regime and debris loads of the stream they are used it. The higher the stream flow is and the more debris that a stream typically carries, the more frequently a device will need to be checked. Flow devices should be checked right after the high flows from spring runoff die down. Typically cleaning a flow device takes less than an hour.

Effectiveness and Reasons for Failure: Flow devices work nearly every time so long as you are willing to upgrade or tweak them if something goes wrong. Culvert fences can bend and fail if poor quality materials are used. Elissa Chott's general rule is that if fence comes on a roll, it is too flimsy to use in the water as a culvert fence. In some cases, beaver have chewed the wooden support posts of culvert fences, even if they are covered by the 6x6 inch mesh. As such, metal fence posts (t-posts) can be preferable. If the culvert fence ends at the bank next to the culvert, rather than extending flush along the bank, beaver may drag debris into the water from the bank and dam the culvert from inside the fence. If the fence openings are too small (typically less than 4x4 inches), such as when using chain link fence, then beaver may pack them with mud and sticks, and/or debris may get caught on the fence encouraging beaver to dam on it. Culvert fences can fail if they are too short. Beaver should not be able to swim over the top of the device during normal flow and typical high flow levels.

Construction Instructions: [9] [99]

References: [4] [8] [12] [13] [14] [16] [17] [18] [20] [22] [30] [32] [38] [41] [43] [46] [54] [61] [62] [67] [70] [71] [79] [80] [89] [91] [94] [95] [96] [99] [112] [115]

Pond Leveler

Beaver baffle, beaver baffler, beaver reliever, cage leveler, Castor Master™, Clemson beaver pond leveler, Clemson leveler, Clemson pond leveler, corrugated tubing, flexible leveler pipe, flexible pipe, Flexible Pond Leveler™, flexible pond leveler pipe, flexpipe, habitat modification, metal pipe drain, pipe system, pond leveler pipe, pond leveller, PVC drain pipe, Snohomish Pond Leveler, water control device, water level control device

Photo Credit: Sherri Tippie, Wildlife 2000

A pond leveler is a device designed to maintain a beaver pond at a specific size or water level under normal flow conditions. The device consists of a pipe that is placed through a free-standing beaver dam and one or more filters that cover and protect the inlet and optionally, depending on location, outlet of the pipe. The height at which the pipe outlet is placed determines the level at which the pond will be maintained under normal water flow rates. The inlet of the pipe is placed in the center of the pond and completely submerged if possible. Submerging the pipe eliminates the sound of water running into the pipe. The size of the pipe should carry the amount of water in the stream under normal flow conditions. Under high flow conditions, such as spring runoff, water will overtop the beaver dam, rather than backing up within the pond. The intake of the pond leveler may clog during these high flow events, if that happens the device should be cleaned soon after, but it is not a critical failure as water would overtop the dam under those flow conditions anyways. Pond levelers should not be placed where this behavior cannot be tolerated. Pond levelers work best in situations where the pond can be maintained at a depth that is

adequate for all of a beaver's needs including safety, lodge access, and access to their food cache in winter. Typically, a pond that meets these requirements is a minimum of three feet deep, although slightly shallower may be sufficient in a secondary beaver pond as opposed to the primary pond where the lodge is located. Pond levelers generally prevent beaver from increasing the height of the dam but are not intended to stop all ponding.

There may be stream systems where placing a single pipe through a beaver dam is insufficient so two or three pipes placed through the dam is required. However, if you can use a single larger pipe it is preferable compared to many small pipes as smaller pipes are easier for beaver to clog with debris, and they will do so more readily. Typically, a 12-inch diameter pipe is the smallest that should be used as it allows for small debris to flow freely through the pipe. The larger the stream system you are in the larger the device will need to be.

The pond leveler works because the filter is large enough to keep beaver away from the intake of the pipe where they can sense water flowing into the pipe. Because of this, they cannot find the 'leak' in the dam and when the water level ceases to rise the beaver stop building the dam any higher and maintain it at the set height. The device also works best when the intake end of the pipe is sufficiently far (typically 10-40ft) from the dam so that the beaver cannot connect any flow of water from the device to water flowing through the dam. The filter may also catch debris that would otherwise clog the pipe. Additionally, the device should be made as quiet as possible, submerging the intake completely, to prevent beaver from noticing water leaving the pond through the pipe. Upon installation, there is no reason to attempt rebuilding the dam over the pond leveler as the beaver will re-do any human made dam work. If you just lay some sticks over the top, the beaver will repair the dam with the pipe in it.

In some situations, pond levelers have been used to prevent beaver damming by draining all water from a pond in a way that the beaver cannot stop the flow of water. This causes the beaver to move upstream or downstream. As a result, when there are no beaver at the site, no ecological benefits of having beaver on the landscape are seen.

There are two main designs of the pond leveler: the Clemson pond leveler and the flexible leveler. The Clemson pond leveler, where the filter consists of a perforated pipe surrounded by wire mesh, was the most commonly used design in the 1990s and 2000s, but has since been replaced in most areas by a simple filter design like that found in the flexible pond leveler design. The more complex Clemson design commonly failed due to beaver filling it with sediment. However, there are still some areas where a modified Clemson pond leveler design is used to lower pond levels to the point that beaver are forced to move to another location. This modification consists of adding two 90° bends onto the PVC pipe so that the intake and outlet of the device are vertical. The modified design can also be placed through a culvert instead of using a culvert fence.

There are additional modifications that can be made to pond leveler designs to allow for fish passage through the device. However, this has primarily been a concern in areas that have threatened and endangered anadromous fish species such as salmon.

Cost: $-$$

- $350-$750 in materials plus labor for 2-3 people for 2-4 hours [63]
- $3,500 on average for an installation [62]

- $450 - $500 [56]
- $500-$1,200 on average [70]
- Upper end of $2,000-$6,000 [47]
- Estimated Materials Price = $320 per 20ft section of 12 in diameter double walled HDPE culvert pipe, plus $80 per galvanized fence panel, plus $4 a bag for galvanized hog rings, plus $10 for a roll of galvanized steel wire, plus $4 a t-post, plus $5-$20 per bar of rebar (comes in many lengths).

Maintenance Requirements: Pond levelers should be checked periodically to ensure that they are still functional. As long as water is flowing through the pipe and there is no sign of beaver damming on the cage around the pipe intake, then no further maintenance is required. The cage(s) around the pipe intake (and outlet if present) should be periodically cleaned of any debris that accumulates. If beaver begin to dam around the pipe intake or outlet, then the device may require tweaking. On average, flow devices should be checked twice a year, depending on the flow regime and debris loads of the stream they are used in. The higher stream flow is and the more debris that a stream typically carries, the more frequently a device will need to be checked. Flow devices should be checked right after the high flows from spring runoff die down. Typically cleaning a flow device takes less than an hour.

Effectiveness and Reasons for Failure: Flow devices work nearly every time so long as you are willing to upgrade or tweak them if something goes wrong. Pond levelers can fail if no filter is placed around the end of the pipe, or if the filter is too small and beaver are able to sense water entering the system and successfully plug it. Pond levelers can also fail if the pipe inlet is not sufficiently far away from the beaver dam and beaver recognize it as a 'leak' in the dam and clog the intake with mud. This is more common with some types of filters than others. If the cage around the intake is not completely enclosed, such as if someone were to build a fence with no bottom, then beaver can dig under the fence and clog the pipe. Typically, the outlet of a pond leveler is left as an unprotected pipe, but in some cases, beaver may notice the water exiting the pipe and can dam on it. If this occurs, the pipe will either need to be extended to be submerged farther away from the dam, or a second cage will need to be placed around the outlet of the pipe in addition to the one on the inlet. A filter can fail when it is not supported and it is located in an area where ponds freeze over in the winter. As the water level in the pond lowers, the ice sheet can crush the filter on the pond leveler to the point where beaver are able to get close enough to the pipe to figure out that water is entering it. This problem can be solved by supporting the cage using t-posts. Pond levelers can also fail if a stream experiences a higher-than-expected sediment load that clogs the device. If this occurs, the sediment will need to be removed from the device, and the device should be put back higher in the water column if possible. As a rodent, beaver have continually growing front teeth. If beaver begin to chew on the pipe, it can be wrapped using 2 x 4 inch mesh fencing. So far this has been documented as a problem in Massachusetts, Oregon, and Washington.

Construction Instructions: [10] [68] [99]

References: [4] [8] [13] [14] [17] [18] [19] [20] [63] [24] [25] [32] [37] [41] [44] [43] [48] [50] [54] [56] [58] [61] [62] [65] [66] [67] [68] [70] [71] [79] [80] [85] [89] [91] [94] [95] [96] [99] [100] [112] [115]

Pipe and Fence System

Beaver exclusion fencing with pipes, combination system, complex wire mesh fences with beaver pipe, culvert fence and pipe, double filters, double filter system, fence and pipe device, flexible pipe and fence system

Photo Credit: Sherri Tippie, Wildlife 2000

Photo Credit: Sherri Tippie, Wildlife 2000

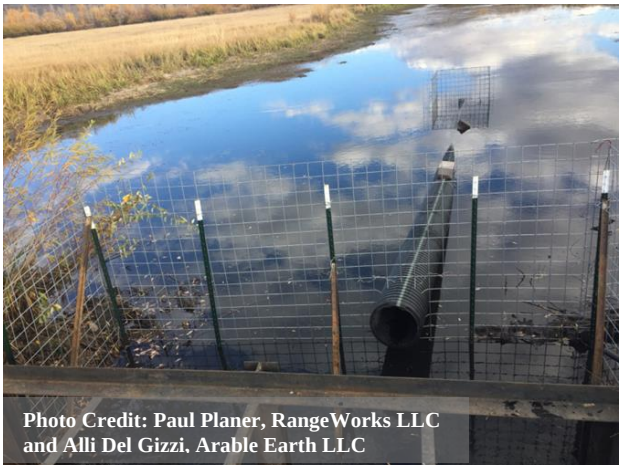


Photo Credit: Paul Planer, RangeWorks LLC and Alli Del Gizzi, Arable Earth LLC

The pipe and fence system is designed to keep water moving through a culvert and prevent culvert plugging in situations where a culvert fence alone is ineffective. The pipe and fence system consists of two parts: the fence and the pipe. First, a fence ~20ft long is placed around the culvert upon which beaver will continue to dam. This fence is designed to act as a starter, or diversionary, dam. Second a pipe is placed through the fence so that water continues to flow through the dammed fence into the culvert. The pipe inlet is placed ~20ft upstream of the fence and is protected using a filter, or cage. Enough pipes should be used to handle normal flow regimes. In high flow regimes the fence and pipe system should behave similarly to a pond leveler with water flowing over the top of the dammed fence and into the culvert.

