

## Appendix A- Restoration Guide

The Restoration Guide is intended to provide a brief overview of currently-accepted and/or locally-relevant technical references for practitioners to use as a resource for planning and implementing restoration projects. This guide is not intended to be exhaustive, and as science and regulations are always evolving, practitioners are encouraged to consult with regulatory agencies and partners in the conservation community to determine the most relevant sources of information on implementation and regulatory processes such as permitting. Practitioners should also consider any requirements restoration funders have when planning restoration work. These requirements may include compliance with NEPA, NHPA, and ESA, and certification that the proposed restoration technique meets relevant and applicable standards and criteria. Also note that Oregon State agencies produce a periodically-updated "State Water Related Permits User Guide" (latest revision Aug. 2012) that provides an overview of potential permits and requirements for restoration practices in wetlands and waterways. Comprehensive stream restoration guides that address multiple actions and provide additional information, case examples, and references are noted at the beginning of the table.

Impairment	Restoration Action	Technical References and Resources	Description	Additional Considerations
Multiple	Stream restoration - multiple actions addressed	Cramer ML. (managing editor). 2012. Stream Habitat Restoration Guidelines. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service. Olympia, WA.	NA	NA
		Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.	NA	NA
		Roni P, Beechie T. 2013. Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats. doi: 10.1002/9781118406618.	NA	NA
		Yochum SE. 2018. Guidance for Stream Restoration. U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center, Technical Note TN-102.4. Fort Collins, CO.	NA	NA

Channelized rivers and streams	Channel reconstruction	Li M-H. 2007. Stream Restoration Design Handbook (National Engineering Handbook, 210VI, Part 654), Bernard JM, Fripp J, Robinson K (Eds.), US Department of Agriculture, Natural Resources Conservation Service. Landscape and Urban Planning 87:97-98. 10.1016/j.landurbplan.2008.05.002.	This handbook covers numerous assessment and design methods, separated as chapters, along with ecological concepts and principles, project considerations, supplemental technical resources, and case studies.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>Projects may need to report any calculated changes to the base flood elevation (County, FEMA).</li> <li>Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.</li> </ul>
		Rosgen DL. 2011. Natural Channel Design: Fundamental Concepts, Assumptions, and Methods. In Simon A, Bennett SJ, Castro JM (Eds.), Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, Geophysical Monograph Series 194. American Geophysical Union: Washington, D.C.	This chapter provides information on the Natural Channel Design method, which uses hydraulic assessments and reference (potential) reach conditions to establish design specifications for reach dimensions, pattern and profile.	
	Stage "0" restoration	Cluer B, Thorne C. 2013. A stream model integrating habitat and ecosystem benefits. River Research and Applications 30(2): 135-154.	This article proposes a Stream Evolution Model as an updated version of previous channel evolution models. The discussion includes considerations for habitat and ecosystem benefits of various stream stages that are relevant to restoration planning and river management.	<ul style="list-style-type: none"> <li>Note that Stage "0" restoration refers to any restoration technique that restores stream morphology to a stage 0 anastomosing stream type; as such, this category includes techniques such as beaver dam analogs, but that specific technique is covered below.</li> <li>Stage "0" projects in grazed areas may require exclusion and/or dedicated watering areas to promote natural stream processes while preserving the ranching operation.</li> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>Projects may need to report any calculated changes to the base flood elevation (County, FEMA).</li> <li>Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.</li> </ul>
		Powers PD, Helstab M, Niezgoda SL. 2018. A process based approach to restoring depositional river valleys to Stage 0, an anastomosing channel network. River Restoration Applications:1-11. <a href="https://doi.org/10.1002/rra.3378">https://doi.org/10.1002/rra.3378</a>	This article presents a discussion of the Geomorphic Grade Line method for Stage "0" restoration with case examples.	
		Roni P, Beechie T. 2013. Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats. doi: 10.1002/9781118406618.	NA	
	Channel incision	Beaver dam analogs	Skinner M, Erdman C, Stoken O. 2020. Considerations for implementation of beaver dam analogs and similar structures in the Upper Klamath Basin of Oregon, USA. Klamath Falls Fish and Wildlife Office, US Fish and Wildlife Service and Trout Unlimited: Klamath Falls, OR.	This literature review provides guidelines and recommendations regarding the installation of beaver dam analogs, with particular emphasis on conditions and scenarios in the Upper Klamath Basin. This document is part of the Upper Klamath Basin Watershed Action Plan, Appendix A.
Wheaton J, Bennett S, Bouwes N, Maestas J, Shahverdian S. 2019. Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0. doi: 10.13140/RG.2.2.19590.63049/2.			This comprehensive design manual provides guidelines for implementing beaver dam analogs (BDAs) and post-assisted log structures (PALS) as approaches to process-based restoration.	
Pollock MM, Lewallen GM, Woodruff K, Jordan CE, Castro CM. 2018. The beaver restoration guidebook: working with beaver to restore streams, wetlands, and floodplains. Version 2.01. U.S. Fish and Wildlife Service: Portland, OR.			This restoration guidebook offers a comprehensive literature review discussing the effects of BDAs on various ecosystem components, a section providing designed considerations, and numerous case studies	
Other stream aggrading practices		Camp R. 2015. Short Term Effectiveness of High Density Large Woody Debris in Asotin Creek as a Cheap and Cheerful Restoration Action. Masters Thesis, Utah State University: Logan, UT. <a href="https://digitalcommons.usu.edu/etd/4417">https://digitalcommons.usu.edu/etd/4417</a>	This Masters Thesis describes large woody debris projects that resulted in channel aggradation. See also the technical references for large woody debris below.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>Projects may need to report any calculated changes to the base flood elevation (County, FEMA).</li> <li>Projects should consider the presence of downstream infrastructure (bridges, culverts) in design decisions for securing materials versus allowing flow manipulation of material placement.</li> </ul>

