Restoring Western Headwater Streams with Low-Tech Process-Based Methods:
A Review of the Science and Case Study Results, Challenges, and Opportunities

Version 2.0, January 2024

AMERICAN RIVERS
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Acknowledgments

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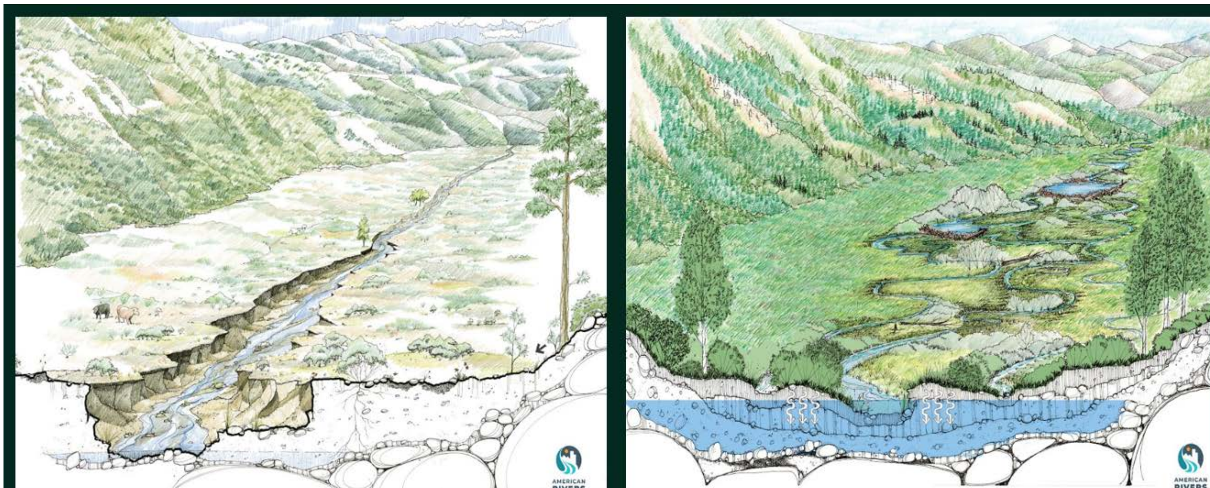
Executive Summary

Over the last decade, interest around utilizing process-based restoration (PBR) approaches to restoring degraded streams has significantly increased, particularly around the Western States. PBR seeks to re-establish natural stream *processes* (hydrology, sediment routing, nutrient cycling), which in many cases involves utilizing methods aimed at reconnecting incised streams with their floodplains to restore the natural inundation frequency and duration. Much of the attention is focused on “low-tech process-based restoration” (LTPBR) which is a subset of PBR.

This paper reviews the rapidly growing published scientific research and unpublished case studies on the effects of restoring degraded incised streams in Western States using LTPBR, while also describing opportunities and potential challenges associated with implementing these projects. It provides research and information on projects where LTPBR has been a successful approach to restoring riverscapes on headwater streams. Finally, the paper recommends best practices and solutions to avoid potential conflicts with these practices.

LTPBR includes cost-effective techniques like beaver reintroductions, beaver mimicry structures/beaver dam analogues (BDA), post-assisted log structures (PALS), placement of large woody debris (LWD), and rock detention structures (RDS). These restoration methods are referred to as “low-technology” techniques because they minimize the use of heavy equipment and ground disturbance during construction, are frequently built by hand or with portable hand equipment such as a hydraulic post-pounder, and do not require engineered design work. However, advanced technologies such as lidar, thermal imaging, remote sensing, GPS surveys, and flow modeling are often used in planning and design.

As explained further in Section 2, LTPBR is a subset of PBR. **PBR first analyzes what caused the disruption of the natural processes that led to the degradation and then determines if that stressor can be addressed**. Common stressors in rural landscapes that lead to stream degradation include mining, logging, stream straightening/channelization, road crossings with undersized culverts, the elimination of beaver, and unmanaged grazing. Many studies have documented the critical role of beaver dams and LWD (trees, rootwads, and large branches that fall into streams) to maintaining the aquatic biodiversity and connectivity of rivers to their floodplains. The historic and continued removal of LWD and beavers “is one of the most widespread drivers of degradation in wadeable streams.” Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., (2019).



This paper synthesizes the published research on what are hydrologic, biologic, and ecosystem services effects of restoring a degraded incised stream to a healthy riverscape

In the context of incised stream restoration where the goal is to reconnect the floodplain, LTPBR projects often utilize temporary, hand-built structures using wood posts, locally sourced shrub and tree branches, native sod plugs, cobble and rocks that mimic some of the effects of natural beaver dams, acting as "speed bumps" that lower velocities during high flow events. The structures help to capture sediment, causing stream bed aggradation that leads to hydrologically reconnecting floodplains. This allows riparian vegetation and adjacent riverine wetlands to recover and be naturally hydrated by the rise in groundwater. With restoration needs greatly exceeding available restoration funding and the urgency of climate change, the use of low-tech methods is a critical strategy for restoring streams because design and construction costs average 10 times *less* per mile than traditional stream restoration work that employs large heavy construction equipment and materials. Additionally, the research reviewed in this paper indicates that LTPBR, when implemented in appropriate settings, can be an effective method to restore stream health and improve ecosystem services.

Not all degraded streams are appropriate LTPBR candidates. Stream systems with profound changes to water or sediment inputs (e.g., some reaches below reservoirs or major diversions that alter the flow regime and trap sediments) may not be good candidates for LTPBR because the alteration of these driving fluvial processes may require larger-scale restoration efforts. Additionally, a key to the success of LTPBR is having sufficient space for natural fluvial processes to occur. Generally, **suitable locations for this type of restoration will be on first to third order "wadeable" streams with a gradient of 3% or less** (if the project is beaver-based) located on rural public or private lands where there is room for the stream to utilize its full floodplain without causing infrastructure or water use conflicts. LTPBR work is also being done to restore mesic meadows in ephemeral drainages and in dryland area streams where beaver populations have been absent for over 200 years due to trapping (e.g., in areas like Arizona).

Projects that utilize BDAs are most successful if located in areas where beaver historically resided and are present up or downstream of the project to increase the probability that they will recolonize the project area. If beaver return, they carry on the long-term work of maintaining a healthy functioning stream and floodplain. Similarly, PALS work best in streams where historically large wood was present, and rock structures work best where rock is naturally present. PALS and RDS can be utilized in streams with higher gradients than what would be suitable for beaver-based restoration. Section 2.4 discusses mapping tools that have been developed to help agencies and other conservation stakeholders determine the best locations to focus restoration efforts, where conflict risks are low and restoration gains can be substantial.

In some cases, discontinuing beaver trapping and managing livestock grazing is all that is needed to allow the stream and riparian corridor to recover over time from an incised channel into a complex, multichannel network (it often takes a decade or more). In other cases, where the stream is significantly incised and disconnected from its floodplain, nature will need more assistance to heal. In these instances, key placement of LWD, BDAs and/or PALS can help jump-start the healing process. Beaver may be able to re-establish themselves in some cases, but if the local populations are too far away or depleted, project managers may also need to relocate beaver from other locations to the project area. Beaver relocations have been used in stream restoration since the 1930s, and BDAs and the concepts of process-based restoration have been in development for a couple of decades. Because the term LTPBR was first coined in 2018, most research papers cited refer to "beaver-related, beaver mimicry, or beaver-based restoration" rather than LTPBR or refer to the particular techniques utilized, such as LWD, BDA, RDS, sod plugs, rock weirs, wicker weaves, or similar terms.

Numerous studies show substantial ecological benefits and enhanced ecosystem services resulting from successful beaver-related projects, such as groundwater recharge, sediment reduction, wildfire risk reduction, and increased forage for livestock and wildlife. More research is needed to fully understand the other effects of LTPBR, such as the potential for later season flows that some case studies have reported, and how to better support human-beaver coexistence in addition to addressing some of the top challenges identified in Section 5 of this paper (organization and labor capacity, education, project monitoring, permits, and perceptions around impacts to water rights). The accelerating impacts of climate change, combined with the strong evidence for enhanced ecosystem services from LTPBR projects, is leading scientists to conclude that it is important to boldly move forward with LTPBR projects while these issues are being resolved. In their 2022 paper in WIREs Water, Dr. Fairfax and Dr. Jordan stated:

"*Our fish, water, and forests depend on our willingness to act. We can't just continue to study the situation without also taking action. There is absolutely more research that needs to be done to optimize and quantify beaver-based restoration impacts across all spatial and temporal scales. However, given the trajectory of climate change and increasingly threatened water resources we simply don't have that kind of time. Thus,* ***we should implement, and continue to study, process-based methods in degraded streams across the continent, now****."* Beaver: North American Freshwater Climate Action Plan, Jordan, C. & Fairfax, E., *WIREs Water*, (2022).

Recent increases in funding for natural infrastructure through the federal Infrastructure Investment and Jobs Act and Inflation Reduction Act, as well as state-level programs, make this an opportune moment to develop and implement these projects. Land and water managers have the opportunity "to address the triple challenge of: (i) restoring ecosystem function and services, (ii) improving security to communities dependent on rivers for irrigation and clean drinking water, and (iii) adapting to climate change." Riverscapes as natural infrastructure: Meeting challenges of climate adaptation and ecosystem restoration, Skidmore, P. & Wheaton, J., *Anthropocene*, (2022). Again, not all river restoration projects are appropriate candidates for this type of restoration and may need other approaches. This paper focuses on providing information on those situations where LTPBR has been a successful approach to restoring riverscapes on headwater streams.

A Colorado stream in need of restoration, likely a good candidate for LTPBR. Photo by Jackie Corday

Top Research Highlights

Research surrounding the effects of connected floodplains and beaver complexes continues to grow, with many reports being published each year. The following effects of beaver-related restoration have been widely documented (further details/citations are provided in the paper):

- **Drought and flood resilience**. Studies indicate that healthy natural stream systems and restored floodplains and wetlands recharge local aquifers. Functioning connected floodplains allow for slow infiltration of runoff into soils and wetlands, providing natural storage of spring runoff. Some studies have shown that this can result in improved drought resilience. Connected floodplains also help attenuate downstream flood peaks.
- **Wildfire resilience**. Protected and restored headwater wetlands can provide important fire breaks from wildfires and refuges for wildlife and livestock during fires. A 2020 study of large western US wildfires found riparian vegetation around beaver complexes had a three times greater rate of survival than around stream segments without beavers.
- **Increased water quality**. Beaver dams and functioning floodplains have been shown to retain nutrients (such as an overabundance of nitrogen), as well as heavy metals, reducing downstream pollution levels. Additionally, studies have shown beaver complexes can provide cool water refuges for aquatic species.
- **Reduced Sedimentation**. A study in England monitored a series of 13 beaver ponds and determined that over the four years of monitoring, each pond trapped on average 7.8 tons of sediment, totaling 101.5 tons. The authors concluded beaver ponds may help mitigate the downstream impacts of erosion and nonpoint source pollution.
- **Improved critical habitat**. Riparian and wetland areas on floodplains represent only about 2% of Colorado's landscape, but are hotspots for biological diversity and provide both refuge and movement corridors for most wildlife species during all or part of their life cycles. LTPBR and beaver dams enhance this critical aquatic and terrestrial habitat and have also been shown to enhance fisheries.
- **Increased water availability and forage for livestock and wildlife**. A 2018 study of LTPBR projects in Colorado, Oregon, and Nevada showed that the projects increased vegetation productivity and extended it longer into the year. A USDA study of LTPBR projects in eastern Oregon, Nevada, and Idaho involved extensive interviews of 53 ranchers, the large majority of whom expressed great enthusiasm for beavers returning to their ranches due to the increased availability of water and better forage for livestock, which can translate into financial gains.

This report also covers the main challenges of implementing LTPBR and recommends some solutions. Top highlights on these topics include:

- **Water rights**. Research conducted for this report did not find any documented cases of LTPBR projects that resulted in measurable harm to water rights from increased evaporation due to more surface water and increased evapotranspiration from riparian/wetland vegetation. More case studies are needed to better understand the hydrological effects of LTPBR of floodplains. Conversations with restoration project managers revealed a few instances where BDAs were installed too densely, which caused a reduction in flows to downstream water users and resulted in them having to be removed. In Section 5.7, we offer some guidelines to help reduce the risk of potential conflicts.
- **Social issues with beaver.** The social barriers to LTPBR and beavers are among the largest challenges to solve. Over the past 10 years, valuable resources have been developed to inform landowners and land managers about the many benefits of allowing beaver to remain in place and how to manage issues that might be problematic, such as flooding roads or pastures and tree removal. This topic is covered in Section 5.3.
- **Funding opportunities**. There is an unprecedented amount of federal and state funding now available for large-scale watershed restoration, which is covered in Section 5.1.

List of Acronyms

Acronym	Meaning
BDA	Beaver dam analogue
BLM	Bureau of Land Management
BMP	Best Management Practice
BMS	Beaver mimicry structure
BOR	Bureau of Reclamation
BRAT	Beaver Restoration Assessment Tool
BRR	Beaver-related restoration
CDFW	California Department of Fish and Wildlife
CDPHE	Colorado Department of Public Health and Environment
cfs	Cubic feet per second
CNHP	Colorado Natural Heritage Program
CPW	Colorado Parks and Wildlife
CSU	Colorado State University
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ET	Evapotranspiration
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
IMW	Intensively Monitored Watershed
LTPBR	Low-tech process-based restoration
LWD	Large woody debris
NBS	Nature-based solution
NIDS	Natural infrastructure in dryland streams
NFF	National Forest Foundation
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PALS	Post-assisted log structures

PBR	Process-based restoration
RDS	Rock detention structure
RMNP	Rocky Mountain National Park
SMP	Sierra Meadows Partnership
TNC	The Nature Conservancy
TU	Trout Unlimited
USACE	United States Army Corps of Engineers
USDA	US Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service
USU	Utah State University

2023 photo by Nathan Seward, Colorado Parks and Wildlife, of the Beaver Creek State Wildlife Area showing where beaver have returned and greatly improved stream habitat in a reach that was a 2019 LTPBR project site.

I. Introduction

Process-based restoration (PBR) seeks to restore the natural physical and biological processes that sustain rivers and their associated floodplains.[1] This is different approach from form-based restoration, which is focused on creating stable, natural-looking engineered channels.[2] Low-tech process-based restoration (LTPBR) of streams is a subset of process-based restoration (PBR) that follows the same principles to re-establish natural stream processes (hydrology, sediment routing, nutrient cycling) that have been disrupted (as is further explained in Section 2 below). LTPBR techniques are minimally invasive and relatively low-cost and require little to no engineering or heavy equipment. Techniques include placement of large woody debris (LWD), beaver dam analogues (BDA), beaver reintroductions, post assisted log structures (PALS), rock detention structures (RDS), and other emerging techniques.[3] Generally, suitable locations for this type of restoration will be on first to third order smaller, "wadeable" streams[4] with a gradient of 3% or less (if the project is beaver-based) located on rural public or private lands where there is room for the stream to utilize its full floodplain without causing infrastructure or water use conflicts.

Interest in LTPBR is rapidly growing as Western States continue to experience the effects of an over 20-year-long drought, less water availability, and ever increasing megafires (fires that burn more than 100,000 acres) that are likely the new normal. Numerous watershed and water stakeholders are realizing that significant needs exist for low-cost, nature-based solutions to build resilience to climate change impacts by restoring the health of our forests and natural water infrastructure: the streams, wetlands, and wet meadows that deliver 80% of Colorado's drinking water.[5] Research synthesized and cited in this paper indicates that LTPBR can be an effective tool to restore stream health and improve water security.[6]

Watershed restoration work has been conducted for many decades, primarily by wildlife, land management, and water quality agencies, as well as nonprofits. The main focus has been on ecological restoration of streams and wetlands to improve wildlife habitat and water quality. However, case studies over the past 10 years are showing that, in addition to ecological lift, restoring headwater streams delivers numerous ecosystem services benefits, including groundwater recharge, sediment reduction and filtration of other pollutants, fire breaks and refuges, and increased forage for livestock and wildlife. Thus, a wider array of stakeholders is becoming interested in supporting such restoration projects, including water providers, water conservation districts, agricultural organizations, private ranch owners, and agencies working to address climate change and drought impacts.

Colorado has over 105,000 river miles.[7] Approximately 61% of smaller steams and about 97% of major rivers have experienced floodplain alteration, rendering them partially or wholly nonfunctional.[8] The chart below, extracted from the report "Disappearing West" by the Center for American Progress, indicates this problem is pervasive across all Western States. *Id*. In fact, studies have estimated that

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[1] Process-based Principles for Restoring River Ecosystems, Beechie, T.J. et al., *BioScience,* (2010).
[2] Applied River Morphology, Rosgen, D. (1996); Natural Channel Design: Fundamental Concepts, Assumptions, and Methods, Rosgen, D. (2011).
[3] Using Beaver Dams to Restore Incised Stream Ecosystems, Pollock, M.et al., *BioScience*, (2014); Relocating Beaver, Chapter 5 in The Beaver Restoration Guidebook Version 2.02: Working with Beaver to Restore Streams, Wetlands, and Floodplains, Pollock, M., USFWS, (2023); Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., (2019).
[4] Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., *Utah State University Restoration Consortium*, Logan, UT (2019). Wadeable streams include perennial, intermittent, and ephemeral streams. Approximately 90% of perennial streams in the U.S. are wadeable. *Id.* citing Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. EPA Office of Water and Research and Development, (December 2006).
[5] Colorado's Water Plan, Chap. 7, page 3 (2015).
[6] **Water security** is the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable and resilient **quantity and quality** of water for human health, ecosystems, and productive economies." What is Water Security? GlobalWaters.org.
[7] Colorado Water Quality Regulations & Surface Water Pollution Info. Colorado Ag Water Quality, (2022).
[8] Chart from Disappearing West, Center for American Progress website.

79% of the 3.3 million miles of rivers in the lower 48 states have been altered by human activity and 19% are flooded by reservoirs, leaving only about 2% unaltered.[9]

Rivers modified by floodplain alteration

STATE	SHARE OF HEADWATERS THAT HAVE BEEN MODIFIED	SHARE OF SMALLER RIVERS AND STREAMS THAT HAVE BEEN MODIFIED	SHARE OF MAJOR RIVERS THAT HAVE BEEN MODIFIED	SHARE OF ALL RIVERS THAT HAVE BEEN MODIFIED
Arizona	32%	56%	96%	**63%**
California	36%	41%	80%	**45%**
Colorado	51%	61%	97%	**63%**

Chart from Disappearing West, Center for American Progress website

The floodplain alteration data is consistent with an Environmental Protection Agency (EPA) finding in its 2013-14 Western Mountain Ecoregion Rivers and Streams Assessment that ranks riparian vegetation condition from poor to fair on 67% of the streams.[10] In upper rural watersheds, the main causes of altered floodplains were reported to be historical mining and timber harvesting practices, historical and present-day agricultural practices, alteration of flows by dams and diversions, roads and other infrastructure development, and removal of beaver.[11] Common physical effects of disconnected floodplains include "lowered groundwater tables, the loss of wetlands, lower summer base flows, warmer water temperatures, and the loss of habitat diversity. Biological effects include a substantial loss of riparian plant biomass and diversity, and population declines in fish and other aquatic organisms."[12] Recent reports have found that the freshwater biodiversity of rivers, streams, wetlands, and lakes is rapidly declining in every major river basin on earth at a faster pace than terrestrial and marine systems.[13]

In Colorado, water quality monitoring of more than 92,000 miles of streams over the past 25 years indicates that about 39,000 miles (43%) either do not meet state water quality standards or the data is missing or not conclusive to make a determination.[14] Because healthy, functioning floodplains and riparian corridors filter out nonpoint source pollution such as nitrogen, phosphorus, and sediments, there is a direct connection between disconnected river floodplains and degraded water quality.[15] Floodplains of all stream types, whether perennial, intermittent or ephemeral, provide these critical ecosystem services.[16]

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[9] Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., *Utah State University Restoration Consortium*, Logan, UT (2019) citing the book Freshwater Ecoregions of North America: A Conservation Assessment, Abell, R, et al., *Island Press*, (2000).
[10] Western Mountains Ecoregion - National Rivers and Streams Assessment 2013-14 | US EPA. This ecoregion covers the mountain ranges located in CO, NM, AZ, UT, WY, MT, ID, WA, OR, and CA. The stats are also consistent with an assessment done for the Colorado Roaring Fork Watershed Plan, which concluded that **two-thirds of their streams** in the ~1,00,000-acre watershed **have moderately to severely degraded riparian habitat.** It is also consistent with a recent 2023 study that analyzed floodplain integrity for the entire lower 48 states and concluded that "the integrity of nearly 70% of floodplains in the United States is poor." Degradation of floodplain integrity within the contiguous United States, Morrison, R., et al., *Communications Earth & Environment*, (2023).
[11] Threats to western United States riparian ecosystems: A bibliography (fs.fed.us) (2012).
[12] Using Beaver Dams to Restore Incised Stream Ecosystems, Pollock, M. et al., *BioScience,* (March 2014).
[13] Scientists' warning to humanity on the freshwater biodiversity crisis, Albert, J. et al., *Ambio 50*, (2021).
[14] Citizen's Guide to Colorado Water Quality Protection Third Edition by Water Education Colorado
[15] The Flow Regulation Services of Wetlands, Kadykalo, A. & Findlay, C., *Ecosystem Services*, (2016); The Natural & Beneficial Functions of Floodplains, A Report for Congress by the Task Force on the Natural and Beneficial Functions of the Floodplains, (June 2002); Reconnecting Rivers to Floodplains, Returning natural functions to restore rivers and benefit communities, Loos, J. & Shader, E., *American Rivers*, (2016).
[16] Recognizing the ephemeral stream floodplain: Identification and importance of flood zones in drylands, Scamardo, J. & Wohl, E., *Earth Surface Processes and Landforms*, (2023).

Degraded incised streams devoid of riparian vegetation, like this one, are very common throughout the Western States. Photo by Jackie Corday of West Creek, located south of Grand Junction, Colorado.

Because the scale of the problem is immense, many academic and agency researchers are currently implementing and studying the relatively new, low-cost LTPBR methods to restore headwater streams to improve water quality, habitat, and drought and fire resilience. Public lands, including National Forests and lands managed by the Bureau of Land Management (BLM), are often the focal locations for such projects, but ranchers and other private landowners are also seeking out such nature-based solutions to improve forage and water reliability. Collaborating across land ownerships in priority watersheds will be critical to attain the greatest beneficial impacts. In addition to summarizing the many benefits that research attributes to LTPBR, this paper also addresses the opportunities and challenges that must be addressed for LTPBR to be effectively implemented.

II. PBR and LTPBR Defined – Why These Approaches Are Different from Other Stream Restoration Approaches

2.1 Overview of Evolving Stream Restoration Approaches

Dr. Ellen Wohl and her co-authors in their 2015 paper on the science and practice of river restoration, explain that river restoration accelerated in the 1980s out of a "growing recognition of how severely and extensively past river engineering has altered rivers," in addition to pressing water quality concerns.[17] For the past three decades, one of the most popular restoration methods involved using heavy equipment to reconfigure the stream channel to a pre-determined and stable channel type to increase channel sinuosity and complexity, often utilizing the placement of large boulders and wood in-channel to improve fish habitat.[18] This type of restoration became a multi-billion-dollar industry across the US.[19] The photo below shows an example of this type of project in which the riverscape had once occupied the width of a mountain valley in central Oregon. It had been graded into a single channel along one side of the valley many decades ago, which resulted in drying up the meadow vegetation. The 2012 project consisted of filling in the channel and constructing a new meandering channel through the meadow.

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[17] The science and practice of river restoration, Wohl, E., Lane, S., & Wilcox, A., *American Geophysical Union Water Resources Research*, (2015).
[18] This is typically referred to as Natural Channel Design or form-based restoration. Natural Channel Design: Fundamental Concepts, Assumptions, and Methods, Rosgen, D., (2011).
[19] Synthesizing U.S. River Restoration Efforts, Bernhardt, E. et al., *Science*, (2005).

2012 form-based river restoration project in Central Oregon. Photo credit: [Toward Stage Zero: (arcgis.com)]

In the early 2000s, academic and agency researchers began to research whether channel reconfiguration approaches were improving stream ecosystems.[20] Their research indicated that most restoration projects were not successful in improving biodiversity.[21] A Colorado study of the hydrologic effects of a form-based channel realignment project in Rocky Mountain National Park determined that the change from pre-project to post-project actually increased water export through a downstream wetland complex, resulting in a "decrease in wetland water storage and lost potential for hyporheic exchange."[22] The authors concluded that there were "unintended consequences of prioritizing the restoration of river form over function" and encouraged practitioners to consider "the process needed to increase, or even maintain, surface water-groundwater interactions and associated ecosystem functions." [23]

While scientists were rethinking approaches to stream restoration, important advancements were made on a parallel track in shifting river health assessments from focusing just on the river channel and adjacent riparian vegetation to thinking more holistically about the entire river corridor, or "riverscape,"[24] and the processes that take place within that space that are vital to overall river health.[25] By looking at the geologic sedimentary record, Robert Walter and Dorothy Merritts in their seminal 2008 *Science* paper found that many streams that were now single thread with a "2-year" floodplain had historically been valley floor spanning complexes of multiple channels, swamps and beaver ponds, thick with vegetation and rich in organic matter.[26] Dr. Ellen Wohl and her co-authors in a *Frontiers in Earth and Science* article noted that "historically, river-wetland corridors were pervasive in wide, alluvial valley reaches, but their presence has been so diminished (due to a diverse range of anthropogenic activities and impacts) that the general public and even most river managers are

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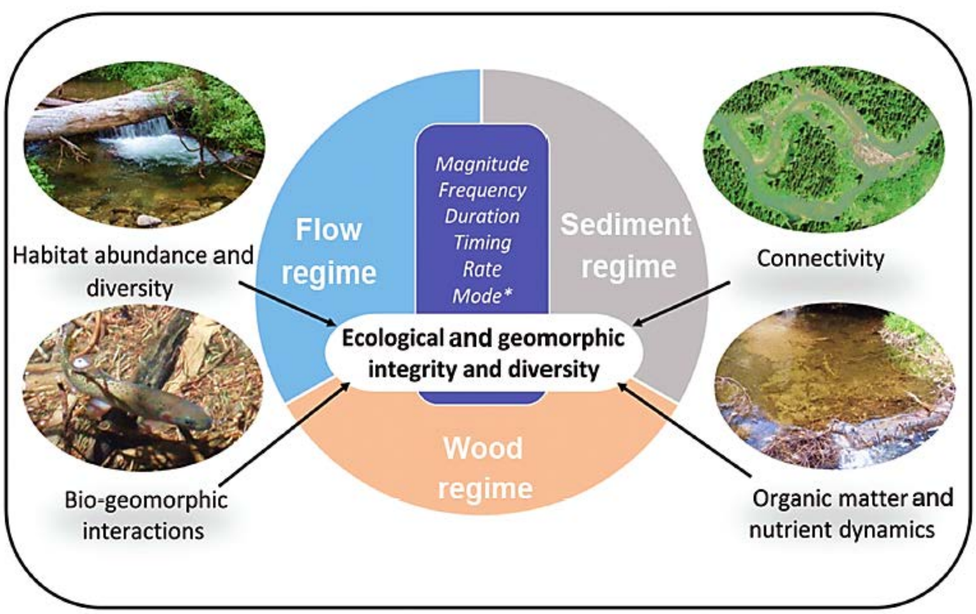
[20] Standards for ecologically successful river restoration, Palmer, M. et al., *Journal of Applied Ecology*, (2005); River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation, Bernhardt, E. & Palmer, M., *Ecological Applications*, (2011).
[21] A Function-Based Review of Stream Restoration Science, Harman, W. et al., *Environmental Law Institute*, (2016). "Both geomorphology and biology were evaluated in 94 projects, but improvement in both stream functions was documented in only 25." *Id.* at page 11. This result is similar to a review of 78 restoration projects. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? Palmer, M., Menninger, H., & Bernhardt, E., *Freshwater Biology*, (2010).
[22] Form-based river restoration decreases wetland hyporheic exchange: Lessons learned from the Upper Colorado River, Sparacino, M. et al., *Earth Surface Processes and Landforms,* (2018).
[23] *Id.*
[24] Landscapes to Riverscapes: Bridging the Gap Between Research and Conservation of Stream Fishes, Fausch, K. et al., *BioScience,* (2002). "We perceive a need to conceptualize rivers not as sampling points, lines, or gradients, but as spatially continuous longitudinal and lateral mosaics. As such, heterogeneity in the river landscape, or riverscape, becomes the focus of study." *Id.* at page 3. "Riverscapes are composed of connected floodplain and channel habitats that together make up the valley bottom." Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., *Utah State University Restoration Consortium*, Logan, UT (2019).
[25] Process-based Principles for Restoring River Ecosystems, Beechie, T. et al., *BioScience,* (2010).
[26] Natural Streams and the Legacy of Water-Powered Mills, Walter, R & Merritts, D., *Science,* (2008).

unaware of their former pervasiveness."[27] Related concepts being embraced to both improve ecological health and reduce flood damage (among many other benefits) include restoring the entire valley bottom when possible so that rivers have space for their dynamic processes to occur.[28] Hence, evaluating river health has evolved from a narrow focus on assessing the stream channel and adjacent riparian vegetation to examining the entire valley floor, which has greatly expanded the conceptual extent of river restoration to include entire fluvial ecosystems rather than simply restoring the form of a stream channel.

In addition to studying how river-wetland corridors once occupied valley widths, many studies over the past thirty years also focused on documenting the importance of large woody debris (LWD) in river systems. LWD is defined as trees, logs, rootwads, and large tree branches greater than 3 feet in length and 4 inches in diameter that fall into streams, the majority of which enters the stream system from bank erosion, landslides, windthrow, and tree mortality.[29] In the1980s, scientists began to recognize that wood in rivers provided a number of physical and biological functions, such as attenuating sediment and slowing flows, creating diverse habitat and cover for fish and other aquatic species, and trapping and retaining organic materials that provide nutrients to aquatic organisms.[30] Dr. Ellen Wohl and her co-authors explain in their *BioScience* paper that "The natural wood regime forms the third leg of a tripod supporting the physical processes underlying river science and management, along with the natural flow and sediment regimes. We define the wood regime in terms of the magnitude, frequency, rate, timing, duration, and mode of wood recruitment, transport, and storage" in river corridors.[31] The paper includes the graphic below to illustrate this concept.



Characteristics of the river corridor influenced by interactions among water, sediment, and wood. Characteristics listed around the margins (e.g., physical habitat template) are influenced by the presence of mobile and stored wood. In the central box, Mode* refers only to the wood regime.

[27] Rediscovering, Reevaluating, and Restoring Lost River-Wetland Corridors, Wohl, E. et al., *Frontiers in Earth Science,* (2021). "We define a river-wetland corridor as a relatively wide valley floor within which there is space for persistent alluvial deposits and sufficient connectivity between surface and subsurface hydrology to create and maintain an interacting system of channels, wetlands, and floodplain ponds and lakes." *Id.* at page 2.
[28] A Process-based Approach to Restoring Depositional River Valleys to Stage 0, an anastomosing channel network, Powers, P., Helstab, M., & Niezgoda, S., *River Research and Applications,* (2018); Design Criteria for Process-Based Restoration of Fluvial Systems, Ciotti, T. et al., *BioScience* Vol. 71, Issue 8, (2021); Freedom to Roam: How Meandering Rivers Can Decrease Destructive Flooding, Vermont Agency of Natural Resources webpage, which is akin to Colorado's Fluvial Hazard Zone Mapping Program.
[29] Wood placement in river restoration: fact, fiction, and future direction, Roni, P., et al., *NRC Research Press*, (2017).
[30] *Id.*
[31] The Natural Wood Regime in Rivers, Wohl, E. et al., *BioScience*, (2019); A Primer on the Wood Regime for Stream Management, Scott, D. (2022).