The larger the stream system you are in, the larger the device will need to be.

Cost: $-$$

- $350-$750 in materials plus labor for 2-3 people for 2-4 hours [63]
- $3,500 on average for an installation [62]
- $1,500-$2,500 installation cost, plus $350 a year for maintenance on a Mike Callahan installation [83]
- $500-$1,200 on average [70]
- Upper end of $2,000-$6,000 [47]
- Estimated Materials Price = $320 per 20ft section of 12in diameter double walled HDPE culvert pipe, plus $80 per galvanized fence panel, plus $4 a bag for galvanized hog rings, plus $10 for a roll of galvanized steel wire, plus $4 a t-post

Maintenance Requirements: Pipe and fence systems should be checked periodically to ensure that they are still functional. As long as water is flowing through the pipe and there is no sign of beaver damming on the cage around the pipe intake, then no further maintenance is required. The cage around the intake pipe should be periodically cleaned of any debris should any accumulate. If beaver begin to dam around the pipe intake, then the device may require tweaking. Damming around the fence is to be expected. On average, flow devices should be checked twice a year, depending on the flow regime and debris loads of the stream they are used in. The higher stream flow is and the more debris that a stream typically carries, the more frequently a device will need to be checked. Flow devices should be checked right after the high flows from spring runoff die down. Typically cleaning a flow device takes less than one hour.

Effectiveness and Reasons for Failure: Flow devices work every time as long as you are willing to upgrade or tweak them if something goes wrong. Flow devices are highly effective. Trained professionals have had devices installed for years without overall failure so long as they were allowed to tweak the devices a little when problems were encountered. Pipe and fence devices can fail if no filter is placed around the end of the pipe, or if the filter is too small and beaver are able to sense water entering the system and successfully plug it. Pipe and fence devices can fail if the pipe is not large enough to carry the desired amount of water. Pipe and fence devices can fail if placed in a publicly visible area and there is no explanatory signage. A ‘helpful citizen’ may mistake the device for a dam that needs to be removed. In some places pipe devices can be damaged by beaver using the pipe to chew on and wear their teeth down. As a rodent, beaver have continually growing front teeth. If beaver begin to chew on the pipe, it can be wrapped using 2 x 4 inch mesh fencing. So far this has been documented as a problem in Massachusetts, Oregon, and Washington, but not in more arid states like Colorado.

Construction Instructions: [9][99]

References: [4] [8] [14] [17] [18] [20] [63] [32] [41] [43] [44] [61] [62] [70] [71] [91] [94] [95] [96] [99] [112]

Other Beaver Management Techniques

Beaver Dam Analogs (BDAs)

AquaDams, artificial beaver dam, beaver fence, beaver mimicry, beaver mimicry restoration, culvert diversion dam, dam analogue, deep water fence, diversion dam, diversionary dam, pre-dam, simulated beaver dam, starter dam

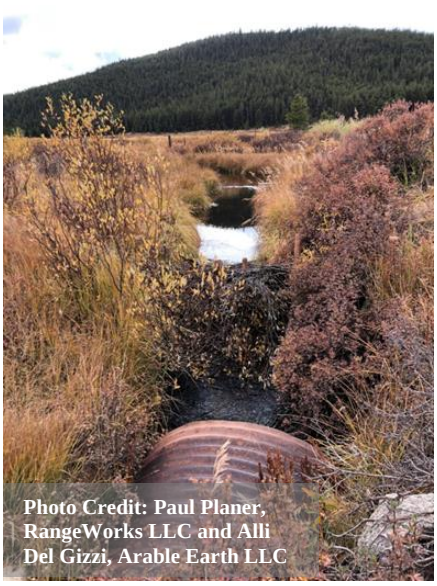


Photo Credit: Paul Planer, RangeWorks LLC and Alli Del Gizzi, Arable Earth LLC

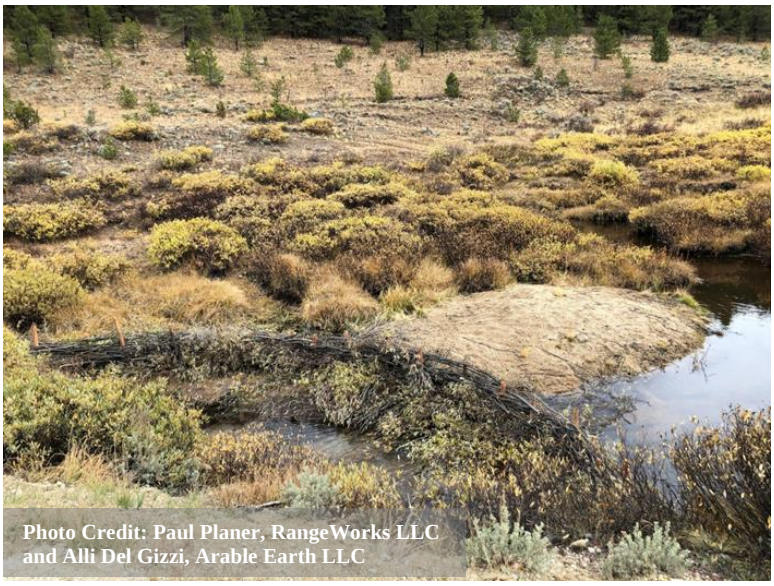


Photo Credit: Paul Planer, RangeWorks LLC and Alli Del Gizzi, Arable Earth LLC

A beaver dam analog or starter dam is any structure which mimics the behavior of a beaver dam when placed across a stream channel. BDAs slow or partially block the flow of water, creating small ponds. BDAs should not be used in areas where there is no beaver or no intent to have beaver, as the purpose of a BDA is to encourage beaver to return to an area and begin damming on top of the BDA. The most common form of BDA is wooden posts driven vertically across a stream with willow branches woven in between the posts to block the stream channel. BDAs can be used to encourage beaver to dam where you would like them to, such as 100ft above a culvert, rather than a nearby location where you do not want them damming.

A subcategory of BDAs are diversionary or starter dams. A diversionary dam is a fence or series of posts placed in a location where you want beaver to dam, such as the fence within a fence and pipe system. Diversionary dams do not necessarily act as a full dam. Instead, they may be a structure placed near a water flow to act as a diversion. Typically, full starter dams are placed 4-6ft in front of a culvert in an area where damming can be accepted. Then, when beaver dam on the starter dam, they will not dam the

culvert. This is because it is only advantageous for beaver to dam if their dams are a certain distance apart. If the dams are too close together then they will not create the ponding the beaver desire. Thus, beaver will not build two dams right next to each other and will not dam on the open culvert right next to the starter dam even though it is accessible. In most high flow events, water will overtop the starter dam and continue through the culvert unimpeded. Starter dams should primarily be used in areas with a low gradient and willowy habitat so that in the rare event that the starter dam blows out, the debris will pass easily through the culvert.

If pounding the posts in by hand, a single BDA can take a 4-6 person crew a single day to install. This time may be significantly decreased when using a hydraulic or gas-powered post pounder. The woven part of the BDA does not need to be compacted very tightly. Beaver will still dam on a porous BDA.

Cost: $

- $50.89 per linear ft. including materials, labor, and maintenance, this is the equivalent of roughly $500 - $1,500 per 10-30ft BDA [100]
- <$1,000 per starter dam [47]

Maintenance Requirements: None. BDAs are intended to be temporary structures on the landscape that are either taken over by beaver or washed away over time. If BDAs are used as a part of a mitigation or restoration project, they should be monitored for beaver activity and habitat improvement over time.

Effectiveness and Reasons for Failure: BDAs or starter dams are effective when installed in the correct location to discourage damming on a culvert, but not risk flooding the road. BDAs can fail if the posts are not pounded deep enough into the substrate and they are blown out by a high flow event. Starter dams can fail if they are placed far enough away from the culvert that beaver see damming both the culvert and starter dam as advantageous.

Construction Instructions: [9] [26]

References: [8] [14] [41] [47] [42] [44] [54] [74] [102]

Culvert Guard

Beaver screen, culvert grate, culvert grills, culvert outlet installations, culvert protector-cleaner, exclusion screen, exclusion tool, fence guard, grate, metal grate, pitchfork guard, removable pull rod grill, trash rack, wire-mesh guard

Photo Credit: Tim Funk, Colorado Department of Transportation

Photo Credit: Alissa Salmore, Idaho Transportation Department

Culvert guard is any grating, metal rod, or chain system that is placed vertically in front of a culvert to catch debris. Typically, culvert guard is designed to catch large natural debris or human created trash that may be present in a stream. It is not designed to prevent beaver from damming on a culvert. In some cases, culvert guard can encourage beaver activity, as beaver can use the existing structure to build their dam on top of. Culvert guard is completely ineffective at preventing beaver from damming up a culvert, but it is effective at preventing damming within the culvert. It physically prevents beaver from building within and plugging the culvert. Instead, the beaver build on top of the culvert guard, where cleaning is safer for maintenance personnel.

Cost: $-$$

- Estimated Materials Price = $100 per square meter of metal grating
- $800-$20,000 for a trash rack, $5,000 on average for a 48in culvert [27]

Maintenance Requirements: Culvert guard must be regularly inspected and cleaned any time a sufficient amount of debris builds up, preventing water flow into the culvert. In systems with active beaver this can be as often as a culvert requiring cleaning every day as beaver build on the culvert overnight. Depending on the size of the culvert this, cleaning may be done by hand or using a backhoe or other similar machinery.