Levees and berms in floodplain	Levee removal, breaching, or setback	Crame, ML. (managing editor). 2012. Stream Habitat Restoration Guidelines. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service. Olympia, WA.	These guidelines discuss activities involving levees as part of Technique 2: Floodplain and Channel Migration Zone Restoration, including methods, construction considerations, risk assessments, monitoring, and permitting.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>Projects may need to report any calculated changes to the base flood elevation (County, FEMA).</li> </ul>
Draining of natural wetlands	Natural wetland restoration	Carpenter KD, Snyder DT, Duff JH, Triska FJ, Lee KK, Avanzino RJ, Sobieszcyk S. 2009. Hydrologic and water-quality conditions during restoration of the Wood River Wetland, upper Klamath River basin, Oregon, 2003-05: U.S. Geological Survey Scientific Investigations Report 2009-5004.	This report provides information on the restoration of the Wood River Wetland, a wetland that was diked and drained for cattle ranching between 1948 and 1994 on Upper Klamath Lake. Although not a restoration guide, the report provides locally-relevant information on the site conditions and changes experienced during the ongoing restoration.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> </ul>
		USDA NRCS. 2008. Ch. 13 Wetland Restoration, Enhancement, or Creation. In Part 650 National Engineering Handbook; 210-VI-EFH	This reference covers a range of wetland types and functions in a multidisciplinary approach to wetland planning and design.	
Grazing in floodplains and riparian areas that is unmanaged or managed inconsistent with restoration objectives	Riparian and floodplain grazing management	Skinner MM, Vradenburg LA. 2020. Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon. Klamath Falls Fish and Wildlife Office, U.S. Fish and Wildlife Service and Klamath Watershed Partnership: Klamath Falls, OR.	This document includes information about the effects of riparian restoration and grazing management and also offers guidance for specific restoration and management techniques. This document is part of the Upper Klamath Basin Watershed Action Plan, Appendix A.	<ul style="list-style-type: none"> <li>ODA regulates the protection of streams in agricultural operations, including enforcement of compliance with measures to control 1) over-grazing of streamside vegetation, and 2) the release of excess sediment or animal waste from entering streams. Although no permits or notifications with ODA are required, it is important to understand if the property is under compliance enforcement as this may affect funding eligibility.</li> <li>Grazing management plans or practices may be developed or incentivized through NRCS or FSA programs; consult with those offices for current opportunities and applicable compliance.</li> <li>Grazing management changes should be evaluated with the landowner to determine feasibility and impacts to the operation.</li> </ul>
		U.S. Department of the Interior. 2006. Riparian area management: Grazing management processes and strategies for riparian-wetland areas. Technical Reference 1737-20. Bureau of Land Management, National Operations Center: Denver, CO.	This technical guide, which is compiled by range and riparian specialists and periodically updated to reflect emerging trends and long-term monitoring, is a thorough overview of grazing management strategies that may generally be applicable to the Klamath Basin.	
	Riparian fencing	Skinner MM, Vradenburg LA. 2020. Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon. Klamath Falls Fish and Wildlife Office, U.S. Fish and Wildlife Service and Klamath Watershed Partnership: Klamath Falls, OR. (Included in Appendix A)	This document includes information about the effects of riparian restoration and grazing management and also offers guidance for specific restoration and management techniques. This document is part of the Upper Klamath Basin Watershed Action Plan, Appendix A.	<ul style="list-style-type: none"> <li>Construction specifications may exist relative to the funding source (e.g. NRCS), and if applicable, supersede referenced guidelines.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Loss of grazeable acres due to fencing should be evaluated with the landowner to determine feasibility and impacts to the operation. A grazing management plan may be needed to ensure the fencing is being used as intended.</li> </ul>
		Paige C. 2012. A Landowner's Guide to Wildlife Friendly Fences. Second Edition. Private Land Technical Assistance Program, Montana Fish, Wildlife & Parks: Helena, MT.	This guide provides a thorough review of fencing styles, applications, and objectives, including technical specifications and additional considerations for site applicability.	
	Riparian planting	Skinner M, Vradenburg LA. 2020. Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon. Klamath Falls Fish and Wildlife Office, U.S. Fish and Wildlife Service and Klamath Watershed Partnership: Klamath Falls, OR. (included in Appendix A)	This document includes information about the effects of riparian restoration and grazing management and also offers guidance for specific restoration and management techniques. This document is part of the Upper Klamath Basin Watershed Action Plan, Appendix A.	<ul style="list-style-type: none"> <li>Plants may need irrigation for 1 year (or more) after planting to promote establishment; water source, appropriate irrigation/delivery equipment, and manpower will need to be part of the planting plan.</li> <li>Planting projects should consider local/regional sources of native seed/stock to ensure they are adapted to the climate and elevation, thereby increasing the likelihood of survival.</li> <li>Depending on the funding source, native plants may be required, or suitable, non-invasive introduced species may be acceptable.</li> <li>Large and/or specific plant orders may need to be ordered a year or more in advance to allow the nursery to grow them out.</li> <li>Plants may need protection from livestock or wild animals (deer, elk, voles, etc.) as well as competition control (pulling/cutting of nearby vegetation).</li> <li>Site disturbance and irrigation may encourage development of noxious weeds in planted areas; a planting plan should including monitoring for and treatment of weeds.</li> </ul>
		Hoag JC, Berg FE, Wyman SK, Sampson RW. 2001. Riparian Planting Zones in the Intermountain West. In the Riparian/Wetland Project Information Series No. 16. March, 2001 (Revised).	This paper covers the riparian planting zones and implications for plant selection. The appendix contains a list of riparian plants in the intermountain west, along with their growth and functional characteristics, site conditions, and commercial availability. Chris Hoag is a plant ecologist that has also published numerous regionally-relevant studies and guides for riparian restoration and streambank bioengineering.	
Crowe EA, Kovalchik BL, Kerr MJ. 2004. Riparian and Wetland Vegetation of Central and Eastern Oregon. Oregon State University: Portland, OR.		This reference provides a classification of plant associations largely applicable to the Klamath Basin as captured in the East Cascades region, and describes the potential natural late seral community for a site's hydrologic, geomorphic, and soil conditions		

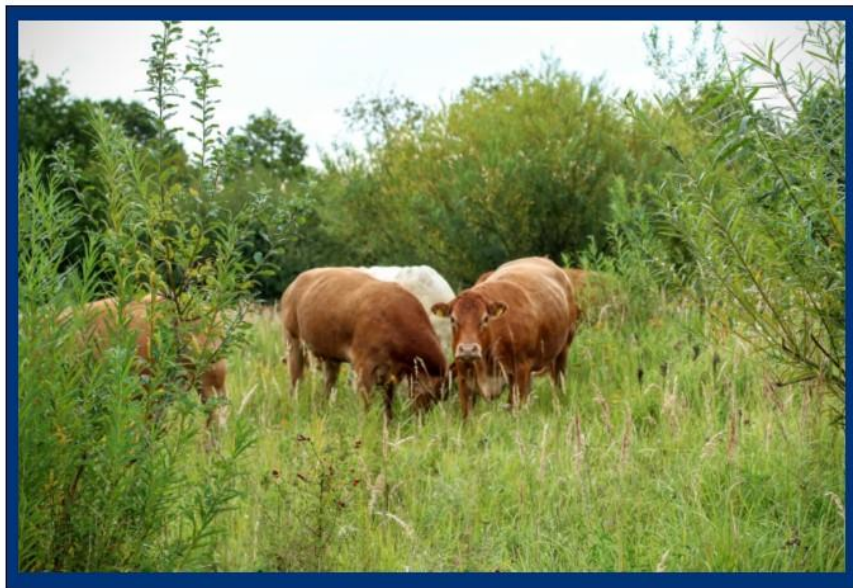
Tailwater return flows that are unmanaged or managed inconsistent with restoration objectives	Irrigation modernization/efficiency work	Peters RT. 2011. Managing Wheel-Lines and Hand-Lines for High Profitability. Washington State University Extension Fact Sheet FS044E.	This reference provides best management practices for sprinkler line irrigation based on an improved understanding and management of soil water, with ultimate objectives of increased producer profitability and more effective water use.	See WAP narrative for caveats regarding the ability of irrigation efficiency/modernization to reduce water diversion for irrigation and increase instream flow. Additionally, note that conversion from gravity-fed flood irrigation to a pressurized system will not result in energy cost savings for landowners.
		Ranch and Range Consulting. 2012. Stretching Water in the Sprague River Valley.	This locally-focused report covers considerations for producers looking to maintain or improve their productivity, especially in the reduction or absence of irrigation. Discussions focus on soil condition and dryland seed/planting options.	
		<a href="https://www.energytrust.org/solutions/agriculture-irrigation-improvements/">https://www.energytrust.org/solutions/agriculture-irrigation-improvements/</a>	Energy Trust offers information about methods to improve irrigation efficiency to improve application efficiency (i.e., reduce return flows) and reduce energy costs for the landowner. The website features fact sheets, success stories, and regional contacts.	
Tailwater return flows that are unmanaged or managed inconsistent with restoration objectives	Diffuse source treatment wetlands	Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, NSI/Biohabitats. 2013. Water quality improvement techniques for the Upper Klamath Basin: a technical workshop and project conceptual designs. Prepared for the California State Coastal Conservancy: Oakland, CA.	This report provides information about diffuse source treatment wetland design. The narrative beginning on page 41 is specific to diffuse source treatment wetlands.	<ul style="list-style-type: none"> <li>• Projects may require 1 year (or more) of water quality monitoring to inform design so project managers should plan their timeline accordingly</li> <li>• Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>• Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>• Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>• Loss of production acreage and impacts to the operation due to construction of DSTWs should be evaluated with the landowner during the planning phase.</li> </ul>
		Stillwater Sciences. 2020. Agency wetlands project-analysis of wetland treatment potential. Prepared for Trout Unlimited: Klamath Falls, OR.	Although this technical memorandum focuses on the treatment potential at a specific site, Section 3.2 offers information about design considerations that would apply to any treatment wetland project.	
		Trout Unlimited and Stillwater Sciences. 2019. Upper Klamath Basin Diffuse Source Treatment Wetlands Pilot Study. Prepared by Trout Unlimited, Klamath Falls, Oregon and Stillwater Sciences, Berkeley, California, for State Coastal Conservancy, Oakland, California, and North Coast Regional Water Quality Control Board, Santa Rosa, California.	This technical memorandum summarizes the design, construction, and initial monitoring process for three DSTWs in the Wood River Valley, Oregon during the period from 2014-2019.	
Over-allocation of water	Instream transfer of water rights	Aylward B. 2013, editor. Environmental Water Transactions: A Practitioner's Handbook. Bend, OR: Ecosystem Economics. <a href="https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/577c8f60c534a5bc31221f68/1467781084671/Handbook+Combined.pdf">https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/577c8f60c534a5bc31221f68/1467781084671/Handbook+Combined.pdf</a>	This handbook covers the science, law, and policy surrounding environmental water transactions, defines transaction types, and then describes the process of developing, implementing, and monitoring an environmental water transaction. Includes examples specific to Oregon but is meant to be a general reference for the Western US.	<ul style="list-style-type: none"> <li>• Coordinate closely with OWRD before and during transfer process.</li> <li>• Project will require a Certified Water Rights Examiner, and may require legal council.</li> <li>• Flow restoration projects funded with public dollars typically require a quantified and permanent instream water rights transfer</li> </ul>
		OWRD's Allocation of Conserved Water program website ( <a href="https://www.oregon.gov/owrd/programs/WaterRights/Conservation/Pages/AOCW.aspx">https://www.oregon.gov/owrd/programs/WaterRights/Conservation/Pages/AOCW.aspx</a> )	This website contains information and application forms for OWRD's program that allows water users that have improved their water efficiency to use 75% of the water that has been conserved in new uses, while allocating 25% of the conserved water to the state for instream use.	