Prior to this research, LWD was routinely removed from rivers starting in the 1800s to improve navigation, to clear the path for sending logs to mills, then in later years for water conveyance, recreation safety, and to reduce risks to bridges among other reasons. [32] The natural supply source and means of getting wood into rivers (the wood regime) was also greatly diminished over the past century by logging, grazing, and clearing of riparian corridors.[33] The historic and continued removal of LWD and beavers "is one of the most widespread drivers of degradation in wadeable streams."[34] This is why process-based restoration is often focused on getting wood back into the stream system with short-term fixes (e.g. PALS, BDAs, LWD placement, riparian plantings), with the intention that these actions lead to longer-term fixes or natural processes taking over (revegetation and rehydration of riparian corridors with floodplain connection and the return of beaver).

In their seminal 2010 paper that set forth principles of process-based restoration of river ecosystems, Dr. Timothy Beechie and his co-authors defined PBR as approaches that aim "to re-establish normative rates and magnitudes of physical, chemical, and biological processes that sustain river and floodplain ecosystems" such as wood and sediment transport, storage and routing of water, and nutrient cycling, as opposed to efforts that focus on creating "structures or channel forms that are perceived to be good habitat."[35] PBR approaches recognize "that streams are not simply a channel, but a complex dynamic and evolving system that includes all of the area on and near a valley floor that has been affected by or directly affects fluvial processes."[36] The Beechie et al. paper sets forth PBR principles to guide river restoration projects to more successful outcomes, the core principle being that "actions should address the causes of degradation, rather than the symptoms of it."[37]

Beechie et al. discuss a wide range of PBR actions to address degradation causes, from actions that cost millions of dollars and require heavy equipment and engineering analysis to accomplish (e.g., road, levee, and dam removals), to methods that are relatively low cost per mile and do not require heavy equipment or engineering (such as beaver reintroduction and riparian plantings). One of the PBR case study examples cited in Beechie, et al. that directly addresses this problem is the Oregon Bridge Creek project initiated by NOAA's Northwest Fisheries Science Center in 2003. This project had the goal of aggrading over 30 km of the incised Bridge Creek in Eastern Oregon. Based on field observations, the researchers hypothesized that the incised stream could be rapidly aggraded if stable beaver dams could become established, and that this would substantially improve fish habitat.[38] Because this project is the origin for the terms BDA and LTPBR, it will be discussed in detail in the next section on page 16.

An example of "high-tech" PBR (as opposed to "low-tech") utilizes heavy equipment to remove miles of river berms/levees installed many decades ago and reset the valley floor grade to reconnect highly altered, channelized rivers to their former valley-wide floodplains.[39] This type of project is often called "Stage Zero restoration," which refers to the pre-disturbance condition of a river in the stream evolutionary model developed by Dr. Colin Thorne and Dr. Brian Cluer as explained in their 2014

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[32] Maintaining Wood in Streams: A Vital Action for Fish Conservation, Opperman, J., Merenlender, A., and Lewis, D., University of California Publication #8157 (2006).
[33] *Id.*
[34] Low-Tech Process-Based Restoration of Riverscapes: Design Manual, Wheaton, J.M. et al., (2019).
[35] Process-based Principles for Restoring River Ecosystems, Beechie, T. et al., *BioScience,* (2010). CSU Professor Dr. Ellen Wohl further explained that by stating, "We should be aiming to restore a dynamic state as characterized by spatial and temporal variations in biotic abundance and composition that reflects those in [undisturbed] reference systems, and channel geometry that changes in response to natural flow variability." The science and practice of river restoration, Wohl, E. et al., *American Geophysical Union Water Resources Research*, (2015).
[36] Design Criteria for Process-based Restoration of Fluvial Systems, Ciotti, T. et al., *BioScience* Vol 71, Issue 8, (2021).
[37] Beechie et al. (2010).
[38] Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream in the interior Columbia River basin Pollock, M. et al., *Earth Surface Processes and Landforms*, (2007).
[39] A Process-based Approach to Restoring Depositional River Valleys to Stage 0, an anastomosing channel network, Powers, P., Helstab, M., & Niezgoda, S., *River Research and Applications,* (2018).

paper.[40] USFS Fisheries Biologist Paul Powers and many of his USFS and NOAA colleagues have been leading efforts to implement and monitor this type of project in Oregon and Washington, and they have created a website to showcase and explain the numerous projects.[41]

Restoration of the South Fork McKenzie River to 'Stage Zero' by the US Forest Service. Left: de-watered channel pre-restoration (aptly described as a 'boulder ditch'), right: immediately post-restoration (2018). Photo credits: Kate Meyer and Johan Hogervorst.

Photos from the website Stage Zero River Restoration

This type of high-tech PBR restoration is not the focus of this paper, however, as outlined here, there are additional resources that thoroughly explain this approach.[42] It is important to note that Stage Zero valley-wide floodplain connectivity is not a *method* of restoration, but rather the *goal* of some restoration projects depending upon many circumstances. The methods to achieve Stage Zero can range from using heavy equipment to remove levies, regrade and place trees as shown in the above photos, or for small streams, it can in some cases be accomplished with beaver reintroduction. Dr. Joe Wheaton, professor at Utah State University, explains in his LTPBR Design Manual that "Stage Zero is not an appropriate target for all restoration projects" when land uses like roads, development, and agriculture occupy where the river floodplain historically existed.[43] Wheaton and Peter Skidmore explain in their 2022 *Anthropocene* paper that "Recovery Potential" for floodplain restoration varies greatly depending on the location and land uses, among other factors.

In the graphic below from their paper, notice the differences between the Recovery Potential where the river reach is by a town (42% recovery possible) compared to the second example, in a rural agricultural setting, where the floodplain recovery potential is shown as 90%.

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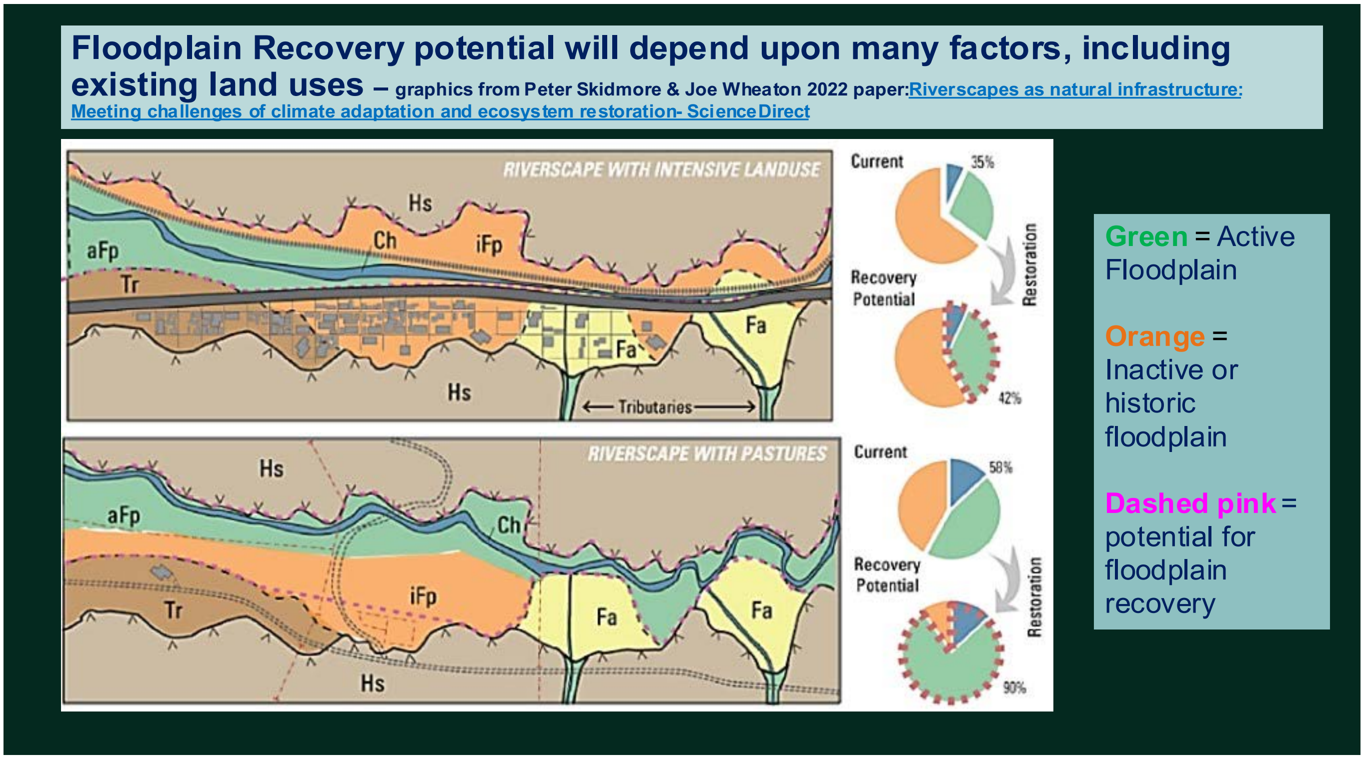
[40] A stream evolution model integrating habitat and ecosystem benefits, Cluer, B. & Thorne, C., *River Research and Applications*, (2104).
[41] Welcome | Stage Zero (stagezeroriverrestoration.com)
[42] Peer-reviewed Articles. Stage Zero, (Viewed July 2023). This webpage features a comprehensive list of published papers on this topic. This synthesis of Stage 0 project results is very informative: Rehabilitating Valley Floors to a Stage 0 Condition: A Synthesis of Opening Outcomes, Flitcroft, R., et al., *Frontiers in Environmental Science*, (2022).
[43] Wheaton J.M., Bennett S.N., Bouwes, N., Maestas J.D. and Shahverdian S.M. (Editors). 2019. Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0. Utah State University Restoration Consortium. Logan, UT.



Graphic from Riverscapes as natural infrastructure: Meeting challenges of climate adaptation and ecosystem restoration, Skidmore, P. & Wheaton, J., *Anthropocene*, (2022).

2.2 Origins of LTPBR

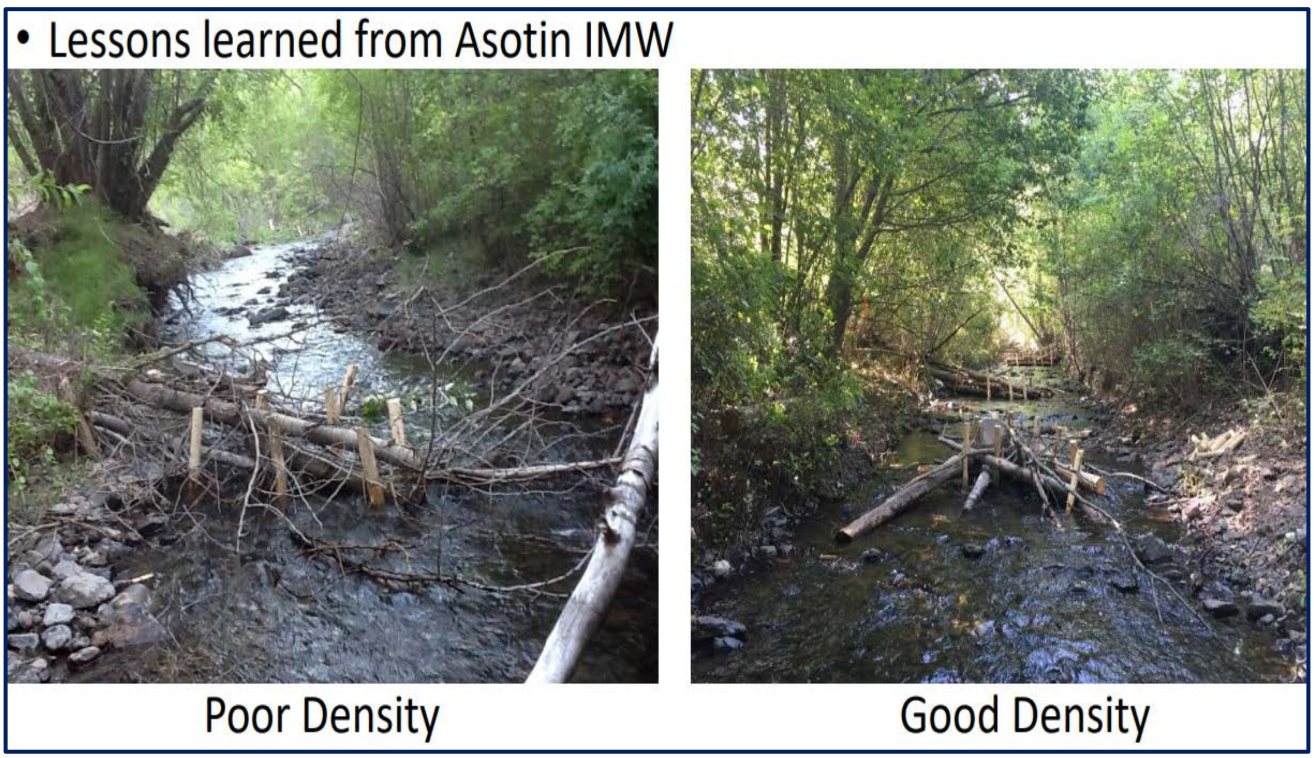
LTPBR grew out of two large-scale, long-term Intensively Monitored Watershed (IMW) stream restoration efforts in Eastern Washington, the Asotin Creek project, and the previously mentioned Eastern Oregon Bridge Creek project. The goal of both projects was to experiment with new, innovative, low-cost, low-tech methods to restore disconnected floodplains on a scale large enough "to produce a population level response in Endangered Species Act (ESA) listed steelhead and salmon species."[44] Discussions with the lead NOAA project manager, Michael Pollock, indicated that the projects were driven by the need to find effective lower-cost restoration methods that could be applied across the tens of thousands of miles of streams in need of restoration in a time frame such that societal objectives such as preventing the extinction of ESA-listed fish species were likely to be achieved.

For the Bridge Creek project, the primary restoration action used small wood posts to support existing beaver dams during high flows so that they remained intact or any damage could easily be repaired and thus encourage aggradation of sediment, elevation of water tables, expansion of riparian vegetation and ultimately beaver population expansion.[45] Where no beaver dams existed, structures were created by weaving cut willow branches in between vertical posts inserted into the substrate perpendicular to the flow to mimic the effects of beaver dams. Direct riparian planting also occurred to a limited extent,[46] but the greatest expansion of riparian vegetation occurred as a result of the elevation of water tables from the beaver dams and structures, as water could be accessed by the roots of plants. This very successful and relatively low-cost project gave rise to the term Beaver Dam

[44] Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0, Wheaton, J.M. et al., *Utah State University Restoration Consortium*, Logan, UT (2019).
[45] Working with beaver to restore salmon habitat in the Bridge Creek intensively monitored watershed: Design rationale and hypotheses, Pollock, M. et al., NOAA Technical Memorandum NMFS–NWFSC–120 (2012).
[46] Hall et al. Methods for Successful Establishment of Cottonwood and Willow Along an Incised Stream in Semiarid Eastern Oregon, USA, *Ecological Restoration,* (2011).

Analogs (BDAs), temporary structures built to mimic the form and function of beaver dams with natural materials to promote similar effects to beaver activity.

For the Asotin Creek Project, Post Assisted Log Structures (PALS) were developed using the same approach as BDAs to pound in posts into the stream substrate and use existing large wood to create simple “low-tech” wood jams, and then the two types of structures were together defined as LTPBR.[47] The Asotin project focused on restoring the processes of wood accumulation by using PALS to facilitate the accumulation of wood in the channel and along the banks that then allowed for sediment accumulation/aggradation to occur over time to reconnect the stream to the floodplain. The PALS differed from conventional log structures in that they were not engineered, there was minimal site design, they were expected to have relatively short life spans, and they did not require heavy equipment for placement. PALS essentially use the BDA methodology to help create and stabilize large wood structures rather than create and stabilize beaver dams. Thus, the Bridge Creek project focused on restoring complexity to the stream by utilizing BDAs and riparian plantings to ultimately increase the abundance of beaver and beaver dams, while the Asotin project used a similar “low” technology to create structural complexity by making wood jams.[48]



Examples of PALS from the presentation **Getting Wood Back in the Stream: LWD and PALS**, Anabranch Solutions, 9/18/2017. The presentation explains that the project on the left had only one PAL in the stream reach, whereas the project on the right has several PALS of varying types (bank-anchored left and right PALS and a mid-channel PALS).

Consistent with LTPBR directives, the causes of degradation for these sites were found to be suitable for restoring with LTPBR. For example, the cause of incision on the Bridge Creek system was linked to loss of beaver and channel straightening, as opposed to profound changes to water or sediment inputs that could have required larger-scale restoration efforts.

The successes and lessons learned from these two projects and others inspired Dr. Joe Wheaton and his co-authors to draft their seminal 2019 LTPBR Design Manual, in which they define LTPBR as:

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[47] Pollock et al. (2014); Wheaton et al. (2019).
[48] LTPBR Design Manual at p. 6.

> "*A practice of using simple, low unit-cost, structural additions (e.g., wood and beaver dams) to riverscapes to mimic functions and promote specific processes. Hallmarks of this approach include an explicit focus on promoting geomorphic and fluvial processes, a conscious effort to use cost-effective, low-tech treatments (e.g., hand-built, natural materials, non-engineered, short-term life-spans) because of the need to efficiently scale-up application.*"

This definition reflects the desire and need to develop and implement low-cost solutions that can be scaled up to match the extent of degraded and incised streams in the West. As stated earlier, LTPBR approaches will not fit every situation – there are locations and situations that will require the use of heavy equipment (e.g., large rivers) and in some cases for form-based stabilization goals (e.g., urban and semi-urban areas where the full extent of the floodplain cannot be restored due to development). This paper focuses on providing the research and information on those projects where LTPBR has been a successful approach to restoring riverscapes on headwater streams.

2.3 Review of LTPBR Goals, Methods, and Advantages

Purpose/goals of projects – Depending upon the partners and funding sources involved, LTPBR project goals may vary, but they usually include improving a stream's health for people and wildlife by restoring the riverscape functions of capturing sediment, filtering pollutants, providing diverse stream, wetland, and terrestrial habitat in the riparian corridor, attenuating flood waters, and improving resilience to drought and wildfires. Dr. David Pilliod, a Research Ecologist for USGS, and his co-authors analyzed 97 beaver relocation and/or BDA projects from nine Western States and noted the top goals for project proponents were increasing water storage of snow and rain runoff, improving riparian vegetation, sediment control, and improving fish and wildlife habitat.[49] The table in Section 3.1 of this paper lists the goals/benefits of LTPBR projects with the corresponding Section where the topic is covered.

Methods used – LTPBR methods seek to use free energy sources to beneficial effect. The main idea behind LTPBR is captured by a quote in the LTPBR Design Manual: "What if restoration was about stream power doing the work, not diesel power?"[50] The idea is to utilize the energy of spring runoff or storm flows that bring sediment and wood downstream that can accumulate behind "speed bumps" such as large woody debris (LWD) (e.g. trees felled into streams and cut trees placed instream and on the floodplain), BDAs, PALS, rocks, and/or native grass sod plugs to help aggrade an incised stream. Many restoration projects use a combination of designs, seeking to use the best type of structures and/or LWD for the particular situation. Hand-built structures are designed to be temporary, deformable, and porous in order to pass baseflows. They are typically made with natural materials such as wood posts or small logs, willow or other shrub or tree branches, cobble, mud, and native sod plugs sourced from the local area. A hydraulic post pounder is often used to help speed up the work of installing BDAs and PALS and mini-excavators are sometimes used to more efficiently harvest and install native grass sod plugs or for use in dual-purpose projects that remove encroaching conifers (e.g., Pinyon Pine and junipers) and utilize the wood for building low-tech structures.

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[49] Survey of Beaver-related Restoration Practices in Rangeland Streams of the Western USA, Pilliod, D. et al., *Environmental Management*, (2017).

[50] LTPBR Design Manual at p. 4 quoting Jared McKee (USFWS).

BDA project in East Canyon Creek, Utah, Photo by Mark Edgley

"In my opinion, BDAs should rarely ever be used if there is not a clear and rather short-term transition from beaver mimicry to actual beaver dam activity by beaver. There is tendency to try to use BDAs in every situation when there are many other flavors of low-tech structures that may achieve the same outcomes for less effort. Even in riverscapes where I want to encourage beaver dam activity, I will sometimes favor using more woody structures than BDAs because they are cheaper, and beaver will co-opt them if they like them."

Email from Dr. Joe Wheaton, Utah State University, December 1, 2022.

The second major source of energy many projects hope to utilize is the free constant labor of a beaver family adopting and building on top of or near project's beaver mimicry structures to continue the process of restoring the stream. As noted in the U.S. Fish and Wildlife Service (USFWS) Beaver Restoration Guidebook, "In incised streams, BDAs can initiate the process restoration, but ultimate success often hinges on active colonization by both vegetation and beaver."[51] Many projects are intentionally located in areas where beaver historically resided are present up or downstream of the project. If beaver don't return, maintenance of installed structures is required as they are not designed to endure more than a few years. While long-term studies have documented if tech structures themselves can continue to provide long-term benefits, immediate hydrologic benefits have been documented[52] as well as improved sediment capture and habitat.[53]

Beaver History

Prior to the commercial fur trade exterminating the majority of beaver populations in North America by the mid-1800s, historic beaver range covered almost the entire United States and their population once numbered 60-400 million. Their influence on river landscapes was extraordinary, creating millions of acres of wetlands. When beavers were removed from watersheds, their ponds and side channels drained, and large areas of naturally stored surface water and surrounding wetlands were lost. As a result, flows concentrated into single-thread, powerful channels that incised and disconnected rivers from their floodplains. Without the "speed bumps" provided by beaver complexes, runoff became flashier, with higher flows immediately after snowmelt and rain events and lower flows later in the summer. Beaver natural history and their critical role in the health of river corridors are fully documented and described in these two books. Saving the Dammed, Why We Need Beaver-Modified Ecosystems, Wohl, E., *Oxford University Press*, (2019); Eager: The Surprising, Secret Life of Beavers and Why They Matter, Goldfarb, B., *Chelsea Green Publishing*, (2018).

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[51] The Beaver Restoration Guidebook Version 2.02 at p. 98, Pollock, M. et al., USFWS, Portland, OR (2023).

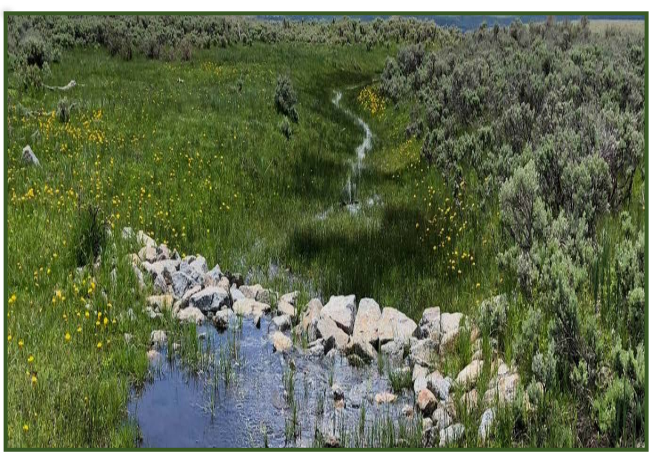
[52] Beaver dam analogues drive heterogeneous groundwater-surface water interactions, Wade, J. et al., *Hydrological Processes*, (2020). "We observed that BDAs effectively replicate the functions and impacts of natural beaver dams in the short term, though it remains unclear if they can maintain these effects over years to decades." *Id.*

[53] Analyzing the Impacts of Beaver Dam and Beaver Dam Analog Complexes to Stream Ecology Within the Intermountain West, Wolf, M., *Utah State University PhD Dissertation*, (2023).

In addition to placement of LWD, BDAs, PALS, and various other constructed speed bumps, LTPBR includes and was inspired by similar methods that have been employed for decades to restore ephemeral streams and rangeland gullies. An example is the restoration work of Bill Zeedyk, who began testing many different low-tech restoration methods in the 1980s and 90s while he worked for the United States Forest Service (USFS) in the dry Southwest. The photo below[54] is from a 2009 Zeedyk presentation shows wicker weirs in a New Mexico ephemeral stream that look and functioned much the same as BDAs, helping to slow the flashy runoffs and retain sediments.

Workshop volunteers build a wicker weir on Largo Creek, Williams Ranch, Quemado, NM. August 2024. Photo by Tamara Gadzia. Slide from the presentation: An Introduction to Induced Meandering: A Method for Restoring Stability to Incised Stream Channels, Zeedyk, Earth Works Institute and Quivira Coalition, (2009).

Beginning in 2012, Zeedyk partnered with the Natural Resources Conservation Service (NRCS), Colorado Parks and Wildlife (CPW), The Nature Conservancy (TNC), BLM, USFS, USFWS and many others to restore mesic areas in ephemeral drainages in the Upper Gunnison Basin using mainly "Zeedyk" hand-built rock structures like the ones pictured below. These are places where beaver will not be able to assist with the restoration work due to water usually only being present during snow-melt or monsoonal storms. The partners have now treated approximately 329 acres of riparian habitat along 37 miles of ephemeral and intermittent streams and are seeing great success at restoring plant diversity, soil moisture, and forage for livestock and wildlife.[55] This type of rangeland meadow restoration is accelerating across Western States with federal funding and the support of USFWS, NRCS, BLM, USFS, state wildlife agencies, and nonprofits as told in an August 2023 storyboard featuring a Utah project.[56]



Photos by Shawn Conner, Bio-Logic, Inc., of LTPBR projects he worked on with many partners that used Zeedyk rock structures to restore rangeland mesic areas in the Upper Gunnison Basin.

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[54] See also Hand-Built Structures for Restoring Degraded Meadows in Sagebrush Rangelands, Maestas, J. et al., *Range Technical Note. No. 40 USDA*, (May 2018), an excellent publication that explains the many different Zeedyk restoration techniques.

[55] Wet Meadows Restoration and Building Project - UGRWCD; Results of this restoration work is published: Restoration of wet meadows to enhance Gunnison sage-grouse habitat and drought resilience in arid rangelands, Rondeau, R. et al., *Restoration Ecology*, (Oct. 2023).

[56] Stitching the Landscape Back Together (arcgis.com), Intermountain West Joint Venture, August 2023.

Dr. Laura Norman, a USGS Research Physical Scientist, introduced the term Rock Detention Structure (RDS) to describe LTPBR methods that includes Zeedyk rock work and larger rock structures, loosely stacked or wrapped in chicken wire (gabions) and keyed into banks.[57] A 2021 paper by Dr. Jennifer Gooden and Dr. Richard Pritzlaff, from the Biophilia Foundation, reviews several RDS case studies in southeast Arizona that indicate that these simple rock structures effectively slow the flow, reduce erosion, and aggrade incised streams.[58] This type of work is happening in areas where beaver have not been present for over 100 years due to trapping and water flow changes, so unlike many BDA-type projects, there isn't an expectation that beaver will recolonize and take over the restoration work.[59] The authors note that there is extensive archeological evidence that "for centuries" Indigenous peoples in the Sky Islands Region of southern Arizona have utilized these types of rock structures to attenuate and extend stream flows later into the dry season. The case studies cited in the paper have been completed and described by the USGS Aridlands Water Harvesting Study.[60] In an invited commentary of the Gooden Pritzlaff paper, Dr. Norman provided additional research describing RDS scalability throughout landscapes, perseverance over time, and contributions to a restoration stewardship economy that supports RDS as a nature-based solution. [61]

Photo of an example of a rock detention structure on an Arizona creek provided by Dr. Laura Norman from the June 2022 video Re-greening a Dryland Watershed | U.S. Geological Survey (usgs.gov).

[57] Quantifying geomorphic change at ephemeral stream restoration sites using a coupled-model approach, Norman, L. et al., *Geomorphology*, (2017); Ecosystem Services of Riparian Restoration: A Review of Rock Detention Structures in the Madrean Archipelago Ecoregion, Norman, L., *Sage Journals*, (2020).

[58] Dryland Watershed Restoration with Rock Detention Structures: A Nature-based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon, Gooden, J. & Pritzlaff, R., *Frontiers in Environmental Science*, (2021).

[59] According to the Arizona Game & Fish, historically beavers were found nearly everywhere in Arizona that had permanent water. The American Beaver in Arizona – Arizona Daily Independent

[60] Aridland Water Harvesting Study. Western Geographic Science Center. U.S. Geological Survey website, (2018).

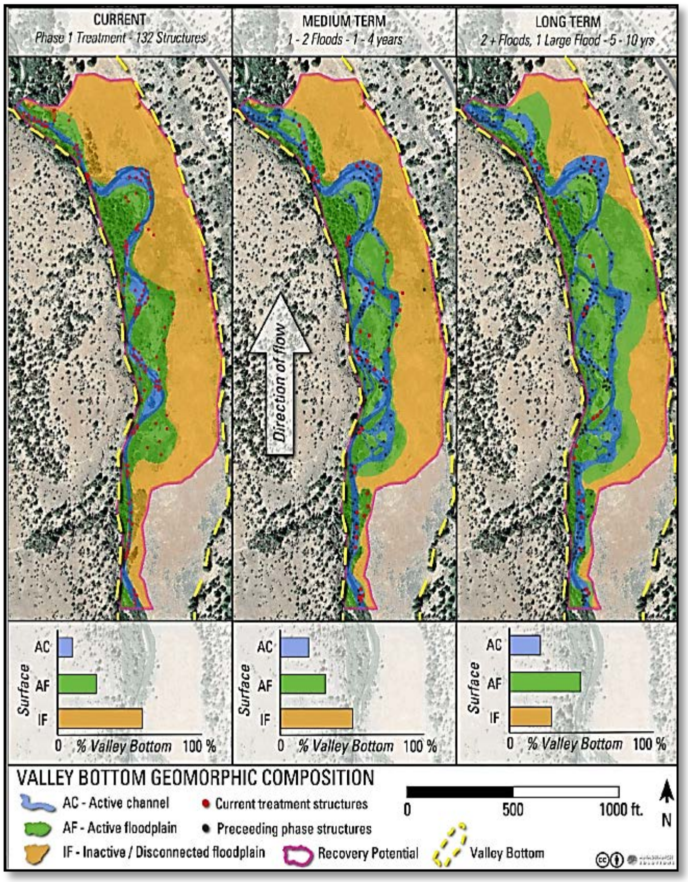
[61] Commentary: Dryland Watershed Restoration with Rock Detention Structures: A Nature-Based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon, Norman, L., *Frontiers in Science*, (2022).

To summarize the various LTPBR techniques, Dr. Wheaton's LTPBR Design Manual provides a chart outlining different LTPBR approaches. He stresses the need to analyze what are/were the causes of the stream degradation and what are the processes that need to be restored. Most often, the loss of wood accumulation is the biggest problem in perennial streams (mainly from logging, loss of riparian vegetation by unmanaged grazing, and the elimination of beaver). Therefore, many LTPBR approaches are aimed at restoring wood that will in turn help with reconnecting the floodplain from sediment accumulation over time.

Table 5 – A list of typical low-tech approaches to promoting specific process-based restoration outcomes.

Name	Helpful Reference(s)
Promoting and/or Mimicking Wood Accumulation	
Seeding of Wood – Direct Recruitment of Unanchored Wood	
Direct Felling	Carah et al. (2014)
Grip-Hoisting	Micelston (2014)
Structural Placement of Wood Accumulations	
Post-Assisted Log Structures	Chapter 4 (Shahverdian et al., 2019a)
Improving Supply of Woody Material	
Riparian Plantings	Hall et al. (2011)
Grazing Management	Swanson et al. (2015)
Promoting and/or Mimicking Beaver Dam Activity	
Beaver Translocation	Woodruff and Pollock (2015)
Beaver Dam Analogues	Chapter 4 (Shahverdian et al., 2019a)
Trapping Closures	Figure 9; (Valachovic)
Erosion Control (often for intermittent & ephemeral channels)	
Baffles	Zeedyk and Clothier (2009)
One Rock Dams	Maestas et al. (2018); Zeedyk and Clothier (2009)
Post and Brush Plugs	Kraebel and Pillsbury (1934)
Tree Dam	Kraebel and Pillsbury (1934)
Tree Plug	Kraebel and Pillsbury (1934)
Vanes	Zeedyk and Clothier (2009)
Wicker Weirs	Kraebel and Pillsbury (1934)
Zuni Bowls	Maestas et al. (2018); Zeedyk and Clothier (2009)

Table reproduced from Wheaton J.M., Bennett S.N., Bouwes, N., Maestas J.D. and Shahverdian S.M. (Editors). 2019. Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0. Utah State University Restoration Consortium. Logan, UT. 286 pp. DOI: 10.13140/RG.2.2.19590.63049/2.