Effectiveness and Reasons for Failure: Culvert guard is highly effective at preventing beaver from damming inside of culverts which makes cleaning easier. Cleaning a beaver dam from inside of a culvert can be both time consuming and dangerous, while cleaning a guard is much simpler. However, culvert guard does not prevent beaver from damming and blocking the culvert and thereby continuing to cause flooding problems. In some cases, beaver may treat the culvert guard as scaffolding for their dam, building on the culvert guard and completely blocking the culvert. Additionally, culvert guards may also collect debris even when beaver are not present. Culvert guard may fail if the heavy machinery used to clean off the guard gets stuck on the device, ripping it out or otherwise damaging it. Removable culvert protective structures, or those with movable parts, can fail, causing more problems than a secured mesh, if they are used incorrectly. For example, a pull-rod grill can result in the debris previously caught on the grill falling into the culvert and plugging it.

References: [13] [14] [23] [40] [41] [44] [71] [94] [95]

Dam Removal

Dam breaching

Photo Credit: Gabriel Cosyleon, Colorado Department of Transportation

Photo Credit: Gabriel Cosyleon, Colorado Department of Transportation


Photo Credit: A still image taken from a video by Gabriel Cosyleon, Colorado Department of Transportation

Dam removal is the process of mechanically removing a beaver dam from a stream channel or culvert. Dam removal is most commonly done either by hand or using heavy machinery. However, dam removal can also be done using explosives. Mechanical removal typically involves the use of a backhoe or trash hook, although other types of large machinery can be used.

In most cases, dam removal alone is highly ineffective, as beaver can rebuild a dam as quickly as overnight. Typically, beaver can even rebuild a dam that has been removed using explosives in one to two weeks. Dam removal can be effective in some cases when combined with lethal control or relocation. However, in most cases, even with trapping and removal, beaver will return to a favorable location within 1-5 years. Additionally, dam removal can exacerbate beaver problems, as removing a beaver dam encourages beaver to fell more trees to rebuild the dam.

In some cases, explosive dam removal has been used by USDA Wildlife Services to create a long-term beaver solution for a short stretch of stream. By adjusting the amount of explosives used, the stream bed where the dam was located can be slightly widened at the dammed location. This encourages the beaver to move slightly up or downstream to where the channel is narrower and easier to dam. However, this is

only effective for small areas and should be used for situations where there is an approximately 100-yard stretch of stream where beaver cannot be tolerated, but beaver are welcome in the area otherwise. Additionally, this technique of explosive dam removal can only be conducted by an agency such as Wildlife Services that conducts their own NEPA process. **Re-channeling the streambed is illegal without a Clean Water Act Permit, and ownership of the appropriate water rights.** Additionally, explosive dam removal is illegal on some public lands. However, explosive dam removal can also be the preferred technique in some situations because of its minimal footprint. Setting explosives does not run the risk of damaging nearby riparian vegetation in the same way large machinery would and makes it easier to avoid walking across nearby properties that would require permissions to enter.

In some states, including Massachusetts and Montana, additional permits are required when removing a beaver dam. These permits are based on wetland or stream protection policies as water and sediment surges after dam removal can impact streams and wetlands below and around the beaver dam. There is currently no similar requirement in Colorado. In some cases, it may be preferable to breach a dam incrementally to mitigate some of the water and sediment surge that occurs when a dam is completely removed. Both the rapid drop in water and the water and sediment surge can damage nearby wetlands and other ecologically sensitive area. If possible, breaching of a large dam should be done incrementally over the course of a day, or longer, at the same time as a flow device is put in or the beaver are removed, in order to maximize the amount of time the stored water has to slowly move downstream. Lowering the water level behind a dam by no more than one foot a day can help minimize erosion and other damages caused by releasing impounded water. Water levels can also be lowered using a siphon prior to dam removal.

Cost: $

- $3000 for both explosive dam removal and trapping [29]
- 1 hour of labor per week for maintenance to clean a single culvert [40]
- Up to several days may be needed to clean a single culvert by hand if it is not regularly cleaned and gets completely plugged [57]
- 20 minutes of labor per day for each clogged culvert when removing the dam using a backhoe [49]

Maintenance Requirements: Locations where a dam is removed must be checked every few days to a week as beaver will often dam them again overnight and the location will require additional cleanings/ removals.

Effectiveness and Reasons for Failure: Dam removal is ineffective as a long-term beaver management technique. Dam removal can provide temporary relief of flooding problems in some scenarios. However, as long as the beaver remain in the area and no other management is done, beaver will rebuild a dam that has been removed as quickly as overnight.

References: [29] [34] [37] [40] [41] [48] [56] [85] [88] [96] [111] [112] [113]

Education

Education can be conducted in many forms including word of mouth, interpretive signs, educational programs, and webpages. While education does not directly impact beaver management, educating the

public and landowners about beaver, their benefits, and their ecology can be one of the most powerful tools when it comes to helping people coexist with beaver on the landscape. Education can be especially important in areas where beaver have recently been reintroduced as it can help to avoid conflict among stakeholders in the area.

It is important to inform maintenance teams about the many options surrounding beaver management so that they are aware of the whole toolbox, rather than using the same fairly ineffective "tool" of trapping over and over. When people are informed of all of the options, they are more prepared to address any issues that come up. Maintenance staff are the most knowledgeable about their section of the road, so if they have all of the information about what strategies can be used, they will be able to say which should work best for their situation. When maintenance staff in CDOT Region 5 were given a presentation about flow devices by Malcom McLeod, one of the maintenance staff then approached Tim Funk about a location where a culvert was continually being blocked by beaver activity and they believed a flow device would work well. Many people are unaware of coexistence techniques as trapping is all they have experience with. But they are willing to try them once they are informed, especially when techniques are low-cost and cost-effective, as flow devices typically are.

Education is also important for overcoming the preconceived idea that flow devices always fail. People will often try to build a device with poor quality materials and no knowledge of beaver biology, because they saw a picture of one online. They may even use the wrong type of device for the situation. Those devices often fail, causing suspicion toward the devices as a whole.

Education works best when it is peers telling each other about these devices. A rancher will trust another rancher who is their neighbor much more than a beaver advocate. The same thing applies with maintenance. Maintenance technicians will trust other maintenance technicians more than someone working for environmental when they say that flow devices can work.

Most Colorado Parks and Wildlife district wildlife managers are happy to provide education/consultation for anyone who calls. Colorado Parks and Wildlife can recommend strategies like relocation over kill trapping, but they cannot require it.

Sherri Tippie believes very strongly in educating everyone about beaver. She is willing to help educate anyone who reaches out to her on everything about beaver. When people understand what beaver do they are less likely to want to get rid of them.

References: [6] [63] [40] [47] [62] [69] [84] [85] [93] [98] [99] [111] [116]

Exclusionary Fence

Animex fencing, exclusion fence, guide-fence, guide-wall systems, silt fence

Exclusionary fence is typically plastic fencing or silt fencing that is too tall for a beaver to climb over. The fencing is then placed along the edge of the roadway in such a way that beaver cannot enter the roadway, but there are exit points where they can leave the roadway if necessary. An escape or jump out may consist of wood pieces stacked and stabilized with sandbags, or gravel fill if the fence is located below the road on a steep slope. The fence is intended to direct beaver and other animals, such as turtles,

to walk along the fence until they reach a culvert or other crossing structure rather than crossing the road itself. This technique has been used in areas where reptile roadkill is a concern and beaver are present.

Cost: $

- $5-20 per linear foot of silt fencing [27]

Maintenance Requirements: Exclusion fencing will need to be repaired any time the fence is damaged. This may include reburying the edge of the fence, replacing broken posts, or reconnecting seams in the fencing.

Effectiveness and Reasons for Failure: Exclusion fence is effective at reducing the amount of roadkill in an area, but no system will prevent 100% of all animals from entering the roadway and being subjected to roadkill. Exclusion fencing can fail if there are any gaps in the fencing that allow animals to pass through and become subjected to roadkill. Exclusion fencing can fail if there are insufficient jump outs along the fencing as animals can overheat and die if exposed for too long walking along the roadside of the fencing.

References: [44]

Non-Lethal Trapping and Relocation

Live trapping, live trapping and relocation, reintroduction, relocation, translocation

Beaver relocation is a system where beaver are trapped using a suitcase style live trap at a donor site and then transported in cages to a new location where beaver are wanted. Relocation requires a permit from Colorado Parks and Wildlife and can only be done during certain times of year. Typically, the season in which beaver can be trapped spans from when kits first leave the lodge around the time of spring green-up until mid-August. Beaver relocated later than mid-August will likely not have enough time to build a dam complex and food cache large enough to survive the winter.

Effectiveness of trapping and relocation at fixing beaver problems at the beaver removal site is the typically the same as lethal trapping. It depends on how close a location is to a source population, the size of the river system, and quality of the habitat. In many cases, if there is good habitat, dispersing beaver may return to the site within a year, although some areas may see a reprieve for up to 5 years. Trapping may be a more permanent solution only when the habitat quality in an area is poor.

Beaver typically survive relocation no more than 50% of the time at prepared sites. Typically, 30% is the highest survival rate seen with relocated beaver. At unprepared sites beaver survival may be as low as 10% as beaver are more exposed to predation risks on land than in the water. Prepared sites are unoccupied and have either a pre-existing beaver dam where the population disappeared, or at least one beaver dam analog installed so the beaver has access to deep water to escape predators. There should also be abundant food available at relocation sites for the beaver to access. Beaver will only colonize a new area if it has all of the components they need to survive: water that's deep enough to swim in at least part of the year, food source, and source of building materials. If these are not all present, reintroduction will fail, the beaver will move elsewhere or die. This is why you should generally place beaver dam analogs in an area before introducing beaver. This is one of many considerations when it comes to relocating beaver that cannot be ignored for relocation to be successful. Additionally, when possible, beaver should always be transported with their entire colony. This may mean that the first beaver caught will have to be housed and cared for for up to two weeks before the entire colony is caught. Never mix beaver families. Also know that some beaver may not be cleared for relocation due to disease concerns in certain drainages. The primary concern in Colorado is tularemia. For even more considerations for correctly setting a trap and live-trapping beaver see: [99].