Fish passage barriers	Mitigation or removal of passage barriers	Fish Passage Guidelines for New and Replacement Stream Crossing Structures. 2002. ODF Forest Practices Technical Note Number 4.  Determining the 50-Year Peak Flow and Stream Crossing Structure Size for New and Replacement Crossings.2002. ODF Forest Practices Technical Note Number 5.	ODF, as the regulatory agency for fish passage on state and private forestland, produced these technical notes consistent with ODFW guidelines. Note 4, supplemented by Note 5, supersedes all previous technical guidance for fish passage on state and private forests, and includes references for detailed technical information.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. Laws regarding fish passage may be found in ORS 509.580 through 910 and in OAR 635, Division 412.</li> <li>Projects may need to report any calculated changes to the base flood elevation (County, FEMA)</li> <li>Follow ODF guidelines, including Notification of Operations and a written plan if in a forested area; otherwise follow ODFW guidelines.</li> </ul>
		Robison EG, Mirati A, Allen M. 1999. Oregon Road/Stream Crossing Restoration Guide.	The guide and associated appendices include guidance and regulatory requirements for the installation or replacement of road/stream crossings. ODF guidance is based on ODFW's criteria and is applicable to forestland. ODFW guidance is intended for non-forested areas.	
		OFRI. 2018. Oregon's Forest Protection Laws: An Illustrated Manual, rev. 3rd ed.	A user-friendly guide to the Oregon Forest Practices Act and Rules that includes planning, construction, and maintenance considerations for roads and stream crossings.	
		Hoffer-Hay D. 2008. Small dam removal in Oregon: A guide for project managers.	Although not a detailed technical report, this guide provides an extensive discussion of the partners, processes, and permits involved in a small dam removal project.	
Roads and culverts	Road decommissioning, redesign, or rerouting (including removal or replacement of culverts)	OFRI. 2018. Oregon's Forest Protection Laws: An Illustrated Manual, rev. 3rd ed. 199p.	A user-friendly guide to the Oregon Forest Practices Act and Rules that includes considerations for road decommissioning.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>Follow ODF guidelines, including Notification of Operations and a written plan if in a forested area.</li> </ul>
		Weaver WE, Weppner EM, Hagans DK. 2014. Handbook for Forest, Ranch and Rural Roads: A Guide for Planning, Designing, Constructing, Reconstructing, Upgrading, Maintaining and Closing Wildland Roads, Mendocino County Resource Conservation District, Ukiah, CA.	This handbook, although not a detailed technical reference, uses photos and case examples to convey fundamental techniques, considerations, and effectiveness of road decommissioning practices.	
		Moll JE. 1996. A Guide for Road Closure and Obliteration in the Forest Service. USDA Forest Service Technology and Development Program: Washington, D.C.	This guide compiles techniques with equipment and site considerations.	
Unscreened irrigation diversions	Screened irrigation diversions	Mefford B. 2014. Pocket Guide to Screening Small Water Diversions. U.S. Bureau of Reclamation.	This guide covers various screen designs and options for small (<25cfs) diversions.	<ul style="list-style-type: none"> <li>Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>See the ODFW Fish Screening webpage (<a href="https://www.dfw.state.or.us/fish/screening/index.asp">https://www.dfw.state.or.us/fish/screening/index.asp</a>) for information regarding screen technologies and maintenance needs, and resources such as cost-share programs.</li> <li>Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>Screening may be required by the funder for projects that involve any work on a diversion. Consult with OWRD regarding water rights and any applicable design requirements and/or measuring gauges.</li> <li>Screening requirements and design criteria may vary based on the presence of ESA-listed, game, or anadromous species; check with ODFW prior to planning and/or consult with NOAA NMFS regarding criteria for anadromous salmonids (<a href="https://www.noaa.gov/sites/default/files/atoms/files/07354626823.pdf">https://www.noaa.gov/sites/default/files/atoms/files/07354626823.pdf</a>)</li> <li>Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.</li> </ul>
		NRCS. 2007. TS-14N Fish Passage and Screening Design.	This Technical Supplement includes descriptions of several types of fish screens along with design and application considerations.	