Weber N, Wheaton JM. and Allen K. 2020. Willow Springs Restoration Design: **[Process-Based Riverscape Restoration in Whychus Creek, Oregon](#)**. Prepared by: Anabranch Solutions and Aequinox for the Upper Deschutes Watershed Council. Bend, OR

Recovery timeframe – For decades, people involved in river restoration have become accustomed to form-based restoration projects reconstructing the channel (or increasing in-channel complexity with wood and boulders) in one construction season and seeing the results of a new channel in Year One and growth of riparian plantings in Year Two and subsequent years. The question is often raised how long it will take for LTPBR-type restoration work to reach common project goals of restoring natural self-sustaining processes that occur on functioning floodplains, such as capturing sediment, recharging the natural hydrology, and providing diverse habitat in the riparian-wetlands corridor. The answer depends on numerous factors, including what caused the degradation (and if it been addressed); the size, flows, and geology of the riverscape; the degree of degradation (e.g. is the stream incised two feet or much greater); the precipitation and snowpack post project; and wildfire effects pre and post project, to name just a few. In general, case study results indicate that benefits often are visible within one to two years post project, such as increased riparian and wetlands vegetation usually due to higher water table, increased plant, aquatic, and terrestrial species diversity, sediment and wood accumulation that is beginning the process of floodplain reconnection, among other indicators of project success. However, project proponents should expect 5 to 10 years or even more depending on the factors listed above.

Economic advantages – A tremendous advantage of LTPBR is the substantially lower cost per mile to install. LTPBR costs range from ~$25,000 to $100,000/mile, while hard engineered, form-based restoration approaches typically cost between $800,000 to $1.5 million/mile.[62] The savings come from hand labor and small equipment and, often, the use of volunteers to help install LTPBR structures, versus large heavy equipment for form-based projects. Further cost savings are realized by using natural materials often located on-site, low to no engineering design costs, much shorter installation time, and lower permitting costs. The significant cost savings is one reason why LTPBR projects are

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[62] Conversations and emails with Utah State University Professor Dr. Joe Wheaton, Dept of Watershed Sciences, and other stream restoration consultants, March 2021. Also stated by Wheaton in this article: What Is Low-Tech Stream Restoration? Working Lands for Wildlife, (August 2018). This is similar to what was reported in a USDA report: “Restoration costs using traditional methods and heavy equipment can exceed $1 million per mile, while BDAs are being installed for about $1,000 to $5,000 per structure, including the cost of design and permitting.” Using Beaver Dam Analogues for Fish and Wildlife Recovery on Public and Private Rangelands in Eastern Oregon, Davee et al., *USDA Northwest Climate Hub*, (2019). Dr. Laura Norman, USGS, and her colleagues also reported a similar price per kilometer of $20,000-$105,000 for RDS restoration projects. A shared vision for enhancing ecological resilience in the U.S. - Mexico borderlands: The Sky Island Restoration Collaborative, Norman, L. et al., *SER News*, Vol 36, Issue 1, p 19-27 (2022).

now being implemented in every western state by public and private landowners.[63] Restoration practitioners interviewed for this paper emphasized there are situations where heavy equipment is needed for PBR projects and that it can be cost-effective for certain projects, such as those where large equipment is already on-site for projects that involve road decommissioning, levee removal, a large amount of LWD placement, and forest fuels reduction projects, among other situations.

A great example of a significant cost savings is the Doty Ravine case study. To help mitigate wildfire risk in the dried out riparian corridor in the Doty Ravine Preserve near Sacramento, California, the Placer Land Trust (local land manager) worked with ecologists to identify a wildfire risk strategy. They were presented with choices to spend over $1,000,000 with a traditional heavy equipment approach or try a LTPBR approach for less than $60,000. The Land Trust chose the latter and built a series of BDAs where beaver took over, speeding up the restoration of over 60 acres with tremendous results according to USFWS biologist Damion Ciotti.[64] He anticipated it would take up to 10 years to reconnect the floodplain, but it only took three with the assistance of beaver.

Reduced environmental impact of implementation – Because LTPBR typically involves utilizing native, locally sourced materials and little equipment, it is gentler on the land and has lower impacts on the stream corridor than form-based methods that involve moving tons of soil, boulders, and large wood with heavy machinery such as bulldozers and excavators. The heavy equipment and the disturbance and exposure of soil, and in some cases the import of fill, are all potential points of introduction of invasive noxious weeds.[65] Additionally, with the use of engine-powered machinery required for extensive earthwork activities in form-based restoration and the transportation of equipment and large materials, significantly more greenhouse gas emissions are emitted during the project implementation process than for LTPBR projects.[66]

2.4 Important Considerations for LTPBR

Dynamic nature – Using nature's energy to restore streams means not everything will go as expected. As a USDA report notes, "You have to take into account that it's a nature-based restoration process that's occurring in dynamic stream environments – you can't always predict what the outcomes will be."[67] Natural beaver dams, BDAs, PALS, LWD and other similar structures can be washed away by high spring runoff events, and beaver may move on to other locations rather than stay where they were released. However, the USFSW Beaver Restoration Guidebook notes that "because BDAs are small in size and use material similar to that in natural beaver dams, if the BDA fails there is less risk to downstream habitat or infrastructure than there is with other types of restoration projects, such as large wood placement."[68]

One of the key principles of LTPBR design is building a large number of diverse structure types that help to "accommodate variability and uncertainty in stream flows."[69] Another hallmark of LTPBR is adaptive management, which addresses uncertainty by applying system monitoring over time to inform a structured, iterative process of robust decision making.[70] For example, rebuilding a washed-out structure in a better location after watching how the stream adjusts is relatively easy compared to making adjustments to projects that count on constructing a static channel with rip rap, boulders, and anchored large wood. Scientific analysis using quantitative models and remotely sensed imagery can

[63] Low-Tech Restoration Explorer (bda-explorer.herokuapp.com) This mapping tool was created to allow LTPBR project partners to share information about their projects by entering basic information about location, miles restored, types of structures used, etc. Over 140 projects have been entered thus far, but based upon the research conducted for this paper to locate case studies, that likely represents less than 30% of existing project.
[64] This California Creek Bed Was A Wildfire Risk, Then The Beavers Went To Work (sunnyskyz.com)
[65] Invasive Species/Vegetation Overview (transportation.org); Monitoring River Restoration Efforts: Do Invasive Alien Plants Endanger the Success? A Case Study on the Traisen River, Lapin, K., *Scientific Research*, (2016).
[66] Quantifying carbon footprint for ecological river restoration, Chiu et al., *Environment, Development, and Sustainability*, (2021).
[67] Ranchers, Beavers, and Stream Restoration on Western Rangelands, Kantor, S. & Charnley, S., *USDA Science Findings*, (July 2020).
[68] The Beaver Restoration Guidebook Version 2.02 p. 98, Pollock, M. et al., USFWS, Portland, OR (2023).
[69] LTPBR Design Manual, Chapter 4. p. 3.
[70] LTPBR Design Manual, Chapter 4. p. 3.

expand site-based RDS experiments into larger regional watersheds and allow forecasting to extrapolate over time.[71]

Beaver suitability tools –Dr. Joe Wheaton, professor at Utah State University, and his colleagues developed the Beaver Restoration Assessment Tool (BRAT), to help identify where beaver were historically, where they currently exist, and where conditions may be best for their return.[72] BRAT has now been further refined and applied statewide in Colorado.[73] The tool is maintained by Colorado Natural Heritage Program (CNHP) and available for free to the public.[74] Another emerging tool is called EEAGER, which Google and beaver scientists, including Dr. Emily Fairfax, created to detect beaver complexes in aerial and satellite imagery "as a tool for restoration, conservation, scientific monitoring and community outreach." [75]

In addition to these tools, project planning must take into consideration other factors that might limit beaver being able to successfully return, such as flows (too low or too powerful) and habitat needs.[76] The Colorado Watershed Resilience Tool is another planning platform that provides mapping data to identify opportunities for improving watershed resilience through riparian, meadow, wetland, and instream restoration and protection at the watershed scale. The tool can be explored in a variety of ways. For example, it can help find and evaluate potential river protection and restoration sites, as well as locate reference sites. It can help identify areas that would benefit from streamflow restoration projects, or illustrate information for grant and permit submittals at the federal, state, and local levels. Additional information is available in the Watershed Resilience Tool's Quick Guide, which describes how to use the tool, provides additional information on the individual layers, and shows users how they can create and download prioritized focus areas based on the values they are interested in.

Infrastructure management – Beavers commonly plug roads and trail culverts that can lead to road flooding and/or undermine the road integrity. Over the past 30 years, many coexistence solutions have been developed to address these problems while allowing beaver to stay in place. It is an important LTPBR planning factor to consider and is covered in Section 5.3 on page 61 of this paper.

Grazing management – An important factor to consider in many restoration projects is that unmanaged livestock grazing of riparian vegetation can be the stressor that causes the cascading effects of lack of vegetation for beaver to survive and lack of roots to stabilize streambanks and minimize erosion that then often leads to stream incision.[77] A recent Colorado study determined that the "loss of suitable vegetation is driving the loss of beaver dam capacity, and vegetation suitability is the dominant limiting factor to beaver dam capacity in all regions of Colorado."[78] In addition to livestock grazing, intense browsing by ungulates when key predators have been eliminated can lead to stream incision. The most famous example was documented in Yellowstone National Park before and after wolf reintroduction. [79] Over-browsing by elk and moose is also evident in Colorado, including in Rocky Mountain National Park.[80]

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[71] Commentary: Dryland Watershed Restoration with Rock Detention Structures: A Nature-Based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon, Norman, L., *Frontiers in Science*, (2022).
[72] UDWR: Beaver Restoration Assessment Tool (BRAT) - Wheaton Ecogeomorphology & Topographic Analysis
[73] Estimating widespread beaver dam loss: Habitat decline and surface loss at a regional scale, Scamardo, J., Marshall, S., and Wohl, E., *Ecosphere*, (2021).
[74] Colorado Beaver Restoration Assessment Tool (BRAT) (arcgis.com)
[75] EEAGER: A Neural Network Model for Finding Beaver Complexes in Satellite and Aerial Imagery, Fairfax, E.et al., *JGR Biogeosciences*, (2023). Google will "run the model across [California] sometime in 2024.That should give the state's wildlife department a good sense of where its beavers are living and where it could use more." Spying on Beavers From Space Could Help Save California | WIRED (12/28/23).
[76] Habitat conditions at beaver settlement sites: implications for beaver restoration projects, Ritter, T. et al., *Restoration Ecology*, (2020).
[77] Practical Grazing Management to Maintain or Restore Riparian Functions and Values on Rangelands, Swanson, S., Wyman, s. & Evans, C., *Journal of Rangeland Applications*, (2015); Livestock grazing limits beaver restoration in northern New Mexico, Small, B., Frey, J. & Gard, C., *Restoration Ecology*, (2016).
[78] Estimating widespread beaver dam loss: Habitat decline and surface loss at a regional scale, Scamardo, J., Marshall, S. and Wohl, E., *Ecosphere*, (2021).
[79] Wolf Reintroduction Changes Yellowstone Ecosystem (yellowstonepark.com). Yellowstone researchers documented that wolves changed elk behavior from lingering in riparian corridors intensively browsing on willows to being more dispersed. A decade after wolf reintroduction, some streams had recovered willow populations enough for beaver to return.
[80] Effects of Elk Herbivory (U.S. National Park Service) (nps.gov)

Studies have shown that managing livestock grazing practices to better protect the riparian corridor led to recovery over the course of many years.[81] This recovery relates back to the PBR principles to address the causes of the degradation and removing the stressors to allow vegetation recovery to occur. The Dixie Creek case study near Elko, Nevada, is one of the best documented case studies of riparian corridor recovery obtained by implementing grazing Best Management Practices (BMPs) over three decades. These photos were taken about 30 years apart by Carol Evans, retired BLM Fisheries Biologist, and are just two of many paired photos featured in a video about the restoration.[82]

Photo by Carol Evans of Dixie Creek near Elko, Nevada, prior to restoration in the late1980s that shows extensive stream and riparian vegetation degradation caused by decades of unmanaged grazing.

Photo by Carol Evans of Dixie Creek of the same reach approximately 30 years later in 2019 showing recovered flows and vegetation achieved by grazing management practices.

Dr. Anthonie Holthuijzen, a Sr. Ecologist for the Idaho Power Company, conducted a comprehensive 11-year study of a nine-mile reach of a small stream in eastern Oregon. Holthuijzen documented before and after results of eliminating or controlling livestock grazing on a former 10,000-acre ranch that had been intensively grazed and managed for livestock for over 100 years.[83] The nine river miles were broken up into lower, middle, and upper reaches for purposes of the study based upon their condition at the beginning of the study. The study results provide important conclusions for land managers.

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[81] Low-tech Riparian and Wet Meadow Restoration Increases Vegetation Productivity and Resilience Across Semi-arid Rangelands, Silverman, N. et al., *Restoration Ecology*, (2018).
[82] Creating Miracles in the Desert: Restoring Dixie Creek - YouTube (Oct 2021), and here is a BLM webpage that highlights the story: Restoring Dixie Creek | Bureau of Land Management (blm.gov)
[83] Passive Restoration of a Small Mountain Stream in Eastern Oregon, Holthuijzen, A., *Northwest Science*, (2021).

The lower reach was in the worse condition of the three reaches. It had been straightened for farming purposes in the early 1900s and had become deeply incised. Even though it had complete elimination of cattle grazing during the 11-year study, the riparian vegetation did not recover. Holthuijzen concluded that "channelization degraded the riparian system to such an extent that its inherent capacity to recover was compromised . . . Here, active restoration is needed."[84] The author noted that beavers had failed to successfully recolonize the lower reach due to dam blow-outs from fast-moving, channelized flows. Similar to the Bridge Creek case study, he suggested that BDAs may be an effective approach under these circumstances to assist beavers to rebuild.[85]

The middle reach was less incised than the lower reach and was not channelized. Willows began recovering after a few years of little to no grazing, and then beaver were able to recolonize portions of the reach. A sixfold increase of woody vegetation around the beaver ponds was observed, compared to a twofold increase where beaver were not located. Overall, grazing management increased the functionality[86] of the middle reach from 26% to 37%. Within beaver complexes the increase was even greater at 57%.[87] Holthuijzen reported that the Upper Reach vegetation did not recover due to trespassing cattle that grazed the area during late summer and fall. "Consistent late-season use, as in the Upper reach, precludes recovery of the riparian system."[88]

Depending on the circumstances, grazing management is often critical after installation of a LTPBR project to allow riverscape recovery to occur. "Restoration project teams and other invested parties should discuss livestock grazing management options early in the restoration planning process when the proposed meadow is currently grazed or may be grazed post-restoration. Because restoration can often result in improved forage for livestock, landowners and livestock operators should have substantial motivation to modify grazing management to achieve and maintain functional meadow conditions."[89] As discussed by Swanson and his co-authors in their paper on grazing management, the measures that are needed will depend on the situation, but often they include providing alternate water sources for livestock, fencing off the riparian corridor in more sensitive locations, pasture rotation, and/or timing, duration, and intensity limitations on grazing.[90]

Dr. Susan Charnley and her colleagues extensively studied the social factors of six beaver-related restoration projects on public lands and private ranches in five Western States. They determined that it is critical to have the conversation with landowners who are interested in implementing LTPBR about the need to adopt riparian grazing management BMPs for successful stream recovery.[91] Charnley noted that "on federal lands, regulatory flexibility to implement different management strategies may be needed. Collaborative approaches in which agency staff and [grazing] permittees work together to develop alternatives are likely to have better outcomes than top-down mandates."[92]

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[84] *Id.*
[85] *Id.*
[86] Stream functionality was based upon the Stream Evolution Model developed by Brian Cluer and Colin Thorne, a comprehensive evaluation of the functionality of a fluvial system that includes both hydro-geomorphological and vegetation metrics. Holthuijzen (2021).
[87] *Id.*
[88] *Id.*
[89] Effects of Livestock Grazing on The Ecology of Sierra Meadows: A Review of The Current State of Scientific Knowledge to Inform Meadow Restoration and Management, Vernon, M., Campos, B., & Burnett, R. *Environmental Management*, (2022). This paper is now the most current and comprehensive literature review on the ecological effects of livestock grazing in mountain meadows.
[90] Practical Grazing Management to Maintain or Restore Riparian Functions and Values on Rangelands, Swanson, S., Wyman, s. & Evans, C., *Journal of Rangeland Applications*, (2015); see also Livestock management, beaver, and climate influences on riparian vegetation in a semi-arid landscape, Fesenmyer, K. et al., *PLoS ONE 13(12)*, (2018).
[91] Ranchers and Beavers: Understanding the Human Dimensions of Beaver-related Stream Restoration on Western Rangelands, Charnley, S. et al., *Rangeland Ecology & Management*, (2020).
[92] *Id.*

III. State of the Science – Reported Effects of LTPBR

3.1 Published Research Overview

Early motivators for LTPBR were generally the same motivators for past decades of restoration, which were mainly driven by improving stream and riparian conditions for aquatic and terrestrial species that depend upon healthy diverse habitats in riverscapes. However, over the last 10 years, as more LTPBR projects were completed, case studies began reporting not only the substantial ecological improvement results, but also improvements in ecosystem services that functioning connected floodplains and beaver complexes provide. These include improved water quality, flood attenuation, the potential for longer seasonal flows, higher quality and quantity forage for livestock and wildlife, and resilience to wildfire.

Research surrounding the science and benefits of connected floodplains and beaver complexes is growing. Today, the available research generally falls into two main categories – the effects of beaver complexes on ecology and ecosystem services, and the effects of LTPBR projects where beaver take over the low-tech structures within a year or two. Some papers report on the effects of just LTPBR structures without beaver present, which will be noted when that's the case. Hundreds of research papers have been published over the last seven decades documenting the positive ecological effects of beaver complexes.[93] As stated by Dr. Ellen Wohl, professor at Colorado State University, "people undertaking soil conservation and river restoration seem to rediscover the abilities and effectiveness of beavers every few decades."[94]

Conversely, as described by Hydrologist Dr. Caroline Nash, relatively few LTPBR projects have been "conducted with rigorous pre- and post-project monitoring due largely to monitoring costs, because these can exceed restoration costs."[95] Conversations with numerous LTPBR project managers indicated their project budget had little to no funds allocated to monitoring. Instead, project benefits are often documented by pre- and post-project photos that indicated positive changes such as increased density and diversity of riparian species and aggradation that raised the stream bed to begin reconnecting with the floodplain. Despite the budget constraints, enough papers have been published to document delivery of multiple ecological and ecosystem services benefits.

The benefits of LTPBR projects include the following documented benefits listed in the chart below, if beaver return, survive, *and build dams*[96] that result in a connected functioning floodplain. It is important to note that these benefits vary by degrees depending upon many factors, such as the river corridor's geomorphology, hydrology, vegetation, and duration of beaver activity**.**

Ecological and Ecosystem Services Benefits of Functioning Floodplains	**Paper Section**
Combination of Surface and Groundwater Effects: Increased Later Season Flows	**3.2**
Surface Water Effects: Attenuating Flows, Increasing Natural Storage	**3.3**
Groundwater Recharge – Higher Water Table, Increased Hyporheic Exchange	**3.4**
Water Quality – Sediment, Nitrogen, Heavy Metal & Temperature Reductions	**3.5**
Reducing the Impacts of Natural Disasters – floods, fire and drought	**3.6**
Economic Benefits	**3.7**
Ecological Benefits – iodiversity and fish habitat	**3.8**
Benefits of Interest to Agricultural Community – Increased Water and Forage Availability	**3.9**

[93] Dam builders and their works: Beaver influences on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems, Larsen, A., Larsen, J. & Lane, S., *Earth-Science Reviews*, (2021). The authors reviewed 1,389 papers on beaver published between 1941 and 2021.

[94] Saving the Dammed, Why We Need Beaver-Modified Ecosystems, Wohl, E., *Oxford University Press*, (2019).

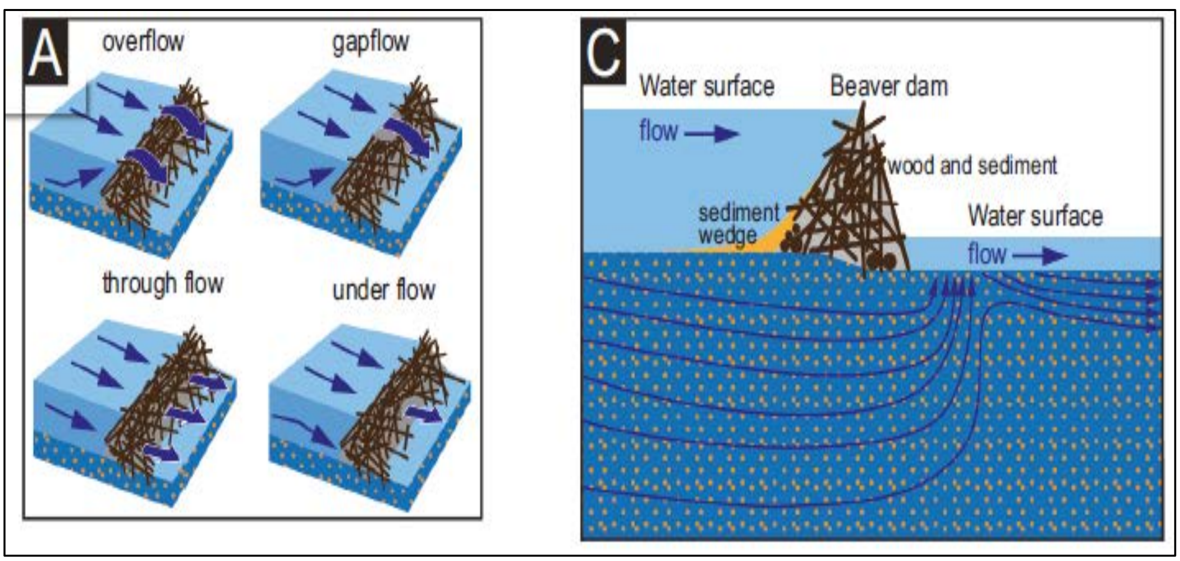
[95] Great Expectations: Deconstructing the Process Pathways Underlying Beaver-Related Restoration, Nash, C. et al., *BioScience*, (2021).

[96] "The desired outcome from beaver-related restoration was . . . contingent on what beavers were expected to do to the landscape, that is, construct dams that then change hydrogeomorphic and ecological conditions." Nash et al., (2021). Beaver do not always build dams – on larger rivers where flows are too strong for dams they create bank side burrows instead.

3.2 Combination of Surface and Groundwater Effects: Increased Later Season Flows

A 2021 comprehensive review of beaver studies by Dr. Annegret Larsen and her co-authors included a key finding that “a complex of beaver dams can increase surface and subsurface water storage” that can result in increased baseflows in the low-flow months.[97] However, there are no definitive answers to the questions of “How much is baseflow increased?” or “Where will this occur?” The answer is almost always “it depends.” Larsen points out that “the extent of these impacts depends firstly on the hydro-geomorphic landscape context, which determines the extent of floodplain inundation, a key driver of subsequent changes to hydrologic, geomorphic, biogeochemical, and ecosystem dynamics. Secondly, it depends on the length of time beavers can sustain disturbance at a given site.”[98]

Larsen provided the graphic below illustrating the flow pathways of both surface and groundwater through beaver dams. Of these four flow pathways, gapflow (flow through gaps and notches in the beaver dam) seems to be “by far the dominant mechanism of water release.”[99] The potential for beaver dams to contribute to enhancing low baseflows is significantly dependent on which type of release dominates. Beaver dams with higher overflow, through flow, and gapflow “will more rapidly deplete surface storage...and have diminished flow releases downstream,” as compared to beaver dams with higher underflow rates that may sustain a higher contribution to baseflows.[100] As pointed out by Nash et al. (2021) and other researchers, whether or not a LTPBR project will result in higher late season flows is highly variable and needs much more research.[101] In the meantime, this benefit should be presented to stakeholders as hoped for but should not be expected.



Conceptual models of the different types of flows through beaver dams. Larsen, A. et al., (2021).

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[97] Dam builders and their works: Beaver influences on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems, Larsen, A., Larsen, J. & Lane, S., 218 *Earth-Science Reviews* (2021).
[98] *Id.*
[99] *Id.*
[100] *Id.*
[101] See also Groundwater-Mediated Influences of Beaver-Mimicry Stream Restoration: A Modeling Analysis, Bobst, A., Payn, R. & Shaw, G., *Journal of the American Water Resources Association*, (2022).

3.3 Surface Water Effects: Attenuating Flows, Increasing Natural Storage

Beaver dams and the increased wetland vegetation surrounding beaver ponds act as speed bumps that "slow the flow" of snow and storm water runoffs.[102] When beavers were extirpated from western watersheds and their ponds and side channels drained, large areas of naturally stored surface water and surrounding wetlands were lost. As a result, flows concentrated into single-thread, powerful channels that incised and disconnected rivers from their floodplains.[103] Without the "speed bumps" provided by beaver complexes, runoff became flashier, with higher flows immediately after snowmelt and rain events and lower flows later in the summer. LTPBR project results are showing that these changes can be reversed. The photos below illustrate the increased surface water footprint before and after beaver colonization on Bridge Creek in eastern Oregon, where BDAs were installed to establish conditions that would encourage the return of beaver to the area.[104]

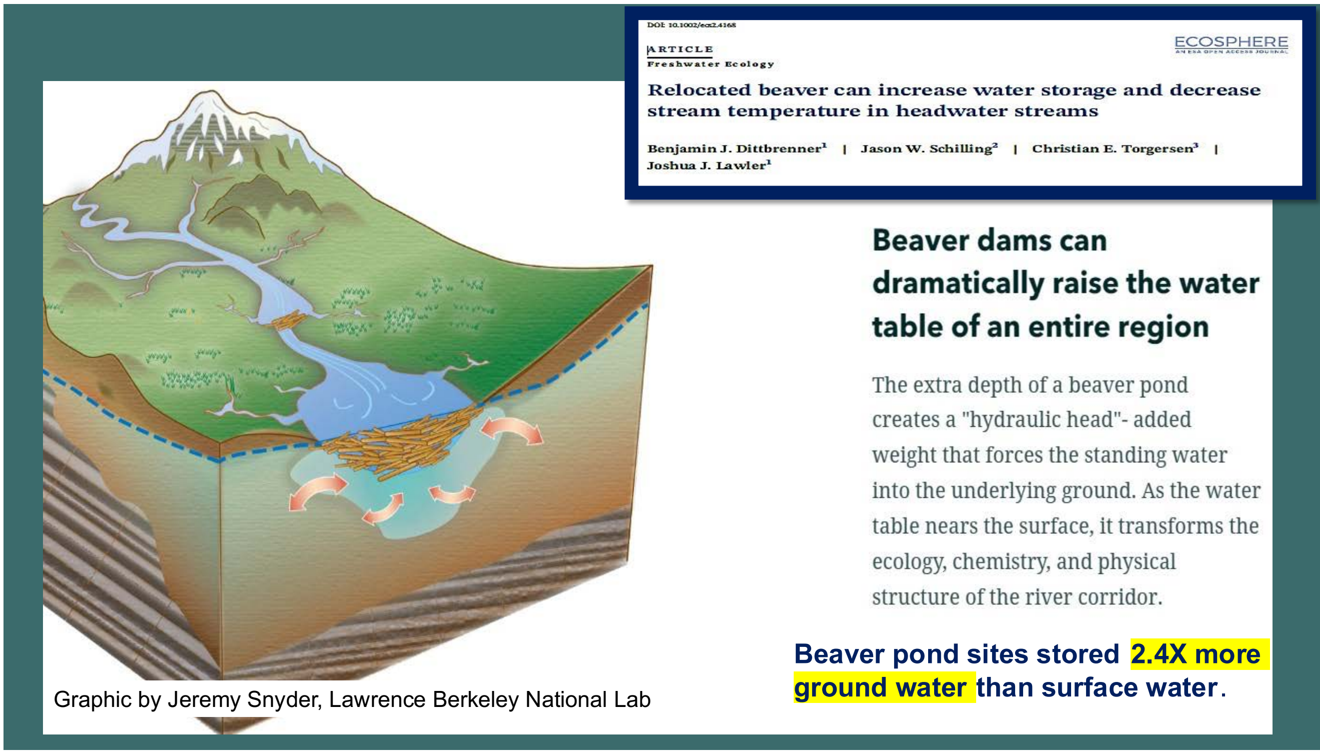
Before and after photos of a LTPBR project that installed BDAs to facilitate the return of beaver to this reach of Bridge Creek in eastern Oregon, Weber et al., (2017).

A study in Poland compared water storage capacities of a 9.2 km reach of a lowland forest stream during years when beaver ponds were expansive (11.4 acres) versus seven years later when beaver ponding activity had decreased significantly (1.5 acres).[105] The study reported a significant decrease in water storage from over 4 million gallons in 2006 to ~1.8 million gallons in 2013. The study concluded "that the cascades of beaver ponds are a natural, efficient and long-term means of increased water retention in forested catchments," and that "this very valuable ecosystem service should be weighed against the downside of loss of trees in the beaver complex area."[106]

This conclusion of substantially increased natural storage was recently echoed by another extensive 3-year PhD study by Benjamin Dittbrenner and his co-authors who evaluated changes in surface and groundwater storage after beaver were successfully relocated to 5 sites in the west Cascade

[102] Nature's ecosystem engineers, Brazier, R. et al., *WIREs Water*, (2020).
[103] Brazier et al., (2020); Legacy effects of loss of beavers in the continental United States., Wohl, E., *Environ. Res. Letters*, (2021).
[104] Alteration of stream temperature by natural and artificial beaver dams, Weber, N. et al., *PLOS/One*, (2017).
[105] Spatial and Temporal Variability of Channel Retention in a Lowland Temperate Forest Stream Settled by European Beaver, Gygoruk, M. & Nowak, M., *Forests*, (2014).
[106] *Id*.

Mountains in Washington.[107] Their calculations indicated that the 5 beaver sites stored roughly 22 times as much surface water as control sites - the control reaches remained relatively constant with a mean volume of 11m³ per 100 m of stream compared to 243m³ per 100 m for the reaches with beaver complexes.[108] "In watersheds with similar conditions and climate trajectories as those in our study area, beaver relocations may be an effective climate adaptation tool to ameliorate elevated temperature and reduced watershed storage."[109]



Slide created by Jackie Corday with info from Relocated beaver can increase water storage and decrease stream temperature in headwater streams, Dittbrenner, B. et al., *Ecosphere*, (2022).

