The North American beaver (*Castor canadensis*) is a uniquely important aquatic mammal with a profound role in ecosystem and watershed maintenance and restoration. Commonly called an "ecosystem engineer," beaver transform the landscape, creating healthier, more resilient watersheds, improving water quality, increasing the availability of fresh water, forming essential wetlands, reducing peak flood levels, limiting damage from forest fires, mitigating climate change, and helping other fish and wildlife species to survive a warming planet. Beaver are considered a keystone species because of this disproportionately large impact they have on the entire surrounding ecosystem, establishing critical habitat for a large variety of fish, amphibians, birds, and mammals.

Beavers Support Biological Integrity. Integrity refers to an unimpaired condition, a state of being complete or undivided. Biological integrity has been defined by the US EPA, as [t]he ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region." This is a result of evolution; each organism is adapted to the environmental conditions in its native biogeographic region. An environment that supports an assemblage of organisms similar to that produced by long-term evolutionary processes has high biological integrity. Changes that result from human activities cause a divergence from biological integrity. Beavers build biological integrity in streams.

Frey, D. G. 1977. Biological integrity of waters: an historical approach. Pages 127–140 in R. K. Ballentine and L. J. Guarraia, editors. The integrity of water: a symposium. U.S. Environmental Protection Agency, Washington, D.C., USA.
https://nepis.epa.gov/Exe/ZyPDF.cgi/P1004625.PDF?Dockey=P1004625.PDF

Beavers Support Hydrological Systems and the Hyporheic Zone

The hydrology of a river with a matured series of beaver structures (ponds, canals, dams, food caches and lodges) is very different than a river with no or few beaver. Principles of healthy riverscapes require the river channel to be connected to the floodplain. Beavers create structures that add complexity to channels and force reconnection to the floodplain. Beaver dams help to combat incision in streams and to restore the natal geomorphology of degraded streams. The reduced energy of the flow causes less disturbance and makes the riverscape more stable. The ponded water caused by beaver activity vastly increases the volume of the hyporheic zone, an area of sediment and porous space under a stream bed where there is a mixing of groundwater and surface water. This sediment zone is critical to restoring chemical stability by filtering pollutants (especially nitrates) out of the stream for cleaner water. As the hyporheic zone cleans water through filtration, it also recharges groundwater.

Dittbrenner, B. J., Schilling, J. W., Torgersen, C. E., & Lawler, J. J. (2022). Relocated beaver can increase water storage and decrease stream temperature in headwater streams. Ecosphere, 13(7). https://doi.org/10.1002/ecs2.4168.

Hood, G. A. and S. E. Bayley (2008), Beaver (Castor canadensis) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. Biological Conservation 141:556-567. https://doi.org/10.1016/j.biocon.2007.12.003

Larsen, A., Larsen, J. R., & Lane, S. N. (2021). Dam builders and their works: Beaver influences

on the structure and function of river corridor hydrology, geomorphology, biogeochemistry and ecosystems. *Earth-Science Reviews*, *218*, 103623. https://doi.org/10.1016/j.earscirev.2021.103623

Rupiper, A. (2022). Dam! Impacts of Beaver Dams on Surface and Groundwater Quality. Iowa Water Conference 2022. https://www.cals.iastate.edu/inrc/projects/2020/dam-impacts-beaver-dams-surface-and-groundwater-quality

Beavers Stabilize Stream Temperature. Recent studies have shown how beaver ponds and wetlands stabilize stream temperatures during times of fluctuation. Stream temperature is critical to maintaining a stable hydrological system for species, such as trout, to survive.

Dittbrenner, B. J., Schilling, J. W., Torgersen, C. E., & Lawler, J. J. (2022). Relocated beaver can increase water storage and decrease stream temperature in headwater streams. *Ecosphere*, *13*(7). https://doi.org/10.1002/ecs2.4168

Majerova, M., Neilson, B. T., Schmadel, N. M., Wheaton, J. M., & Snow, C. J. (2015). Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream. *Hydrology and Earth System Sciences*, *19*(8), 3541–3556. https://doi.org/10.5194/hess-19-3541-2015

Weber, N., Bouwes, N., Pollock, M. M., Volk, C., Wheaton, J. M., Wathen, G., Wirtz, J., & Jordan, C. E. (2017). Alteration of stream temperature by natural and artificial beaver dams. *PLOS ONE*, *12*(5). https://doi.org/10.1371/journal.pone.0176313

Beavers Improve Water Quality. Beaver ponds remove nutrients such as nitrogen and phosphorus and sediment. Breaching beaver dams destabilizes and releases sediments causing increased sediment loads downstream.