Lack of large woody debris	Large woody debris placement	ODSL, ODF, ODFW, OWEB. 2010. Guide to placement of wood, boulders, and gravel for habitat restoration.	This technical reference provides LWD project design considerations and criteria that comply with applicable DSL and ACOE criteria; however, note that the form in the appendix is no longer valid.	<ul style="list-style-type: none"> <li>• Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>• LWD or similar activities conducted as part of a forestry operation are covered under the Oregon Forest Practices Act as enforced and reviewed by ODF, and therefore DSL permits are not required. Projects that are not conducted as part of a forestry operation may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>• Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>• Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>• Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>• Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.</li> </ul>
		Wheaton JM, Bennett SN, Bouwes N, Maestas JD, Shahverdian SM. (Editors). 2019. Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0. Utah State University Restoration Consortium. Logan, UT.	This design manual covers the concepts behind restoration that uses low-tech structures and tools to initiate specific processes in riverscapes that ultimately let the system do the work. Relevant to LWD is the design and construction guidance for post-assisted log structures (PALS), which mimic natural wood accumulation through use of natural materials with a short-term project life span.	
		Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC). 2016. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure.	This thorough publication covers the role of wood in aquatic ecosystems, including assessing the need for wood; planning, designing, and implementing wood placement projects; and management and maintenance of wood in streams. Discussions are illustrated and supported by case examples, photos, and diagrams.	
		Cramer ML. (managing editor). 2012. Stream Habitat Restoration Guidelines. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service: Olympia, WA.	This compilation of stream restoration guidelines addresses large wood replenishment, as well as placement and trapping, as part of a comprehensive and detailed section (Technique 7) on Large Wood and Log Jams. Linkages to hydraulic considerations for logs as instream structures are also covered in this resource.	
	Other actions that increase large woody debris placement	See references for channel incision, levees and berms, riparian and floodplain grazing, and over-allocation of water	See reference descriptions for channel incision, levees and berms, riparian and floodplain grazing, and over-allocation of water	
Lack of available spawning gravel	Spawning gravel additions	ODSL, ODF, ODFW, OWEB. 2010. Guide to placement of wood, boulders, and gravel for habitat restoration.	This technical reference provides gravel placement project design considerations and criteria that comply with applicable DSL and ACOE criteria; however, note that the form in the appendix is no longer valid.	<ul style="list-style-type: none"> <li>• Follow ODFW in-water work period or obtain variance approval from ODFW.</li> <li>• Projects may require notifications or permits from DSL, ACOE, and/or ODEQ. Permit requirements can change frequently, so project managers are advised to contact these agencies well in advance to clarify requirements.</li> <li>• Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information.</li> <li>• Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information.</li> <li>• Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.</li> <li>• Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.</li> <li>• Specialized equipment, such as a conveyor truck, may be used to direct placement of spawning gravel while minimizing stream disturbance.</li> </ul>

## Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon

---





# Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon

September 2020

Prepared by  
Megan Skinner, Ph.D.\* and Leigh Ann Vradenburg<sup>†</sup>

Recommended citation:

Skinner M, Vradenburg LA. 2020. Considerations for riparian fencing, planting, and grazing management in the Upper Klamath Basin of Oregon. Klamath Falls Fish and Wildlife Office, U.S. Fish and Wildlife Service and Klamath Watershed Partnership: Klamath Falls, OR.

---

\* U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Klamath Falls, Oregon

<sup>†</sup> Klamath Watershed Partnership, Klamath Falls, Oregon

## *Contents*

Abstract.....	1
Introduction.....	1
Role of Riparian Buffers.....	3
Riparian Fence Placement.....	3
Width.....	4
Vegetation Type .....	5
Slope.....	5
Riparian Grazing Management.....	5
Riparian Grazing or Exclusion? .....	6
Riparian Pastures.....	7
Grazing Timing and Intensity .....	7
Additional Considerations for Grazing Management .....	9
Riparian Planting .....	10
Additional Considerations for Riparian Restoration.....	10
Conclusion .....	11
Acknowledgments.....	12
References.....	12

## *Abstract*

Vegetated riparian buffers provide a number of ecosystem functions including capture or slowing of overland flow that reduces sediment and nutrient loads, shading that prevents increases in stream temperatures, vegetation components that supplement physical instream habitat, and terrestrial habitat. Riparian degradation and loss of these benefits may result from grazing that is unmanaged or managed inconsistently with restoration objectives. In these scenarios, restoration of riparian function may require one or more practices that could include infrastructure improvements (e.g., fencing, hardened access points), management modifications (e.g., rotational grazing, changes to timing and duration), and vegetation restoration (e.g., planting).

The guidelines presented in this paper are intended to be used as a reference by local restoration professionals for riparian fencing, grazing, and planting. Riparian buffers established by fencing at least 30 feet from the ordinary high water mark, and up to 100 feet for maximum benefit, will substantially reduce sediment and nutrient loads to surface water bodies and allow for the growth of vegetation leading to improvement in riparian condition. Fencing alone is unlikely to facilitate recovery of riparian corridors if appropriate grazing management is absent. Livestock exclusion is the most straightforward and immediate strategy to facilitate riparian recovery. However, careful management of riparian grazing, with consideration of timing and intensity, as well as inter-annual variability and periods of rest, may also be compatible with restoration objectives. Riparian planting may be necessary in addition to fencing and/or grazing management, but restoration professionals are encouraged to assess conditions for at least two years prior to implementing a planting plan in order to determine the potential for natural vegetative recovery and/or the need for a site-specific planting plan.

The principles of adaptive management are critical in implementing effective riparian restoration projects. In particular, monitoring the effects of, and subsequently adapting, riparian grazing plans will increase the likelihood of achieving riparian restoration objectives. Monitoring also provides additional information for future riparian restoration projects, helping to fill any knowledge gaps regarding specific conditions in the Upper Klamath Basin.

## *Introduction*

The riparian corridor or zone is defined as an area outside of the wetted stream channel that acts as a transition between aquatic and upland terrestrial environments (Molles 2008). A functioning riparian corridor, as defined here, is one that supports ecosystem functions including capture or slowing of overland flow that reduces sediment and nutrient loads, shading that prevents increases in stream temperatures, vegetation components that supplement physical instream habitat, and terrestrial habitat. Riparian impairment is most often caused by construction of levees and berms, channel incision (which may be caused directly or indirectly by a variety of land use practices), and grazing that is unmanaged (or managed inconsistent with restoration objectives) (Popolizio et al. 1994, Clary 1995, Masters et al. 1996, Bravard et al. 1997, Hupp and Rinaldi 2007, Pollock et al. 2014, Skarpich et al. 2016). In the Upper Klamath Basin, riparian areas are considered key in improving water quality and physical aquatic habitat (ODEQ 2002). Indeed, the Upper Klamath Basin Watershed Action Plan (The Watershed Action Plan Team *in*

*prep.*) will assess the condition of Upper Klamath Basin riparian areas and prioritize river reaches for riparian restoration, based on the degree of riparian impairment.

The National Research Council (2002) suggests the following definition for ecological restoration of riparian areas:

“The reestablishment of...riparian functions and related physical, chemical, and biological linkages between aquatic and terrestrial ecosystems; it is the repairing of human alterations to the diversity and dynamics of indigenous ecosystems. A fundamental goal of riparian restoration is to facilitate self-sustaining occurrences of natural processes and linkages among the terrestrial, riparian, and aquatic ecosystems.”