Similarly, a 2022 northern Minnesota study spanning many decades evaluated how beaver population recovery influenced surface water dynamics in relation to population density over 70 years across multiple spatial scales (pond, watershed, and regional).[110] This comprehensive study determined that the combination of active and abandoned ponds created stability for regional-scale surface water area over decades and "demonstrated precipitation had little influence on surface water stored in beaver ponds at the landscape-scale . . . [because] the accumulation of abandoned ponds that continue to store surface water can preserve important ecological functions like mitigating drought effects."[111] The authors concluded that restoring beavers to their historical locations in upper watersheds "could be used to increase surface water storage and promote freshwater conservation efforts in forested ecosystems."[112]

To further understand existing research on the impacts of beaver and BDA projects on stream flows, PhD candidates Niall Clancy and Marshall Wolf identified case studies that monitored for hydrologic effects. Of the six published studies they found, four studies "observed minimal or no difference" in

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[107] Relocated beaver can increase water storage and decrease stream temperature in headwater streams, Dittbrenner, B. et al., *Ecosphere*, (2022).
[108] *Id.*
[109] *Id.*
[110] Relics of beavers past: time and population density drive scale-dependent patterns of ecosystem engineering, Johnson-Bice, S. et al., *Ecography*, (2022).
[111] *Id.*
[112] *Id.*

stream flows pre- versus post-project and two showed increased baseflows during the summer months.[113] The authors concluded that small BDA projects “tend not to have observable impacts on streamflow” and that “larger BDA projects (~20 or more structures) can store runoff and increase baseflows.”[114] One of the studies the authors cited for increased base flows was located in northern Utah, where researchers collected stream flow data on a half-mile reach of a first order mountain stream before beaver were present. Grazing management was implemented along the study reach (fencing off the riparian corridor), which allowed willows to recover and enticed the beaver to return. The researchers then monitored stream flows two and three years after beavers recolonized the stream reach and built a series of 10 dams.[115] Data from this study indicated that the reach “transitioned from slightly losing in year one (pre-beaver colonization period) to gaining in year three (second year into beaver colonization).” This resulted in a slight increase in stream flows post-beaver colonization.[116]

No data appears to be available to support making an *assumption* that there will be measurable loss due to increases in riparian vegetation detectable by stream gages where water rights are measured. Our search found only one study that tries to directly answer this question, which was conducted by Andrew Bobst, Sr. Hydrologic Engineer for Montana Bureau of Mines, as part of his Montana State University PhD research. For his 2016-2020 study of a SW Montana BDA project on Alkali Creek, he monitored for hydrologic changes and determined that by year three post-project the riparian vegetation had increased by ~25%, which resulted in a 0.7gpm increase in ET per BDA.[117] This small amount of decreased flow (0.0015cfs) calculated by Bobst was well below an amount that could be detected by a stream gage.[118]

Dr. Laura Norman, a USGS Research Physical Scientist and her colleagues in Arizona led a paired-watershed study in southeast Arizona comparing an untreated watershed (the control) to an adjacent watershed that had thousands of rock detention structures (RDS) installed over the course of three decades.[119] Norman sought to determine the hydrologic effects of 3 miles of RDS in West Turkey Creek. The private ranch landowners had installed the hand-built rock structures to control erosion and noticed that they had also improved riparian vegetation and later season water availability. Norman and her colleagues calculated the water balances and measured stream discharge in the treated stream and the control sub-watershed and were able to document the benefits that the landowner had reported. “Concerns that downstream flows would be reduced in the treated watershed, due to storage of water behind upstream check dams, were not realized.”[120] Instead, the RDS on West Turkey Creek resulted in “28% more flow volume per area in the treated watershed compare[d] to the untreated watershed. The cause for this delayed but increased response was hypothesized to be increased baseflow incurred from the RDS installed in arid and semiarid environments.”[121]

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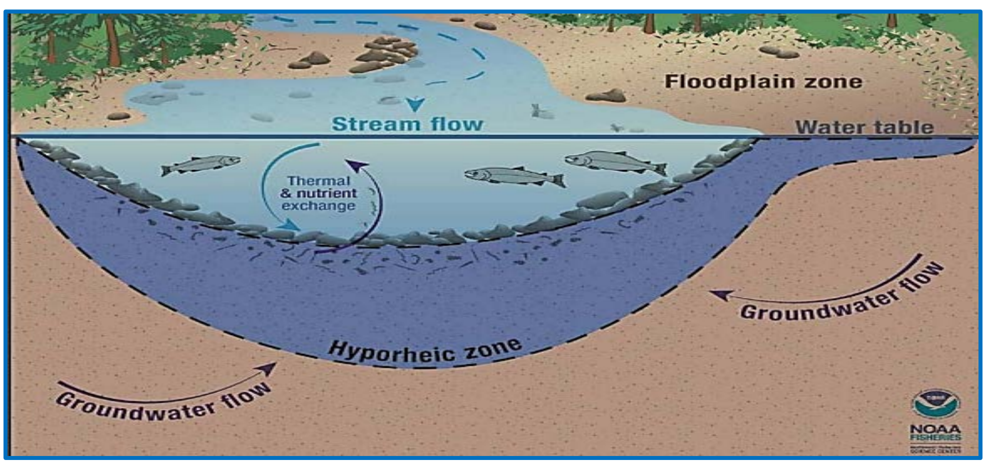
[113] A Brief Summary of Beaver Mimicry and Streamflow, Clancy, N. & Wolf, M., *University of Wyoming Factsheet,* (2022).
[114] *Id.*
[115] Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream, Majerova, M. et al., *Hydrology and Earth System Sciences Discussions*, (2015).
[116] *Id.*
[117] Andrew Bobst, Sr. Hydrologist for Montana Bureau of Mines, PowerPoint presentation to the Riverscape Restoration Network on August 2020. Bobst has been working to prepare his research for publication.
[118] “We estimated actual ET (AET) using high resolution NDVI imagery obtained with drone flights. We combined NDVI with potential ET (PET) calculated at nearby Agrimet stations (Penman-Monteith) to get AET. Then to get the groundwater component of that we subtracted off the AET estimated in the uplands (where groundwater is not available to the plants).” Email from Andrew Bobst to Jackie Corday July 8, 2022.
[119] Hydrologic Response of Streams Restored with Check Dams in the Chiricahua Mountains, Arizona, Norman, L. et al., River Research and Applications, (2016).
[120] *Id.*
[121] Ecosystem Services of Riparian Restoration: A Review of Rock Detention Structures in the Madrean Archipelago Ecoregion, Norman, L., *Air, Soil, and Water Research Volume 13*, (2020). In the original Norman et al. 2016 research paper, the authors posited that check dams could help increase baseflows in arid lands. Previous to this 2016 study, Norman documented in a 2014 study higher greenness and vegetation water content levels in riparian areas where gabions had been installed to slow flows and reduce erosion near the Arizona-Mexico border versus similar stream reaches without gabions. Remote sensing analysis of riparian vegetation response to desert marsh restoration in the Mexican Highlands, Norman, L. et al*., ScienceDirect*, (2014).

In August 2022, Norman collaborated with other scientists to publish a related paper that introduced a new term, natural infrastructure in dryland streams (NIDS), which encompasses both naturally occurring structures (log jams, beaver dams, geologic features) and human-made flow speed bumps (e.g., BDAs, PALS, RDS) that "all affect streamflow hydraulics and sedimentation and can enhance riparian plant establishment."[122] This paper is a comprehensive review of published studies on the effect of NIDS and includes charts that summarizes the many ecological and ecosystem services of NIDS, including surface water and natural storage. The authors are careful to explain the difference between infrastructure that intentionally **retains** stormwater (such as stormwater retention ponds, rain barrels, reservoirs, etc.) versus NIDS that **detain** water temporarily – attenuating/slowing the flow with the NIDS but allowing it to pass through as should all well-designed LTPBR structures. This distinction is very important in regards to water rights, which is reviewed in Section 5.6 of this paper.

3.4 Groundwater Recharge – Higher Water Table, Increased Hyporheic Exchange

Numerous studies have demonstrated that beaver complexes increase groundwater storage, raise the local water table, and increase hyporheic exchange (where surface and shallow groundwater converge through porous sediment around a river). In Dr. Emily Fairfax's abstract from the American Geophysical Union 2016 Fall Meeting, she wrote, "The hyporheic exchange of water between streams and adjacent subsurface sediments, is an important process connecting groundwater and surface water. Knowing the location and magnitude of hyporheic exchange is useful in evaluating fish spawning habitats, biogeochemical processes, and capacity for aquifer recharge of a given stream."[123] The extent to which groundwater storage occurs is dependent on the hydraulic characteristics of both the river and the aquifer. "Provided high open water levels in a beaver pond and backwater areas can be maintained, they may serve as an effective recharge pathway, either via the channel boundary or as floodplain infiltration, causing a rise in local groundwater levels."[124] Aquifer recharge "may be the most important beaver-related factor in mitigating effects from climate change because groundwater is released more gradually than surface water and has no evaporative losses."[125] This important factor of no evaporative loss is further enhanced by a recent study that determined five beaver "relocation sites with established ponds stored 2.4 times more groundwater than surface water in ponds."[126]



Graphic from the National Oceanic Atmospheric Administration

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[122] Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience, Norman, L. et al., *Science of the Total Environment*, (2022.)
[123] Hyporheic Exchange in a Stream Dammed by Beaver: A 1D Simulation with Spatial Energy Head Gradients and Heterogeneous Hydraulic Conductivity as Drivers, Fairfax, E. & Small, B., *American Geophysical Union*, Fall Meeting 2016, abstract #H53E-1747.
[124] Dam builders and their works: Beaver influences on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems, Larsen, A., Larsen, J. & Lane, S., *Earth-Science Reviews*, (2021).
[125] The Beaver Restoration Guidebook Version 2.02 at p. 7, Pollock, M. et al., USFWS, Portland, OR (2023).
[126] Relocated beaver can increase water storage and decrease stream temperature in headwater streams, Dittbrenner, B. et al., *Ecosphere*, (2022).

Colorado State University researchers Cheri Westbrook and David Cooper, and USGS Hydrologist Bruce Baker, examined the hydrologic influences of two beaver dams on a 1.5 km reach of the Colorado River in Rocky Mountain National Park (RMNP) in a broad alluvial valley with a focus on surface inundation, groundwater levels, and flow patterns.[127] After three years of monitoring and research, they concluded that the beaver dams and ponds greatly enhanced the depth, extent, and duration of inundation on the landscape following flood events, with elevated water table during both high and low flows.[128] They found that "the main effects of beaver on hydrologic processes occurred downstream of the dam rather than being confined to the near-pond area. Beaver dams on the Colorado River caused river water to move around them [their dams] as surface runoff and groundwater seepage during both high- and low-flow periods. The beaver dams attenuated the expected water table decline in the drier summer months for 9 and 12 ha of the 58 ha study area."[129] Westbrook and her co-authors conducted a similar study to determine the influence of beaver dams on the water table dynamics of a Rocky Mountain fen.[130] They monitored water tables in the peatland for four years with a network of 50 shallow wells while beaver dams were intact and two years after they were breached by an extreme flood event. "We found that, because of the unique way in which dams were built, they connected the peatland to the stream and raised and stabilized already high-water tables within a 150-m radius."[131] They concluded that the beaver dams "increased surface and groundwater storage, which has implications for regional water balances, especially in times of drought."[132]

Westbrook's studies were most recently cited by Andrew Bobst, a Sr. Hydrologist for the Montana Bureau of Mines and Geology and PhD candidate, who recently published a 2022 study that used "MODFLOW groundwater models of hypothetical stream corridors to evaluate the general nature of hydrologic effects from varied beaver mimicry restoration (BMR) treatment designs in different hydrologic settings.[133] The models were run for five years for five different BMR designs that were "inspired by the choices in BMR design frequently considered in the intermountain western United State."[134] The study's modeling results "showed increases in groundwater levels [around the BMR site] by up to 78 cm (~31"), which is similar to values reported in other studies (citing Westbrook and others)."[135]

3.5 Water Quality

Research has demonstrated many benefits of functioning, connected floodplains and beaver complexes for pollution filtration, reduction of suspended sediments, and temperature regulation. Most relevant to the LTPBR focus is a Colorado Department of Public Health and Environment (CDPHE) conclusion that nonpoint source pollution, such as sediments and nutrients, are "the leading remaining cause of water quality problems" in Colorado.[136] Reductions in pollution from excessive sediments and nutrients from beaver-related activities are discussed in detail below, along with temperature benefits.

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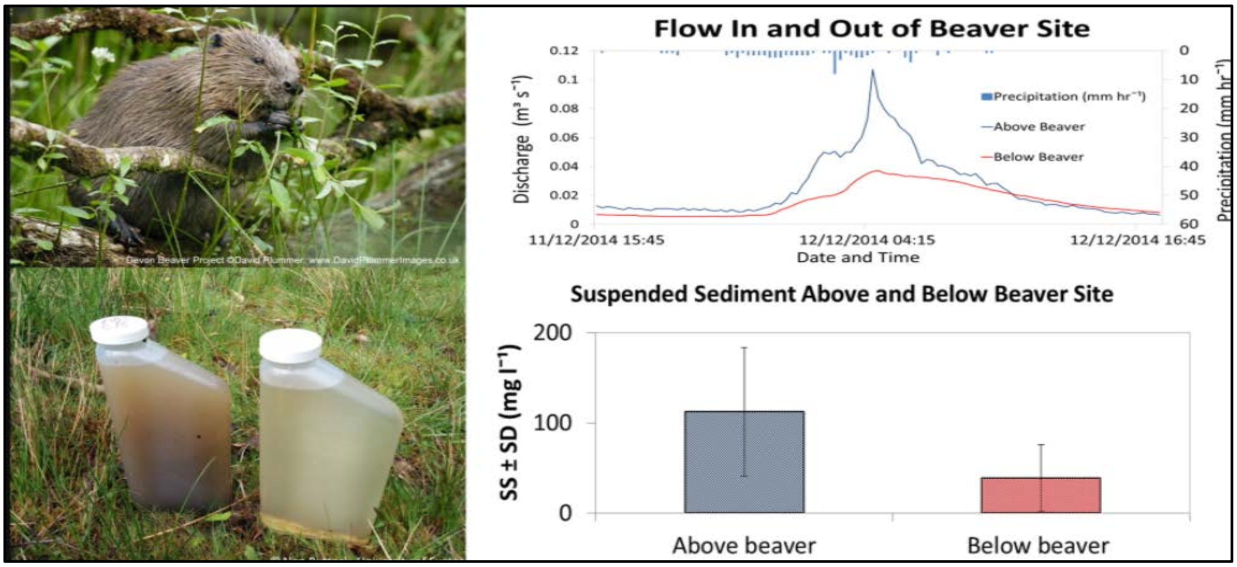
[127] Beaver dams and overbank floods influence groundwater-surface water interactions of a Rocky Mountain riparian area, Westbrook, C., Cooper, D. & Baker, B., *Water Resources Research*, (2006).
[128] *Id.*
[129] *Id.*
[130] Beaver-mediated water table dynamics in a Rocky Mountain fen, Karran, D., Westbrook, C. & Bedard-Haughn, A., *Ecohydrology*, (2017).
[131] *Id.*
[132] *Id.* An Arizona study found similar impacts at rock gabions situated on the Babacomari River, where the structures increased infiltration rates by about 10%, most notably in lateral flow contributions. Modeling Riparian Restoration impacts on the hydrologic cycle at the Babacomari Ranch, SE Arizona, Norman, L., (2019).
[133] Groundwater-Mediated Influences of Beaver-Mimicry Stream Restoration: A Modeling Analysis, Bobst, A., Payn, R. & Shaw, G., *Journal of the American Water Resources Association*, (2022).
[134] *Id.*
[135] *Id.*
[136] Nonpoint Source Pollution Management | Department of Public Health & Environment (colorado.gov)

3.5.1 Sedimentation

Excessive fine-grained sediments deposited on stream bottoms can smother or otherwise damage aquatic habitats and spawning areas and reduce species' survival and growth rates. Sedimentation may also impair food sources, or fill in shallow and slow-water habitats, which provide important cover and refuge for aquatic life.[137] Several studies have focused on how beaver complexes, depending on the size, can greatly reduce suspended stream sediments to improve downstream water quality. Researchers hypothesize that sediment reduction downstream of beaver complexes is owed to two key mechanisms, slowing the flow of water and "an increase in both ponded water and a local rise in water tables that results in an overall increase in wetness altering the biogeochemical cycling of nutrients."[138]

A study in England monitored 13 beaver ponds built from 2011 to 2016 by beavers introduced to a controlled 4.5-acre site that had no ponds on the stream prior to the reintroduction, except for one pond that had been created to help facilitate beaver survival.[139]



Photos/graphs from Eurasian beaver activity increases water storage, attenuates flow, and mitigates diffuse pollution from intensively managed grasslands, Puttock, A. et al., *Science of the Total Environment*, (2017).

Their monitoring over four years determined that the beaver ponds each trapped on average 7.8 tons of sediment over the four years, totaling 101.5 tons for all 13 ponds that predominately came from the intensively managed agricultural grasslands upstream.[140] The authors concluded their "results indicate that beaver ponds may help to mitigate the negative off-site impacts of accelerated soil erosion and diffuse pollution from agriculturally dominated landscapes."[141] A similar study in Russia determined beaver dams along the Sumka River reduced sediment mass per liter of water by 53% flowing downstream of the beaver dams.[142] A 2023 CSU Master's Thesis by Dunn found that focused on assessing sediment capture in beaver complexes after the 2020 Cameron Peak wildfire surveyed 48 beaver ponds, half of which were located wildfire burn areas.[143] On average, each beaver pond stored 281 tons of sediment "and burned ponds have less remaining storage area than unburned ponds, indicating that beaver ponds are storing significant amounts of post-fire sediments."[144] In

[137] Water Quality | Colorado Water Knowledge | Colorado State University (colostate.edu)
[138] Nature's ecosystem engineers, Brazier R. et al., *WIREs Water*, (2020) citing Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands, Puttock et al., *Science of the Total Environment*, (2017).
[139] Sediment and Nutrient Storage in a Beaver Engineered Wetland, Puttock, A. et al., *Earth Surface Processes and Landforms*, (2018).
[140] *Id.*
[141] *Id.*
[142] Is it possible to use beaver building activity to reduce lake sedimentation? Gorshkov, D., *Lutra,* (2003).
[143] Dammed Ponds! A study of Post-Fire Sediment and Carbon Dynamics in Beaver Ponds and Their Contributions to Watershed Resilience, Dunn, S., *CSU Masters Thesis*, (2023).
[144] *Id.*

addition to beaver dams, other studies have documented significant sediment capture at gabions, check dams, RDS, and leaky weirs.[145]

3.5.2 Nitrogen, Heavy Metals

As noted by Dr. Murray and her co-authors, beaver handywork can "laterally expand riparian habitat, increase floodplain connectivity, and create hydric wetland soils, all of which are processes that inherently decrease concentrations of pollutants."[146] Murray et al studied three headwater beaver ponds in Utah and concluded that "beaver ponds can attenuate heavy metals at a rate 2 to 4 times greater (increasing with pond age) than a riffle stream reach." Another study of an Oklahoma stream impacted from mine drainage documented that beaver complexes resulted in a decrease in downstream aqueous iron and cadmium concentrations at the rate of 57% and 63% respectively.[147] A Montana Technological University's master's thesis by Peach in Montana involved taking many soil core samples of an abandoned beaver pond in an area impacted by historic mining. The core samples indicated that the highest concentrations of heavy metals were concentrated in the clay-rich fine sediments of the former pond bottom.[148] In Colorado, researchers are currently studying how beaver can help clean up pollution from mines, including the threat of continued heavy metals pollution from leaching.[149] A series of beaver complexes downstream from mines could help abate and settle out heavy metals before they reach downstream ecosystems and communities. In addition to attenuating heavy metals, studies from Lazar, et. al and Puttock, et. al also show that beaver ponds "can remove 5 to 45% of watershed nitrate loading from rural watersheds with high N loading (i.e., 1000 kg km^{-2}). Thus, beaver ponds represent an important sink for watershed nitrate."[150]

3.5.3 Temperature

Rising stream temperatures in Colorado is a major concern for cold water trout species and other aquatic life. Increased stream temperatures led Colorado Parks and Wildlife to issue fishing closures on many Colorado streams, such as the Yampa and Colorado Rivers in 2020, 2021, and again in 2022.[151] Restoring native riparian vegetation canopy can help decrease water temperature, a key water quality issue for aquatic life. A 2018 study by Dr. Trimmel and her colleagues affirmed the importance of shading and riparian vegetation along riverbanks for aquatic biodiversity, especially in the context of rising stream temperatures due to climate change: "One of the most influential factors regulating stream temperature is riparian vegetation . . . by reducing the solar radiation input at the river surface by shading."[152] Beaver generally promote the health and abundance of riparian vegetation, but they can also reduce the taller shading vegetation (i.e., trees and shrubs).

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[145] Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience, Norman, L. et al., *Science of the Total Environment*, (2022.) Leaky weirs are another version of RDSs used for slowing flows to recharge the aquifer and capture sediment. Hydrologic Data Collected at Leaky Weirs, Cienega Ranch, Arizona, Coy, H., et al., (2020).

[146] Source or sink? Quantifying beaver pond influence on non-point source pollutant transport in the Intermountain West, Murray, D., Neilson, B. & Brahney, J., *Journal of Environmental Management*, (2021).

[147] Metals retention in a net alkaline mine drainage impacted stream due to the colonization of the North American Beaver, Shepard & Nairn, *Science of the Total Environment*, (2020).

[148] Beaver Ponds as Catchment-wide Retention Basins for Heavy Metals Sequestration, Peach, C., Master's Thesis, *Montana Technological University*, (2021).

[149] Beavers could be Colorado's secret weapon to cleaning rivers and abandoned mines, Clarissa Guy, Rocky Mountain PBS, Oct. 23, 2021.

[150] Beaver Ponds: Resurgent Nitrogen Sinks for Rural Watersheds in the Northeastern United States, Lazar, J. et al., *Journal of Environmental Quality*, (2015). See also Sediment and Nutrient Storage in a Beaver Engineered Wetland, Puttock, A. et al., *Earth Surface Processes and Landforms*, (2018).

[151] CPW News Release - Voluntary Fishing Closure July 2021; Colorado's Fly-Fishing Industry Faces the Growing Threat of Climate Change (5280.com); Eagle River under full-day fishing closures, July 25, 2022 - VailDaily.

[152] Can riparian vegetation shade mitigate the expected rise in stream temperatures due to climate change during heat waves in a human-impacted pre-alpine river? Trimmel et al., *Hydrology and Earth System Sciences*, (2018). See also Steamboat looks to new program to address high river temperatures - Aspen Journalism (Sept. 28, 2021). The City of Steamboat Springs hired experts to determine solutions for reducing high water temperatures in a 57-mile segment of the Yampa River to help improve compliance with their wastewater treatment plant permit. One of the solutions recommended and adopted by the City involved re-establishing tall willows and native cottonwoods on key reaches where they once grew prior to removal for agriculture or development.

Additional research is needed to further understand the effects of beaver complexes on stream temperature, as existing research shows highly variable results. Dr. Majerova, a Water Resources Specialist/Hydrologist with BIO-WEST, Inc., and her co-authors found that "the temporal and spatial scales considered within individual studies vary widely, leading to inconsistent conclusions regarding beaver dam impacts on stream systems."[153] A 2012 literature review[154] of 24 articles on the topic cited 13 papers that concluded positive effects of beaver complexes from creating a mosaic of temperature variability and 11 articles that indicate negative impacts from summer temperature increases, but Majerova noted that "only one [of the 11] was data driven while the rest were speculative."[155]

In one of the longest and most data intensive temperature studies, the authors collected temperature data for eight years over a 21-mile stretch of Bridge Creek in eastern Oregon, a hot and dry area dominated by sagebrush and juniper.[156] Over the course of several years, 134 BDAs were installed, which resulted in 46 being taken over by beaver. Natural beaver dams also increased from 24 to 120 over the eight-year study. The study "results identified two distinct ways by which stream temperature may be affected by beaver dams: a moderation of summer temperature extrema at the reach scale, and increased channel scale temperature heterogeneity. Our reach scale analyses showed a pronounced buffering of diel stream temperature cycles downstream of beaver impounded reaches during summer baseflow periods … that manifested as increased minimum and decreased maximum daily temperature, with no change in the daily mean."[157] These results were attributed to the fact that beaver complexes "often increase groundwater exchange because of increased groundwater storage and deposition of alluvial material behind dams."[158]

In a 3-year study from Washington to evaluate the temperature effect of new beaver dams on 5 stream reaches, researchers used continuous temperature data loggers that recorded every 30 minutes.[159] "Beaver complexes in our study basin had an overall mean cooling effect of -2.3℃ on streams. Four of these sites exhibited a mean change of -3.18℃ from before to after relocation. One site exhibited a change of +1.1℃ following relocation. This trend was observed in the summer of 2015, which was particularly hot, and highlights the role of environmental factors on temperature outcomes at a given site."[160]

3.6 Reducing the Impacts of Natural Disasters

Restoring headwater floodplains and wetlands has been shown to reduce the risk of natural disasters, including drought, wildfires, and floods. As noted by Dr. Fairfax and Dr. Jordan in WIREs Water, "When we reconnect streams and rivers to their floodplains, we perform both climate mitigation work (slowing the trajectory of global warming) and climate adaptation work (building resilience and resistance to climate-driven disturbances that are already occurring."[161]

3.6.1 Improved Drought Resilience – Snowpack/Storm Flow Attenuation

As discussed in Section 3.2, studies indicate that healthy natural stream systems and restored headwater floodplains and wetlands recharge local aquifers. Enhanced water storage capacity in floodplains allows for slow infiltration of runoff into soils and wetlands and provides natural storage

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[153] Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream, Majerova, M. et al., *Hydrology and Earth System Sciences Discussions*, (2015).
[154] Qualitative and quantitative effects of reintroduced beavers on stream fish, Kemp, P. et al., *Fish Fisheries*, (2012).
[155] Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream, Majerova, M. et al., *Hydrology and Earth System Sciences Discussions*, (2015).
[156] Alteration of stream temperature by natural and artificial beaver dams, Weber, N. et al., *PLOS/One*, (2017).
[157] *Id.*
[158] *Id.*
[159] Relocated beaver can increase water storage and decrease stream temperature in headwater streams, Dittbrenner, B. et al., *Ecosphere*, (2022).
[160] *Id.*
[161] Beaver: The North American freshwater climate action plan, Jordan, C. & Fairfax, E., *WIREs Water*, (2022).

during spring runoff that can be slowly released to streams during the summer months.[162] In Western States, the most important water storage comes not from reservoirs, but from mountain snowpack, which slowly releases water through a mix of runoff and soil and groundwater infiltration.[163] Given that snowpack continues to decrease,[164] many scientists are studying how beaver complexes could provide the "second snowpack," or natural water storage, to help improve resilience to drought.

Slide from the Spring 2022 update on the Roaring Fork Watershed Biodiversity & Connectivity Study

In two similar studies, Utah State University Watershed Science master's student Konrad Hafen and University of Washington PhD candidate Ben Dittbrenner sought to understand if increasing beaver ponds "could provide a conceptually similar function to snowpack by delaying the delivery of precipitation by increasing surface and groundwater storage."[165] Each student developed a model to estimate the increased surface and groundwater storage potential under different beaver population scenarios. Hafen collected basic characteristics of over 1,700 beaver dams to parameterize, calibrate, and validate his model.[166] Dittbrenner took a three-step approach by first developing a "predictive beaver habitat model" to help identify where beaver could exist in a given watershed. Then he relocated 91 "nuisance" beavers into Washington's upper Skykomish River Watershed and monitored for changes to surface and groundwater storage. He utilized that data to create a regional model "that explored the degree to which beaver reintroductions could offset reductions in water availability under various climate scenarios and time frames."[167] Both studies concluded that overall, beaver ponds in snow-dominated basins cannot offset how fast snowpack is being lost to climate change,[168] but both studies saw situations where beaver have the potential to increase summer water availability. Dittbrenner concluded that in rain-dominated basins beaver could increase "summer water availability

[162] Beaver mitigate the effects of climate on the area of open water in boreal wetlands in western Canada, Hood, G. & Bayley, S., *Biological Conservation*, (2008).
[163] In the Western US, "snowmelt provides more than 75% of the total freshwater supply.' NASA Opens New Era in Measuring Western U.S. Snowpack, NASA, (2013).
[164] Climate Change Indicators: Snowpack, US EPA website, (2023). This website provides a map showing how much the snowpack has decreased across the Western States from 199-2022, which averages about a 23% decline.
[165] To What Extent Might Beaver Dam Building Buffer Water Storage Losses Associated with a Declining Snowpack? Hafen, K., Master of Science Thesis Utah State University, (2017); Restoration potential of beaver for hydrological resilience in a changing climate, Dittbrenner, B., PhD Dissertation University of Washington, (2019).
[166] Hafen (2017).
[167] Dittbrenner (2019).
[168] These findings are consistent with a key study by Dr. Rosemary Carroll from the Rocky Mountain Biological Lab and her colleagues that examined the ability of monsoon rains to mitigate stream streamflow depletions from reduced snowfall in a Colorado snow-dominated headwater basin. The authors concluded that while monsoonal rain is an important contribution to streamflow (represents up to 10% of flows), it "is unable to fully replace streamflow from lost snow accumulation even for the largest historical monsoon event." Efficiency of the Summer Monsoon in Generating Streamflow Within a Snow-dominated Headwater Basin of the Colorado River, Carroll, R., Gochis, D. & Williams, K., *Geophysical Research Letters*, (Nov. 2020).

by up to 20 percent" and Hafen concluded beaver restoration strategies "may prove beneficial for ecosystems where human-made reservoirs are not available to regulate hydrologic regimes."[169]

Cameron Peak Fire burned everything around this beaver pond in 2020. Photo taken in June 2021 by Evan Barrientos, Audubon Rockies. Beavers Offer Help for Western Waters | Audubon Rockies

3.6.2 Wildfire – Beaver Complexes Serve as Wildfire Breaks and Refugia

Wetlands can provide important fire breaks for wildfires and in some instances these areas have been found to rebound more quickly post-wildfire. A 2020 study by Fairfax and Whittle of five large wildfires in Colorado, California, Oregon, Idaho, and Wyoming showed that riparian vegetation around beaver complexes has a three times greater rate of survival from wildfire than stream segments without beavers.[170] Photos like the one below taken in 2021 after the 2020 Cameron Peak Fire in Colorado are important visual tools to show the dramatic losses from mega wildfires, except where there were sizeable beaver complexes.[171] In addition to continuing to function and provide ecosystem service benefits such as debris ash flow filtration, the complexes also serve as important refugia to increase wildlife survival during and following wildfires.[172] Moreover, healthy riparian corridors provide higher survivorship of post-fire mature trees, providing valuable seed sources for recovery.[173] All of these benefits are summed up well by the Utah Summit County Public Lands Manager Jess Kirby, who stated during an interview that her agency is involved and supports LTPBR projects because:

> "*We started connecting how restoration work in stream areas and improving riparian zones can become natural fire breaks for areas. And so, it aligned with a lot of the work we were doing in the county to reduce fuels and create buffers for a wildfire. Then you've got the added benefit of a restored stream, restoring habitat, more water in the ground, and keeping the system wet. It's increasing the water table and allowing vegetation to come in naturally.* ***There's just such a benefit to having the full system working as it should***." Jess Kirby, Utah Summit County Public Lands Manager, Sageland Collaborative calls for volunteers in East Canyon Creek restoration work - TownLift, Park City News (Sept. 14, 2022).

[169] Dittbrenner (2019) and Hafen (2017).
[170] Smokey the Beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western United States, Fairfax, E. & Whittle, A., Ecological Society of America, Vol. 30, Issue 8 (2020).
[171] Beaver Dams Help Wildfire-Ravaged Ecosystems Recover Long after Flames Subside, Whitcome, I., Scientific American, 2-7-22.
[172] *Id.*
[173] Still standing: Recent patterns of post-fire conifer refugia in ponderosa pine-dominated forests of the Colorado Front Range, Chapman, T. et al., *PloS One* 15, no. 1 (2020).