Any relocation in Colorado requires a Colorado Parks and Wildlife permit. Most of the time Colorado Parks and Wildlife is ok with relocations as long as you have a plan in place and there are no disease (Tularemia) concerns. A permit from Colorado Parks and Wildlife requires: good beaver habitat where they are likely to survive, landowner/manager agreement to take the beaver, no disease concerns be present, and a date of relocation between spring green up and mid-august. Colorado Parks and Wildlife doesn't usually do relocations because they are too busy, but Wildlife Services will. You can usually find someplace to relocate beaver as long as you have good communication with your public lands managers (they want to rehab drainages, etc.) However, relocation is usually cost prohibitive compared to lethal trapping due to the additional transportation and labor costs it incurs. Additionally, live trapping can be delayed by waiting for a permit while kill trapping can be done right away. It typically takes 1-2 weeks of trapping to trap a whole colony of beaver, but an individual may take 1 day -1 week. During that time traps must be checked at least once a day and are typically removed or shut during the day. Additionally, beaver have a great homing instinct so they must be relocated outside of the drainage that they were caught in or they will find their way back. Beaver can travel up to 60 miles to get home. An example of this is when Sherri Tippie and Mark Lamb once caught a beaver that then escaped from her backyard and made its way back to its home 24 miles away on Bear Creek, presumably through the stormwater sewers to the Platte River and then back to Bear Creek.

Because beaver populations are increasing across the United States, it is currently getting more difficult to find places to relocate beaver to. However, because Sherri Tippie has been the face of beaver relocation in many news outlets, she gets people reaching out to her because they want beaver. If relocation is an option for a site, you can reach out to Sherri to potentially find a location that will take the beaver.

The only time you should be live trapping and relocating beaver is when they would be on the equivalent of death row otherwise.

Cost: $

- Approximately $70 an hour including all transportation time from where the beaver are trapped to where they will be relocated [34]
- More expensive than lethal trapping because of additional labor to relocate.
- Wildlife 2000 charges $340 a beaver [98]

Maintenance Requirements: Traps must be checked daily when they are in use, and in many areas traps must be removed during the day and re-set the following night.

Effectiveness and Reasons for Failure: Live-trapping and relocation has the same effectiveness as lethal trapping so long as beaver are moved into a different watershed. If the beaver are moved within the same watershed they can find their way back, making the removal ineffective. Beaver removal is ineffective as a long-term solution. If an area has good quality habitat, beaver will find their way back in 1-5 years. Relocation may be effective at relieving the beaver problem temporarily.

Live Trapping and Relocation Instructions: [99]

References: [4] [23] [28] [29] [34] [37] [41] [43] [45] [47] [54] [55] [58] [63] [64] [69] [71] [79] [80] [89] [95] [98] [99] [115] [116] [117]

Oversized Culvert

Multi-culvert, oversizing, Resilient Crossings

Oversizing is the practice of purposefully installing a culvert that is larger than that predicted to carry the expected flow of water within a drainage. An oversized culvert often will carry the entire width of a stream or more during normal flow levels so there is no constriction in the stream. This will encourage beaver to dam elsewhere on the stream as there is no attractive constriction in the water encouraging them to dam at the culvert. Oversized culverts or replacement structures should be a minimum of 1.5 times the width of the active channel. Oversizing is effective most of the time, but there can be situations where oversizing fails. For example, the Idaho Transportation Department had a location where they installed a bridge on a road that passed through a marsh where there had been beaver activity, and the beaver just created a wider dam. In general, beaver problems occur when beaver habitat intersects infrastructure that is poorly designed for the area. By using small bridges instead of multiple culverts in these areas there will be fewer beaver problems.

Multi-culverts can also be considered oversizing. A multi-culvert contains several culverts, typically three culverts all sized to carry the entire flow of the stream or drainage, spaced slightly away from each other. Thus, if beaver block one of the culverts the other(s) will still carry the stream flow until the first can be unblocked.

It typically does not make financial sense to replace culverts with an oversized culvert or small bridge solely because of a beaver conflict. However, oversized structures should be considered when these

sections of roads need significant repairs, or when building new roads through areas that are known to have beaver activity and/or very high-quality beaver habitat. Oversized culverts can also act as wildlife crossings.

Cost: $$-$$$

- Bridge materials: $8,000-$2,000 per square foot of bridge deck plus $6,000-$86,000 per linear foot of girder [27]

Maintenance Requirements: An oversized culvert or bridge should require the normal amount of maintenance for a structure of its size. This should be the same, or in some cases, less maintenance than the original culvert in the same location. The oversized culvert will need to be periodically monitored for beaver activity at the same rate as routine culvert maintenance for culverts unaffected by beaver.

Effectiveness and Reasons for Failure: Oversized culverts are effective most of the time at preventing beaver from damming at a location, but they are not 100%. Occasionally, a location will still be attractive to beaver for damming even when the stream is no longer constricted by the original culvert.

Construction Instructions: [39]

References: [29] [39] [41] [51] [60] [84]

Tree Painting

Abrasive tree paint, Textural repellent

Abrasive tree paint is a mixture of latex house paint and playground or construction grade sand. The sand and paint mixture is then painted onto trees from the base of the tree to 4ft up the trunk making sure to completely coat the surface. Abrasive tree paint should only be used on trees with a minimum diameter at breast height of 8 inches as it can affect the growth of saplings with a trunk diameter that is smaller than 8 inches.

Abrasive tree paint deters beaver from chewing on painted trees so long as there is sufficient other food and building materials available nearby. Abrasive tree paint is a deterrent, not a preventative measure, as beaver can chew through it. However, beaver will choose not to chew through abrasive tree paint if there are sufficient alternatives nearby, as it is uncomfortable for them to do so. As such, tree painting works best when there is only a subset of trees in an area you wish to protect, such as painting healthy, native trees and leaving unhealthy and non-native trees available to the beaver. Tree painting should only be used when some tree loss is acceptable. When possible, approximately 1/3 of the trees in an area should be left unpainted as beaver still need to fell some trees for food and lodge/dam maintenance.

For aesthetic reasons the color of the paint used should closely match the color of the tree bark on which it is being applied. This is also preferable as it makes the painting less noticeable to the public.

Tree painting is typically done using volunteers due to the large numbers of trees being protected and the time-sensitive nature of open buckets of paint that can dry out and become unusable. When working with volunteers, a small number of paid staff members can mix the paint, assuring that it is mixed in the correct ratio, approximately half a bucket of sand to one bucket of paint. Volunteers can be given the pre-mixed paint and instructions on which trees to paint to a 4ft height.

There have been some concerns raised about the toxicity of titanium dioxide in house paint to beaver. Due to the small amount of painted bark that beaver would actually consume, it is unlikely that any one beaver would consume enough paint to reach levels of toxicity.

Cost: $

- Estimated Materials Price = $224 for a 5-gallon bucket of outdoor latex paint that will cover approximately 50 yards of stream bank or 10 trees, plus $4 for a 50 pound bag of play sand, enough to mix with several buckets of paint, plus $2 per 4 inch paint brush used.

Maintenance Requirements: Trees should be checked every couple years for damage and may require a new coat of paint as old paint that is damaged or cracked can provide an opening for beaver to access the tree and begin cutting. Typically, trees will need to be repainted every 4-5 years as paint is damaged by UV light and tree growth.

Effectiveness and Reasons for Failure: Abrasive tree paint is highly effective at protecting painted trees when paint is in good condition and a subset of the trees are left unpainted. Tree paint can fail if the incorrect ratio of sand to paint is used. If too little sand is used, beaver will be unfazed by the paint and continue to fell the trees anyway. If too much sand is used, the paint and sand mixture may not stick to the tree or it may crack and fall off. Tree paint can fail if paint is not added in a thick enough layer to achieve the gritty, unpleasant texture that deters beaver from gnawing on painted trees. Tree paint can fail if paint is not applied high enough up the trunk, so that beaver can still reach and gnaw on the unpainted portions of the tree.

Construction Instructions: [7] [101]

References: [7] [23] [71] [75] [79] [80] [85] [88] [95] [96] [112]

Tree Wrapping

Beaver cage, fencing, rigid wire fencing, tree cage, tree exclosure, tree protection

Photo Credit: Sherri Tippie, Wildlife 2000

Tree wrapping is a tree protection technique that prevents beaver from damaging and felling trees. Tree wrapping consists of placing 4ft high, 2x4 inch wire mesh fencing all the way around a tree, leaving several inches between the fence and the tree. The fence cylinder is then secured using wire or heavy-duty zip-ties. When fencing saplings, the fencing may be placed slightly farther away from the tree and secured in place using t-posts.

Tree wrapping is highly effective at protecting individual and small groups of trees. Similar to sand paint, tree wrapping is most effective when some smaller trees are left available to beaver for foraging and use.

Additional notes: Never use chicken wire for wrapping trees against beaver as they can chew through or break it. Also, make sure that there is a sufficient gap between the fencing and the tree to prevent girdling and death of the trees you are trying to protect. Always make sure that the fence is in contact with the ground all the way around the tree so beaver will not go under it. The 4ft height prevents beaver from using snowbanks to overtop the fencing. Groups of trees can be protected by extending the fencing to enclose all trees in a tight group rather than wrapping each tree individually.

Tree wrapping may also protect saplings from other herbivores such as deer in addition to beaver.

Cost: $

- Estimated Materials Price = $120 for 100 ft of 48 inch welded wire utility fabric that will cage approximately 8-12 trees, plus $4 a t-post at 2 t-posts a cage, plus $10 for a roll of galvanized steel wire.

Maintenance Requirements: Tree wrapping should be checked every couple of years to ensure it is still in place and that the trees being protected are not being girdled. If the tree has grown into the fence and is starting to be girdled or is at risk of being girdled, the fencing must be replaced. Fencing should also be replaced if the fencing material has started to deteriorate. In areas with high levels of human activity, tree wrapping will need to be checked more frequently to ensure that the wrapping is still in place and has not been vandalized. If wrapped trees are located inside the active stream channel, they will need to be checked after large storm events as they can catch debris which renders them less effective and aesthetically pleasing.