Lazar, J. G., Addy, K., Gold, A. J., Groffman, P. M., McKinney, R. A., & Kellogg, D. Q. (2015). Beaver Ponds: Resurgent nitrogen sinks for rural watersheds in the Northeastern United States. *Journal of Environmental Quality*, *44*(5), 1684–1693. https://doi.org/10.2134/jeq2014.12.0540

Levine, R., & Meyer, G. A. (2014). Beaver dams and channel sediment dynamics on Odell Creek, Centennial Valley, Montana, USA. *Geomorphology*, *205*, 51–64. https://doi.org/10.1016/j.geomorph.2013.04.035

Puttock, A., Graham, H. A., Carless, D., & Brazier, R. E. (2018). Sediment and nutrient storage in a Beaver Engineered Wetland. *Earth Surface Processes and Landforms*, *43*(11), 2358–2370. https://doi.org/10.1002/esp.4398

U.S. Fish and Wildlife Service (USFWS) (2023), *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains* (2023 Beaver Restoration Guidebook), v. 2.02, https://www.fws.gov/sites/default/files/documents/The-Beaver-Restoration-Guidebook-v2.02_0.pdf

Beavers Create Flood Water Storage. A 2020 study found that restoring beaver to the Milwaukee River Watershed could reduce the peak flow during high water events by over 37%

on average and provide as much as $3.346 billion in ecological services by creating stormwater storage to prevent downstream flooding. Researchers also estimated that beaver wetland restoration could protect over 500 homes that are currently in the floodplains, protecting these communities from potential destruction of infrastructure. Restoration of wetlands and floodplains has also been identified as an important climate adaptation strategy to reduce flood risk and protect water quality in the Midwest.

Liao, Q., Boucher, R, and Rock, M. (2021). 2019/2020 Beaver Restoration Study: Modeling the Milwaukee River watershed to measure the potential flood mitigation benefits of beaver created wetlands to restore the natural hydrology and reduce flooding during high water events. [Presentation]. College of Engineering and Applied Sciences, University of Milwaukee, Wisconsin.

Liao, Q., Boucher, R., Wu, C., Noor, S. M., Liu, L., Rock, M., Flanner, M., & Holloway, L. (2020). Hydrological Impact of Beaver Habitat Restoration in the Milwaukee River Watershed. https://www.superiorbioconservancy.org/scientific-publications/project-hydrological-impact-of-beaver-habitat-restoration-in-the-milwaukee-river-watershed

Beavers Protect Against Drought and Wildfire

Fairfax, E., & Whittle, A. (2020). Smokey the Beaver: Beaver‐dammed riparian corridors stay green during wildfire throughout the Western United States. *Ecological Applications*, *30*(8). https://doi.org/10.1002/eap.2225

Beavers Increase Biodiversity and Species-Richness. The ponds and wetlands that beaver create provide habitat and forage areas for other aquatic mammals such as mink, muskrat and otters; raptors such as eagles and osprey; rare songbirds such as Kirtland's warblers; waterbirds such as the endangered whooping crane, and a wide variety of reptiles, amphibians, and insects. Due to the uncertainty of climate change, beaver activity plays an increasingly critical role in maintaining and stabilizing habitat for a wide range of wetland-dependent species.

Anderson, N. L., Paszkowski, C. A., & Hood, G. A. (2014). Linking aquatic and terrestrial environments: Can beaver canals serve as movement corridors for pond-breeding amphibians? *Animal Conservation*, *18*(3), 287–294. https://doi.org/10.1111/acv.12170

Cooke, H. A., & Zack, S. (2008). Influence of beaver dam density on riparian areas and riparian birds in shrubsteppe of Wyoming. *Western North American Naturalist*, *68*(3), 365–373. https://doi.org/10.3398/1527-0904(2008)68[365:iobddo]2.0.co;2

Law, A., Gaywood, M. J., Jones, K. C., Ramsay, P., & Willby, N. J. (2017). Using ecosystem engineers as tools in habitat restoration and rewilding: Beaver and wetlands. *Science of The Total Environment*, *605–606*, 1021–1030. https://doi.org/10.1016/j.scitotenv.2017.06.173

LeBlanc, Gallant, Vasseur, & Léger (2007). Unequal summer use of beaver ponds by river otters: Influence of beaver activity, pond size, and vegetation cover. *Canadian Journal of Zoology*, *85*(7), 774–782. https://doi.org/10.1139/z07-056

Zero, V. H., & Murphy, M. A. (2016). An amphibian species of concern prefers breeding in active beaver ponds. *Ecosphere*, *7*(5), https://doi.org/10.1002/ecs2.1330

Hood, G. A., & Larson, D. G. (2013). Beaver-created habitat heterogeneity influences aquatic

invertebrate assemblages in Boreal Canada. *Wetlands*, *34*(1), 19–29. https://doi.org/10.1007/s13157-013-0476-z

Hossack, B. R., Gould, W. R., Patla, D. A., Muths, E., Daley, R., Legg, K., & Corn, P. S. (2015). Trends in Rocky Mountain Amphibians and the role of beaver as a keystone species. *Biological Conservation*, *187*, 260–269. https://doi.org/10.1016/j.biocon.2015.05.005

Johnson, G. E., & van Riper, C. (2014). Effects of reintroduced beaver (castor canadensis) on riparian bird community structure along the upper San Pedro River, southeastern Arizona and northern Sonora, Mexico. *Open-File Report*. https://doi.org/10.3133/ofr20141121

Nummi, P., Liao, W., Huet, O., Scarpulla, E., &; Sundell, J. (2019). The beaver facilitates species richness and abundance of terrestrial and semi-aquatic mammals. *Global Ecology and Conservation*, 20:1. https://doi.org/10.1016/j.gecco.2019.e00701

Beaver Support Fish. Numerous academic papers and peer reviewed studies now show that beaver complexes have a significant beneficial impact on trout and salmonid species, because they increase forage, create greater biodiversity, improve stream health and water quality, reduce flooding, and stabilize stream temperature. It is critical to examine newer studies that debunk outdated assumptions about beaver-trout relationships.