This profound effect of beaver complexes surviving fire is now catching the attention of those focused on reducing the impacts of wildfire. A recent article in Wildfire Today noted that the Idaho Sharp Flats Fire "burned all of the land around Baugh Creek, but the Beavers' dams and the wetland they created were left unburned."[174] The contrast was so stark that researchers at Boise State University and Utah State University teamed up with NASA to start building tools to measure the benefits of beaver reintroduction in other areas of the country."[175]

3.6.3 Reduce Flood Risks

Floods are the most common and widespread natural hazard in Western States, including Colorado and flood-prone areas have been identified in all 64 counties and almost all municipalities.[176] Wheaton and Skidmore note in *Anthropocene* that, "As the frequency and magnitude of devastating storms and floods increases, some local and state governments, including Colorado, Montana, Oregon, and Washington, are now mapping channel migration or flood hazard zones to inform planning and development."[177] Colorado is also developing mapping to show where natural sediment and flood water attenuation can best take place to help reduce future flood damage to communities.[178] Restoring floodplains and wetlands upstream from communities and transportation infrastructure prone to flooding can help reduce losses by attenuating snow melt and stormwater runoff events.[179]

In 2013, Westbrook and her colleagues monitored the largest recorded flood in the Canadian Rocky Mountains west of Calgary, Alberta to challenge the commonly held assumption that beaver dams fail during large floods. A goal of the study was to provide "information needed to evaluate the risk of relying on beaver as a nature-based solution" in response to the impacts of climate change.[180] The authors determined that the majority (68%) of beaver dams fully or partially persisted. Additionally, the water storage offered by beaver dams (even failed ones) delayed downstream flood peaks. This finding has "important implications for reintroducing beaver as part of nature-based restoration and climate adaptation strategies."[181]

Another recent study reported in the Journal of Flood Risk Management provides insights into the human dimensions of utilizing beaver as a "Natural Flood Management" measure, including the need to provide opportunities for localized engagement with communities and stakeholders at the catchment scale.[182] A factor to consider when determining appropriate locations for LTPBR/BRR is that heavy storm events can cause beaver dams to breach. There are reported instances of sudden rushes of water from beaver dam breaches in the vicinity of road infrastructure causing damage when the water and debris fills in and overtops the road culverts that are too small to handle such events.[183]

3.6.4 Carbon Sequestration

Protection, restoration, and improved management of floodplain and wetland areas is now widely recognized for the potential to increase carbon storage and avoid greenhouse gas emissions resulting from conversion of natural habitat.[184] A recent paper by Dr. Cody Reed and her co-authors found that montane meadows contain high densities of soil carbon and can be large sinks of carbon, and,

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[174] Humans mimicking beavers to combat wildfires and restore wetlands - Wildfire Today (Oct. 29,2023).
[175] NASA satellites reveal restoration power of beavers, Mongabay Conservation News, (Sept. 2023).
[176] Flood Information & Resources | DNR CWCB (colorado.gov)
[177] Riverscapes as natural infrastructure: Meeting challenges of climate adaptation and ecosystem restoration, Skidmore, P. & Wheaton, J., *Anthropocene*, (2022).
[178] Colorado Fluvial Hazard Zone Program Overview
[179] Levees don't protect, they disconnect: A critical review of how artificial levees impact floodplain functions, Knox, R., Wohl, E. & Morrison, R., *Science of the Total Environment*, (2022); Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany, Serr-Llobet, A. et al., *Frontiers in Environmental Science*, (2022).
[180] Hydrological functioning of a beaver dam sequence and regional dam persistence during an extreme rainstorm, Westbrook, C., Ronquist, A. & Bedard-Haughn, A., *Hydrological Processes*, (2020).
[181] *Id.*
[182] Beavers and flood alleviation: Human perspectives from downstream communities, Auster, R., Barr, S. & Brazier, R., *Journal of Flood Risk Management*, (2022).
[183] Beaver dam collapse destroys almost 250 foot section of ALCAN Highway (alaskasnewssource.com) (July 2, 2022).
[184] Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation, Were, D. et al., *Earth Systems and Environment*, (2019); What the world needs now to fight climate change: More swamps (theconversation.com)

conversely, degraded meadows can be net carbon sources.[185] In a study comparing carbon stocks in degraded floodplains to restored and reference floodplains, Dr. Sarah Hinshaw found that the majority of degraded floodplains contained lower carbon stocks than healthily functioning floodplains such as beaver meadows.[186] The restoration of meadows and wetlands can be designed to improve hydrologic function while also mitigating soil carbon losses. Groups like The Nature Conservancy and the Colorado Natural and Working Lands Task Force are currently working to produce a high-level estimate of the carbon benefits of protection and restoration of wet meadows and wetlands.

3.7 Economic Benefits

Several reports have begun quantifying the economic benefits of the ecosystem services beaver complexes can provide. That said, additional analysis is needed understand the value of ecosystem services depending on the specifics of the project. It is important to note that some of the studies referenced in this section make assumptions about ecosystem service benefits that the scientific literature previously reviewed in this report indicates may not apply equally in all circumstances, such as cooling of water and increasing late-season flows.

The most comprehensive report around the economic benefits of beaver created wetlands, prepared by PhD candidate Stella Thompson and her co-authors, analyzed 43 studies that focused on the ecosystem services of North American and Eurasian beaver, as listed in the author's chart below.[187] The 2020 study determined that habitat and biodiversity, non-consumptive recreation, and moderation of extreme events (flood/drought) are particularly valuable services, in addition to water purification.[188] Based upon their calculations of approximately 1 million hectares (~2.5M acres) of the estimated beaver range in the Northern Hemisphere, "you'll find that beavers have the capacity to provide upwards of half a billion dollars of value in ecosystem services [annually]."[189]

Table 5. Annual per-hectare service values and aggregated economic value of beaver wetland ecosystem services in the Northern Hemisphere, calculated using our meta-regression value function, and the density coefficient used to aggregate per-hectare values. Meta-regression variable names are given in parentheses

Ecosystem service	Per-hectare service value USD(2017) ha^{-1} yr^{-1}	Value of ponds created by dam-building beavers (|1 million ha) USD(2017) yr^{-1}	Density coefficient used in calculations
Habitat and biodiversity provision (HabBio)	133	133 million	1
Greenhouse gas sequestration (GHG)	75	75 million	1
Non-consumptive recreation (Recreation)	167	43 million	0.26
Moderation of extreme events (FloodDrought)	124	32 million	0.26
Water purification (Quality)	108	28 million	0.26
Water supply (Supply)	77	20 million	0.26
Recreational hunting and fishing (HuntFish)	6.1	1.6 million	0.26

Chart from Ecosystem services provided by beavers (Castor spp.), Thompson, S. et al., *Mammal Review*, (2020).

[185] Montane Meadows: A Soil Carbon Sink or Source? Reed, C., et. al., *Ecosystems,* 2020.
[186] Monitoring heterogeneity and carbon sequestration of restored river-wetland corridors, Hinshaw, S., Doctoral dissertation, Colorado State University. *ProQuest Publication* No. 29257255 (2022). See also Dr. Ellen Wohl's research on beaver complexes carbon storage: The persistence of beaver-induced geomorphic heterogeneity and organic carbon stock in river corridors, Laurel, D. & Wohl, E., *Earth Surface Processes and Landforms*, (2018).
[187] Ecosystem services provided by beavers (Castor spp.), Thompson, S. et al., *Mammal Review*, (2020).
[188] *Id.*
[189] Busy beavers: Calculating the value of ecosystems services provided by beavers. | Yale Environment Review This article provided a review of the Thompson et al. (2020) study.

Another 2020 study conducted an Oregon statewide public lands ecosystems benefits analysis to determine the potential economic benefits if beaver were re-established in their historical ranges. This study focused on stream temperature reductions, increased natural water storage, improved habitat, and better recreational opportunities when stream water and habitat are improved. [190] In the chart on the next page, the authors compare the average cost per mile of beaver-related restoration efforts (which could be installation of BDAs that lead to the return of beaver and/or beaver relocation) to reduce stream temperatures on 303(d) listed streams versus more expensive traditional restoration methods. The comparison indicates a potential for substantial savings.[191]

Table 9. Estimated costs to decrease stream temperatures on 303d listed streams.

Category	**5th order or greater streams**	**1st - 4th order streams**
Stream miles	11,057	23,413
Restoration cost @ $74,000/mile	$818,218,000	$1,732,562,000
Restoration cost @ $411,000/mile	$4,544,427,000	$9,622,743,000

Economic Benefits of Beaver-created and Maintained Habitat and Resulting Ecosystem Services, Niemi, E. et. al., (2020).

The study also looked at the value of "increased surface and groundwater storage" on Oregon's federally managed public lands. The chart below was generated by applying the BRAT tool in the North Fork Burnt River watershed near Baker City in eastern Oregon. The study estimated how much natural water storage could occur behind the modeled capacity of 7,019 beaver dams and the economic benefit it would have. The study used a value of $50/acre-foot for naturally stored water.[192] The study assumed that this naturally stored water would otherwise not be available for water users in the later season under the existing conditions, which were characterized by flashy, short flows in incised streams, in which water moves out of the watershed quickly instead of being attenuated and released later in the season. It is interesting to note the use of $50/acre foot, a value that represents a small fraction of the value of water in Colorado. A Water Education Colorado article cites that on the urban Front Range, water has been leased for $500/acre foot and up.[193] On the western slope, where agricultural producers voluntarily enrolled in the System Conservation Program, run by the Upper Colorado River Commission, participants were willing to accept an average payment of $394/acre foot in Colorado and $422/acre foot across the Upper Basin to temporarily reduce their water use for irrigation.[194]

[190] Economic Benefits of Beaver-created and Maintained Habitat and Resulting Ecosystem Services, Niemi, E., Fouty, S. & Trask, S., (2020). A large part of the study was also devoted to forecasting the economic benefits of improved salmon populations that comes from restoring riverscapes.
[191] Niemi, Fouty & Trask at p. 21 (2020). The term "303(d) listed" is short for a state's list of impaired waters caused by exceedance of pollution standards set under the Clean Water Act, including stream temperature. Overview of Listing Impaired Waters under CWA Section 303(d) | US EPA
[192] *Id.* at page 26
[193] Front Range housing boom sends water prices soaring - Water Education Colorado
[194] Colorado River commission reviews lessons learned from water conservation program. Sackett, H. Aspen Journalism, (September 6, 2023).

Table 14. Economic benefit of stored water behind beaver dams upstream of Unity Reservoir, Baker County as a function of number and size of beaver ponds. Valued at $50/acre-foot.

Ecosystem Service Provided	Water stored (gallons)	Water stored (acre-feet)	Households served for a year	Economic Benefit
Delayed water flow upstream of reservoirs if the watershed is at maximum modeled dam capacity (7019 dams)	4.2 to 12.7 million	725 -2,175	220 -660	$10,997 - $32,990
Delayed water flow upstream of reservoirs if the watershed is at half modeled dam capacity (3510 dams)	2.1 to 6.3 million	363 -1,088	110 - 330	$5,499 - $16,497

Economic Benefits of Beaver-created and Maintained Habitat and Resulting Ecosystem Services, Niemi E. et al., (2020)

In 2011, Dr. Mark Buckley, a natural resources economist, and his co-authors prepared an ecosystem services study for the Escalante River Basin in Utah to determine the potential value of beaver repopulating the basin they once historically occupied.[195] As explained by Buckley, "managing the Escalante Basin for beaver restoration holds the potential to improve several ecosystem functions that residents, businesses, and visitors rely upon, particularly in terms of water availability, water quality, instream flows, and habitat. In this analysis, we consider the potential impacts of restored beaver populations in the Escalante Basin and the values that beaver restoration would provide to local communities and beyond."[196] Buckley determined that the sparsely beaver populated basin (due to historic human causes), if recolonized by beaver at similar densities to other comparable Utah basins, could provide substantial sediment reduction and water quantity and quality benefits as shown in this exert from one of the many charts in his study.

Table 22. Summary of Quantified Services in the Northern Portion of the Escalante Basin

Ecosystem Service	Demand	Supply	Price	Valuation Method	Total Value
Sediment Retention	Agricultural Users Municipal Users Recreationists Water Agencies	33.6 million cubic yards per year	$2 per cubic yard	Dredging Costs	$67.2 million per year
		2,400 cubic yard per river mile per year			$4,800 per river mile per year
		1,100 cubic yard per dam per year			$2,200 per dam per year
Delayed Water Flow upstream of Wide Hollow Reservoir	Agricultural Users Recreationists Water Agencies	9,200 acre–feet per year	$520 per acre–foot	Avoided Cost	$4.8 million per year
		6.6 acre–feet per river mile per year			$3,400 per river mile per year
		0.3 acre–feet per dam per year			$156 per dam per year

Portion of a chart from The Economic Value of Beaver Ecosystem Services, Escalante River Basin, Utah

195 The Economic Value of Beaver Ecosystem Services, Escalante River Basin, Utah, Buckley, M. et al., (2011).
196 *Id.*

TABLE 3 Estimates of potential surface water storage volumes (in cubic kilometers) based on historical and current beaver dam capacities across the hydrologic regions of Colorado, as well as percent change (decline) in volumes

Region	Historic capacity (km^3)	Current capacity (km^3)	Difference (%)
Plains	0.143	0.098	−31.3
Foothills	0.055	0.034	−37.8
Mountains	0.113	0.055	−51.4
Rio Grande	0.023	0.013	−43.5
Northwest	0.083	0.039	−53.5
Southwest	0.045	0.024	−45.7
Total	0.461	0.263	−42.9

TABLE 4 Estimates of potential sediment storage volumes (in cubic kilometers) based on historical and current beaver dam capacities across the hydrologic regions of Colorado, as well as percent change (decline) in volumes

Region	Historic capacity (km^3)	Current capacity (km^3)	Difference (%)
Plains	0.0819	0.0567	−30.8
Foothills	0.0396	0.0253	−36
Mountains	0.105	0.0579	−44.8
Rio Grande	0.0151	0.0097	−35.7
Northwest	0.0702	0.0361	−48.5
Southwest	0.0419	0.0243	−41.8
Total	0.353	0.21	−40.5

In a 2021 Colorado study, CSU PhD candidate Julie Scamardo and her co-authors were the first to analyze what the historical loss of beaver ponds and potential recolonization could mean for Colorado. Specifically, the authors looked at the benefits of recovered water and sediment storage volume in our watersheds where conditions are suitable for beaver.[197] The authors applied the BRAT to determine the difference between where beaver complexes currently exist and where they were absent, but conditions indicated that they could be successfully reintroduced. They determined that "beaver-associated surface water and sediment storage capacities have decreased by approximately 40%" on average across the state.[198]

Millions of dollars are spent each year across Colorado to dredge reservoirs to remove accumulated sediments, which are often delivered by degraded incised stream reaches located upstream from the reservoirs. This dredging cost could be substantially reduced in some locations by restoring degraded incised stream reaches above the reservoir to increase sediment retention in adjacent floodplain areas and beaver complexes.[199]

3.8 Ecological Benefits

The beaver is a keystone species that has a disproportionately large ecologic, geomorphic, and hydrologic effect on their environment compared with their abundance."[200] Cataloging the numerous ecological benefits of beaver has been widely documented by many excellent sources, and thus this paper focuses on just a couple of benefits of particular importance in Colorado.[201]

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[197] Estimating widespread beaver dam loss: Habitat decline and surface loss at a regional scale, Scamardo, J., Marshall, S. & Wohl, E., *Ecosphere*, (2021).
[198] *Id.*
[199] Dredging will provide access to last 5 feet of irrigation water in parched McPhee Reservoir - The Durango Herald (Aug. 6, 2021). "Denver Water has spent $28 million in reservoir dredging, facilities repair, and landscape-restoration projects at Strontia Reservoir. Denver Water dredged for sediment as recently as five years ago but may need to do so again this year." East Troublesome Fire could cause water-quality impacts for years - Aspen Journalism (Jan 18, 2021).
[200] Scamardo et al., (2021).
[201] Saving the Dammed, Why We Need Beaver-Modified Ecosystems, Wohl, E., *Oxford University Press*, (2019); Eager: The Surprising, Secret Life of Beavers and Why They Matter, Goldfarb, B., *Chelsea Green Publishing*, (2018); The Beaver Restoration Guidebook Version 2.02, Pollock, M. et al., USFWS, Portland, OR (2023).

3.8.1 Biodiversity and Habitat Resiliency

The two photos below speak volumes of the difference between a beaver occupied reach and unoccupied reach in otherwise similar conditions on the same stream.[202] The visual comparison makes evident the substantial differences in habitat available for aquatic and terrestrial species. Riparian and wetland areas on floodplains are hotspots for biological diversity[203] and provide both refuge and movement corridors for most wildlife species during all or part of their life cycles.[204] Biodiversity of fish, amphibian and reptile species, birds, and mammals is higher in water ways with beaver complexes than in those without them.[205] These habitat areas also serve as buffers and critical refuge for many species during natural disturbances such as droughts and wildfires.

Two sections of the River Utah, where the North American beaver is present on the left, and absent on the right.
Credit: Stacy Passmore, "Landscape with Beavers," Places Journal, July 2019

3.8.2 Benefits of Beaver Activity to Fisheries

Similar to the stream temperature issue (see Section 3.5.3), continued study of the effect of beaver complexes on fisheries is warranted due to the variance of study results and social perspectives. Specifically, even though beavers and fish species co-evolved for millions of years together, and beaver were pervasive across the entire North American continent, debate is still ongoing regarding whether beaver dams hinder fish passage and reduce oxygen levels in ponds. As with stream temperature studies, results appear highly dependent on methodology and level of scientific rigor of the studies.

Extensive review of available literature shows that reporting of positive benefits notably outweighs reporting of negative impacts, and a large majority of negative reports relied on speculation to support conclusions.[206] The USFWS Beaver Restoration Guidebook provides an overview of available studies on beavers and fisheries. This review was updated in a 2020 study by Dr. Richard Brazier and his co-

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[202] Landscape with Beavers, Passmore, S., *Places Journal*, (July 2019).

[203] Water Is Life: Importance and Management of Riparian Areas for Rangeland Wildlife, Maestas, J. et al., Chap. 7 in the book: Rangeland Wildlife Ecology and Conservation, McNew, L.B., Dahlgren, D.K., Beck, J.L. (eds), *Springer*, (2023).

[204] Riparian Areas: Functions and Strategies for Management, Washington D.C. National Academies Press, (2002).

[205] A Biodiversity Boost from the Eurasian Beaver in Germany's Oldest National Park, Orazi, V. et al., *Frontiers in Ecology and Evolutions*, (2022). A Wyoming study of 11 streams in sagebrush steppe areas in Wyoming found that "total species richness, total abundance, and aquatic assemblage abundance were each positively correlated with dam density, suggesting that dam density is related to other riparian characteristics selected by birds." Influence of beaver dam density on riparian areas and riparian birds in shrubsteppe of Wyoming, Cooke, H. & Zack, S., *Western North American Naturalist*, (2007).

[206] Qualitative and quantitative effects of reintroduced beavers on stream fish, Kemp, P. et al., *Fish and Fisheries*, (2012).

authors,[207] which upheld the overall conclusion that positive effects of beaver on fisheries outweigh potential negative impacts. The table below summarizes findings from the Beaver Guidebook. Another benefit to add to this list was determined by a Wyoming study that concluded that the negative impacts of drought on Bonneville cutthroat trout populations were to some extent mitigated where beaver were active and there was less intensive livestock grazing.[208]

Table 3. Potential Impacts of Beaver Modifications on Fish Species

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

Chart from the USFWS Beaver Restoration Guidebook Version 2.02, pages 15-16 (2023).

One of the most comprehensive studies on the beaver/fisheries topic came out of the eastern Oregon Bridge Creek project (described on pages 14, 16, 37 and 48) in which the researchers hypothesized that BDAs and the return of beaver "can greatly accelerate the incision recovery process" of Bridge Creek, and second, that stream recovery would significantly improve "the hydrologic, thermal, geomorphic, and vegetation characteristics of the stream and riparian habitat, which in turn would improve habitat conditions for steelhead."[209] Their study data provided strong support for their hypotheses. Four years after installing a series of BDAs that led to beaver recolonization, juvenile steelhead population increased 175% and their survival rate increased by 52% in comparison to the control stream.[210] "Despite the dramatic increase in beaver dams and BDAs [over the course of the seven-year study], we observed no changes in upstream spawner migration success."[211]

A recent study by Dr. Michael Pollock and his co-authors involved tracking PIT tagged juvenile coho salmon and steelhead trout to test their ability to cross BDAs.[212] They "hypothesized that, because these salmonids have evolved in the presence of beaver dams for millions of years, that they have also evolved strategies for crossing them, and that by constructing dams similar to beaver dams in terms of size, location and materials, these fishes would also be able to cross these human-built structures."[213] Their study results documented that both species "had little difficulty crossing the BDAs, whether by jumping over a 40-cm waterfall or swimming up a short side channel with 8-11% slope."[214] They noted "that because outmigrating juveniles time their downstream movements to coincide with high flows, concerns over possibility at this life-stage are less warranted. The same can be said for adult salmon, especially coho salmon, which generally time their movements to coincide with high

[207] The Beaver Restoration Guidebook Version 2.02 pages 16-17, Pollock, M. et al., USFWS, Portland, OR (2023); Beaver: Nature's ecosystem engineers, Brazier, R. et al., *WIREs Water*, (2020).
[208] Complementation of Habitats for Bonneville Cutthroat Trout in Watersheds Influenced by Beavers, Livestock, and Drought, White, S. & Rahel, F., *Transactions of the American Fisheries Society*, (2008).
[209] Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead, Bouwes, N. et al., Scientific Reports, (2016).
[210] *Id.*
[211] Bouwes et al., (2016). See also Beaver activity increases habitat complexity and spatial partitioning by steelhead trout, Wathen, C. et al., *Canadian Journal of Fisheries and Aquatic Sciences*, (2019); Juvenile salmonid growth, survival, and production in a large river floodplain modified by beavers, Malison, R. et al., *Canadian Journal of Fisheries and Aquatic Sciences*, (2015).
[212] Field experiments to assess passage of juvenile salmonids cross beaver dams during low flow conditions in a tributary to the Klamath River, California, USA, Pollock, M., Witmore, S. and Yokel, E., PLoS ONE 17(5): e0268088, (2022).
[213] *Id.*
[214] *Id.*

flows."[215] They concluded by suggesting "unless there is clear and compelling evidence that a beaver dam or and BDAs are preventing the movement of fishes that this is likely to have a population-level effect, such structures should not be removed. Options such as temporarily notching may be an alternative under some conditions, such as the presence of adult salmon stacking up below a dam, but guidelines need developing."[216]

3.8.3 Benefits to Pollinators[217]

Studies have documented the importance of prairie wetlands[218] forested wetlands,[219] and riparian areas[220] as key habitats for many pollinator species. Healthy wetlands are typified by high plant species diversity and structural complexity, creating distinct niches for diverse invertebrate species. [221] The NRCS Conservation Practice Stream Habitat Improvement and Management for farmers notes that "maximizing plant diversity along riparian corridors will result in more pollinators and other terrestrial insects to feed fish in the streams."[222] Diverse microhabitats support a greater variety of plant species for food and shelter for pollinators. In turn, pollinators, through their reproductive services, contribute to supporting plant species diversity in wetlands and adjacent areas.[223] Research has also shown that "many pollinator species that fed on plants in wetlands also visited crop fields providing a free source of crop pollination.[224]

Due to concerns of the impacts to agriculture and native plants from declining pollinator populations, in 2022 Colorado legislators passed SB22-199 that requires the Department of Natural Resources to conduct a study to be completed by January 2024 "to gain a better understanding of Colorado's pollinators that keep our ecosystems healthy and resilient."[225] The study was conducted by CSU Extension and other partners and just released in January 2024.[226]

[215] *Id.*
[216] *Id.*
[217] Thanks to Melody Daugherty, Executive Director of Manitou Pollinators, for suggesting the addition of this pollinator section to the paper and to Amy Yarger, Director of Horticulture of the Butterfly Pavilion, for providing a draft to work from.
[218] Pothole wetlands provide reservoir habitat for native bees in prairie croplands, Vickruck, J. et al., *Biological Conservation*, (2019). The authors studied the role that in-field or nearby prairie pothole wetlands play in supporting native pollinators. Their study "results suggest that wetlands play an important role in providing critical resources for native pollinators, and encouraging farmers not to drain or plow through these wetlands will have beneficial impacts for native pollinators in the area." *Id*.
[219] Bumble bee (Bombus spp.) diversity differs between forested wetlands and clearcuts in the Acadian forest, Brooks, D. & Nocera, J., *Canadian Journal of Forest Research*, (2020). "Differences in presence and abundance of bumble bee species may be explained by forested wetlands having a greater variety of flowering plants than forest harvest sites." *Id*.
[220] Riparian buffer strips: Their role in the conservation of insect pollinators in intensive grasslands systems, Cole, L. et al., *Agriculture, Ecosystems & Environment*, (2015). This study in Scotland concluded that "while intensively managed grassland fields offered little in the way of foraging resources for insect pollinators, their adjacent riparian field margins (both fenced and unfenced) were floristically more diverse and supported richer more abundant assemblages of insect pollinators. Pollinators were more abundant and assemblages were richer and more diverse in wide riparian buffer strips (i.e. over 5 m wide) when compared with narrow buffer strips (i.e. less than 3.5 m wide) or unfenced riparian." *Id*.
[221] Pollinator Biology and Habitat (usda.gov), *NRCS Michigan Technical Note No. 20*, (April 2013).
[222] *Id.* at page 15. See also Wetlands as Pollinator Habitat, Nizzi, S. & Powers, R., Xerces Society for Invertebrate Conservation Blog, (May 2021).
[223] Pollination Ecology of the Rare Orchid, Spiranthes diluvialis: Implications for Conservation, Pierson, K., USDA publication, (2002). The authors studied the habitat and pollinator needs of a federally listed threatened species of riparian orchid found only in the Western US. They determined that having a variety of pollinating plant species in the orchid's habitat for native bees to have multiple sources of pollen was important to an overall conservation plan. "Conservation efforts for S. diluvialis must be designed and implemented at a community or ecosystem level to be successful. Healthy populations of S. diluvialis will be realized not simply by protecting riparian habitat; in addition, managers must be cognizant of the natural nesting habitat and floral needs of the bee pollinators that make reproduction and continued existence of this rare plant possible." *Id*.
[224] Take Care to Manage Wetlands for Pollinators, Southern Sustainable Agriculture Research and Education (March 2018); Pothole wetlands provide reservoir habitat for native bees in prairie croplands, Vickruck, J. et al., *Biological Conservation*, (2019).
[225] CO Dept of Natural Resources Launches study on Native Pollinating Insects | Colorado Governor Jared Polis
[226] Colorado Native Pollinating Insects Health Study, Armstead, S. et al., Colorado Department of Natural Resources, (2024).

3.9 Benefits of Interest to Agricultural Community – Increased Water and Forage Availability

As the broad range of studies discussed above establish, beavers and LTPBR projects can help restore riverscapes, improving wildfire and drought resilience. This section addresses research showing restored riverscapes can also provide greater water and forage availability. Landowners are hearing about these benefits and are becoming interested in learning more about such projects, as was evidenced by about 500 people registering for a LTPBR webinar offered by the Western Landowners Alliance to their members in December 2023.[227]

Increased quantity and quality of forage – A 2018 study by Dr. Nick Silverman, a Water Resources Engineer with Anabranch Solutions, utilized freely available satellite remote sensing data to determine changes in vegetation productivity before and after three different types of LTPBR projects – BDAs at the Oregon Bridge Creek project, grazing BMPs on Maggie Creek in Nevada, and Zeedyk structures in the Upper Gunnison Basin in Colorado.[228] The Colorado project involved installing Zeedyk structures in four different Upper Gunnison Basin mesic areas.[229] The study determined that vegetation productivity increased in quantity and duration at all three study sites post restoration. The Colorado Gunnison vegetation productivity increased four years post-project by 24% and extended longer into the growing season, with October and November rates holding the largest increases (83% and 721% respectively).[230] The authors noted another important aspect: the restoration activities at all three study sites enhanced soil water storage, which "lessens dependence of vegetation productivity on precipitation, allowing water resources and overall ecosystem function to remain intact during periods of low precipitation . . . which is particularly important in regions where drought is expected to increase in intensity, frequency, and/or duration."[231]

These study results of substantially increased forage availability for livestock and wildlife post restoration are consistent with a California study that "quantified changes in forage quality, forage production, and cattle production associated with the return of wet or moist meadow vegetation, when downcut channels are restored."[232] The authors concluded that restoring the stream results in raising the water table, which restores the natural hydrology, allowing for the meadow plants to transition from dryland species back to the former higher diversity of moist and wet plant species. This "results in substantially more cattle production (lb of stocker/ acre) as a result of improved forage quality and higher potential stocking rates."[233]

Water availability – Susan Charnley, a USDA Social Science Researcher, and her colleagues performed numerous interviews with landowners for a LTPBR project that involved five different stream locations on private lands along the Scott River, a major tributary to the Klamath River in northern California.[234] BDAs were installed at each of the sites with the intention that beaver would recolonize the area. Ranchers indicated that their top two reasons for participating in the project were to improve surface and groundwater availability, as detailed in the table below. Several years after the installation of the BDAs, monitoring results and interviews with landowners determined that the structures had succeeded in producing "longer seasonal duration of streamflows; slowing down and

[227] What landowners need to know about process-based restoration – On Land (westernlandowners.org). This Western Landowners Alliance webpage contains a link for the webinar and a summary of the topics covered.
[228] Low-tech Riparian and Wet Meadow Restoration Increases Vegetation Productivity and Resilience Across Semi-arid Rangelands, Silverman, N. et al., *Restoration Ecology*, (2018).
[229] Mesic areas are landscapes such as riparian areas, wet meadows, springs and seeps, irrigated fields, and high-elevation habitats that have a well-balanced supply of moisture throughout the growing season. Sage Grouse Initiative. Water Is Life: Introducing SGI's Sage Grouse Mesic Habitat Conservation Strategy
[230] *Id.*
[231] *Id.*
[232] Forage and Cattle Response to Sierra Meadow Restoration. Tate, K., et al., (2016).
[233] *Id.*
[234] Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California, Charnley, S., *USDA Northwest Climate Hub*, (2018).

holding back water causing increased streamflows and water ponding in reaches that previously ran dry above and below dams; increased water availability."[235]

Table 1—Landowners' reasons for participating in beaver dam analogue (BDA) projects (n = 9)

Reasons	Number of landowners participating
Raise groundwater levels (benefits cited = increased water availability for sub-irrigation of hay fields and pastures to enhance their productivity and reduce the need to irrigate, lower cost of pumping groundwater for agricultural uses, improved surface water flows)	6
Improve surface water flows (i.e., slow runoff, spread water across channels, increase late-summer streamflows, reduce summer surface water disconnections to prevent rivers from drying up)	6

Chart from Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, Charnley, S., *USDA Northwest Climate Hub*, (2018).

Charnley and her colleagues also extensively studied the social aspects of LTPBR projects on public and private lands in dry eastern Oregon, Nevada, and Idaho.[236] In 53 interviews with ranchers who participated in the study, the large majority expressed great enthusiasm for beavers based upon the "increased availability of water and better forage" for livestock "that can translate into financial gains."[237] An Idaho rancher said this about taking actions to assist the return of beavers to his ranch:

> *"[It] worked well for everything because, one, it provided water, year-round water all the time, which is a godsend for wildlife, for my cattle, everything. Two, it enhanced the wet meadows that were there, so you had better forage production for cattle, wildlife, everything else."* Ranchers and Beavers: Understanding the Human Dimensions of Beaver-related Stream Restoration on Western Rangelands, Charnley, S. et al., *Rangeland Ecology & Management*, (2020).

Another key finding from the study concluded that assisting ranchers with reducing the downside of beaver (plugging culverts, flooding fields, etc.) helps ensure beaver benefits outweigh the drawbacks and increases landowner willingness to participate in restoration projects.[238] Similarly, a 1996 Black Hills National Forest report provides a concise description about the profound beneficial impacts beaver can have for western ranch managers:

> "*A complex of beaver dams with associated wet meadow soils and vegetation* ***functioned like a sponge****, discharging lower volumes in the spring and extending flows to later in the summer. Consequently,* ***beaver could convert intermittent drainages to perennial flows****."* A century of change in Black Hills forest and riparian ecosystems," Parrish, J. et. al., USFS Region 2, (1996).