Effectiveness and Reasons for Failure: Tree wrapping can be nearly 100% effective as it prevents beaver from reaching the tree to cut it down. Tree wrapping can fail if the cage is made too small and tight around the tree as trees may grow into the fencing and become girdled. Girdling, if not remedied in time by removing and replacing the fence, can kill the tree you are trying to protect. Generally, a minimum of 3-6 inches should be left between the fencing and tree trunk. Tree wrapping can fail if the fencing is too short. Generally, 4ft is tall enough that beaver cannot chew the trunk above the fencing. In areas with heavy snowfall, the fence should extend 2ft above the highest expected snow levels to ensure beaver cannot reach the tree trunk on top of the snow. Tree wrapping can fail if the wire used is too flimsy, such as chicken wire, as beaver can push the fence against the tree trunk to continue gnawing at the tree and cause damage, even if they are not able to fully fell it. This can also be prevented by anchoring the fencing using two t-posts. Tree wrapping can fail if the fencing used is not protected from the elements and rusts. Typically, galvanized or vinyl coated fencing will survive the elements better than chicken wire. If the fencing is not flush with the ground, beaver can push the fencing up and access tree, ensure that the fencing is a snug fit with the ground or is anchored with t-posts.

Construction Instructions: [7]

References: [7] [23] [37] [43] [71] [79] [80] [88] [95] [96] [99] [112] [115]

Not Recommended and Uncommon Non-Lethal Beaver Management Techniques

Beaver Pipes

Perforated culvert pipe, perforated fiber pipes, wooden pipes, wood-fiber pipes

Beaver pipes are rigid single-walled pipes placed through a beaver dam meant to allow water to continue to flow through the beaver dam, similar to a pond leveler. Often beaver pipes are capped on the end with perforations along the pipe to allow water in.

Beaver pipes are ineffective most of the time, as beaver are able to figure out how to block small holes in the pipe with sticks, or shovel mud into the device so it stops working. They may also be clogged with natural debris from a stream as the holes are typically too small to pass most debris.

Beaver pipes were an early precursor to pond levelers before filters were added to systems.

Cost: $

- Estimated Materials Price = $500 per 10ft of 12in diameter pvc pipe, plus $200 for a 12in pvc plug

Maintenance Requirements: Beaver pipes require frequent cleaning as they easily get filled with sediment or blocked by debris.

Effectiveness and Reasons for Failure: Beaver pipes are typically ineffective when compared to their successor, pond levelers, as they clog and require cleaning frequently. Beaver pipes can fail if the pipe is not large enough to carry the desired amount of water. Beaver pipes can also fail if they lack an endcap and beaver plug them as they would a culvert.

References: [14][41][94][112]

Beaver Proof Add On

Beaver-proof culverts

The Beaver Proof Add On is a patented design of culvert extension shaped like a T with water flowing into the culvert from the end of the T that is underwater, while the sound of running water is directed out of the top of the T. Beaver can dam over the top of the device without affecting its function. Beaver Proof Add Ons can be purchased in galvanized steel or plastic and should remain functional indefinitely.

The Beaver Proof Add On is reportedly highly effective for any culvert as long as it is installed correctly. It should be noted that the claim of effectiveness comes from a single case study and the manufacturers website.

Cost: $$

- $35,000 install in Alberta, Canada [67]

Maintenance Requirements: None

Effectiveness and Reasons for Failure: Beaver Proof Add Ons are highly effective as beaver can dam over the top of the device without affecting device function. The Beaver Proof Add On can fail if not properly sized for the stream or culvert and/ or if installed improperly. Other reasons for failure are unknown.

References: [11] [67]

Berm

Dyke, mound

Photo Credit: Paul Planer, RangeWorks LLC and Alli Del Gizzi, Arable Earth LLC

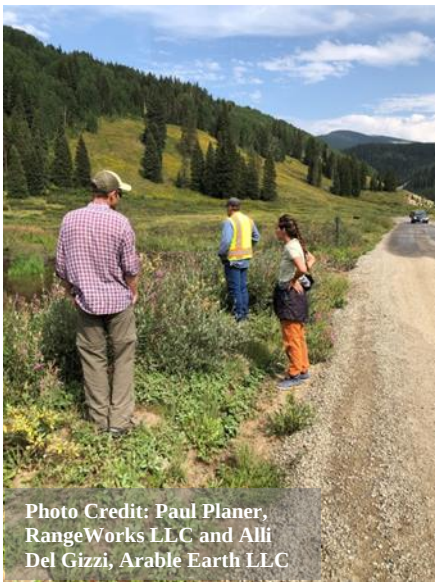


Photo Credit: Paul Planer, RangeWorks LLC and Alli Del Gizzi, Arable Earth LLC

A berm is an elongated mound of compacted dirt placed parallel to a road in between the road and a nearby stream. The berm physically prevents water from a beaver pond from reaching a road and flooding it. Berms are best suited for situations where the height of the beaver pond next to the road is within a few inches of the road surface. Historically berms were used along the sides of dirt roads. Some berms in Gunnison County are close to 50 years old and still effective today. Berms can be made easily using heavy machinery owned by most counties and transportation agencies. Additionally, if there is a beaver pond next to the road and close to the road level, a berm can provide extra security for if the beaver were to suddenly raise the dam height. The berm will prevent water from flooding the highway, buying additional time while another solution to the beaver problem is worked on.

Cost: $-$$

- $9-$24 per linear foot [27]

Maintenance Requirements: Berms can require little to no maintenance for long periods of time, depending on the sediment type they are made of. Any time a section of the berm should fail or wash out, the berm will need to be repaired.

Effectiveness and Reasons for Failure: Berms are highly effective at preventing beaver ponds next to the road from causing flooding. Berms can fail over time due to hydraulic pressures of water on the berm, or due to animals causing a nick in the berm.

References: [32] [47]

Chemical Repellents

Commercial deer repellent, general herbivore repellent, predator odors, repellents, taste aversive tree protection

Chemical repellents are any chemical compound or mixture that is used to deter beaver from using an area or eating vegetation. Chemicals that have been used include commercial large herbivore repellents, castoreum placed in imitation scent mounds, and oil infused with cayenne pepper.

In some cases, chemical repellents have been used to reduce the palatability of certain vegetation types, but results do not last long as chemicals wash away and degrade in the environment. Chemical repellents are not effective at deterring beaver from building dams in an area.

Most of the time castor is used as a lure for beaver in traps, as beaver are territorial and will investigate, thinking it is an intruder in their territory. However, in some situations where dispersing juvenile beaver have just set up shop in an area with marginal habitat, they may think it is more mature beaver in the same area and they will move along, not wanting to get into a fight.

Cost: $

- Estimated Materials Price = $30 a bottle for deer repellent, $6-$10 for a bottle of vegetable oil and cayenne pepper, and $8 a bottle for beaver lure

Maintenance Requirements: Chemical repellents must be reapplied frequently; the exact interval is determined by weather patterns in an area and the repellent being used, but results rarely last more than a week.

Effectiveness and Reasons for Failure: Effectiveness of chemical repellents depends on the type of repellent being used. Generally, repellents that are applied directly to trees to prevent tree felling are more effective than repellents meant to make beaver avoid an area entirely. Repellents can fail if not applied frequently enough, as beaver will return or begin taking trees once the repellent has worn off. In some cases, thin-barked trees have died as a result of being painted with cayenne pepper infused oil.

References: [7] [37] [95] [96] [117]

Culvert Blocks

Culvert blocks are wood board or metal sheets placed in front of a culvert to slow water flow enough that beaver are not tempted to dam the culvert. The slight gaps between the boards allow water through at a trickle. In some cases the boards may also be perforated. Culvert blocks can only be used on very low velocity streams with low flow rates at least part of the year. These blocks are removed during periods of high flow.

Cost: $

- Estimated Materials Price = $15 per 8-12ft wood board depending on wood type and thickness

Maintenance Requirements: Culvert blocks must be removed during high flow periods.

Effectiveness and Reasons for Failure: Effectiveness of culvert blocks is unknown. Culvert blocks can fail if they are placed in a stream that is too large or fast so that either the water coming through the boards is enough to be noticeable, or the boards blow out entirely.

References: [71]

Culvert Extensions

Beaver baffler, Beaver Stop, cone-shaped extension cages, cylindrical extension cages, cylindrical fences, enlarged cylinder, exclusion device, exclusion tool, horizontal cylindrical wire mesh beaver guard, vertical cylindrical wire mesh beaver guard, wire mesh basket

Photo Credit: Nick Gerich, USDA Forest Service [41]

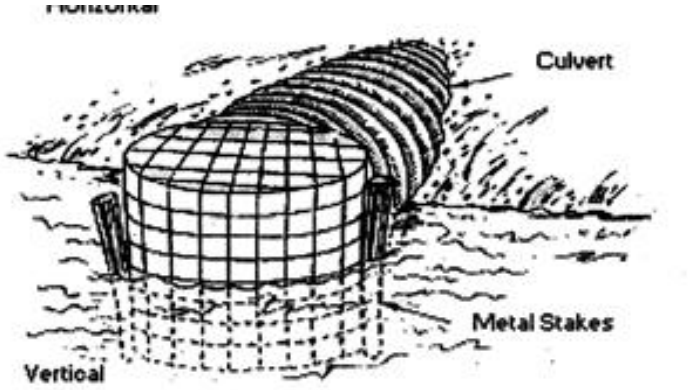


Photo Credit: Nick Gerich, USDA Forest Service [41]

Culvert extensions are devices made of permeable materials that 'extend' the culvert inlet. Many culvert extensions designs are similar to flow device filters in construction. Wire mesh or fencing is shaped into a cylinder with the same diameter as the culvert it is attached to. Thus, the culvert extension increases the inlet surface area and number of directions through which water can flow into the culvert.

Most culvert extensions are ineffective as beaver can still sense the water flow through them and will dam over them, in them, or fill them with mud, just as they were previously doing with the culvert. If the diameter of the culvert extension is the same as that of the culvert it is protecting, the culvert extension will act like a culvert guard and require cleaning as frequently as every day. Culvert extensions are most effective when placed on small culverts where the diameter of the extension is three times the size of the culvert pipe diameter. The greater size of the extension may move beaver away from the feel of flowing water and make it easier for debris to pass through the device. In addition to the culvert extension on the culvert inlet, a mesh screen or secondary culvert extension should be placed over the culvert outlet of culverts >6 inches to prevent beaver from entering the culvert that way. A secondary culvert extension may help small debris pass through the culvert more readily than the mesh screen.