Restoration and preservation of riparian corridors (including floodplains) is widely recognized as a means to reduce sediment and particulate nutrient loads to streams (Bukaveckas 2007, Kroes and Hupp 2010), reduce solar radiation to stream surfaces (Opperman and Merenlender 2004), and provide, and help to maintain, physical habitat for native aquatic biota (Opperman and Merenlender 2004). Additionally, riparian corridors add to the aesthetic and recreational value of surface waterbodies (Wenger 1999, Fischer and Fischenich 2000). Techniques that may aid in the restoration process include levee and berm removal, set-back, or breaching; actions to mitigate or reverse channel incision; fencing; grazing management (which may include livestock exclusion); and riparian planting. This document focuses specifically on riparian fencing, planting, and grazing management. In many instances, these actions will be effective in improving riparian condition and restoring critical process and function as described below, however there are also circumstances in which additional work will be necessary. Specifically, where levees or other structures limit the size of the riparian corridor (to an area smaller than that discussed in the “Width” subsection below) or where incision is severe enough to prevent establishment of riparian vegetation, levee removal, setback, and/or breaching, and techniques to reverse incision will be necessary in addition to the strategies described in this document. The Upper Klamath Basin Watershed Action Plan (Watershed Action Plan Team *in prep.*) provides an assessment of these other restoration techniques necessary to improve and restore riverine, riparian, floodplain, and wetland process and function.

In the Upper Klamath Basin, ranching operations began in the late 19<sup>th</sup> century with cattle populations reaching a peak of approximately 140,000 head in the mid-1960s (ODEQ 2002). The number of livestock in Klamath County has decreased in recent decades to approximately 73,000 in 2020 (USDA NASS 2020). Despite this decrease, riparian impairments associated with grazing that is unmanaged (or managed inconsistent with restoration objectives) remains an issue, and such grazing is considered a contributing factor to water quality issues in the Upper Klamath Basin (ODEQ 2002, Walker et al. 2015). The Watershed Action Plan Team (*in prep.*) provides a watershed-scale assessment of riparian conditions and other factors (presence of levees and berms and degree of channel incision) that affect riparian condition.

In the Upper Klamath Basin, riparian planting and fencing installed to exclude livestock or facilitate riparian grazing management tend to be the most commonly applied riparian restoration techniques and are generally considered effective, inexpensive, and socially-acceptable methods for improving stream health, particularly water quality.

This document was primarily developed based on feedback from the Upper Klamath Basin restoration community that indicated a need for additional information and guidance regarding riparian fencing, planting, and grazing management. Although numerous reviews provide information on these various aspects of riparian restoration, a publicly available and concise summary tailored to regional needs does not currently exist. As such, the purpose of this document is to provide guidance for restoration decisions involving installation of riparian fencing, riparian grazing plans, and riparian planting to restore and maintain functioning riparian buffers in the Upper Klamath Basin in support of numerous restoration goals and objectives. This review is intended for use by restoration professionals and natural resource managers.

### *Role of Riparian Buffers*

A riparian buffer is defined as a riparian corridor or zone that “buffers” the stream spatially from the impact of land use activities such as farming and timber harvest (Wenger 1999). The term “riparian buffer” is typically used in specific reference to an area that separates land use activities from surface water bodies (Wenger 1999). The terms “riparian area” and “riparian zone” may be used interchangeably with “riparian buffer,” but are not as specific as “riparian buffer”. Vegetated riparian buffers can reduce sediment loads (and therefore particulate nutrient loads as well) to streams in numerous ways. Specifically, functioning riparian buffers:

- Move sediment-producing activities away from the stream channel;
- Trap terrestrially-derived sediment and particulate matter in surface runoff;
- Reduce the velocity of high flow events such that sediment and particulate matter settle out of the water column and are deposited on the floodplain, and scour within the active channel and floodplain is reduced;
- Stabilize streambanks and thereby prevent channel erosion; and
- Contribute large woody debris (LWD) to streams, which in turn facilitates sediment deposition within the channel and floodplain (Wenger 1999).

Relative to nutrients, riparian buffers are typically effective in short-term control of sediment-bound total phosphorus (TP), but have low net soluble reactive P (SRP; the form of P most readily available to plants and algae) retention (Lowrance et al. 1997). Specifically, sediment-bound and organic P retained in riparian buffers is captured and subsequently mineralized (converted to inorganic P through microbial activity). This P can then be sequestered through uptake into plants or slowly released into the stream if binding sites for SRP within the buffer soil are saturated (Omernik et al. 1981, Osborne and Kovacic 1993, Mander et al. 1997) or otherwise unavailable (Vidon et al. 2010). However, even when binding sites are saturated, riparian buffers can still benefit waterbodies by regulating the flow of P between land and water (Vidon et al. 2010), preventing large pulses of nutrients from entering waterbodies (Vidon et al. 2010), and transforming P such that it can be utilized by plants within the riparian area.

### *Riparian Fence Placement*

While riparian fencing is not always a critical component of riparian restoration projects, it is typically installed to delineate the outside edge of a riparian buffer in grazing scenarios. When assessing options for riparian fencing placement, it is important to consider physical riparian

buffer characteristics that affect the capacity of buffers to trap and sequester sediment and nutrient loads within watersheds, and provide other ecosystem services such as aquatic and riparian habitat. It is also important to consider a grazing management or livestock exclusion plan or agreement to ensure that the existence of fencing supports restoration objectives; grazing management is discussed in further detail below.

### Width

Buffer width appears to be the most critical controllable variable affecting the capacity of riparian buffers to improve water quality and protect stream health (Gilliam et al. 1997). However, the specific functions required of a buffer impact the range of widths that must be considered (Castelle et al. 1994). Several studies (Dillaha 1988, Dillaha 1989, Magette et al. 1989) indicate that 30 foot-wide vegetated buffers reduced total suspended solids concentrations (a proxy measurement for sediment load) in surface runoff by 65 to 91 percent, while buffers wider than 30 feet performed only slightly better (Young et al. 1980, Peterjohn and Correll 1984; as cited in Wenger 1999 and Fischer and Fischenich 2000). Numerous studies (Shisler et al. 1987, Dillaha 1989, Chaubey et al. 1994, Lee et al. 2000, Barden et al. 2003; as cited in Buffler et al. 2005) also indicated that buffers between 30 and 60 feet in width reduced TP concentrations in surface runoff by between 50 and 94 percent. Buffers within this width range were also capable of reducing SRP concentrations in surface runoff, though to a lesser extent than TP (Chaubey et al. 1994, Lee et al. 2000; as cited in Buffler et al. 2005).

With respect to stream temperature, the height and density of surrounding vegetation, as well as the orientation and width of the stream are relevant factors. Based on review of 24 studies across dozens of streams, Sweeney and Newbold (2014) determined that forested buffers of at least 65 feet kept stream temperatures within 2 degrees Celsius of those observed in completely forested streams, due to the level of shading provided by a buffer of this width. Additionally, streams with buffers around 100 feet in width exhibited no increase in stream temperature (Sweeney and Newbold 2014).

Fischer and Fischenich (2000) concluded that buffers at least 30 feet wide were likely to improve and protect water quality and increase streambank stability, but buffers 60 feet and wider (up to 1,500 feet or more in some cases) were necessary for flood attenuation and to provide suitable riparian habitat for a variety of terrestrial biota.

Finally, specific local hydrology and hydrogeologic setting should also be taken into account when considering riparian buffer widths and their relative ability to achieve specific functions. Hydrology, specifically the paths and quantity of surface and subsurface flows, have a direct impact on the ability of a riparian area to influence nutrient sequestration (Baker et al. 2001). For example, in poorly drained soils or areas with a high water table where drain tiles or ditches are used for agricultural purposes, groundwater pathways are redirected, and the potential role of riparian areas in nutrient uptake is minimized (Baker et al. 2001).