This phenomenon is exactly what happened on Jay Wilde's cattle ranch in central Idaho. He recalls Birch Creek flowing through their ranch all year long when he was a child. After beaver were removed many decades ago, it began drying up each summer. Wilde decided to try reintroducing beaver to Birch Creek to see if it once again it could flow year-round. He obtained assistance from Dr. Joe Wheaton, professor at Utah State University, to help determine where to place BDAs to maximize the

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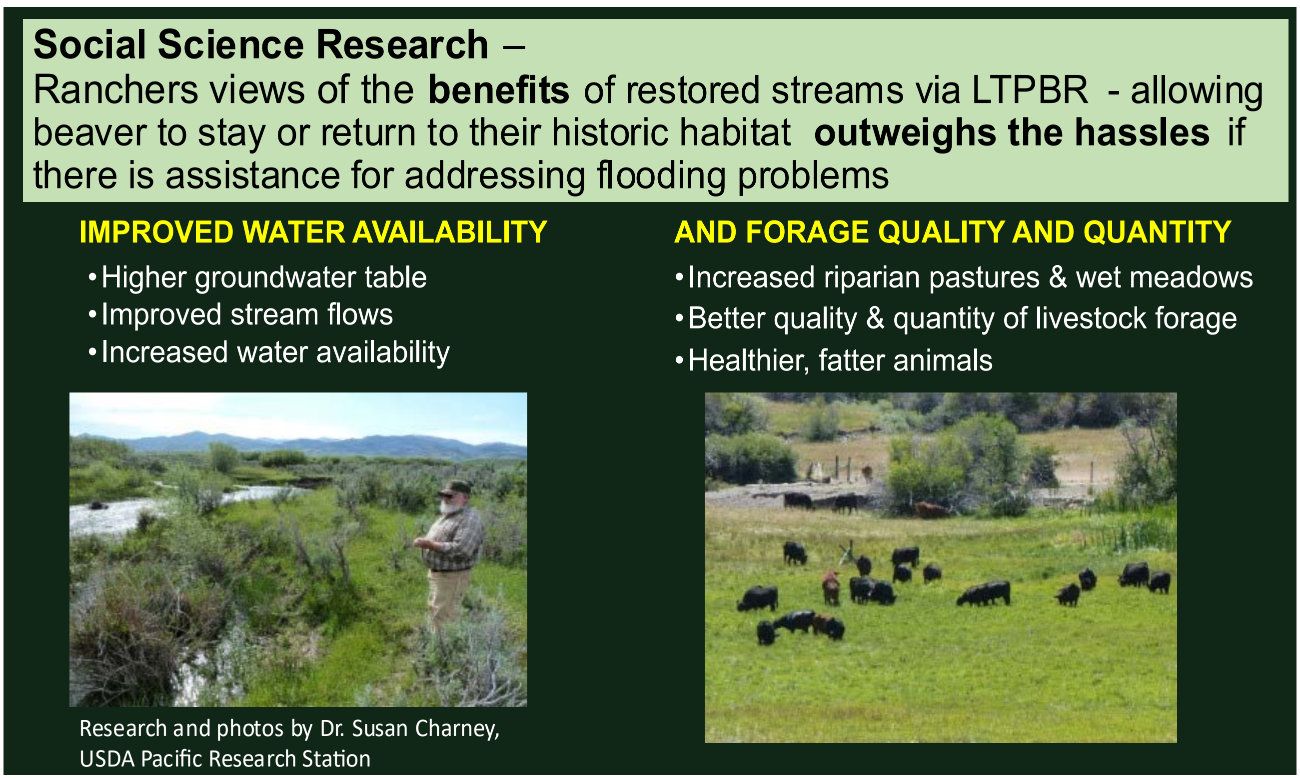
[235] *Id. at pages 26-27*
[236] Staff from the USDA NW Climate Hub created a storyboard to highlight the successes, challenges, and lessons learned from these dryland LTPBR case studies. Going with the Flow (arcgis.com)
[237] Ranchers, Beavers, and Stream Restoration on Western Rangelands, Kantor, S. & Charnley, S., *USDA Science Findings issue 229*, (July 2020).
[238] *Id.*

probability that beaver would return, survive, and thrive in the creek.[239] Nineteen BDAs were installed in 2015 and seven the following year. Wilde then partnered with the USFS and Idaho Fish and Game to relocate five beavers into Birch Creek and the beaver successfully re-established themselves building upon some of the BDAs. As of autumn 2019, Wilde counted 149 dams present on the creek. Wheaton and Wilde reported that the “stream flowed 42 days longer (until it froze in October), effectively running all season long again.”[240] Wilde and Wheaton also documented that the Bonneville cutthroat trout populations are 10 to 50 times higher in the ponded sections of the creek than before beaver returned to the stream.[241]

How beavers can benefit ranchers recently made the front page of the New York Times, which featured a northeast Nevada ranch owner who, along with his father, had blown up many beaver dams over the years.[242] But severe drought and hearing from others about how beavers can improve water and forage availability changed Agee Smith’s views. Smith talked about how beaver ponds kept his cattle watered during one of the worst Nevada droughts on record last year, and the beaver dams attenuated heavy rain showers that otherwise would have flooded his crops. He explained that “welcoming beavers to work on the land is one of the best things I’ve done.” [243]

To summarize the benefits of greatest importance to agricultural landowners, Dr. Susan Charnley created this slide to explain her beaver-related restoration research of the benefits the agricultural community has seen with LTPBR restoration on their lands.



[239] Beaver power provides year-long water to Idaho ranch (beefmagazine.com), Randall, B., (Feb. 2020). See also Life on the Range webpage dedicated to Jay Wilde’s restoration story and this excellent video that tells and shows the whole story: Idaho rancher Jay Wilde restores beaver to Birch Creek in a big way! - YouTube

[240] *Id.*

[241] *Id.*

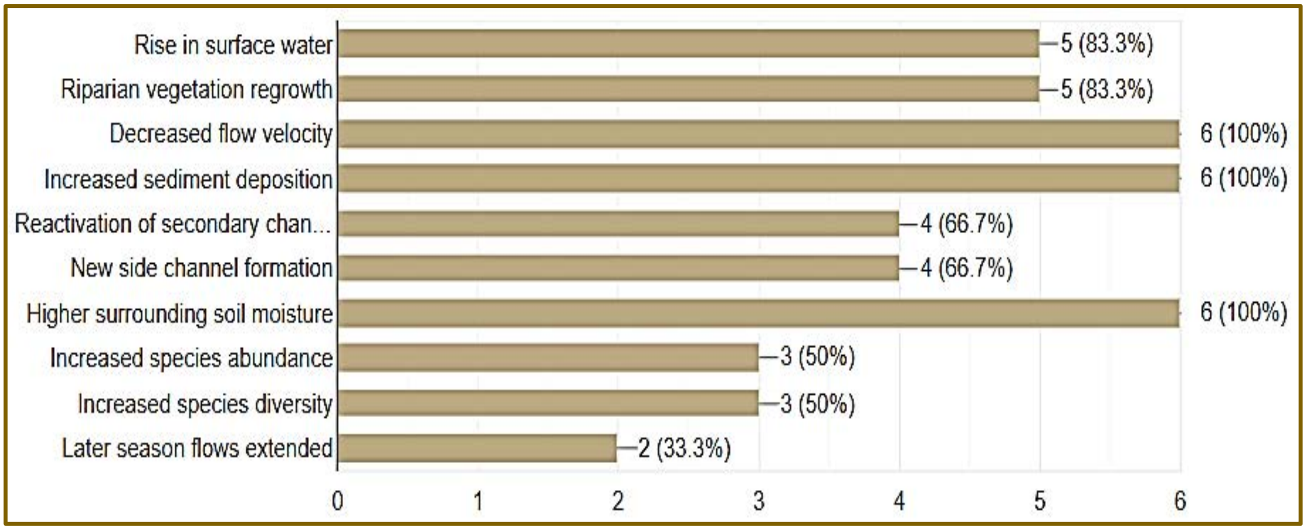
[242] It Was War. Then, a Rancher’s Truce With Some Pesky Beavers Paid Off. (nytimes.com)(Sept. 6, 2022).

[243] *Id.*

IV. Unpublished LTPBR Case Studies

Extensive outreach to LTPBR practitioners, researchers, conservation organizations, and state and federal agencies uncovered numerous additional LTPBR projects that are happening all around the Western States on both private and public lands.[244]

While researching this paper, Dr. Sarah Hinshaw created and conducted an online survey of LTPBR project managers in the Western States with questions about project goals, designs, challenges, and outcomes among other topics. Six responses were received (three from UT, two from NM, and one from MT) that indicated their LTPBR project outcomes were similar to those documented by numerous other case studies cited in this paper.[245]



There are now too many projects happening across the West to document in this paper, but these standouts warrant inclusion as particularly good resources:

1) **Triple Creek, Okanogan County in NE Washington** – This 2018 Triple Creek Case Study Report and this Okanogan Highlands Alliance webpage detail how USFWS, NOAA, Trout Unlimited, and the Okanogan Highlands Alliance came together to restore a 100-acre formerly wet meadow where three creeks converge that had deeply incised, disconnecting the floodplain/meadow. The report includes numerous before, during, and after project photos of various BDA designs that are very helpful to understand project logistics and lessons learned. The main goal was to reconnect the floodplain by aggrading the river with the hopes that beaver would return to take over the work of fully restoring the once flourishing meadow.

2) **Doty Ravine Preserve, Lincoln, California** – To help mitigate wildfire risk of the dried out riparian corridor in the Doty Ravine Preserve, the Placer Land Trust (local land manager) worked with ecologists to identify a wildfire risk strategy. They had a choice to spend over $1,000,000 with a traditional heavy equipment approach or try a LTPBR approach for less than $60,000. The Land Trust chose the latter and built a series of BDAs that beaver took over, which sped up the restoration of over 60 acres with tremendous results according to USFWS biologist Damion Ciotti.[246] He initially

[244] Project Map | Low-Tech Restoration Explorer (bda-explorer.herokuapp.com). This mapping tool was created to allow LTPBR project partners to share information about their projects by entering basic information about location, miles restored, types of structures used, etc. Over 120 projects have been entered thus far, but based upon the research conducted for this paper to locate case studies, that likely represents less than 30% of existing projects.
[245] Process Based Restoration Survey - Google Forms - this spring 2022 survey was created by Dr. Sarah Hinshaw.
[246] This California Creek Bed Was A Wildfire Risk, Then The Beavers Went To Work (sunnyskyz.com)

thought it would take up to 10 years to reconnect the floodplain, but it only took three with the assistance of beaver.

3) **Sierra Nevada Meadow Restoration, California** – The largest coordinated restoration effort to work at landscape scale is the California Sierra Meadows Partnership (SMP), which consists of approximately 30 different entities, including federal agencies (USFS, USGS, USFWS), state agencies (CA Dept. of Fish and Wildlife, CA Dept. of Water Resources), academics (UC Davis, UC Merced), and many nonprofits (American Rivers, CA Trout, TU, NFF, NFWF, TPL, and others). Their main goals are to provide education, science, and policy support to help coordinate efforts to restore the approximately 140, 000 acres of degraded Sierra Nevada Mountain meadows that are critical to California's water supplies. They have a wealth of PBR information to share on their website and are tracking meadow restoration projects across the Sierras, which now total 89 projects.[247]

4) **The Madrean Sky Islands, Southern Arizona/Northern Mexico -** The Sky Island Restoration Collaborative (SIRC) is a bi-national, community-based collaboration of governmental organizations, private landowners, ranchers, students, volunteers, scientists, and land managers have been working together since 2014 to improve restoration outcomes across the Madrean Sky Islands, a 56-million-acre mountainous pine-oak woodland region that spans from Southern Arizona into Northern Mexico. SIRC's goal is to facilitate effective landscape restoration in both small scale, high priority habitats and across entire watersheds through collaborative community-based projects. RDSs are being used to restore natural watershed dynamics and nutrient cycles in arid ecosystems, creating and restoring wetland-like environments. USGS's leadership role in implementing SIRC's restoration work and research was included in the White House's 2022 publication Nature-Based Solutions Resource Guide. [248] The Guide was highlighted in 2022 at COP27.[249]

5) **Weber River Watershed, Fish Creek near Coalville, Utah** – Sageland Collaborative, Trout Unlimited, Utah Division of Wildlife Resources, a private ranch owner, and USU student Lily Bosworth partnered to use BDAs to restore a reach of Fish Creek near Coalville, Utah, on a private ranch. Bosworth and fellow USU students quantified the hydrologic impacts of building 17 beaver dam analogs along a 0.3Km reach of Fish Creek, a first-order tributary to Chalk Creek, situated in the Weber River watershed. Bosworth used a before-after-control-impact experimental design to determine the impacts of BDAs on streamflow amount and timing, installing streamflow gages upstream and immediately downstream of the BDA installation. The BDAs were built in late-August 2019 and streamflow monitoring took place during the growing season of 2019 and 2020 (May – November). She also compared flow changes with a USGS gauge on the main stem of Chalk Creek and performed a changepoint analysis of the seasonal hydrographs for 2019 and 2020. Monitoring results for both 2019 and 2020 indicated that the BDAs had no measurable effect on daily average streamflow or on the seasonality of flows relative to the control or reference sites. This study is in preparation for submission to JAWRA. Preliminary results were presented by Bosworth at the Salt Lake Watershed Symposium in 2020.[250]

Since the 2019/2020 study concluded, project partners including Sageland Collaborative, Trout Unlimited, private landowners, and Utah Department of Agriculture & Food have continued stream restoration efforts in Fish Creek. A second round of BDAs (Phase 2) were built in the fall of 2020 approximately 2 miles upstream from the control reach, covering 0.7km. In 2022, 75 additional structures were installed in two reaches. Phase 3 installed 39 structures directly downstream of Phase 2 over 0.7km, and Phase 4 covered another 36 structures directly upstream of Phase 1 on a 0.8Km reach. These 4 phases combined cover 2.5 kilometers of stream. In 2022, following a Wet Meadows Restoration Workshop held at the Fish Creek project site, partners at the Division of Wildlife

[247] SMP Project Tracking Results 2020 (sierrameadows.org)
[248] Nature-Based Solutions Resource Guide, Olander, et. al., (November 2022). "The resource guide shares 30 Federal examples of nature-based solutions and over 150 resources aimed at those who are ready to take action." *Id*.
[249] President Biden Announces New Initiatives at COP27 to Strengthen U.S. Leadership in Tackling Climate Change, White House Briefing Room Statement, Nov. 11, 2022.
[250] Stream Restoration With Beaver Dam Analogues: What Happened to the Water? - YouTube

Resources and Utah's Beaver Ecology and Relocation Center released 6 beavers at the site. As of fall 2022, (three months after release), project partners have not seen additional signs of beaver establishment, such as new chew marks, new dam-building activity, or lodges. The fate of the released beavers is currently unclear. A combination of factors, including predation, flash floods, and migration to more suitable habitat upstream or downstream are likely at play. Continued monitoring and possibly additional releases will be needed to achieve beaver recolonization in Fish Creek. In 2023, project partners continued to work with landowners in the watershed to develop more restoration projects upstream, downstream, and in adjacent tributaries.

V. Challenges and Opportunities with Implementing LTPBR

Like much of the rest of the country, Colorado has lost approximately half of its wetlands since European settlement.[251] In addition to land and water development, another major cause of the loss of Colorado wetlands can be attributed to the substantial reduction of historical beaver populations. However, even though a Colorado State University study concluded that Colorado beaver dam capacity has been reduced to 42.7% of historical capacity, "most regions in Colorado have not experienced a large increase in stream reaches with no capacity to support beaver. This suggests that beaver restoration could be a useful tool in many stream reaches."[252] The authors noted that in many mountain region streams, "beaver reintroduction could push river corridors into a self-sustaining, wet steady state."[253] In other areas where streams have shifted to a drier state, LTPBR methods can be utilized in appropriate locations to restore hydrology and vegetation for future beaver occupation.

These conclusions indicate that an opportunity exists to significantly scale up LTPBR and beaver re-establishment in Colorado's headwaters stream. However, there are many challenges to utilization of LTPBR at a large landscape scale. This Section does not address every challenge identified in the research and conversations conducted for this report, it focuses on the top six.[254]

5.1 Funding for Stream and Wetlands Restoration

In the past five years, federal land management agencies, such as the USFS, BLM, and USFWS, have begun moving forward with scaling up stream and wetland restoration on public lands using LTPBR methods. Federal agencies are also providing substantial funding through programs that LTPBR projects can qualify for on private and public lands, including the WaterSMART Program through the Bureau of Reclamation (BOR), the USFWS Partners for Fish and Wildlife Program, the 319 Nonpoint Source Watershed Program and other Clean Water Act programs through the EPA, as well as several different NRCS programs. Additionally, programs that focus on improving watershed health got a substantial increase in funding from 2021–2026 through the November 2021 Bipartisan Infrastructure Law (BIL)[255] and in the August 2022 Inflation Reduction Act (IRA).[256] However, significant challenges remain for organizations and agencies to apply for and utilize federal funding, as described in a July 2022 report prepared for the Theodore Roosevelt Conservation Partnership.[257]

In Colorado, there are two state programs that fund stream/wetlands restoration that have included projects using LTPBR methods: Colorado Parks & Wildlife's Wetlands for Wildlife Program and the Colorado Water Conservation Board's Watershed Restoration Grants. In 2021, Colorado Parks and

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[251] National Water Summary Wetland Resources: Colorado (fws.gov)
[252] Estimating widespread beaver dam loss: Habitat decline and surface loss at a regional scale, Scamardo, J., Marshall, S. & Wohl, E., *Ecosphere*, (2021).
[253] *Id.*
[254] For further information on barriers and the technical needs to scale up nature-based solutions see pages 59-69 in the recent report State Climate Policy and Nature-Based Solutions: A Match That Provides Multiple Benefits for Climate, Water, and More, Marcus, F., *Water in the West, Stanford Digital Repository* (2022).
[255] Infrastructure bill a win for Colorado land, water - Colorado Trout Unlimited (coloradotu.org) (Dec. 14, 2021).
[256] How the private sector got public funding for nature-based climate solutions | Greenbiz (Sept. 1, 2022); What the Inflation Reduction Act Means for Water in the West | Audubon (Aug. 18, 2022).
[257] Challenges in Accessing and Utilizing Federal Funding to Support Cross-Boundary Watershed Scale Restoration (July 2022).

Wildlife (CPW) leadership approved the beaver as a Wetlands Program priority species, "which means that wetland/riparian restoration projects that are designed to benefit beaver and their habitats will be considered a higher priority for program funding through the annual wetlands grant cycle."[258] Another significant source of funding is the RESTORE Colorado Program, a partnership among the National Fish and Wildlife Foundation, Great Outdoors Colorado, and others to provide funding for landscape-scale restoration and stewardship projects on public and private lands. One of the top priorities is listed as river corridors, riparian areas, and wetlands. Finally, at the local level, several Conservancy and Conservation Districts have passed ballot measures that support many different efforts to improve water resources, including stream and riverscape restoration. This includes grant programs like the Colorado River Water Conservation District's Community Funding Partnership.

Despite the many funding sources, one of the biggest challenges for scaling up LTPBR is limited resources for project development and permitting, as well as securing match funding for both state and federal grants. This is especially true for rural communities that have fewer resources and capacity to plan for and apply for such grants. In early October 2022, the Center for American Progress released two reports assessing the challenges that rural communities face with responding to wildfires and floods and offered solutions for federal and state agencies to consider.[259] Finally, funding to support monitoring and evaluation once a project is implemented is also limited as discussed in the next Section.

5.2 Gaps in Research, Lack of Project Monitoring, and Need for LTPBR Monitoring Framework

Although LTPBR builds upon knowledge about the benefits of beaver and the importance of healthy, functioning floodplains and wetlands for ecological and ecosystem services that has been around for almost a century, the need for education, training, and acceptance from stakeholders and regulators will continue to take time to build. There are now excellent training opportunities from the National Association of Wetland Managers (six webinars addressing all aspects of LTPBR/beaver), numerous free resources provided on Utah State University's Professor Dr. Joe Wheaton's website, and a long list of LTPBR conference presentations and other similar resources listed on the Beaver Institute website.[260]

Although there is a fairly substantial body of research documenting the multiple ecological benefits of restoring stream corridors with LTPBR, further research and consistent monitoring of case studies is needed on ecosystem services. Monitored demonstration projects are needed in each basin of Colorado (and all other Western States) to help achieve greater understanding of this restoration approach among stakeholders in the agricultural and water communities.[261] Moreover, in addition to needing more data on the effects of LTPBR, "more research is needed to determine the optimal configurations of [BDAs] for a specific site"[262] as well as the factors that lead to successful beaver recolonization.[263]

In addition to the agricultural community, many water management agencies are interested in understanding more about utilizing natural solutions to improve drought resilience. At the request of the US Senate Committee on Energy and Natural Resources, the Congressional Research Service

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[258] Colorado Parks & Wildlife - Living with Beavers (state.co.us)

[259] President Joe Biden's Historic Infrastructure and Climate Investments Will Require Building Rural Capacity - Center for American Progress Oct. 6, 2022.

[260] NAWM-BLM Beaver-Related Restoration Training Series; Riverscapes Restoration Design Manual (usu.edu), Stream Restoration | Beaver Institute, Inc.. This Blackfeet Nation Beaver Mimicry Guidebook is filled with lots of practical information on project management: beaver-mimicry-guidebook.pdf (wordpress.com)

[261] Survey of Beaver-related Restoration Practices in Rangeland Streams of the Western USA, Pilliod, D. et al., *Environmental Management*, (2017).

[262] Beaver: North American Freshwater Climate Action Plan, Jordan, C. & Fairfax, E., *WIREs Water*, (2022).

[263] More studies similar to this one from Utah are needed, in which the authors studied the difference in movement patterns of translocated beavers compared to resident beavers to help "inform translocation expectations and outcomes." Movement Patterns of Resident and Translocated Beavers at Multiple Spatiotemporal Scales in Desert Rivers, Doden, E. et al., *Frontiers in Conservation Science*, (2022).

prepared a report examining opportunities for the BOR to integrate nature-based solutions into water supply strategies and included “reconnecting rivers to floodplains” as an example.[264] The report noted that the primary opportunity for BOR to incorporate natural solutions into its activities could “involve efforts to improve natural water storage, in particular storage available in groundwater aquifers by . . . restoration of riverine ecosystems and floodplains to a more natural state that allow for surface waters to replenish groundwater supplies.”[265] The report concludes by stating, “when considering whether and how to make available additional authorities and funding to BOR for natural water infrastructure, Congress may wish to consider:

- What is known and what research is underway to understand the efficiency and efficacy of natural infrastructure for enhancing water availability?
- How do natural infrastructure options compare to other alternatives in terms of life-cycle costs, reliability, and environmental and social impacts?”[266]

To assist with defensible data collection, there is a need for a flexible LTPBR monitoring framework and protocols that are designed to quantify project impacts to water metrics, such as surface and ground water flows, temperature, and sediment and other water quality metrics. Currently, there are some LTPBR monitoring protocols in various stages of development, but none are being actively used across multiple agencies, states, and organizations.[267] All the experts we interviewed agreed that building a consistent and flexible framework is necessary to collect and analyze data on the effects of restoring streams via LTPBR.

Dr. Caroline Nash and her co-authors developed a “process expectation framework that links beaver-related restoration tactics to commonly expected outcomes by identifying the set of process pathways that must occur to achieve those expected outcomes.”[268] The authors encourage LTPBR project monitoring and assessment to move away from “the binary paradigm of success and failure developed for form-based restoration towards a greater understanding of *why* restoration projects are or are not effective at meeting goals and desired outcomes.” More robust monitoring will cost more than using photo points, drone imagery, and aerial photo tools, which are the typical low-cost monitoring methods. While it will not be feasible for all projects, more extensive monitoring should be incorporated into project budgets whenever possible to further increase information on the effects of LTPBR.

5.3 Social Issues – Coexistence Issues with Beaver

After Harvard graduate Stacy Passmore toured the Mountain States to study “humans and beavers working together to restore wetlands and river systems,” and after interviewing numerous ranchers, researchers, and restoration practitioners and visiting their projects, she was persuaded by what she saw and concluded her 2019 research article in Places Journal by stating:

> “*People complain that beavers are destructive, they’re unpredictable, they cause flooding. These things are all true. Living with such a willful species requires careful negotiation. Humans have to recognize the ecological benefits beavers bring and be willing to give up some control.”*
> Landscape with Beavers, Passmore, S., Places Journal, (July 2019).

[264] Water Infrastructure for the 21st Century: The Viability of Incorporating Natural Infrastructure in Bureau of Reclamation Water Management Systems (everycrsreport.com)
[265] *Id. at page 3.*
[266] *Id. at page 6.*
[267] One exception appears to be for those involved with the Sierra Meadows Partnership, who collaborated to create the Sierra Meadows Wetland and Riparian Area Monitoring Program (SM-WRAMP). The SM-WRAMP is a set of standardized protocols for a variety of metrics (veg, soil carbon, surface water, groundwater, wildlife) that other Western States can look to as they work to develop PBR monitoring protocols.
[268] Great Expectations: Deconstructing the Process Pathways Underlying Beaver-Related Restoration, Nash, C. et al., *BioScience*, (2021).

Over the past 10 years, valuable resources have been developed to inform landowners and land managers about the many benefits of allowing beaver to remain in place and how to manage issues that might be problematic, such as flooding roads or pastures and tree removal. One of the most comprehensive resources, The Beaver Restoration Guidebook, was developed in partnership with NOAA, USFWS, and USFS staff.[269] Another helpful resource was published in 2010 by Sherri Tippie after 25 years of experience live-trapping, relocating, caring for, and helping install numerous coexistence measures.[270] Additionally, the Colorado Department of Transportation hired Katherine Millman in 2021 to research nonlethal beaver best management practices for road right-of-way issues. Millman prepared a comprehensive report in which she describes "highly effective" management techniques and provides information on others that "are not effective at all."[271]

The Miistakis Institute at Mount Royal University Calgary Alberta, studied the issue of the costs of traditional beaver management to address typical flooding issues (using a backhoe or explosives to remove dams and killing the beavers) compared to the costs of co-existence measures.[272] They then prepared a Fact Sheet entitled Cost-benefit Analysis of Beaver Coexistence Tools in which they cited many examples of local governments saving significant money by switching to coexistence measures, some of which are shown in the chart below.

Chart from the Miistakis Institute Fact Sheet: Cost-benefit Analysis of Beaver Coexistence Tools

A survey administered by USDA social scientist Dr. Susan Charnley and her colleagues of 1,512 private landowners from all regions of Oregon, including 432 from eastern Oregon "indicated that the public is interested in coexisting with beavers and that incentive programs that supply materials to reduce beaver damage would likely increase tolerance of beavers even when they have caused

269 The Beaver Restoration Guidebook Version 2.02 (fws.gov) This guidebook is in the process of being updated in 2024.
270 Working with Beaver for Better Habitat Naturally, Sherri Tippie & Grand Canyon Trust, (2010). See also a report prepared by USDA How To Keep Beavers from Plugging Culverts (fs.fed.us) (2005) and Beaver, Best Management Practices, Grand Canyon Trust, (2013).
271 Beaver Management Along Roads and Within the Right-of-Way (codot.gov) (2022).
272 Miistakis Institute Fact Sheet: Cost-benefit Analysis of Beaver Coexistence Tools. The Miistakis Institute also developed a "working with beaver" website that contains many useful public education materials.

damage."[273] Charnley also performed numerous interviews with ranchers in the Scott River Basin in northern California for a BDA project that involved five different stream locations on private lands as well as interviews for four other case studies on ranches in Oregon, Idaho, and Nevada.[274] The interviews included questions about what the landowners saw as the negative impacts of beaver recolonizing the area. Top responses included beavers plugging irrigation infrastructure, cutting down trees, and causing flooding of pastures. These negative effects are localized in nature and can be addressed with cost-effective solutions like the beaver deceiver shown in the photo below. When these impacts are mitigated, landowners overwhelmingly agree that the benefits of beaver on their property outweighed the negatives.[275]

It will be important for federal and state programs to develop landowner assistance programs to cost-share installation of coexistence measures, similar to the program developed by Defenders of Wildlife that assists landowners by providing expertise and funding to address common beaver issues like flooding.[276]

In addition to assisting landowners to live with beaver, Dr. Fairfax and Dr. Jordan note in WIREs Water that it will also be important for states to "start rewriting our beaver management policies today to actively support coexistence over lethal management so that if and when beavers arrive in a riverscape they can thrive."[277] Like almost all the Western States, Colorado hunting regulations allow beaver to be killed year-round if they are a "nuisance" causing any property damage (such as flooding)[278] and there is no limit on beaver take during the hunting season from October 1 to April 30.[279]

Photo by Dr. Susan Charnley showing a method to stop beaver flooding of a ranch road culvert.

[273] Using Beaver Dam Analogues for Fish and Wildlife Recovery on Public and Private Rangelands in Eastern Oregon, Davee, R., Gosnell, H. & Charnley, S., USDA Northwest Climate Hub, (2019).
[274] Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California, Charnley, S., USDA Northwest Climate Hub, (2018); Ranchers, Beavers, and Stream Restoration on Western Rangelands, Kantor, S. & Charnley, S., *USDA Science Findings*, (July 2020).
[275] *Id.*
[276] Bothered by Beavers? | Defenders of Wildlife
[277] Beaver: North American Freshwater Climate Action Plan, Jordan, C. & Fairfax, E., WIREs Water, (2022).
[278] Nuisance Wildlife Laws in Colorado (state.co.us); CPW does have a "Living with Beavers" webpage that lists beaver benefits and encourages nonlethal alternatives. Colorado Parks & Wildlife - Living with Beavers (state.co.us)
[279] 2023 Colorado Small Game & Waterfowl Brochure (state.co.us)

LTPBR project managers can be proactive in preventing beavers from plugging road culverts located within or near the project reach by building "starter dams" or essentially a BDA in front of but far enough away from the culvert to entice beaver to build upon the BDA instead of the culvert as shown in the photo below from a project in the Gunnison National Forest. Two years after installment, the BDA is still in place and beaver have not built upon it or the culvert.

Photo by Jackie Corday, a "starter dam" installed to protect a road culvert.

To help project managers assess and minimize the risks of utilizing large wood or reintroducing beaver in restoration projects, Dr. Ellen Wohl and her co-authors drafted a report and guidelines to evaluate risks to downstream infrastructure and property.[280] "Our intent is to provide tools that can be used to move away from management practices in which logjams and beaver dams are immediately assumed to create sufficient hazards that warrant automatic removal and toward more nuanced stream management that explicitly recognizes the many beneficial effects of logjams and beaver dams."[281] In some situations, such as where beaver have been absent and the landowner is not open to their return, or the location is not historic beaver habitat, then RDS, LWD, or other LTPBR techniques can be used to restore streams without introducing beaver.[282]

5.4 Building Capacity in Agencies, Nonprofits, and Practitioners

Two primary types of capacity issues will need to be addressed to facilitate an increase in the use of LTPBR to improve upper watershed health in Colorado. First, while the large influx of funding from the BIL and IRA for improving watershed health greatly increases the resources available to do this work,[283] lead time is required to build federal, state, and nonprofit staff capacity to identify and plan for priorities, administer grants, contract for services, submit permit applications, and design or oversee design and implementation of projects. In addition to internal staff, external capacity is also needed, specifically to have trained LTPBR practitioners in Colorado and other Western States to respond quickly to the influx of funding. Further, ensuring agencies consider the need for long-term restoration funding is important to attract and sustain skilled restoration practitioners beyond the years of BIL and IRA funding.

Scaling up beaver-related restoration would also benefit from having dedicated staff within CPW to assist with restoring beaver to Colorado watersheds where appropriate and when existing populations are too low to naturally repopulate historic ranges. Utilizing a public process to draft and adopt a statewide beaver management plan, similar to the process Utah undertook, is an important early step.[284] Creating and maintaining beaver holding facilities to translocate nuisance beaver to where they are needed is another crucial step.[285] A model for funding beaver restoration is provided in

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280 Managing for Large Wood and Beaver Dams in Stream Corridors, Wohl, E., Scott, D., and Yochum, S., Gen. Tech. Rep. 404. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, (2019).