Culvert extensions may be effective for some situations. However, the situations for which a culvert extension would be used are typically similar to culvert fencing, and culvert fencing is preferred during high flow events where debris may get caught on the culvert extension but flow over the top of a fence and through the culvert. If debris is not regularly removed from the culvert extension, the device may clog and cause flooding during high flow events, even without beaver present.

A culvert extension can be built by a single person in one hour.

Cost: $

- Estimated Materials Price = $300 per roll of fencing, plus $4 a t-post, plus $10 per roll of galvanized steel wire.

Maintenance Requirements: Just like culvert fences, culvert extensions must be periodically inspected and cleaned whenever sufficient debris has accumulated to the point that it blocks water flow. This can be once a day or once a month depending on the size of the stream, the amount of debris in the stream, and the size of mesh used to construct the extension.

Effectiveness and Reasons for Failure: Effective for small culverts where the extension can be built with a diameter three times that of the culvert. Ineffective elsewhere as culvert extensions can easily clog with

debris. Culvert extensions may fail even when built large enough if they are made with a mesh that is too small for debris to readily pass through, causing the device to clog, or that is too flimsy to hold up to storm events, causing the device to be crushed. Culvert extensions should be built using similar materials to culvert fences - heavy gauge wire mesh with 4x4 or 6x6 inch openings.

References: [14] [18] [37] [41] [71] [91] [94]

Culvert Wing Extension

Culvert wing extensions are added wings, or flat surfaces, that broaden the streambed at the exit of a culvert. These areas are cleared of any debris such as rocks, or even willows. Widening and smoothing the area beyond the culvert makes it less attractive for beaver to dam just below the culvert. Beaver will typically dam at the end of the wing extensions away from the end of the culvert. This helps prevent beaver from backwatering through the culvert, especially in situations where the culvert inlet has been protected and beaver may find damming downstream to be attractive.

Cost: $$

- $10,000-30,000 per acre for packed dirt culvert wing extensions [27]
- $85 per square foot for pre-cast concrete culvert wing extensions [27]

Maintenance Requirements: Unknown.

Effectiveness and Reasons for Failure: Culvert wing extensions are effective some of the time. Culvert wing extensions can fail if beaver decide to dam the culvert despite their presence. Culvert wing extensions can also fail if they are not long enough and a beaver damming at the end of the extensions still causes problems to the roadway.

References: [12] [112]

Electric Fence

Electric barriers, electro-shocking device

Electric fence can be used to deter beaver when placed 4 inches above the ground around areas you do not want beaver to access. Electric fence requires a power source such as a solar panel. Electric fence may be desirable in areas where aesthetics are important as it is less noticeable than many other beaver management tools. Electric fence is primarily used for tree protection, as most electric fence devices cannot be used in/around water and those that are designed for water cannot be used outside of the water, making them impractical for culvert protection.

Cost: $

- Estimated Materials Price = $160 for a solar energizer and wire

Maintenance Requirements: Electric fence should be monitored frequently to ensure that it is still functioning and repaired or replaced should it stop functioning. In some cases, the fence may need to be moved slightly if beaver have found a way around it.

Effectiveness and Reasons for Failure: Electric fence is sometimes effective when beaver cannot find an alternative route to avoid the device. However, there are numerous ways in which electric fence can fail. Electric fence can fail if beaver find a route around the device. Electric fence can fail if the power source fails, such as a solar panel being covered by dirt or debris, or batteries running out of power. And electric fence can fail if the wire is disrupted in any way such as by vandals, by other animals, or by branches or other vegetation falling on the wire and shorting it out.

References: [7] [71] [96] [112]

Frightening Devices

Beaver deterrent

Beaver deterrents, or frightening devices are any device meant to scare beaver away from a site. These include devices that make loud noises or flash lights. These devices can also include simple structures such as a sheet tied between two t-posts that flaps in the wind creating noise and motion.

Beaver deterrents are typically only effective for a very short period of time, usually no longer than two weeks, as the beaver quickly get habituated to the deterrent. Beaver deterrents can be effective at keeping beaver away from a site while another structure such as a flow device is put in or if you only need the beaver to not construct a dam for a week during a high flow period. In order for a deterrent to be effective long-term, it has to be constantly changing and as multi-faceted as possible. If you can design a device that flashes lights at different locations and at differing intervals in addition to playing a variety of sounds in a random order, then you can successfully deter beaver from entering an area you don't want them. If a plastic owl or coyote is used as a part of your multi-faceted deterrence device, then it should be moved every one to two days. Beaver will ignore any unmoving object as they have poor eyesight, and to them if an object does not move, it is likely not a threat.

Cost: $

- Estimated Materials Price = $20 - $500 for a rotating beacon light, some versions also produce sounds

Maintenance Requirements: Beaver deterrents must be moved frequently from one location to another within the area beaver are being kept out of. If electronic devices are used, they will need to be checked periodically to ensure both the device and power supply are working properly. This may include changing batteries in the device.

Effectiveness and Reasons for Failure: Typically, beaver deterrents are highly effective at short-term prevention against beaver entering an area, but highly ineffective at long-term prevention of beaver problems. Beaver deterrents can fail if the deterrent is not changed over time. Beaver quickly become accustomed to any noise or light that is repetitive and will ignore it.

Construction Instructions: [79] [80]

References: [60] [71] [79] [80] [89] [96]

Logger's Road Crossing

Dip, low water crossing, spillway

A logger's road crossing is a low point across a road where water is allowed to flow over the road, especially during high flow periods. The crossing may be reinforced using coarse gravel, riprap or logs so that water flowing over the road causes little damage. This technique is typically used on backcountry forest roads which see a low number of vehicles annually. As the water is allowed to flow over the road in these locations, the stream is not constricted the same way it would be with a culvert, thus decreasing the likelihood that beaver will choose to dam on the road itself. A logger's road crossing may also be placed in an area where protected culverts are the primary method of water conveyance. In these areas the crossing is a backup in case the culvert fence becomes plugged due to lack of cleaning, then water can still safely cross over the road.

Cost: Unknown

Maintenance Requirements: As long as there is no beaver activity on the road, this method, when used in the backcountry, requires little to no maintenance. The road crossing should still be checked occasionally for any erosion that beaver activity may cause in the area.

Effectiveness and Reasons for Failure: Logger's road crossings can be effective in certain situations, but they do not work with heavily traveled or paved roads that would suffer from roadbed saturation issues. Logger's road crossings are typically built into unpaved roads. If they are used on paved roads there may be issues with roadbed saturation and surface cracking.

References: [41][112]

Partial Dam Breach

Notching

Notching a dam is the creation of a small hole, or notch in the dam, allowing water levels to drain without removing the entire dam.

Can be effective for short periods of time when combined with a beaver deterrent.

Cost: $

- Can often be done by hand with no tools, a potato hoe (Estimated Material Price = $50), or whatever simple hand tool is readily available. Thus, can typically be done for only the cost of labor.

Maintenance Requirements: Similar to dam removal, dam notching needs to be checked frequently and redone if beaver remain in the area, as beaver can fill in the notch overnight.

Effectiveness and Reasons for Failure: Notching is effective when only temporary relief is required or in areas where beaver have been removed but one does not want to release the entire amount of water stored by the dam at once. In these situations, the worst of the beaver flooding can be alleviated while the rest of the dam stays in place, preventing sediment surges downstream that would result from a full dam breach. Notching can easily fail if beaver are not removed from the area and no deterrent is used as they will rebuild the dam in a single night. Additionally, even if a deterrent is used, beaver can become acclimatized to the deterrent within days or weeks and ignore it in favor of repairing the notched dam.

References: [79] [80] [89] [115]

Piping

Piping is the use of pipes to convey irrigation water rather than ditches. If an irrigation ditch along the side of the road, or elsewhere, is continually being dammed by beaver pipes may be used to convey the water instead. Pipes can be laid inside of the ditch and used to carry water more efficiently. Pipes prevent beaver from accessing the water to dam and water loss to the environment. Pipes are also safer in areas where there may be children present.

Cost: $$

- Estimated Materials Price = $800 per 20ft of 24in culvert pipe, price will vary depending on size of pipe needed to convey flow

Maintenance Requirements: Unknown

Effectiveness and Reasons for Failure: Piping is highly effective at preventing beaver from damming irrigation water. Reasons for failure are unknown.

References: [47]

Raising the Roadbed

Lifting the road

Raising the roadbed involves adding material to or moving a road so that it sits higher than the level at which a beaver pond would affect the road. This technique would be used when a road runs through the bottom of a valley and experiences chronic road damage from roadbed saturation by beaver ponds. This technique would typically be used when a road both dips and is already in need of repairs, so raising the roadbed could be covered in the scope of those repairs. Thus, raising the roadbed occurs when areas of concern for the road are matched with areas where there are beaver conflicts.

Cost: $$-$$$

- $10,000-$30,000 per acre for clearing and grubbing costs plus $60-$130 per ton of asphalt [27]

Maintenance Requirements: After the roadbed has been raised, no additional maintenance on the road is required. The road will still have the same maintenance requirements as any other road of the same type.

Effectiveness and Reasons for Failure: Highly effective, especially in circumstances where the road is moved up a hill. This technique can fail if the roadbed is not increased or moved far enough from its previous position and is thus still affected by beaver activity.

References: [32] [41] [60]

Sterilization

Fertility control

Sterilization is a process by which beaver are caught using live traps, made infertile, typically through surgical means, and then re-released into the wild. This is primarily a population control method and not a damage control method.

Sterilization is almost completely ineffective as a damage control method and is impractical at a landscape scale. Sterile beaver still maintain dams and mark/protect their territory so new beaver do not enter the territory. Thus, sterile beaver still fell trees and dam structures, however they do not reproduce, and the territory may remain empty for a few years after the active pair's death before their scent marking fades and new dispersing beaver come in.

