

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

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## 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).

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

[Badger Creek: Big Country with Some Big Problems](#). Keidel, J. Colorado Central Magazine, (1996).

[Badger Creek Headwaters Wet Meadow and Riparian Restoration Opportunities](#). Beardsley, M., (2016).

[Badger Creek Restoration Hydrologic Monitoring Update](#). Sholtes, J., (2022).

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.](#) Matteson, C., (July 5, 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).

[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).

[Central Colorado Conservancy Makes Progress with Badger Creek Watershed Project.](#) Gilmore, B., *Ark Valley Voice*, (July 2021).

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

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

[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 Water Plan.](#) Colorado Water Conservation Board, (2015).

[Colorado Water Quality Regulations & Surface Water Pollution Info.](#) Colorado Ag Water Quality, (2022).

[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).

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).

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).

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.

[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).

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).

[Flood Information & Resources.](#) Colorado Water Conservation Board.

[Forage and Cattle Response to Sierra Meadow Restoration.](#) Tate, K., et al., (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](#).

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

[Going with the Flow.](#) Edwards, P. and the 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).

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

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.](#) United States Forest Service. (2005).

Hydrological functioning of a beaver dam sequence and regional dam persistence during an extreme rainstorm, Westbrook, C., Ronnquist, 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.

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).

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.

[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).

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).

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

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

[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).

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).

[Partnering with Beaver Part 2: A Landscape View.](#) Jessica Doran, (May 2021).

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

[Pond Management & Restoration Projects](#). Division of Water Resources, Colorado Department of Natural Resources.

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 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).

[Low-Tech Restoration Explorer](#).

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).

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.

[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 and 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).

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

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

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

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., (2020).

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

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



[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).

[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).

[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).

[The Beaver Restoration Guidebook Version](#). Pollock, M. et al., USFWS, Portland, OR (2015).

[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 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 12, 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 et al., *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).

[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: 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.

[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.

[What is Water Security?](#) GlobalWaters.org.

[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).