281 *Id*.

282 Harvesting water in arid lands, don't forget your NIDS (Natural Infrastructure in Dryland Streams). Norman,L, Global Water Forum, (2022).

283 Infrastructure bill a win for Colorado land, water — Colorado Trout Unlimited (coloradotu.org)

284 Utah Beaver Management Plan, Utah Division of Wildlife, (2010, updated 2017).

285 Scientists Are Relocating Nuisance Beavers to Help Salmon, Smithsonian, May 21, 2021. Molly Alves, a biologist with the Tulalip Tribe, helped launch the Tulalip Beaver Project in 2014 with the aim of using beavers to boost declining salmon numbers. The tribe converted an

California Governor Newsom's enacted budget for fiscal year 2023, which created a new statewide Beaver Restoration Program.[286] The program seeks to recolonize beaver in appropriate locations in upper watersheds where they historically lived to help restore streams and wetlands as another tool for climate mitigation.[287] The governor's budget proposal includes $1.67 million for FY23 and $1.44 million for FY24 and the creation of five new Department of Fish and Wildlife positions to run the program.[288]

In addition to needing more staff to scale up LTPBR projects, there is a need for building capacity, understanding, and awareness among *existing* agency staff on how to incorporate LTPBR into short- and long-term watershed health plans and projects, including how to navigate the challenges that will arise. USDA social scientist Dr. Susan Charnley in her California Scott River LTPBR report described a successful approach taken by some agencies to address this issue:

"*In 2016, state and federal agency representatives involved in funding and permitting BDAs in the Scott Valley—including the USFWS, NOAA, CDFW, Army Corps of Engineers, and the Water Quality Control Board—formed a BDA technical team. They meet periodically to discuss BDA projects, coordinate the permitting process and compliance with permits to promote consistency, ensure that each agency can meet its mission in the process of implementation, identify monitoring needs, discuss design features, and find ways of making the permitting process easier*." Quote from Susan Charnley, Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California (2018).

This collaborative approach could serve as a model for Colorado and other states. To help provide and share information on LTPBR best practices, lessons learned, science, and policy, two PBR networks have formed, one in 2022 by federal, state, and nonprofit partners in California called the CAL PBR Network. In their September 2022 newsletter, the editors encourage folks to "join forces to speed the progress to retain water, support biodiversity, create fire resiliency, and adapt to climate change" via PBR of streams and wetlands."[289] The other formed in 2020 called the Riverscape Restoration Network covers all Western States and has over 200 members. Jackie Corday and Fay Hartman lead this group with quarterly presentations from experts on the latest science, policy, and overcoming challenges to LTPBR.

old fish hatchery to a beaver holding facility. Since the low-cost project began, scientists have relocated more than 200 "nuisance" beavers and created dozens of salmon-friendly beaver ponds.

[286] State Leaders Enact Historic Beaver Restoration Program (oaec.org) (June 30, 2022).

[287] Beaver Restoration Program-FY23 and FY24 Budget (ca.gov) ;

[288] Staff were hired in early 2023 and the Program is now up and rolling. Beaver. California Department of Fish and Wildlife, Department website,(2023).

[289] CAL PBR Network newsletter, Issue 2, Sept. 9, 2022.

5.5 Permitting – Federal and State Permits

State and federal, and sometimes local, agencies, have authority over stream restoration projects, which often results in needing to obtain multiple permits. An online survey of LTPBR project managers was conducted for this paper that included questions about project challenges. The responses indicated that the project permitting process is often one of the biggest challenges.[290] One survey response echoed many conversations with project managers we had during the research for this paper:

"*One major hurdle that we encountered in this project, and in previous projects similar to this one, is the permitting aspect of this project. Current permitting standards don't quite apply to this type of low-tech, processed-based approach. Communicating to permitting agencies the intricacies of this work is sometimes difficult. Many agencies understand that this project is unique and different from classic, engineered, stream restoration projects, however, they still need to meet all the same permitting requirements, especially the USACE 404. For such a simple and low-cost project like this, the permitting process is often time-consuming, excessive, and expensive. The Wetland Delineation can sometimes cost more than the project itself*." Response from the 2022 LTPBR survey from Ben LaPorte, Program Manager for Big Hole Watershed Committee, out of Divide Montana.

Another challenge identified during the paper's research is that USACE Districts are not providing consistent interpretations of what triggers the need for a 404 permit – sometimes permits are required for LTPBR projects in one district, but not another. Sometimes wetland delineations are required, other times not. Regulatory challenges in California can be particularly daunting due to multiple agencies requiring permits, which is discussed in a 2021 American Rivers paper that offers solutions that could be applicable to other Western States.[291] Dr. Susan Charnley noted during her extensive beaver-related restoration research that the relative newness of LTPBR and the lack of monitoring data has contributed to longer permit processing times. "Monitoring data that document the effects of BDAs on water, fish, wildlife, vegetation, and hydrology will help with permitting. As evidence that demonstrates positive impacts mounts, and that allays concerns over detrimental fish impacts, regulators will become more comfortable permitting them."[292] This American Rivers' webpage on Permitting Restoration Projects provides a good resource for all of the potential permits that may need to be obtained with links to more resources for each type of permit. Below is just a very short summary of the typical permits needed for LTPBR projects.

In most cases, LTPBR projects on either public or private lands will require a US Army Corps Engineers (USACE) Nationwide 27 Permit (Aquatic Habitat Restoration, Enhancement, and Establishment Activities), which is a general Clean Water Act 404 permit (as opposed to an individual permit) that is meant to streamline the permitting process.[293] Most states require a permit for working in streams, whether it is for restoration purposes or installing a culvert, to protect aquatic habitat and water quality. The USACE permit is often combined in a joint application with a state Stream Alteration Permit.[294]

Any ground-disturbing activities on federal public lands, including LTPBR projects, require the federal government to comply with the National Environmental Policy Act (NEPA) process. Generally, LTPBR projects, specifically beaver-related restoration work, qualify for a Categorical Exclusion (CE) review

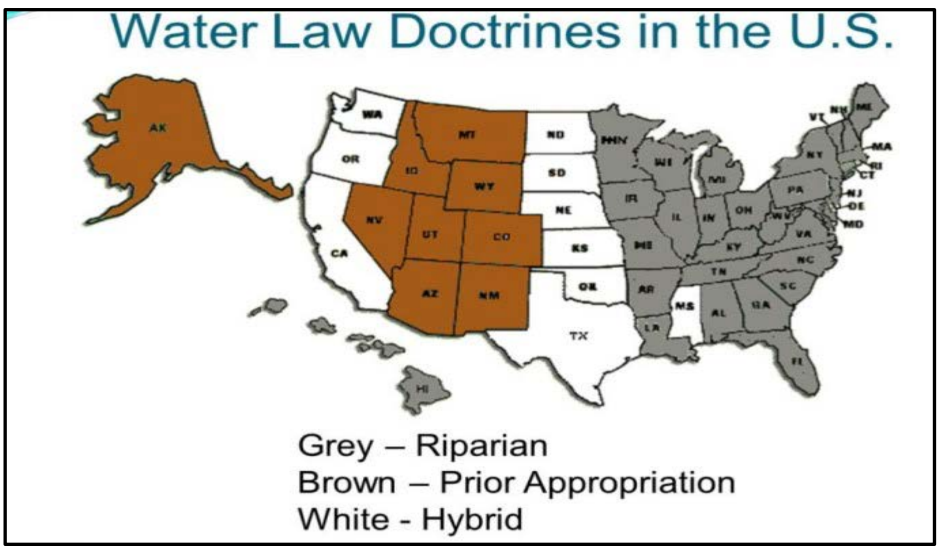
[290] Process Based Restoration Survey - Google Forms – this spring 2022 survey was created by Sarah Hinshaw.
[291] Regulatory Challenges and Solutions for Sierra Nevada Meadow Restoration, Fair and Wingo, (Aug 2021)
[292] Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California, Charnley, S., *USDA Northwest Climate Hub*, (2018).
[293] Streamlining Restoration Projects with Nationwide Permit 27: An Explainer - Environmental Policy Innovation Center. The NW 27 permit was reauthorized in Dec. 2021 for another five years.
[294] See for example Idaho's Instruction Guide Joint Application for Stream Alteration Permit.pdf

because the restoration work does not individually or cumulatively have a significant effect on the human environment.[295] Typically, the applicable CE category is 36 CFR 220.6 (e)(18)(Decision Memo Required), meaning that a CE template will be used by agency staff to evaluate the project and review regulatory considerations of the project, including rules under the Clean Water Act, Endangered Species Act, the National Historic Preservation Act, and Tribal Consultation. From the time a land agency official accepts a project proposal, a CE can take anywhere from a few months to more than a year.

5.6 Water Rights

5.6.1 Water Law Basics

All 12 Western States adopted their own version of the Prior Appropriation Doctrine and regulations to enforce administration of water rights, which in its most basic description is referred to as “first in time, first in right.”[296] Water rights holders are given the right to divert a specified amount of water from streams for a defined beneficial use, such as irrigating a crop. In all Western States except Colorado, states use a permit system to issue water rights. In Colorado, water rights are obtained in water court by a decree. In water-short times, holders with the oldest date of priority are given first priority access. If there is a surplus beyond what is necessary to fulfill the senior rights, the water rights holder with the next oldest priority date can take what is available. In most cases, senior water rights were obtained in the mid to late 1800s.[297]



5.6.2 Potential Issues Raised by Water Users

For decades, form-based river restoration has generally not raised any water rights issues because stream flows were not changed by the typical project that confined streams to a single channel. To a water rights holder or a water administrator, there did not appear to be any impact from grading back incised channels and/or placing boulders and logs in-stream or along the bank to create small pools and riffles as the water was still flowing downstream just the same as before the project. It's important for the restoration and LTPBR advocacy community to acknowledge concerns from water users that LTPBR projects look different than traditional form-based approaches in how they spread water back into the area formerly occupied by the stream before it became incised, which in some cases may

[295] The CE list was revised and expanded in November 2020. U.S. Forest Service releases final NEPA rule - The Wildlife Society (Dec. 3, 2020).
[296] Water Rights | Division of Water Resources (colorado.gov)
[297] Citizen’s Guide to Colorado Water Law 5th Edition, Water Education Colorado, (2021).

attenuate flows and change timing as described in Section III of this paper. It is also important for water users to not *assume* that LTPBR projects will harm water rights.

One concern raised by water users and administrators is that LTPBR projects can result in increased evaporation from more surface water and increased transpiration from increased riparian vegetation (combined referred to as evapotranspiration, ET). In short, they wonder if restoring the stream/riparian corridor will equate to less water in the stream for their water rights. The extensive research for this paper did not find a documented case of any measurable harm to water rights from increased ET. As noted in Section 3.3 of this paper, no data appears to be available to support making an *assumption* that there will be measurable loss detectable by stream gages where water rights are measured.

The second concern raised by some water users is that installation of BDAs may attenuate stream flows during the "filling of the sponge" stage – rewetting of the soils and floodplain behind and around the BDAs. Many factors contribute to how long and how much flows may be attenuated, including the size and geology of the stream, the soils and vegetation (and how dry they are), the degree of incision, porosity of the structures, and the timing of the project installation (before or after the irrigation season versus during). The author had numerous conservations with practitioners who indicated they have generally observed the initial attenuation on small streams happens within 24 hours to several days,[298] but can take longer in arid systems and more research is needed. In one case from Idaho, stream flows were impacted by placement of numerous BDAs during the summer low-flow months that were not well designed for porosity. This situation is further explained in the Idaho section below in Appendix 1. A similar situation also happened in Colorado where BDAs were installed too densely that caused a reduction in flows to a downstream water user, which resulted in the BDAs having to be removed. Both situations potentially could have been avoided if the guidelines such as those suggested below had been followed.

5.7 LTPBR Guidelines to Reduce Potential Conflicts for Projects

Based upon lessons learned from LTPBR projects around the Western States (mainly BDA-type projects), the authors of this paper developed suggested guidelines for such projects to help reduce the risk of conflicts, including those related to water rights and potential flooding from beaver returning to the area. Numerous discussions with stream restoration practitioners, federal and state agency and nonprofit staff involved with such projects, and academic researchers contributed to developing the guidelines.[299]

Following these guidelines cannot guarantee project proponents will be protected from a potential claim of injury by the owner of a downstream water right, but may help to lower such risks.

Project Planning Considerations to reduce the risk of potential water rights and beaver concerns:

1. **Location** – Project proponents should look for opportunities and places that minimize risk of conflicts with the perception of impacts to water rights and flooding from beavers, such as:
    - Upper watersheds above reservoirs and diversions on public lands and large-parcel private lands – working ranches and farms.
    - Low-gradient first to third order unconfined stream reaches with 3% or less slope are generally going to have lower risk of structures blowing out and beaver being able to successfully recolonize and maintain their dams.

[298] A Brief Summary of Beaver Mimicry and Streamflow, Clancy, N. & Wolf, M., *University of Wyoming Factsheet,* (2022).
[299] Paper author Jackie Corday developed these guidelines, with input and review from many colleagues cited in this paper, after receiving numerous inquiries from agencies and organizations on how to manage the water rights issue.

- Look for opportunities and places where the river corridor has room to access its full floodplain as it historically did prior to the disturbance without threatening infrastructure such as roads, bridges, agricultural fields, and structures. If there are road culverts or other infrastructure in the project reach that beaver might plug up, be proactive on prevention measures such as building “starter dams” as discussed and shown on page 63.
- Look for opportunities to partner with senior water rights holders (who often own large ranches in the upper watersheds) and their downstream neighbors, as they are most likely the folks who may be concerned about water impacts of your proposed project.

2. **Historic Footprint (HF)** – Design the project to restore the stream and riparian corridor to its historic footprint and not beyond. There are three main elements to the HF:
   - The project **will not result in expansion** of the riparian/wetland/river **historic footprint that existed prior to disturbance**.
   - **No water consumption beyond the historic conditions** – This translates to there will not be any more evapotranspiration from the restored riparian/wetland species or the expanded water surface area than there was historically prior to the stream disturbance.
   - **No water diverted for irrigation** of planted wetland or riparian plants unless in free river conditions or provided by an appropriate decreed source.

   The historic footprint can typically be determined based upon aerial photos, reference reaches, LiDAR topographic mapping, soil profiles, or other data indicating where the floodplain and riparian vegetation were present prior to disturbance(s).

3. **LTPBR method** – Beaver mimicry-type structures should mimic naturally occurring beaver structures that are porous, temporary, deformable, and made of natural materials that allow base flow and fish passage through, under, and around. Each situation may need a different approach, taking into consideration how to match the size of stream and the number and type of LTPBR structures that will lead to restoration success while avoiding conflicts. In cases where water users have expressed concern about BDAs, PALS might be the best choice. The authors did not come across a case during the research for this paper where PALS raised any water rights concerns, which can be attributed to their lack of pooling/high porosity.

   Additionally, if your project is on a working ranch, consider this advice from Nathan Seward, CPW Wildlife Conservation Biologist: “*While beaver are the "gold standard" for wetland and riparian restoration, we need to understand that beaver may create a headache and increased workload to the producer, so start the conversation by suggesting smaller, low risk techniques which can accomplish great results, but will take more time, and describe the trade-offs with various techniques (Zeedyk rock structures vs. BDA/PALS vs. beaver conservation/reintroduction). It's important to consider this gradient in restoration*.”[300]

4. **Timing of installation** – Be careful during low-flow summer months – project proponents should ensure the project does not reduce flows for any significant time (one day can be significant). Also, when possible, projects that can be installed before or after the irrigation season (generally October – March) can substantially lower the risk of conflicts with water users.

5. **Engagement, transparency, many partners** – Project planning that proactively includes water users and other watershed stakeholders who would potentially be concerned has many benefits, including gaining wider community support, increasing funding opportunities, and

[300] Email from Nathan Seward, CPW Wildlife Conservation Biologist, to Jackie Corday on June 16, 2022.

reducing risk of raising water rights concerns. Who would potentially be concerned about your project? Include them or at least address their concerns.

Post project considerations to help with continued success of projects:

1. **Adaptive management** – The project budget should include time for post-installation assessment of what worked well and what didn't, look for opportunities to apply lessons learned and make adjustments where needed.

2. **Monitoring changes** – Documenting baseline conditions of the stream corridor with photo points, drone imagery, and field notes of the stream/riparian condition and monitoring for these same data points for 2-3 years is relatively inexpensive and the least that should be done. Monitoring the changes of water surface area and water flows coming into the project reach and water flows downstream of the project would be good to budget for the project if the project is in an area where water right issues have been raised. Changes to the stream bed elevation/degree of incision/sediment capture are also important metrics to consider.

3. **Assist private landowners with beaver coexistence issues** or other post project aspects if needed – this could also fit under adaptive management, but is important enough to call it out separately. It is important to plan for at least 2-3 years of potential landowner assistance beyond project installation – e.g., if beaver return to the site and cause flooding issues – assist with coexistence measures to address the problem.

Trout Unlimited project in Utah – private ranch

Loss of riparian vegetation due to grazing– fence installed to rest the area from grazing and BMSs were installed in ~1 mile reach

Photos by Francisco Kjolseth, Salt Lake Tribune article Oct. 18, 2023

Example of BMS installed that reflect the guidelines above - porous, temporary, deformable, and made of natural materials that allow base flow and fish passage through, under, and around.

VI. Conclusion

Substantial research and emerging case studies are documenting the need to restore the health of the natural water infrastructure in Western States in the face of climate change impacts that have already greatly reduced water availability. Research is showing the benefits of approaches that restore natural processes to reclaim the geomorphic, hydrological, and ecological steam functions in our upper watersheds.

Case studies indicate that restoring floodplain connection can improve water quality, attenuate storm flows, increase wildfire and drought resilience, and provide benefits of particular interest to the agricultural community – increased quality and quantity of forage, reduced sedimentation of irrigation infrastructure, and in some cases, later season water availability. Research also shows that beaver can be our greatest assets for effectively and inexpensively restoring miles of headwater streams where they formerly lived. LTPBR methods, primarily BDAs, have proven successful in assisting the return of beaver to historical ranges once riparian and flow conditions are sufficient for their survival.

Despite the documented benefits and low cost of LTPBR projects, significant challenges are impeding scaling up these projects. The social barriers to LTPBR and beavers are the largest challenges to solve. These include the potential impacts to human infrastructure from beaver dams, such as road and irrigation infrastructure flooding. This has stimulated the development of numerous solutions for preventing beaver from blocking water conveyances and ensuring sufficient water passage through beaver dams to prevent flooding problems.

In addition to addressing social issues, more research is needed to understand the hydrologic effects of LTPBR projects and beaver complexes, including on late-season flows and if there are potential water rights impacts that can be avoided or mitigated. Demonstration projects in different types of stream systems and elevations are needed to allow for more scientific understanding of these effects. Consulting with local stakeholders prior to developing an LTPBR project, carefully choosing location and project design, as well as ensuring compliance with any permitting requirements, can help overcome these challenges and enhance the chances for project success.

Natural beaver complex on Middle Beaver Creek, Uncompahgre National Forest, Photo by Jackie Corday

Appendix 1: Further Information on Western States Water Rights Policies

This appendix provides an overview of how different states across the West have adopted policies (or not) around LTPBR, primarily BDAs, as they are the structures that have caused the most concern to water users due to their channel-spanning dam-like designs and resulting pooling water. This information is up to date as of fall 2023.

California

In a 2013 letter from the CA State Water Resources Control Board responding to a request to investigate whether or not a proposed stream restoration project would impact water rights, the agency began by noting that such determinations must be made on a case-by-case basis with site specific facts.[301] A site inspection of the proposed project reach revealed that downcutting of the stream "artificially lowered the groundwater level and dried up the meadow . . . [The project is] intended to return the natural groundwater to its previous elevation beneath the meadow . . . to correct the current damage." The agency concluded that there was no actionable harm to water rights nor what constituted a diversion because "the Project is intended to restore a natural flow regime, and appropriators are only entitled to divert from the natural stream flow."

This acknowledgment of water rights taking subject to the natural system appears to continue to be how California is approaching LTPBR projects. California has not adopted a specific policy or regulation of LTPBR projects in regard to water rights thus far. A California survey performed by USDA social scientist Dr. Susan Charnley found that "None of the people interviewed for this [Scott River, CA] study reported hearing any complaints about the impacts of BDAs on water rights. Several interviewees cited positive impacts of BDAs on water rights. These included slowing water flows down so that they can be more easily diverted for irrigation; raising the water table, which helps with sub-irrigation; and creating more available downstream water in the summer as stored groundwater (enhanced by BDAs) is released."[302]

Oregon and Washington

Similar to California's approach, Oregon and Washington have not passed any LTPBR regulations pertaining to water rights and discussions with organizations in those states who are implementing LTPBR projects, indicating they have not had any issues. "During the Oregon Department of State Lands' rulemaking process between 2015 to 2017 to streamline permitting for BDAs, public comments included concerns about water rights potentially being affected. However, according to Oregon Water Resources Department staff involved in drafting the State Lands permit, "there have been no complaints by individuals about BDAs affecting their water rights."[303] A conversation with NOAA's Chris Jordan indicated that in the dry landscapes of Eastern Oregon, water rights concerns have been raised around such projects, but he was not aware of a water user filing a claim or showing actual harm.[304]

Montana

In March 2016, Montana's Department of Natural Resources and Conservation (DNRC) issued the *Guidance for Landowners and Practitioners Engaged in Stream and Wetland Restoration Activities* with a preamble that stated, "this document offers guidance for the development and implementation of wetland and stream and restoration projects as they pertain to Montana water rights. There is a

[301] Barbara Evoy, Deputy Director, CA Division of Water Rights, to Paul Minasian (Sept 3, 2013).
[302] Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California, Charnley, S., USDA Northwest Climate Hub, (2018).
[303] Using Beaver Dam Analogues for Fish and Wildlife Recovery on Public and Private Rangelands in Eastern Oregon, Davee et al., USDA Northwest Climate Hub, (2019).
[304] Phone conversation with Chris Jordan, NOAA Research Fisheries Biologist, Program Manager, on July 6, 2023.

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concern that inappropriately assuming a water right is required for wetland and stream restoration projects, including beaver mimicry, might limit ongoing ecological restoration efforts."[305] The guidance also addresses wetland and stream restoration projects that "intentionally divert, impound, or withdraw a quantity of water through a human-controlled diversion for a beneficial use clearly require a water right."[306] The guidance gives examples of when this would be the case, including projects that *create* new wetlands that didn't historically exist. The authors reached out to two organizations that implement many LTPBR projects each year in Montana, Trout Unlimited (TU) and Great West Engineering and asked if any of their PBR projects have required a water right and if there have been any water rights complaints from downstream users. They responded no to both questions and added "we haven't had any issues," which was later confirmed in an email from the DNRC Water Planning Section Supervisor.[307]

Idaho

In December 2019, the Idaho Dept of Water Resources (IDWR) Water Compliance Bureau Chief issued a Memo to the IDWR Stream Channel Protection staff entitled "Processing Joint Applications for Permit Proposing BDAs and PALS."[308] The memo set forth new requirements for submitting Idaho's Joint IDWR/USACE Stream Channel Alteration Permits in order to "minimize potential reductions to streamflow that may be caused by BDA/PALS."[309] Conversations with Idaho organizations that are involved in beaver-related stream restoration indicated this policy was adopted in response to a BDA project that was designed and installed without careful communication and consideration that resulted in a complaint being made to the State Engineer by an influential downstream water user. The new policy was designed to greatly reduce the possibility of any further complaints by requiring, among other things, that applicants submit a list of water rights located downstream from the project and seek comments or support for the proposed project from downstream holders of water rights. Additionally, applicants "must measure and report the streamflow for stream reaches where they propose to install BDA/PALS . . . to establish baseline data on stream reach gains or losses before the construction." This requirement can be waived if the proposed project is "located in a remote headwater stream that is far removed from downstream water rights."[310]

Utah

In December 2018, Utah's state engineer (SE) issued an *Internal Correspondence* to all Utah Division of Water Rights (UDWR) staff entitled "Policy for Beaver Dam Analogue Construction."[311] Utah's statutes prohibit the alteration of "the beds and banks of a natural stream" without first obtaining a permit from UDWR. UCA 73-3-29(1). Citing this statute, the SE declared that "any BDA construction will require that a Stream Channel Alteration Permit be filed with and approved by the UDWR." The policy directs region engineers (RE) to review such BDA project permit applications to determine if water rights may be impacted – if so, then a *temporary* one-year water right is needed to cover "anticipated impacts"; if the RE determines water rights will not be impacted, then only the Stream Channel Alteration Permit is needed.

The policy states "It is assumed that impacts to the system will be stabilized during the one-year time frame the Temporary Change Application is in effect." This finding by UDWR equates to a finding of *no permanent harm* and hence no permanent water right is needed to restore a stream to its natural condition. The policy has a very important exemption: "In areas affected by wildfire events or another

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[305] *Guidance for Landowners and Practitioners Engaged in Stream and Wetland Restoration Activities, DNRC, (2016).* This document was available on DNRC's website until the website was overhauled in 2023. The Guidance is still in effect and has not been replaced. Phone conversation with Nate Ward, Montana Water Rights Bureau Chief, Dec. 22, 2023.
[306] *Id.*
[307] Emails with Laura Ziemer, TU Senior Council and Water Policy Advisor and Amy Chadwick, Great West Engineering, in Jan. 2022. Amy reached out to Michael Downey, DNRC Water Planning Section Supervisor and shared his email with us.
[308] Examples of PALS and BDAs are provided on page 9 of the memo.
[309] Stream Channel Alteration Rules adopted pursuant to authority under Title 42, Chapter 38, Idaho Code.
[310] *Id.*
[311] Utah Policy for BDA Construction

similar incidence where it is critical to stabilize channels and help diminish debris flows, no water right will be required."

The authors reached out to two organizations that implement many PBR projects each year in Utah, Trout Unlimited (TU) and Sageland Collaborative (SC), to inquire about how projects have been going over the past three years since the policy was issued. They confirmed the policy is still in effect and has not been amended. SC staff stated "We have now pulled about a dozen Stream Alteration Permits for LTPBR *without* needing a temporary water right. Our project scale is typically between 30 to 80 individual BDAs. I feel we have gotten to know **how to match the size of stream and number of LTPBR structures** that our Engineers are comfortable with signing off on (without a temporary water right). If we feel like water rights could be an issue, we tend to do more non-channel spanning LTPBR structures (i.e., PALS), as they do not pool water."[312]

TU staff stated, "Essentially, in the places where we are working, we put significant time into outreach with local water users and watershed stakeholders. In fact, one of the local Conservation Districts has become a very vocal advocate of PBR projects as they have started to see cumulative benefit from a couple of projects in deeply-incised streams." Additionally, TU indicated that like SC, their BDA projects have not required the temporary water right. "The way we are accomplishing this is by constructing shorter BDAs, that don't flood historically unirrigated areas. Implementing PBR projects that are composed of smaller BDAs has been quite successful. The stream response is probably not as significant, but I think the response is more sustainable (e.g., slow aggradation), and catastrophic loss in BDAs is less probable."[313]

Wyoming

In April 2018, the State Engineer's Office (SEO) issued a memorandum that addressed the application/permitting requirements for BDA projects. The memo states that staff were "directed to determine a method by which multiple small BDA reservoirs could be permitted by filing one Surface Water (SW-3) application." The permit is not considered an appropriation of a surface water right "due to the anticipated limited life of the facilities," but it gives the SEO a way to track them by requiring notice of completion and a field inspection. The memorandum does not state that the permit was adopted to address any concerns about water rights (unlike the ID and UT policies that did mention that issue as the main reason for their policies), but it was a topic of discussion during a series of meetings between the WY Game and Fish and the SEO in 2018. There was some concern raised by the SEO "over a number of stream restoration techniques that involved any sort of slowing or impoundment of the smallest amounts of water."[314] The permit application resolved that by setting a limit of 10 BDAs and 20 AF per permit and giving the SEO a way to track and inspect upon completion. The 20 AF is an amount of water that TNC stated would never be reached in their restoration projects, making it easy for them to comply with the limit.

New Mexico

As of fall 2023, New Mexico has not issued any regulations pertaining to LTPBR related to water rights issues. Conversations with restoration project managers indicate that they are moving forward with implementing LTPBR in careful consideration of location, methods, and collaboration with landowners and partners in order to avoid any conflicts.

Colorado

The Colorado Division of Water Resources (DWR) does not have any permitting authority over stream restoration projects, unlike in Idaho, Utah, and Wyoming, and has not issued a guidance document

[312] Emails with Rose Smith and Janice Gardner, Sageland Collaborative ecologists in Jan. 2022.
[313] Emails with Paul Burnett, TU Utah Water and Habitat Program Lead in Jan. 2022.
[314] Email with John Coffman, The Nature Conservancy, Southern WY Land Steward in Jan. 2022.

like Montana. In the spring of 2022, DWR clarified when their authority may apply to a restoration project on their webpage entitled "Pond Management & Restoration Projects," and gave this advice: "*Those doing restoration work in the stream should be mindful to comply with Colorado law, not injure water rights or interstate compact obligations, and not impact the function of existing decreed diversions and flow measurement structures.*[315] Their authority would kick in if restoration structures (such as BDAs) impeded flows significantly enough to cause a material injury to downstream water users. In that case, they could order removal of the structures.[316] They also cite their authority to "discontinue a diversion that is causing material injury" and to order the "release [of] any water that has been illegally or improperly stored."[317]

The lack of clarity of whether or not a project may be considered a diversion (and thus the potential need for a water right) was a strong motivation for the Department of Natural Resources to take the lead in drafting and shepherding legislation through the 2023 Session called SB23-270 Projects to Restore Natural Stream Systems.[318] The bill's preamble stated "The general assembly therefore declares that, because of the vast amount of benefits that natural streams provide the state's communities and environment, ***the state should facilitate and encourage the commencement of projects that restore the environmental health of natural stream systems***."[319] The bill passed and was signed into law after many amendments that were based on concerns expressed from water stakeholders of potential impacts to water rights.[320]

The final bill created six types of "**Minor Stream Restoration Activities**" that can proceed without being subject to water rights administration. These include stabilizing the banks or *substrate* of a natural stream with bioengineered or natural materials, installing porous structures in ephemeral or intermittent streams to stop degradation from erosional gullies and headcuts, and installing structures in stream systems to help recover from and mitigate the tremendous impacts that occur to water supplies from wildfires and floods.[321] The first draft of the bill also provided a process for larger PBR floodplain reconnection projects to obtain a rebuttable presumption of no harm to water rights, but that part was deleted from the bill as explained in this article.[322]

For projects that do not fit within the six minor restoration activities, the bill provided an important provision that states "nothing in this subsection (9) creates a presumption of injury for any activity that does not meet the definition of a Minor Stream Restoration Activity."[323] In other words, there is no *presumption* of harm to water rights by projects that don't fit within the minor categories. Thus, for those projects, it is still up to restoration project managers to decide how to reduce the risk of any water rights issues, which was the case before the bill passed. The authors drafted the LTPBR Guidelines (see Section 5.7 of this paper) to help provide some suggestions to reduce risk of conflicts. In addition to the "no presumption of injury" language, another important provision has been dubbed the "grandfather clause" because it states that a stream restoration project that "has obtained any applicable permits or

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[315] Pond Management & Restoration Projects | Division of Water Resources (colorado.gov)
[316] CRS 37-92-502(7). "The state engineer, division engineer, and their duly authorized assistants have the power and duty to issue orders so that the streams of the state may be kept clear of unnecessary dams or other obstructions which may restrict or impede the flow of water to the water users of the state."
[317] CRS 37-92-103(7) defines "diversion" as **removing water from its natural course** or location, or **controlling water in its natural course or location**, by means of a control structure, ditch, canal, flume, reservoir, bypass, pipeline, conduit, well, pump, or other structure or device." CRS 37-92-10.8 defines "storage" as the "impoundment, possession, and control of water by means of a dam" hence the importance of building low, porous, deformable temporary structures.
[318] SB23-270_signed.pdf (colorado.gov)
[319] *Id.*
[320] Colorado lawmakers OK millions in new water funding, stream restoration rules and a Colorado River task force - Water Education Colorado (May 2023)
[321] SB23-270_signed.pdf (colorado.gov)
[322] Stream restoration bill watered down - Aspen Journalism (May 2023).
[323] SB23-270_signed.pdf (colorado.gov)

is under construction or completed by August 1, 2023, does not cause material injury to any vested water right."[324]

Translating the legal language of the new law for implementing projects on the ground quickly became a strong need across Colorado for all the various stakeholders that are often involved in planning, funding, and implementing restoration work. The Co-chairs of the Colorado Healthy Headwaters Working Group (HHWG), Jackie Corday, Abby Burk (Audubon), and Fay Hartman (American Rivers), worked together in the fall of 2023 to research and prepare an in-person 3-hour SB270 training session that has now been given in six locations around the state and many virtual webinars reaching over 500 people, including Division of Water Resources leadership staff. The training has been very well received as a timely and helpful resource. A recorded SB270 training webinar is available on the HHWG Resources webpage.