On a larger scale and in the Upper Klamath Basin specifically, there is a range of hydrologic conditions within sub-basins. For instance, some systems (e.g., the Sprague and Sycan Rivers and Sevenmile Creek) are considered “flashy” with hydrographs rising and falling rapidly during rain-on-snow and snowmelt runoff events, while others (e.g., Williamson and Wood Rivers)

have a more consistent hydrograph owing to substantial groundwater influence. In “flashy” systems, it is worth considering that high flow events may extend farther laterally, sediment loads may be greater, and that dynamic river channels (i.e., those with more lateral migration) are more common, relative to systems with a more stable hydrograph (Higson and Singer 2015). As such, wider riparian buffers may be necessary in “flashy” systems to achieve restoration objectives such as reduced sediment and nutrient loads and reduced bank erosion, relative to groundwater-dominated systems.

### Vegetation Type

Another factor influencing the capacity of riparian buffers to intercept and reduce sediment and nutrient load is vegetation type. Generally, buffers composed of healthy and diverse native vegetation (or non-native vegetation with similar function) are likely to offer the greatest benefit to instream habitat, water quality, and riverine process and function (Wenger 1999, Fischer and Fishenich 2000). However, certain vegetation components are more effective than others in achieving specific restoration goals and objectives. For instance, grass, as defined in the cited studies, appears to be the most effective vegetation type for trapping and retaining sediment and particulate nutrients (Dosskey et al. 1997, Fisher and Fishenich 2000, Buffler et al. 2005), while shrubs and trees are considered most effective in reducing bank erosion and failure (Dosskey et al. 1997, Fisher and Fishenich 2000, Buffler et al. 2005). Early successional vegetation is likely to assimilate and retain soluble nutrients such as SRP, while mature riparian vegetation may be a source of SRP to surface water bodies (Mander et al. 1997, Vidon et al. 2010). Trees are considered most effective for increasing recruitment of large woody debris and allochthonous detritus contributions, regulating stream temperature, and attenuating high flows (Dosskey et al. 1997, Fisher and Fishenich 2000, Buffler et al. 2005). However, in many areas, site-appropriate riparian vegetation may not include trees. Regardless, it appears that buffer width has a greater influence on capacity to reduce sediment and nutrient loading to surface water bodies than vegetation type (Gilliam et al. 1997).

### Slope

There is limited information regarding the effect of slope on the capacity of riparian buffers to reduce sediment and nutrient loads, however, the general consensus appears to be that increasing slope angle results in decreased interception and sequestration of sediment and nutrients in runoff. Slopes greater than 11 percent likely have a significant negative effect on the ability of a riparian buffer to retain and sequester sediment and nutrients (Dillaha et al. 1988, Dillaha et al. 1989). Conversely, Ghaffarzadeh et al. (1996) found riparian buffers at least 9 feet wide on slopes of 7 and 12 percent were still capable of reducing sediment load by 80 to 90 percent, relative to areas without riparian buffers. Regardless, the majority of Upper Klamath Basin sediment and nutrient load originates in valley-bottom areas with very low slope angle (Walker et al. 2015), making slope less of a concern in designing riparian buffer projects in this region.

### *Riparian Grazing Management*

In floodplains and riparian areas, the direct results of grazing that is unmanaged (or managed inconsistent with restoration objectives) include decreased plant density and diversity (Clary 1995, Masters et al. 1996a, Clary 1999); decreased bank cover (Clary and Webster 1990, Popolizio et al. 1994, Lucas et al. 2004); soil disturbance and compaction (Trimble 1994, Clary

1995); increased direct urine and manure inputs (Stephenson and Rychert 1982, Tiedemann and Higgins 1989); and disturbance and compaction of the streambed and banks (Clary 1999, Del Rosario et al. 2002). Additional effects include a general decrease in riparian and floodplain process and function, specifically:

- Decreased capacity to intercept and retain nutrients and sediment due to decreased riparian and floodplain complexity and roughness necessary to attenuate flows and allow sediment and particulate nutrients to be deposited within the watershed (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010);
- Decreased bank stability via a decrease in root strength and abundance due to a reduction in site-appropriate vegetation (Opperman and Merenlender 2004, Pollock et al. 2014);
- Decreased stream shading due to a reduction in vegetation (Opperman and Merenlender 2004, Weber et al. 2017); and
- Channel widening due to increased soil disturbance and a decrease in bank-stabilizing riparian vegetation (Marlow et al. 1989, Myers and Swanson 1995).

Given this information, riparian grazing management is an essential component of any riparian restoration plan involving lands subject to grazing and ranching. The existence of a riparian fence to establish a riparian buffer is one step in the management process, but certainly is not the only tool or final step. While riparian fencing may at times be in place to facilitate cattle exclusion from the riparian buffer, this is not always the case. When and where riparian grazing is expected to continue, appropriate grazing timing and intensity that strikes a balance between achieving restoration objectives and meeting landowner needs must be considered.

#### Riparian Grazing or Exclusion?

Livestock exclusion is clearly effective in restoring riparian corridors (Clary 1999, Kauffman et al. 2004, Yeo 2005, Herbst et al. 2012, Batchelor et al. 2015) and is therefore the most straightforward grazing management option for riparian restoration. Therefore, when riparian grazing management to meet project objectives is not feasible or not desired, livestock exclusion should be considered. Some landowners may prefer to exclude livestock from riparian corridors, focusing on grazing in upland areas with off-channel watering infrastructure.

Regardless, riparian restoration and riparian livestock grazing are not mutually exclusive and livestock exclusion may not be desirable, particularly when working on private lands. Numerous studies (Keller and Burham 1982, Clary and Webster 1990, Masters et al. 1996a, 1996b, Kidd and Yeakley 2015) indicate carefully managed riparian grazing can have minimal, or even beneficial, effects on riparian corridor function, physical habitat, and stream health in general. For instance, it appears that properly managed grazing or other forms of vegetation harvest and removal may increase the capacity of riparian buffers to trap and sequester SRP (Fischer and Fishenich 2000, Vidon et al. 2010). Additionally, grazing may be an effective technique for controlling the establishment and proliferation of invasive riparian vegetation (Kidd and Yeakley 2015). It is critical, however, that manure production associated with riparian grazing does not offset reductions in nutrient loads via vegetation removal (Wenger 1999). Regardless, it may be necessary to apply a period of grazing rest, or full grazing exclusion, prior to implementation of a grazing plan, if conditions warrant (as discussed in more detail below).



## Riparian Pastures

There is clear evidence that in mixed upland and riparian pastures, utilization of riparian vegetation tends to be disproportionately higher relative to that of upland vegetation, and assessments conducted over the pasture as a whole may not be representative of forage consumption specifically within riparian corridors (Platts and Nelson 1985, Clary 1999, Swanson et al. 2015). Although it is possible to prevent over-utilization of riparian areas in these mixed pastures through use of salt placements, off-stream watering, herding, and culling of loitering animals (Masters et al. 1996a, 1996b, Swanson et al. 2015), these approaches tend to be labor intensive. Alternatively, establishing riparian pastures that can be managed separately from upland areas allows landowners to more easily manage utilization of riparian vegetation (Keller and Burham 1982, Platts and Nelson 1985, Marlow et al. 1989, Swanson et al. 2015) and also establishes a clearly-delineated riparian buffer, which is often desired in riparian restoration projects. As such, unless landowners are interested in more intensive livestock management, establishment of riparian pastures (using the information presented in this document regarding fencing placement) is worth consideration. Installation of fencing that excludes livestock or creates riparian pastures is generally the most common livestock management approach applied in the Upper Klamath Basin within privately owned alluvial valleys where nutrient and sediment loading is a concern due to riparian impairment.