Bouwes, N., Weber, N., Jordan, C. E., Saunders, W. C., Tattam, I. A., Volk, C., Wheaton, J. M., & Pollock, M. M. (2016). Ecosystem Experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (Oncorhynchus mykiss). *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep28581

Johnson-Bice, S. M., Renik, K. M., Windels, S. K., & Hafs, A. W. (2018). A review of Beaver salmonid relationships and history of management actions in the Western Great Lakes (USA) region. *North American Journal of Fisheries Management*, *38*(6), 1203–1225. https://doi.org/10.1002/nafm.10223

Law, A., McLean, F., & Willby, N. J. (2016). Habitat Engineering by Beaver Benefits Aquatic Biodiversity and ecosystem processes in agricultural streams. *Freshwater Biology*, *61*(4), 486–499. https://doi.org/10.1111/fwb.12721

Lokteff, R. L., Roper, B. B., & Wheaton, J. M. (2013). Do beaver dams impede the movement of trout? *Transactions of the American Fisheries Society*, *142*(4), 1114–1125. https://doi.org/10.1080/00028487.2013.797497

McCaffery, M., & Eby, L. (2016). Beaver activity increases aquatic subsidies to terrestrial consumers. *Freshwater Biology*, *61*(4), 518–532. https://doi.org/10.1111/fwb.12725

Popelars, J. (2008). Using GIS to Reevaluate Beaver Dam Effects on Local Environments in Northern Wisconsin Brook Trout Streams During the 1980s. Graduate Thesis. Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987. https://gis.smumn.edu/GradProjects/PopelarsJ.pdf

Smith, J. M., & Mather, M. E. (2013). Beaver dams maintain fish biodiversity by increasing habitat heterogeneity throughout a low-gradient stream network. *Freshwater Biology*, *58*(7), 1523–1538. https://doi.org/10.1111/fwb.12153

Wathen, G., Allgeier, J. E., Bouwes, N., Pollock, M. M., Schindler, D. E., & Jordan, C. E. (2019).

Beaver activity increases habitat complexity and spatial partitioning by Steelhead Trout. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(7), 1086–1095. https://doi.org/10.1139/cjfas-2018-0171

Beaver Support Carbon Storage. Beaver are essential to mitigating climate change because the wetlands that they create act as a natural carbon storage sink.[22] As carbon storage continues to grow in importance to combat the climate crisis, protecting carbon sinks will be critical to expand climate resiliency.

Productive wetlands restored for carbon sequestration quickly become net CO2 sinks with site level factors driving uptake variability. *PLOS ONE*, *16*(3). https://doi.org/10.1371/journal.pone.0248398

Wohl, E. (2013). Landscape-scale carbon storage associated with Beaver Dams. *Geophysical Research Letters*, *40*(14), 3631–3636. https://doi.org/10.1002/grl.50710

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Johnston, C. A. (2015). Fate of 150-year-old beaver ponds in the Laurentian Great Lakes Region. *Wetlands*, *35*(5), 1013–1019. https://doi.org/10.1007/s13157-015-0688-5

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Valuing Beavers Ecosystem Services

Buckley, M., Souhlas, T., Niemi, E., Warren, E., & Reich, S. (2011). (rep.). *The economic value of beaver ecosystems services: Escalante River Basin, Utah* (pp. i-64). ECONorthwest. https://www.beaverinstitute.org/library_author/m-buckley/

Industrial Economics. (2011). (rep.). Economic valuation of wetland ecosystem services in Delaware. Dover, DE. https://www.nawm.org/state_meeting/2014/economic_evaluation_of_wetland_ecosystem_services_in_delaware.pdf

Niemi, E., Fouty, S., & Trask, S. (2020). Economic Benefits of Beaver-Created and Maintained

Habitat and Resulting Ecosystem Services. Natural Resource Economics, Petition to the Oregon Fish and Wildlife Commission. https://www.oregonlegislature.gov/marsh/Documents/EconBenefitsBeaver.pdf

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Beavers Restore Riverscapes Through Process-Based Restoration

Charnley, S., Gosnell, H., Davee, R., & Abrams, J. (2020). Ranchers and beavers: Understanding the human dimensions of beaver-related stream restoration on Western Rangelands. *Rangeland Ecology & Management*, *73*(5), 712–723. https://doi.org/10.1016/j.rama.2020.04.008

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