[324] *Id*.

Appendix 2: Works Cited

A Biodiversity Boost from the Eurasian Beaver in Germany's Oldest National Park, Orazi, V. et al., *Frontiers in Ecology and Evolutions*, (2022).

A Brief Summary of Beaver Mimicry and Streamflow, Clancy, N. & Wolf, M., *University of Wyoming Factsheet,* (2022).

A century of change in Black Hills forest and riparian ecosystems, Parrish, J. et al., USFS Region 2, (1996).

A Function-Based Review of Stream Restoration Science, Harman, W. et al., *Environmental Law Institute*, (2016).

A Process-based Approach to Restoring Depositional River Valleys to Stage 0, an anastomosing channel network, Powers, P., Helstab, M., & Niezgoda, S., *River Research and Applications,* (2018).

A shared vision for enhancing ecological resilience in the U.S. - Mexico borderlands: The Sky Island Restoration Collaborative, Norman, L. et al., *SER News*, Vol 36, Issue 1, p 19-27 (2022).

A stream evolution model integrating habitat and ecosystem benefits, Cluer, B. & Thorne, C., *River Research and Applications*, (2104).

Alteration of stream temperature by natural and artificial beaver dams, Weber, N. et al., *PLOS/One*, (2017).

Analyzing the Impacts of Beaver Dam and Beaver Dam Analog Complexes to Stream Ecology Within the Intermountain West, Wolf, M., *Utah State University PhD Dissertation*, (2023).

Applied River Morphology, Rosgen, D. (1996); Natural Channel Design: Fundamental Concepts, Assumptions, and Methods, Rosgen, D. (2011).

Aridland Water Harvesting Study. Western Geographic Science Center. U.S. Geological Survey website, (2018).

Beaver. California Department of Fish and Wildlife, Department website,(2023).

Beaver activity increases habitat complexity and spatial partitioning by steelhead trout, Wathen, C. et al., *Canadian Journal of Fisheries and Aquatic Sciences*, (2019).

Beavers and flood alleviation: Human perspectives from downstream communities, Auster, R., Barr, S., & Brazier, R., *Journal of Flood Risk Management*, (2022).

Beaver: Best Management Practices, Grand Canyon Trust, (2013).

Beavers could be Colorado's secret weapon to cleaning rivers and abandoned mines, Guy, C., *Rocky Mountain PBS*, (Oct. 23, 2021).

Beaver dam analogues drive heterogeneous groundwater-surface water interactions, Wade, J. et al., *Hydrological Processes*, (2020).

Beaver dams and overbank floods influence groundwater-surface water interactions of a Rocky Mountain riparian area, Westbrook, C., Cooper, D. & Baker, B., *Water Resources Research*, (2006).

Beaver dam collapse destroys almost 250-foot section of ALCAN Highway (alaskasnewssource.com) (July 2, 2022).

Beaver Dams Help Wildfire-Ravaged Ecosystems Recover Long after Flames Subside. Whitcomb, W. *Scientific American*, (February 7, 2022).

Beavers, Landowners, and Watershed Restoration: Experimenting with Beaver Dam Analogues in the Scott River Basin, California, Charnley, S., *USDA Northwest Climate Hub*, (2018).

Beaver Management Along Roads and Within the Right-of-Way. Millian, K. Colorado Department of Transportation, (March 2022).

Beaver-mediated water table dynamics in a Rocky Mountain fen, Karran, D., Westbrook, C. & Bedard-Haughn, A., *Ecohydrology*, (2017).

Beaver-mimicry-guidebook.pdf (wordpress.com), Blackfeet Nation Beaver Mimicry Guidebook is filled with lots of practical information on project management.

Beaver mitigate the effects of climate on the area of open water in boreal wetlands in western Canada, Hood, G. & Bayley, S., *Biological Conservation*, (2008).

Beaver Ponds as Catchment-wide Retention Basins for Heavy Metals Sequestration, Peach, C., Master's Thesis, *Montana Technological University*, (2021).

Beaver Ponds: Resurgent Nitrogen Sinks for Rural Watersheds in the Northeastern United States, Lazar, J. et al., *Journal of Environmental Quality*, (2015).

Beaver power provides year-long water to Idaho ranch., Randall, B., *Beef Magazine*, (Feb. 2020).

Beaver Restoration Program-FY23 and FY24 Budget.. State of California, (2022).

Beaver: The North American freshwater climate action plan, Jordan, C. & Fairfax, E., *WIREs Water*, (2022).

Bothered by Beavers? Defenders of Wildlife, (2022).

Bumble bee (Bombus spp.) diversity differs between forested wetlands and clearcuts in the Acadian Forest, Brooks, D. & Nocera, J., *Canadian Journal of Forest Research*, (2020).

Busy as a Beaver, Moe Clark. Headwaters Magazine, Water Education Colorado, (2023). (July 2023).

Busy beavers: Calculating the value of ecosystems services provided by beavers. Chang, L. *Yale Environment Review*, (October 7, 2021).

CAL PBR Network newsletter, Issue 2, (Sept. 9, 2022).

Can riparian vegetation shade mitigate the expected rise in stream temperatures due to climate change during heat waves in a human-impacted pre-alpine river? Trimmel et al., *Hydrology and Earth System Sciences*, (2018).

Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation, Were, D. et al., *Earth Systems and Environment*, (2019).

Challenges in Accessing and Utilizing Federal Funding to Support Cross-Boundary Watershed Scale Restoration, (July 2022).

Citizen's Guide to Colorado Water Law 5th Edition, Water Education Colorado (2021).

Citizen's Guide to Colorado Water Quality Protection Third Edition. Water Education Colorado., (Jan. 3, 2022).

Climate Change Indicators: Snowpack, EPA Website (viewed Nov. 2023).

Colorado Beaver Restoration Assessment Tool. Colorado BRAT mapper was developed by the Colorado Natural Heritage Program, and BRAT mapping was produced by J. Scamardo., (2021).

Colorado Department of Natural Resources Launches study on Native Pollinating Insects | Colorado Governor Jared Polis

Colorado Fluvial Hazard Zone Program. Colorado Water Conservation Board.

Colorado's Fly-Fishing Industry Faces the Growing Threat of Climate Change. Hunt., N. *5280.com*, (May 2022).

Colorado Native Pollinating Insects Health Study, Armstead, S. et al., Colorado Department of Natural Resources, (2024).

Colorado River commission reviews lessons learned from water conservation program, Sackett, H. *Aspen Journalism*, (August 30, 2023).

Colorado SB23-270 signed bill Colorado.gov, (viewed July 2023).

Colorado Water Plan. Colorado Water Conservation Board, (2015).

Colorado Water Quality Regulations & Surface Water Pollution Info. Colorado Ag Water Quality, CSU Extension, (viewed November 2023).

Commentary: Dryland Watershed Restoration with Rock Detention Structures: A Nature-Based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon, Norman, L., *Frontiers in Science*, (2022).

Complementation of Habitats for Bonneville Cutthroat Trout in Watersheds Influenced by Beavers, Livestock, and Drought, White, S. & Rahel, F., *Transactions of the American Fisheries Society*, (2008).

Creating Miracles in the Desert: Restoring Dixie Creek. Intermountain West Joint Venture., (Oct 2021).

Creating Miracles in the Nevada Desert: Restoring Dixie Creek. Headquarters Public Affairs and Bureau of Land Management. (May 3, 2022).

Dam builders and their works: Beaver influences on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems, Larsen, A., Larsen, J. & Lane, S., *Earth-Science Reviews*, (2021).

Dammed Ponds! A study of Post-Fire Sediment and Carbon Dynamics in Beaver Ponds and Their Contributions to Watershed Resilience, Dunn, S., *CSU Master's Thesis*, (2023).

Degradation of floodplain integrity within the contiguous United States, Morrison, R., et al., *Communications Earth & Environment*, (2023).

Design Criteria for Process-Based Restoration of Fluvial Systems, Ciotti, T. et al., *BioScience* Vol. 71, Issue 8, (2021).

Disappearing West, Center for American Progress, (viewed November 2023).

Dredging will provide access to last 5 feet of irrigation water in parched McPhee Reservoir. Mimiaga, J., *The Durango Herald.* (Aug. 6, 2021).

Dryland Watershed Restoration with Rock Detention Structures: A Nature-based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon, Gooden, J. & Pritzlaff, R., *Frontiers in Environmental Science*, (2021).

Eager: The Surprising, Secret Life of Beavers and Why They Matter, Goldfarb, B., *Chelsea Green Publishing*, (2018).

Eagle River under full-day fishing closures. LaConte, J. *Vail Daily.* (July 25, 2022).

East Troublesome Fire could cause water-quality impacts for years. Best, A., *Aspen Journalism,* (Jan 18, 2021).

Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead, Bouwes, N. et al., *Scientific Reports*, (2016).

Ecosystem Services of Riparian Restoration: A Review of Rock Detention Structures in the Madrean Archipelago Ecoregion, Norman, L., *Air, Soil, and Water Research Volume 13*, (2020).

Ecosystem services provided by beavers (Castor spp.), Thompson, S. et al., *Mammal Review*, (2020).

EEAGER: A Neural Network Model for Finding Beaver Complexes in Satellite and Aerial Imagery, Fairfax, E. et al., *JGR Biogeosciences*, (2023).

Effects of Livestock Grazing on The Ecology of Sierra Meadows: A Review of The Current State of Scientific Knowledge to Inform Meadow Restoration and Management, Vernon, M., Campos, B., & Burnett, R. *Environmental Management*, (2022).

Efficiency of the Summer Monsoon in Generating Streamflow Within a Snow-dominated Headwater Basin of the Colorado River, Carroll, R., Gochis, D. & Williams, K., *Geophysical Research Letters*, (Nov. 2020).

Estimating widespread beaver dam loss: Habitat decline and surface loss at a regional scale, Scamardo, J., Marshall, S., and Wohl, E., *Ecosphere*, (2021).

Eurasian beaver activity increases water storage attenuates flow and mitigates diffuse pollution from intensively-managed grasslands, Puttock et al., *Science of the Total Environment*, (2017).

Field experiments to assess passage of juvenile salmonids cross beaver dams during low flow conditions in a tributary to the Klamath River, California, USA, Pollock, M., Witmore, S. and Yokel, E., PLoS ONE 17(5): e0268088, (2022).

Firefighting beavers | US Forest Service (usda.gov) Cleveland, J., (Oct. 2, 2023).

Flood Information & Resources. Colorado Water Conservation Board.

Flow-Device-Cost-Analysis-Mistakis-Institute.pdf (beaverinstitute.org)

Forage and Cattle Response to Sierra Meadow Restoration. Tate, K., et al., a collaborative report from American Rivers, The Cosumnes American Bear Yuba Integrated Regional Water Management Group, Environmental Defense Fund, and Tuolumne County Resource Conservation District, (2016).

Form-based river restoration decreases wetland hyporheic exchange: Lessons learned from the Upper Colorado River, Sparacino, M. et al., *Earth Surface Processes and Landforms,* (2018).

Freedom to Roam: How Meandering Rivers Can Decrease Destructive Flooding, Vermont Agency of Natural Resources webpage.

Freshwater Ecoregions of North America: A Conservation Assessment, Abell, R, et al., *Island Press*, (2000).

Front Range housing boom sends water prices soaring. Smith, J., *Water Education Colorado,* (May 1, 2019).

Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream in the interior Columbia River basin Pollock, M. et al., *Earth Surface Processes and Landforms*, (2007).

Going with the Flow. Edwards, P. and the USDA Pacific Northwest Climate Hub. (March 12, 2021).

Great Expectations: Deconstructing the Process Pathways Underlying Beaver-Related Restoration, Nash, C. et al., *BioScience*, (2021).

Groundwater-Mediated Influences of Beaver-Mimicry Stream Restoration: A Modeling Analysis, Bobst, A., Payn, R. & Shaw, G., *Journal of the American Water Resources Association*, (2022).

Guidance for Landowners and Practitioners Engaged in Stream and Wetland Restoration Activities. Montana Department of Natural Resources and Conservation, (2016).

Habitat conditions at beaver settlement sites: implications for beaver restoration projects, Ritter, T. et al., *Restoration Ecology*, (2020).

Hand-Built Structures for Restoring Degraded Meadows in Sagebrush Rangelands, Maestas, J. et al., *Range Technical Note. No. 40 USDA*, (May 2018).

Harvesting water in arid lands, don't forget your NIDS (Natural Infrastructure in Dryland Streams). Norman, L., Global Water Forum, (2022).

Headset Erosion in Wyoming's Sweetwater Subbasin, Cox, S., Booth, D., & Likins, J., *Environmental Management*, (2015).

How the private sector got public funding for nature-based climate solutions. Daley, J., *GreenBiz.* (Sept. 1, 2022).

How To Keep Beavers from Plugging Culverts, Nolte, D., et al., *USFS Technology & Development Program Report*, (2005).

Humans mimicking beavers to combat wildfires and restore wetlands - Wildfire Today (Oct. 29,2023).

Hydrologic Data Collected at Leaky Weirs, Cienega Ranch, Arizona, Coy, H., et al., (2020).

Hydrological functioning of a beaver dam sequence and regional dam persistence during an extreme rainstorm, Westbrook, C., Ronquist, A. & Bedard-Haughn, A., *Hydrological Processes*, (2020).

Hydrologic Response of Streams Restored with Check Dams in the Chiricahua Mountains, Arizona, Norman, L. et al., *River Research and Applications*, (2016).

Hyporheic Exchange in a Stream Dammed by Beaver: A 1D Simulation with Spatial Energy Head Gradients and Heterogeneous Hydraulic Conductivity as Drivers, Fairfax, E. & Small, B., *American Geophysical Union*, Fall Meeting 2016, abstract #H53E-1747.

Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream, Majerova, M. et al., *Hydrology and Earth System Sciences Discussions*, (2015).

Influence of beaver dam density on riparian areas and riparian birds in shrubsteppe of Wyoming, Cooke, H. & Zack, S., *Western North American Naturalist*, (2007).

Infrastructure bill a win for Colorado land, water. Colorado Trout Unlimited. (Dec. 14, 2021).

Instruction Guide Joint Application for Stream Alteration Permit. State of Idaho, US Army Corps of Engineers.

Invasive Species/Vegetation Overview, Center for Environmental Excellence, (Viewed July 2023).;

Is it possible to use beaver building activity to reduce lake sedimentation? Gorshkov, D., *Lutra,* (2003).

It Was War. Then, a Rancher's Truce with Some Pesky Beavers Paid Off. Einhorn, C. *The New York Times,* (Sept. 6, 2022).

Juvenile salmonid growth, survival, and production in a large river floodplain modified by beavers, Malison, R. et al., *Canadian Journal of Fisheries and Aquatic Sciences*, (2015).

Landscapes to Riverscapes: Bridging the Gap Between Research and Conservation of Stream Fishes, Fausch et al., *BioScience,* (2002).

Landscape with Beavers, Passmore, S., *Places Journal*, (July 2019).

Legacy effects of loss of beavers in the continental United States., Wohl, E., *Environ. Res. Letters*, (2021).

Levees don't protect, they disconnect: A critical review of how artificial levees impact floodplain functions, Knox, R., Wohl, E. & Morrison, R., *Science of the Total Environment*, (2022).

Livestock grazing limits beaver restoration in northern New Mexico, Small, B., Frey, J. & Gard, C., *Restoration Ecology*, (2016).

Livestock management, beaver, and climate influences on riparian vegetation in a semi-arid landscape, Fesenmyer, K. et al., *PLoS ONE 13(12*), (2018).

Living with Beavers. Colorado Parks and Wildlife, (viewed September 2022).

Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0 (researchgate.net), Wheaton, J. et al., *Utah State University Restoration Consortium*, Logan, UT (2019).

Low-tech Riparian and Wet Meadow Restoration Increases Vegetation Productivity and Resilience Across Semi-arid Rangelands, Silverman, N. et al., *Restoration Ecology*, (2018).

Managing for Large Wood and Beaver Dams in Stream Corridors, Wohl, E., Scott, D., and Yochum, S., Gen. Tech. Rep. 404. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, (2019).

Metals retention in a net alkaline mine drainage impacted stream due to the colonization of the North American Beaver, Shepard & Nairn, *Science of the Total Environment*, (2020).

Methods for Successful Establishment of Cottonwood and Willow Along an Incised Stream in Semiarid Eastern Oregon, Hall et al. USA. Ecological Restoration (2011).

Modeling Riparian Restoration impacts on the hydrologic cycle at the Babacomari Ranch, SE Arizona, Norman, L., (2019).

Monitoring heterogeneity and carbon sequestration of restored river-wetland corridors, Hinshaw, S., Doctoral dissertation, Colorado State University. *ProQuest Publication* No. 29257255 (2022).

Monitoring River Restoration Efforts: Do Invasive Alien Plants Endanger the Success? A Case Study on the Traisen River, Lapin, K., *Scientific Research*, (2016).

Montane Meadows: A Soil Carbon Sink or Source? Reed, C., et. al., *Ecosystems,* 2020.

Movement Patterns of Resident and Translocated Beavers at Multiple Spatiotemporal Scales in Desert Rivers, Doden, E. et al., *Frontiers in Conservation Science*, (2022).

NASA Opens New Era in Measuring Western U.S. Snowpack, NASA, (2013).

NASA satellites reveal restoration power of beavers, Mongabay Conservation News, (Sept. 2023).

National Water Summary - Wetland Resources: State Summaries, Colorado. Walton-Day, K. U.S. Geological Survey Water-Supply Paper 2425.

Natural Channel Design: Fundamental Concepts, Assumptions, and Methods, Rosgen, D., (2011).

Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience, Norman, L. et al., *Science of the Total Environment*, (2022).

Natural Streams and the Legacy of Water-Powered Mills, Walter, R & Merritts, D., *Science,* (2008).

Nature-Based Solutions Resource Guide, Olander, et. al., (November 2022)..

Nature's ecosystem engineers, Brazier, R. et al., *WIREs Water*, (2020).

NAWM-BLM Beaver-Related Restoration Training Series. Webinar Series, National Association of Wetland Managers, (2022).

Nonpoint Source Pollution Management. Colorado Department of Public Health and the Environment.

Nuisance Wildlife Laws in Colorado. Colorado Parks and Wildlife. (August 1, 2022).

Overview of Listing Impaired Waters under CWA Section 303(d). United States Environmental Protection Agency, (August 31, 2022).

Passive Restoration of a Small Mountain Stream in Eastern Oregon, Holthuijzen, A., *Northwest Science*, (2021).

Peer-reviewed Articles. Stage Zero, (viewed July 2023).

Pollinator Biology and Habitat (usda.gov), *NRCS Michigan Technical Note No. 20*, (April 2013).

Pollination Ecology of the Rare Orchid, Spiranthes diluvialis: Implications for Conservation, Pierson, K., USDA publication, (2002).

Pond Management & Restoration Projects. Division of Water Resources, Colorado Department of Natural Resources.

Pothole wetlands provide reservoir habitat for native bees in prairie croplands, Vickruck, J. et al., *Biological Conservation*, (2019).

Practical Grazing Management to Maintain or Restore Riparian Functions and Values on Rangelands, Swanson, S., Wyman, s. & Evans, C., *Journal of Rangeland Applications*, (2015).

President Biden Announces New Initiatives at COP27 to Strengthen U.S. Leadership in Tackling Climate Change, White House Briefing Room Statement, Nov. 11, 2022.

President Joe Biden's Historic Infrastructure and Climate Investments Will Require Building Rural Capacity. George, S., et. al. (Oct. 6, 2022).

Process-based Principles for Restoring River Ecosystems, Beechie, T. et al., *BioScience,* (2010).

Home | Low-Tech Restoration Explorer (bda-explorer.herokuapp.com) (viewed Nov. 2023).

Qualitative and quantitative effects of reintroduced beavers on stream fish, Kemp, P. et al., *Fish and Fisheries*, (2012).

Quantifying carbon footprint for ecological river restoration, Chiu et al., *Environment, Development, and Sustainability*, (2021).

Quantifying geomorphic change at ephemeral stream restoration sites using a coupled-model approach, Norman, L. et al., *Geomorphology*, (2017).

Ranchers and Beavers: Understanding the Human Dimensions of Beaver-related Stream Restoration on Western Rangelands, Charnley, S. et al., *Rangeland Ecology & Management*, (2020).

Ranchers, Beavers, and Stream Restoration on Western Rangelands, Kantor, S.& Charnley, S., *USDA Science Findings*, (July 2020).

Rancher Jay Wilde realizes long-time dream of bringing beaver back to Birch Creek. Life on the Range, an educational project sponsored by the Idaho Rangeland Resources Commission.

Recognizing the ephemeral stream floodplain: Identification and importance of flood zones in drylands, Scamardo, J. & Wohl, E., *Earth Surface Processes and Landforms*, (2023).

Reconnecting Rivers to Floodplains: Returning natural functions to restore rivers and benefit communities, Loos, J. & Shader, E., *American Rivers*, (2016).

Rediscovering, Reevaluating, and Restoring Lost River-Wetland Corridors, Wohl, E. et al., *Frontiers in Earth Science,* (2021).

Regulatory Challenges and Solutions for Sierra Nevada Meadow Restoration, Fair & Wingo, (Aug 2021)

Relics of beavers past: Time and population density drive scale-dependent patterns of ecosystem engineering, Johnson-Bice, S. et al., *Ecography*, (2022).

Rehabilitating Valley Floors to a Stage 0 Condition: A Synthesis of Opening Outcomes, Flitcroft, R., et al., *Frontiers in Environmental Science*, (2022).

Relocated beaver can increase water storage and decrease stream temperature in headwater streams, Dittbrenner, B. et al., *Ecosphere*, (2022).

Restoration potential of beaver for hydrological resilience in a changing climate, Dittbrenner, B., PhD Dissertation University of Washington, (2019).

Restoration of wet meadows to enhance Gunnison sage-grouse habitat and drought resilience in arid rangelands, Rondeau, R. et al., *Restoration Ecology*, (October 2023).

Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany, Serr-Llobet, A. et al., *Frontiers in Environmental Science*, (2022).

Riparian Areas: Functions and Strategies for Management, Washington D.C. *National Academies Press*, (2002).

Riparian buffer strips: Their role in the conservation of insect pollinators in intensive grasslands systems, Cole, L. et al., *Agriculture, Ecosystems & Environment*, (2015).

River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? Palmer, M., Menninger, H., & Bernhardt, E., *Freshwater Biology*, (2010).

River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation, Bernhardt, E. & Palmer, M., *Ecological Applications*, (2011).

Riverscapes as natural infrastructure: Meeting challenges of climate adaptation and ecosystem restoration, Skidmore, P. & Wheaton, J., *Anthropocene*, (2022).

Low-Teach Process Based Restoration of Riverscapes: Design Manual, Resources, Workshops. Utah State University Restoration Consortium.

Roaring Fork Watershed Plan: Executive Summary. Roaring Fork Conservancy, (2019).

Sageland Collaborative calls for volunteers in East Canyon Creek restoration work. Cody, K. *Park City News.* (Sept. 14, 2022).

Saving the Dammed, Why We Need Beaver-Modified Ecosystems, Wohl, E., *Oxford University Press*, (2019).

Scientists Are Relocating Nuisance Beavers to Help Salmon, VanSomeren, L., *Smithsonian*, May 21, 2021.

Scientists' warning to humanity on the freshwater biodiversity crisis, Albert, J. et al., *Ambio 50*, (2021).

Sediment and Nutrient Storage in a Beaver Engineered Wetland, Puttock, A. et al., *Earth Surface Processes and Landforms*, (2018).

Sierra Meadows Wetland and Riparian Area Monitoring Program, The Sierra Meadows Partnership, (2018).

2022 Colorado Small Game Waterfowl. Colorado Parks and Wildlife, (2022).

Smokey the Beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western United States, Fairfax, E. & Whittle, A., *Ecological Society of America*, Vol. 30, Issue 8 (2020).

Sierra Meadows Partnership Project Tracking Result. Fair, J. and Page, M., American Rivers. (May 2022).

Source or sink? Quantifying beaver pond influence on non-point source pollutant transport in the Intermountain West, Murray, D., Neilson, B. & Brahney, J., *Journal of Environmental Management*, (2021).

Spatial and Temporal Variability of Channel Retention in a Lowland Temperate Forest Stream Settled by European Beaver, Gygoruk, M. & Nowak, M., *Forests*, (2014).

Spying on Beavers From Space Could Help Save California, Goldfarb, B., *WIRED,* (Dec. 28, 2023).

Stage Zero Restoration Website, (viewed July 2023).

State Climate Policy and Nature-Based Solutions: A Match That Provides Multiple Benefits for Climate, Water, and More, Marcus, F., *Water in the West, Stanford Digital Repository,* (2022).

State Leaders Enact Historic Beaver Restoration Program. Occidental Arts & Ecology Center, (June 30, 2022).

Stream restoration bill watered down, Sackett, H., *Aspen Journalism*, (May 3, 2023).

Stream restoration projects focused on beavers present 'unsettled' issue. Sacket, H. *Aspen Journalism,* (Oct. 8, 2022).

Steamboat looks to new program to address high river temperatures. Sackett, H., *Aspen Journalism,* (Sept. 28, 2021).

Standards for ecologically successful river restoration, Palmer, M. et al., *Journal of Applied Ecology*, (2005).

Still standing: Recent patterns of post-fire conifer refugia in ponderosa pine-dominated forests of the Colorado Front Range, Chapman, T. et al., *PloS One* 15, no. 1, (2020).

Stitching the Landscape Back Together (arcgis.com), Intermountain West Joint Venture, (August 2023).

Streamlining Restoration Projects with Nationwide Permit 27: An Explainer. Madsen, B., Environmental Policy Innovation Center, (2022).

Stream Restoration with Beaver Dam Analogues: What Happened to the Water? Recorded Presentation at Salt Lake County Watershed Symposium, (Nov 17, 2020).

Survey of Beaver-related Restoration Practices in Rangeland Streams of the Western USA, Pilliod, D. et al., *Environmental Management*, (2017).

Synthesizing U.S. River Restoration Efforts, Bernhardt, E. et al., *Science*, (2005).

Take Care to Manage Wetlands for Pollinators, Southern Sustainable Agriculture Research and Education (March 2018); Pothole wetlands provide reservoir habitat for native bees in prairie croplands, Vickruck, J. et al., *Biological Conservation*, (2019).

The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Version 2.02., Pollock, M. et al., United States Fish and Wildlife Service, Portland, Oregon (2023). Online at: https://www.fws.gov/sites/default/files/documents/The-Beaver-Restoration-Guidebook-v2.02_0.pdf.

The Economic Value of Beaver Ecosystem Services, Escalante River Basin, Utah, Buckley, M. et al., (2011).

The Flow Regulation Services of Wetlands, Kadykalo, A. & Findlay, C., *Ecosystem Services*, (2016).

The Natural & Beneficial Functions of Floodplains, A Report for Congress by the Task Force on the Natural and Beneficial Functions of the Floodplains, (June 2002).

The Natural Wood Regime in Rivers, Wohl, E. et al., *BioScience*, (2019); A Primer on the Wood Regime for Stream Management, Scott, D. (2022).

The persistence of beaver-induced geomorphic heterogeneity and organic carbon stock in river corridors, Laurel, D. & Wohl, E., *Earth Surface Processes and Landforms*, (2018).

The science and practice of river restoration, Wohl, E., Lane, S., & Wilcox, A., *American Geophysical Union Water Resources Research*, (2015).

This California Creek Bed Was A Wildfire Risk, Then The Beavers Went To Work. *Sunny Skyz,* (July 2021).

To What Extent Might Beaver Dam Building Buffer Water Storage Losses Associated with a Declining Snowpack? Hafen, K., Master of Science Thesis Utah State University, (2017).

Threats to western United States riparian ecosystems: A bibliography. Poff, B. et. al, United States Forest Service, (December 2012).

UDWR: Beaver Restoration Assessment Tool (BRAT) - Wheaton Ecogeomorphology & Topographic Analysis. Wheaton, J.

U.S. Forest Service releases final NEPA rule - The Wildlife Society (Dec. 3, 2020).

Using Beaver Dam Analogues for Fish and Wildlife Recovery on Public and Private Rangelands in Eastern Oregon, Davee, R., Gosnell, H. and Charnley, S., *USDA Northwest Climate Hub*, (2019).

Using Beaver Dams to Restore Incised Stream Ecosystems, Pollock, M. et al., *BioScience,* (March 2014).

Utah Beaver Management Plan. Utah Division of Wildlife Resources, (May 2017).

Utah Policy for Beaver Dam Analogue Construction. State of Utah, Department Natural Resources, (December 28, 2018).

Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. EPA Office of Water and Research and Development, (December 2006).

Water Infrastructure for the 21st Century: The Viability of Incorporating Natural Infrastructure in Bureau of Reclamation Water Management Systems. Stern, C. Committee on Energy and Natural Resources Subcommittee on Water and Power, United States Senate, (March 24, 2021).

Water Is Life: Importance and Management of Riparian Areas for Rangeland Wildlife, Maestas, J. et al., Chap. 7 in the book: Rangeland Wildlife Ecology and Conservation, McNew, L.B., Dahlgren, D.K., Beck, J.L. (eds), *Springer*, (2023).

Water Is Life: Introducing SGI's Sage Grouse Mesic Habitat Conservation Strategy, *Sage Grouse Initiative*, (April 5, 2017).

Water Quality. *Colorado Water Knowledge*, Colorado State University, (2022).

Water Rights. Colorado Division of Water Resources website.

What Is Low-Tech Stream Restoration? Working Lands for Wildlife, (August 2018).

Western Mountains Ecoregion - National Rivers and Streams Assessment 2013-14. Environmental Protection Agency.

Wet Meadows Restoration and Building Project. Upper Gunnison River Water Conservancy District.

Wetlands as Pollinator Habitat, Nizzi, S. & Powers, R., Xerces Society for Invertebrate Conservation Blog, (May 2021).

What is Water Security? GlobalWaters.org.

What landowners need to know about process-based restoration – On Land. Western Landowner Alliance, (December 5, 2023).

What the Inflation Reduction Act Means for Water in the West. Wall, C. Audubon, (Aug. 18, 2022).

What the world needs now to fight climate change: More swamps. *The Conservation.* (September 13, 2018).

Wolf Reintroduction Changes Yellowstone Ecosystem. Farquhar, B. *Yellowstone National Park Trips,* (June 30, 2021).

Working with Beaver for Better Habitat Naturally, Sherri Tippie & Grand Canyon Trust, (2010).

Wood placement in river restoration: fact, fiction, and future direction, Roni, P. et al., *NRC Research Press*, (2017).

Working with Beavers website, Miistakis Institute (viewed November 2023).

Working with beaver to restore salmon habitat in the Bridge Creek intensively monitored watershed: Design rationale and hypotheses, Pollock, M. et al., *NOAA Technical Memorandum* NMFS–NWFSC–120 (2012).

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Life Depends on Rivers℠