## Grazing Timing and Intensity

A period of grazing rest (i.e., livestock exclusion) prior to implementation of managed riparian grazing may be necessary in areas with a history of heavy unmanaged grazing, or grazing management that was inconsistent with riparian restoration objectives (Clary and Webster 1990, Myers and Swanson 1995, Kidd and Yeakley 2015, Swanson et al. 2015). Clary and Webster (1990) recommend a period of rest for areas with early seral vegetation and suggest that the rest period should continue until mid to late seral vegetation is observed<sup>‡</sup>. Similarly, Swanson et al. (2015) recommend grazing rest if a riparian area of interest is “functional-at-risk” with a static or downward trend, or if the area is “nonfunctional” (per the Proper Functioning Condition survey technique; USDI 2015); it may be possible to slowly and conservatively reintroduce riparian grazing if the riparian area of interest is “functional-at-risk” with an upward trend. While formal survey methods such as those described in Winward (2000) and USDI (2015) provide comprehensive assessments of riparian condition, using professional judgement to determine riparian condition is likely more realistic in most cases. Regardless, the restoration practitioner must develop an understanding of the hydrologic, vegetative, and geomorphic characteristics of a site to assess the ability of the riparian area to perform the functions described earlier.

Once riparian areas have recovered sufficiently to allow for grazing, seasonal grazing timing is also a critical consideration. Specifically, allowing grazed riparian vegetation to recover during the growing season is essential for restoring and maintaining riparian condition (Swanson et al. 2015). Opportunity for herbaceous and woody regrowth diminishes as the growing season advances such that early season grazing is more likely to facilitate regrowth prior to the fall

---

<sup>‡</sup> Seral stage describes the succession of vegetation types after disturbance. Much of the work regarding seral stages relates to silviculture and conifer forests (e.g., Powell 2012). For riparian areas, particularly those within the Great Basin, early seral stages are likely composed of fast-growing grasses and forbs, while mid and late seral stages may include communities of rush and sedge or woody vegetation including riparian forests where soil type allows (Winward 1989). Winward (1989) provide additional information on determining seral status.

dormancy period (Clary and Webster 1990, Swanson et al. 2015). Additionally, the degree to which riparian vegetation can recover biomass and complexity before the end of the growing season has a direct effect on the ability of riparian corridors to attenuate high flows and trap and sequester sediment and particulate nutrient loads associated with these flows during the late fall, winter, and spring (Clary and Webster 1990, Boyd and Svejcar 2004). Furthermore, late growing season grazing tends to result in preferential browsing of woody vegetation as sedges and grasses lose palatability (Kauffman et al. 1983, Clary 1999). Given that woody vegetation plays an important role in reducing bank erosion and failure (as described above), sustained browsing of woody vegetation, especially just prior to winter high flows, is likely not consistent with restoration objectives. Grazing intensity (as described below) is a key consideration in determining how late into the growing season grazing can occur while still allowing for sufficient biomass to protect stream channels and banks during winter and spring high flows. For instance, the typical effects of mid to late growing season grazing may be avoided with low intensity use (as defined below) (Swanson et al. 2015). Regardless, it is recommended to retain riparian stubble heights of greater than 5 inches in the fall to facilitate deposition of sediment and particulate nutrient loads, as well as to protect stream banks from erosion and failure during winter and spring high flows (Clary et al. 1996, Carter et al. 2017).

While grazing in the late spring and early summer generally allows riparian vegetation the maximum amount of time for recovery prior to the end of the growing season, this early growing season time period may be associated with relatively high soil moisture. Wet or moist soils and streambanks are more easily compacted and deformed by livestock, relative to drier soils (Mosley et al. 1997), meaning that early-season grazing may have a disproportionately greater effect on bank stability and erosion relative to grazing later in the growing season once soils have dried. Marlow et al. (1987) found that streambank soil moisture and the extent of channel alteration were positively correlated until soil moisture levels decreased to 20 percent (by weight) and below. Therefore, when considering seasonal grazing timing, it is necessary to balance the need for riparian regrowth with soil moisture such that restoration objectives including decreased bank erosion and bare ground, and increased riparian plant cover and density can be achieved.

Many publications suggest that grazing duration is an important consideration in grazing management plans, but the concern with duration is often specifically related to grazing intensity. Grazing intensity can be measured directly (via utilization) and this document therefore focuses on intensity, rather than duration, as a method to control the amount of biomass removed from riparian pastures. Intensity is typically divided into three categories:

1. Light intensity, which is defined as 20 to 30 percent biomass utilization (or removal);
2. Moderate intensity, which is defined as 40 to 50 percent biomass utilization (or removal);  
and
3. High intensity, which is generally defined as greater than 50 percent biomass utilization (or removal) (Clary 1999, Lucas et al. 2004).

Overall, high intensity grazing is not advised if riparian and stream health and continued forage production are specific project goals (Swanson et al. 2015). Moderate to light intensity grazing typically maintains leaf area for continued photosynthesis, which increases the likelihood that

vegetation will survive and recover quickly, and generally strengthens forage plants necessary to achieve restoration objectives (Swanson et al. 2015). Additionally, regularly monitoring utilization within the riparian pasture ensures that vegetation is not repeatedly browsed; repeated browsing should be avoided as it typically results in a reduced capacity for recovery and growth (Swanson et al. 2015). As mentioned above and described further below, adjusting intensity can mitigate otherwise negative impacts to riparian vegetation associated with late season grazing. If grazing intensity (and monitoring of utilization) is included in a grazing plan, careful monitoring of riparian and stream conditions is also necessary to determine if the appropriate grazing intensity is being applied.

Finally, in addition to an initial rest period after fence installation, Carter et al. (2017) recommend rest rotation (most commonly using three pastures [Masters et al. 1996a]), which within a given year results in two pastures grazed at different times and the third pasture in grazing rest. In a scenario where a riparian area is divided into three pastures, a potential plan could include moderate intensity early to mid-season (once soil moisture is less than 20 percent by weight or sufficiently dry to prevent soil compaction and streambank deformation) grazing in riparian pasture 1, followed by light intensity late season grazing in riparian pasture 2, and full growing season rest in riparian pasture 3 (with timing and intensity then shifting between pastures the next year). Such a plan would allow for season-long riparian grazing, while also meeting restoration objectives. Generally, rest rotation facilitates expression of the full annual suite of vegetation life history stages over subsequent years (Swanson et al. 2015, Carter et al. 2017) and allows for rest during an entire growing season for each pasture in one out of three consecutive years to further assist in the recovery or maintenance of riparian vegetation. A similar approach can be used where there is one riparian pasture and two or more upland pastures, ensuring that the riparian pasture is not grazed in the same season each year and is given periodic rest.

#### Additional Considerations for Grazing Management

Fencing and creation of riparian pastures is not always necessary for grazing management that is consistent with riparian restoration objectives. As mentioned previously, this document focuses on the use of riparian pastures, defined with fencing, given the support in the literature for this approach and because this is a popular strategy employed in the Upper Klamath Basin. For restoration professionals interested in grazing management that does not include use of fenced riparian pastures, numerous scholarly articles (e.g., Swanson et al. 2015, which provides a concise, but thorough, summary) describe other grazing management techniques to support riparian restoration. Generally, buy-in from, and participation of, the landowner or surrogates (e.g., ranch manager) is more critical to successful grazing management than any one grazing management technique, approach, or method (Swanson et al. 2015). Therefore, it is essential that grazing plans are consistent with both restoration objectives and landowner needs and capacity.