One experiment attempted to use sterilization to decrease the amount of trees a beaver colony would fell to create their food cache in the fall, and thus the amount of damage caused. But the experiment failed when the supposedly sterilized female was found showing signs of successful pregnancy.

Cost: Unknown

Maintenance Requirements: Anytime the sterilized beaver at a colony die off or are killed by transient beaver, and they are then replaced by dispersing beaver, the process must be repeated.

Effectiveness and Reasons for Failure: Sterilization is ineffective as sterilized beaver still behave the same as unsterilized beaver felling trees and building dams. Sterilization can fail if the vet is unfamiliar with beaver and the vasectomy or tubal ligation does not work so the beaver are still able to reproduce.

References: [37] [58] [95]

Straight Fence

Fences

Straight fence is any fence placed around an area that you do not want beaver to access. Fences should be made from panels that have 6x6 inch square holes or smaller, 2x4 inch is preferred, and extend up to 4 ft high. Fencing may be secured in place using t-posts or trees. In areas that receive significant snowfall fence should extend 2ft above the expected highest level of snowfall. Straight fence can be used to protect entire groves of trees when individually caging trees would be too time-consuming or impractical. Straight fence is typically used to prevent tree damage but may also be used to prevent damming by preventing access to damming materials.

Cost: $-$$

- Estimated Materials Price = $120 per 100ft of 2x4 inch wire fencing, plus $4 a t-post and $10 for a roll of galvanized wire

Maintenance Requirements: Fence should be inspected periodically to ensure that no sections of fence have fallen over and that no gaps have opened up underneath that would allow beaver to dig under the fence. If any parts of the fence have been compromised, they should be repaired.

Effectiveness and Reasons for Failure: Straight fence is highly effective at keeping beaver out of small areas as long as the fencing is in contact with the ground and not damaged or compromised. Fences can be compromised by beaver digging underneath them, particularly if the ground is muddy or if there are any gaps left between the fence and the ground. Fence can fail if the fence is too short and beaver are able to climb over the top of it. This is primarily a concern in areas with heavy snowfall. Fence can be compromised if insufficient support is used and a section of the fence falls over.

References: [7] [30] [71] [112]

Supplemental Food Provision

Supplemental food provision is the process of leaving branches or human-felled trees next to a beaver pond for beaver to use. This is a technique meant for situations where flooding is not an issue, or is controlled using a pond leveler, but tree damage is still a problem.

Supplemental food provision greatly reduces the amount of tree felling that occurs in the area, as beaver use the easy-to-access provided branches in their food caches rather than felling new trees for food. This technique does not prevent all tree felling, just a majority of it. This is typically most effective if done in the fall when beaver are preparing their winter food cache.

Cost: $

- Can be done for the cost of labor and transportation if there is a nearby property that branches can be cut from

Maintenance Requirements: Typically, supplemental food is provided once a week and requires a person to cut branches from an acceptable site and drive or walk them to the edge of the beaver pond.

Effectiveness and Reasons for Failure: Supplemental food provision is typically effective at short-term prevention of tree-felling as beaver will use the resources provided rather than felling new trees. Supplemental food provision is not a long-term solution to tree felling, as beaver will still fell some of their own trees. Supplemental food provision can fail if the amount of branches provided are not enough to satisfy the beaver.

References: [37]

T-Culvert

The t-culvert is a culvert extension that can be placed on the end of a culvert that slopes down from the road into the water. The t-culvert is formed by cutting a hole in the side of a large culvert that is the same diameter as the culvert under the road. The large culvert is then placed over the road culvert and the ends of the large culvert are covered with 6-gauge reinforcing wire mesh. The large culvert should have a diameter of 4ft if the road culvert has a diameter of 6-18in. The large culvert should have a diameter of at least 5-6ft if the road culvert is 18in-3ft in diameter. The large culvert should be a minimum of 6-8ft in length. This design causes water to be drained over a larger surface area making it less audible to beaver.

Cost: $

- Estimated Materials Price = $1,300 for a section of 36in culvert pipe, plus $80 per panel of 6-gauge wire utility panel

Maintenance Requirements: Unknown

Effectiveness and Reasons for Failure: Effective only in areas where a specific set of criteria are met. The culvert should be 3ft in diameter or smaller, stream flow must be moderate and at a rate where normal flow fills approximately ¼ of the culvert, both ends of the T-culvert must rest in calm water approximately 4-6ft deep, and the streambed must consist of a solid substrate. The device will fail in other conditions.

References: [71] [94] [95]

Three-log Drain

The three-log drain consists of a wooden board or a sheet of metal and three or more logs inserted through the middle of a beaver dam in such a way that water flows along the logs through the dam lowering water levels behind the dam. To create a three-log drain a beaver dam is first notched and then a board or piece of sheet metal is placed in the notch. Next two logs are placed perpendicular to the beaver dam on the board so that the logs are slightly farther apart at the top, on the pond side of the beaver dam, than at the bottom. Then, a third log is placed on top of the first two completing the ‘funnel’ through which water will drain from behind the beaver dam. Finally, the removed material is placed back on top of the drain for the beaver to repair the dam with. The three-log drain can be modified using green logs and sticks or additional sheet metal to improve drainage. Beaver generally do not like to chew through submerged hardwood logs and will leave the device alone.

The three-log drain can help reduce flooding in some situations but cannot drain water fast enough to be used where there are high flows. The three-log drain was one the earliest flow device designs, and a precursor to modern pond levelers.

Cost: $

- Estimated Materials Price = $20 per wood fence post, plus $15 per 8-12ft wood board, or $25 per galvanized metal sheet

Maintenance Requirements: Unknown

Effectiveness and Reasons for Failure: Unknown

References: [71] [94]

Contractors

Note: Availabilities are specific to Colorado. Virtual consultations will require high quality photographs, measurements, and maps of a site. Additionally, a technician may need to fill out a set of datasheets if the contractor is a part of BeaverCorps. These materials allow the contractor to complete preliminary flow device design without visiting the site in person.

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Available for virtual flow device consultations and limited in-person flow-device installations; based out of Grafton, VT. While Beaver Deceivers will do installations across the United States, it may be more effective to contact Colorado-based contractors for in-person installations and reserve Beaver Deceivers for virtual consultations.

Recommendations

When beaver or beaver activity is seen near the side of a road:

Don't panic. Assess the situation. The first step in beaver management is determining if there is an actual problem in a given location. There are many situations where a beaver sighting at a location does not indicate that there is a problem with beaver in that location. Beaver require riparian vegetation as a food source, so if beaver are seen in an area with no vegetation they may just be passing through as they disperse. Additionally, beaver typically only cause issues with roadways in locations where a road and stream cross paths, or where a stream closely parallels the road. If beaver activity occurs in a stream far enough from the road that there is no concern of roadbed saturation, then the beaver can be left alone, and no action is needed. If beaver activity is seen near the road where roadbed saturation or flooding could be a concern, but the beaver have not built a dam, routinely monitor the site until such a time that there is dam building activity, then take action. Some beaver, especially in large drainages, never dam and live their entire lives in bank dens where they do not cause any risk of road damage.

When beaver have dammed a stream running parallel to a road in an area where there is concern of roadbed saturation or flooding:

Consider using a pond leveler first. If the pond height is acceptable, but any higher would risk flooding or roadbed saturation, installing a pond leveler can easily keep the water level where it is. Additionally, if there are roadbed saturation issues but lowering the pond level only a few feet would solve those issues, installing a pond leveler should still work. Pond levelers work best when a beaver pond can be maintained at a depth great enough for beaver to store their winter food cache underneath a layer of ice, this is typically a minimum of about 3ft in depth. When the pond leveler is installed, it will maintain the water behind the dam at the level of the outlet pipe. Be careful that the outlet pipe is at an acceptable height for the pond where it will no longer cause issues with the road. When beaver notice that the water level is no longer increasing, they will stop increasing the height of the dam.

If no ponding can be tolerated directly adjacent to the road, but there is a section of stream within 100 meters upstream or downstream where some ponding can be tolerated, a starter dam can be considered. If the problem dam is removed and a starter dam is placed nearby along the stream, away from the road, in an area where damming would be acceptable, beaver may preferentially choose to dam the starter dam instead of continuing to dam the previous location. Additionally, one can remove the dam by hand, place a deterrent, such as a flapping sheet over the dam's previous location, and install a starter dam. The deterrent will likely only be effective for one to two weeks, but it can encourage beaver to move to a new location if one is provided.

Finally, if the only concern at a location is flooding, not roadbed saturation, adding a compacted earthen berm between the beaver pond and road is an effective solution.

When beaver activity is seen near a culvert:

Monitor the culvert closely and consider a starter dam. If there are signs of beaver activity near a culvert, but there are no signs that the beaver have started damming the culvert, add the culvert to a routine monitoring rotation, and have maintenance check for activity when they pass. As long as there are no changes to the culvert, no action is needed. However, if there is an acceptable spot for a dam just upstream of the culvert, installing a starter dam for the beaver to build on can be used as a preventative measure. Beaver require some distance between multiple dams on a single stream, or they will merge together and be ineffective at ponding water. Thus, the starter dam must be close enough to the culvert to prevent beaver from damming on the culvert, but far enough away that there are no risks to the road. If a starter dam is installed, the location should be occasionally monitored to check if the beaver have taken it over.

When beaver have dammed on or in a culvert:

Consider using a culvert-protective fence or a fence and pipe system. If beaver have started damming a culvert, the dam should be removed, and a fence or fence and pipe system should be installed. An effective fence will keep beaver far enough away from a culvert that they do not feel the water flowing into the culvert. However, if a fence is too small, or if it is the same width as the stream channel, beaver may begin to dam on the fence. In these cases, a fence and pipe system should be installed. The fence will then act as a starter dam while the pipe through the fence acts like a pond leveler, effectively keeping the stream flowing through the fence.

When significant beaver tree felling has occurred close enough to a road to be unsightly or causes a risk of being a road hazard:

Consider using sand paint or wrapping the trees adjacent to the road. When aesthetics along the side of the road is a concern, or there are a large number of trees that pose a hazard to the public if damaged or felled by beaver, use sand paint. Sand paint is more aesthetically pleasing than tree wrapping when the paint color is closely matched to the tree bark color. When there are only a few trees that cause a significant hazard risk to the road, wrap the trees. Tree wrapping is more effective than sand paint, as a determined beaver can chew through sand paint, but not metal fencing. When possible, sand paint trees that are in an active stream channel where water regularly flows, as fencing can catch debris during high flow events, rendering it ineffective until cleaned off. If possible, sand paint or cage only those trees that are a safety risk or right next to the road. Leave the trees that are farther away from the road untouched. When there is a mix of painted and unpainted trees, beaver will preferentially fell the unpainted trees, so trees that would be an acceptable loss should be left alone.

When a section of road or culvert is being replaced or added in areas with documented beaver activity or high-quality beaver habitat:

Consider oversizing culverts or replacing a culvert with a small bridge. Beaver prefer to dam points in a stream that are constricted and where there are significant sounds of running water. By installing a culvert or bridge that is 1.5 times the width of the stream channel, the constriction in the stream caused by a normal culvert is removed. Additionally, the wider features reduce the sound of water running through a pipe. These larger road features can also act as wildlife crossings for many species, potentially reducing roadkill.

When there have been multiple occurrences of beaver road-kill along a single section of road:

Consider adding exclusion fencing along the roadside. Exclusion fencing prevents beaver and other animals from entering the roadway and directs them to safe road crossings such as culverts. If extensive exclusion fencing is installed, escapes from the roadway side of the fence will need to be included. Escapes may consist of wood pieces stacked and stabilized with sandbags, or gravel fill if the fence is located below the road on a steep slope.

Other Recommendations and Considerations:

- **Lethal control should be the last choice when it comes to beaver management options**. Lethal control is relatively ineffective, as new beaver re-colonize the area after the initial beaver are trapped out. As beaver populations increase across the state, the efficacy of lethal beaver management will likely begin to decrease. The reason that lethal control has been effective for 3-5 years in some areas of Colorado is because beaver populations were relatively low. However, when there are more beaver, there are more dispersing juveniles starting their own territories. If an area has good beaver habitat, it will continue to attract these dispersing beaver. If there is a situation where the beaver must be removed for whatever reason, attempt to live-trap and relocate before resorting to lethal control. There are many areas on the landscape where beaver can be beneficial if they are relocated. However, as beaver relocation is more expensive than lethal trapping and has a similar efficacy, it should also not be a primary technique for beaver management along roads.

- Education or trainings should be made available to CDOT personnel, who often use lethal control techniques as that is what they are familiar with. Education should include the specific situations in which beaver pose an actual threat to the road, the benefits of having beaver on the landscape, the unique adaptations and family structures of beaver, and the ways in which humans can coexist with beaver. This level of education can inspire people to care about the beaver along their section of road and encourage them to work with the beaver rather than against them.

- Any devices that are installed that are highly visible from the road and are accessible by the public should have signage attached explaining what the device does and why it is there. This will help prevent damage from any vandals who believe the device is a beaver dam that should be removed.

- If there is an area or region with a lot of beaver activity, consider sending a person in that region through the Beaver Corps training program, or establish a good relationship with consultants in the region who have gone through the program, as they will have the knowledge to properly install flow devices. Poorly-made devices, with improper materials, fail. Well-made devices with high-quality materials do not fail as long as they are maintained. All flow device installations should be completed by experienced professionals, such as those who have completed the Beaver Corps training program or have years of experience installing flow devices in the field like Skip Lisle (>20 years of experience). **Flow device installation should not be contracted out to engineering firms that have no experience working with beaver.** Be aware that all flow device installations are site-specific and may require some tweaking after the initial installation in order for them to continue working

properly. Trained beaver professionals understand how to tweak devices in such situations and will often include such device maintenance in their installation prices.

- Invite maintenance staff and other stakeholders to a site to observe or help with flow device installation so they can ask questions, feel included, and be more likely to consider flow devices in the future.
- If the area seems like poor quality habitat with no riparian vegetation, try dam removal. It may just be a dispersing beaver that will move on if it fails once. If that doesn't work, or there is good quality habitat, then the site will require other coexistence techniques.
- CDOT should create a plan for how beaver will be managed, including contingencies should initial methods fail. This plan should include likely locations for beaver conflicts, what signs of beaver and beaver activity to look for, the point(s) at which beaver activity should begin to be monitored and addressed, and solutions to likely problems. The plan should not neglect short-term solutions that can quickly and temporarily prevent or help mitigate beaver damage while a long-term solution is being contracted and installed.

Examples of Beaver Management Plans and Policy Elsewhere

- **Anabranch Solutions adaptive beaver management plans.** These are a series of adaptive beaver management plans created by Joe Wheaton and others at Anabranch Solutions. The plans provide a framework for how to approach beaver conflicts and information on possible solutions to expected beaver conflicts [79] [80] [89] [115].
- **Best Management Practices for Resolving Human-Beaver Conflicts in Vermont.** This guidance provides information on beaver problems and instructions for performing beaver management techniques to address a set of specific beaver conflicts [112].
- **City of Longmont's Wildlife Management Plan.** This wildlife management plan includes guidance for the city on how to manage many wildlife species, including a brief section on beaver. The plan includes a set of management strategies the city can employ and the specific circumstances under which they are to be used [23].
- **Colorado State Parks Beaver Management Prescription.** This management prescription provides information on beaver, a list of recommended techniques for managing beaver, and suggested management actions for park staff [37].
- **Draft: State of Ohio Department of Transportation Office of Environmental Services Beaver Dam Removal Guidance.** This guidance provides considerations for Ohio Department of Transportation maintenance personnel any time they encounter a beaver dam that may impact the roadway [73].
- **The North Carolina Beaver Management Assistance Program.** The North Carolina BMAP provides assistance to public and private landowners in North Carolina to help with addressing

beaver damage concerns. Their website includes annual reports of the work done by the North Carolina BMAP and information on their policies [72].

- **Wildlife Services environmental assessments for aquatic rodent and beaver damage management programs in multiple states.** These are a series of environmental assessments for beaver damage control programs across a number of Eastern and Southern states in the United States. The reports include information on several management techniques, decision trees, and regulations. There is some variation between states, but overall, these reports are similar [33] [92] [103] [104] [105] [106] [107] [108] [109] [110].

Recommended Additional Readings and Resources

Titles of recommended readings and resources below include links to the resource. Click on the title to follow the link.

Resources About Beaver Coexistence Techniques

- **The Beaver Institute** is an organization founded by Mike Callahan which works to spread awareness about the ecological benefits of beaver and the methods of coexisting with them. Their website includes many resources including a curated list of articles about beaver, instructions for installing coexistence solutions, and information about the BeaverCorps Training Program for professionals wishing to start a business installing flow devices.
- **The Beaver Restoration Guidebook** was a collaboration prepared by Michael Pollock, Gregory Lewallen, Kent Woodruff, Chris Jordan, and Janine Castro with additional input by many others. The guidebook covers all aspects of using beaver as a tool for habitat restoration including tools such as flow devices for minimizing potential human conflict as a result of beaver restoration.
- **The Evolution of Flow Devices Used to Reduce Flooding by Beavers** by Jimmy D. Taylor II and Russel D. Singleton provides an overview of many types of flow devices and the history of how they were developed over time.
- **Putting Beavers to Work for Watershed Resiliency and Restoration** is a collaboration between the organizations Cows and Fish Alberta Riparian Habitat Society and The Miistakis Institute. The collaboration focuses on facilitating the coexistence of beaver and humans. The website includes research on beaver-human coexistence techniques including landowner interviews, information on how to install beaver coexistence techniques, and information about beaver ecology.
- **Working with Beaver for Better Habitat Naturally** by Sherri Tippie is a short guidebook that describes her experiences trapping beaver in Colorado and provides instructions for installing flow devices, tree wrapping, and successfully live trapping and relocating beaver.
- **Working With Beavers** by Nick Gerich provides a number of beaver management techniques, whether or not those techniques should be used, and what uses the techniques are best for. The recommendations given are based on experiences in the San Isabel National Forest located in Colorado.

Resources About Beaver Biology, History, and Social Movements

- **Anabranch Solutions** is a company started by Joe Wheaton, a professor at Utah State University. The company focuses on riverscape restoration primarily through the use of low-tech process-based restoration strategies such as beaver dam analogs.
- **The Beaver Believers** is a documentary by Sarah Koenigsberg which highlights the experiences of beaver activists and the importance of beaver on Western North American Landscape.
- **BeaverCON** is a biennial convention that brings together professionals to discuss beaver management, ecology, and restoration. Presentations from previous years are posted on their website.
- **The Colorado Beaver Summit** was an online seminar held in October 2021 discussing the role of beaver on the landscape in Colorado and many aspects of beaver management.
- **The Colorado Beaver Working Group** is a collaboration working to bring together individuals and organizations working to promote beaver on the landscape in Colorado. The group holds regular meetings and has a newsletter. Their website includes resources on beaver basics, coexistence with beaver, process-based restoration, policy, mapping, beaver around agricultural and ranching water, and funding beaver work.
- **Eager: The Surprising, Secret Life of Beavers and why they Matter** by Ben Goldfarb is a book that includes information on everything beaver from evolutionary history to social movements around beaver.
- **Once They Were Hats** by Frances Backhouse is a book that covers the relationship between humans and beaver throughout history and in many cultures.
- **Worth a Dam – The Martinez Beavers** is a website created by Heidi Perryman which details the story of the beaver colony that built a dam in the middle of Martinez, CA. The website is also updated regularly with current worldwide examples of beaver in the news.

Conclusion

Dealing with beaver is often difficult and, in many cases, requires a context specific solution. There are many coexistence strategies that can help beaver and humans live alongside each other without conflict when properly implemented. Additionally, coexistence techniques are often more cost-effective in the long term than repeated dam removal and trapping. By working with beaver and their ecology we can gain many benefits from having beaver on the landscape while mitigating for the damage they would otherwise cause. These coexistence techniques do not work in all situations but are a valuable tool and should be considered for many sites which have perpetual beaver conflict problems.

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