Finally, applying the principle of adaptive management is necessary for any riparian grazing management program. Specifically, monitoring of vegetation utilization, plant community characteristics, bank condition, amount of bare ground present, and possibly more complex assessments such as Proper Functioning Condition should be included as part of grazing plans to

ensure that restoration objectives are being met. For specific information regarding monitoring methods, see Appendix B in The Watershed Action Plan Team (*in prep.*).

### *Riparian Planting*

Riparian planting is often considered in addition to riparian fencing and grazing management, however the need for planting is highly site and project-dependent. A period of passive restoration (e.g., grazing management) is generally recommended prior to engaging in more active forms, such as a planting program (Kauffman et al. 1997, McIver and Starr 2001). This approach is advantageous for numerous reasons, including that it allows the project site to indicate to the restoration professional what types of vegetation may be best suited for conditions at the site, where certain types of vegetation are more likely to establish and survive, where sufficient natural revegetation is occurring, and any indication of additional issues that should be addressed prior to planting. Regardless, the timing, density, and species included in any planting program require a great deal of professional discretion and should be tailored to specific project sites.

If riparian planting is necessary, determining the watershed type (e.g., montane, alluvial valley, etc.) and elevation, habitat type (e.g., wetland, riparian, terrace, etc.), and soil type, and adjusting planting plans to account for these characteristics, will increase the likelihood of plant survival and establishment (Murphy 2012). Additionally, it is often useful to observe vegetation in similar nearby sites and any vegetation currently present at the project site to better understand site characteristics such as water table elevation (Castelli et al. 2000). Regionally specific plant associations as described in Crowe et al. (2004) are particularly helpful in determining the potential natural vegetation at a site. Furthermore, locally derived seed or planting stock will ensure that the plants are better adapted to Klamath Basin climate and growing conditions. Finally, many successful Upper Klamath Basin riparian planting efforts include protective fencing to minimize rodent and wild or domestic ungulate damage to new plantings.

### *Additional Considerations for Riparian Restoration*

Longitudinally continuous buffers are generally considered more effective in restoring and maintaining water quality, aquatic habitat, and riverine process and function than segmented, but appropriately wide buffers (Fischer and Fischenich 2000). However, given that riparian restoration primarily occurs on private land in the Upper Klamath Basin, it may not be feasible to have many miles of longitudinally continuous buffers, so focusing on suitable buffers where restoration opportunities exist is warranted. Generally, protecting riparian corridors in low-order streams (i.e., headwater streams and other small streams) likely offers the greatest benefit for stream networks as a whole (Binford and Buchenau 1993) since sediment and nutrient loading issues can be addressed where they occur, rather than downstream of the site of origin. However, as noted previously, the majority of Upper Klamath Basin sediment and nutrient load originates in valley-bottom areas (Walker et al. 2015) where streams are likely to be of higher order, making it appropriate and necessary to continue focusing on riparian restoration along these higher order streams.

## *Conclusion*

Vegetated riparian buffers provide a number of ecosystem functions including capture or slowing of overland flow that reduce sediment and nutrient loads, shading that prevents increases in stream temperatures, vegetation components that supplement physical instream habitat, and terrestrial habitat. In the Upper Klamath Basin, riparian restoration typically involves installation of fencing to manage riparian buffers of a specific width. The focus of these projects is often water quality or aquatic habitat improvements.

It appears that riparian buffers at least 30 feet in width substantially reduce sediment and nutrient loads to surface water bodies, while buffers 100 feet or wider are likely necessary to provide riparian habitat suitable for a variety of terrestrial biota, and to effectively attenuate high flows. Vegetation type, slope, and local hydrology should be considered when designing riparian fencing and buffer projects; the degree of importance of these variables will depend on project objectives, landowner needs, and local conditions.

Riparian fencing alone is unlikely to facilitate recovery of riparian corridors if appropriate riparian grazing management is absent. Livestock exclusion is effective in restoring riparian corridors and is therefore the most straightforward strategy to achieve restoration objectives. However, permanent livestock exclusion is not always feasible or desired. In these scenarios, riparian grazing and riparian restoration are not mutually exclusive if grazing is managed carefully. When and where riparian grazing is desired, an initial period of grazing rest (i.e., livestock exclusion) is advised if riparian condition is poor to moderate (as determined by professional opinion, seral status, or surveys such as Proper Functioning Condition). If riparian condition is supportive of grazing, moderate intensity grazing during the early and mid-growing season after soils have dried sufficiently to prevent soil compaction and bank deformation is likely to maintain riparian condition. Similarly, light intensity grazing during the late growing season is also likely consistent with riparian restoration objectives. Regardless, once grazing has resumed after the period of rest, a rest rotation grazing strategy is preferred to ensure that riparian pastures are not grazed during the same portion of the growing season each year, and that a portion of the riparian corridor has a full growing season of rest every few years.

While installation of fencing to create riparian pastures is recommended, and the most common riparian restoration approach in the Upper Klamath Basin, there may be interest in other grazing management options. There is an extensive body of literature that describes other grazing management techniques consistent with riparian restoration objectives (e.g., Swanson et al. 2015). Generally, buy-in from, and participation of, the landowner or surrogates (e.g., ranch manager) is more important to successful grazing management than any one grazing management technique, approach, or method. Therefore, it is critical that grazing plans are consistent with both landowner needs and capacity, and restoration objectives. Conversely, landowners may be interested in full livestock exclusion in riparian areas, negating the need for a riparian grazing management plan other than an acknowledgement that the preferred management strategy is exclusion.

A period of passive restoration (e.g., grazing management) is generally recommended prior to engaging in more active forms, such as a planting program. This approach is advantageous for

numerous reasons, including that it allows the project site to indicate to the restoration professional what types of vegetation may be best suited for conditions at the site, where certain types of vegetation are more likely to establish and survive, where sufficient natural revegetation is occurring, and any indication of additional issues that should be addressed prior to planting. If riparian planting is necessary, determining physical site characteristics, and adjusting planting plans accordingly, will increase the likelihood of plant survival and establishment. Including some form of protection from rodent and wild or domestic ungulate damage in the planting plan is also advised.

Finally, the principles of adaptive management are critical in implementing effective riparian restoration projects. In particular, monitoring the effects of, and subsequently adapting, riparian grazing plans will increase the likelihood of achieving riparian restoration objectives. Similarly, monitoring riparian corridors for vegetation recolonization and establishment is necessary when restoration professionals take a passive approach to restoration (i.e., do not implement a planting program or plan). Monitoring also provides additional information for future riparian restoration projects, helping to fill any knowledge gaps regarding specific conditions in the Upper Klamath Basin.

### *Acknowledgments*

The authors would like to acknowledge the numerous individuals that reviewed and provided feedback on draft forms of this literature review, including members of the Watershed Action Plan Team, Josh Rasmussen, Adam Johnson, and Dan Blake.

### *References*

- Baker ME, Wiley MJ, Seelbach PW. 2001. GIS-based hydrologic modeling of riparian areas: Implications for stream water quality. *Journal of the American Water Resources Association* 37(6):1615-1628.
- Barden C, Geyer W, Mankin K, Ngandu D, Devlin D, McVay K. 2003. Assessing effectiveness of various riparian buffer vegetation types. *Keeping Up with Research* 137. Kansas State University, Agriculture Experiment Station and Cooperative Extension.
- Batchelor JL, Ripple WJ, Wilson TM, Painter LE. 2015. Restoration of riparian areas following the removal of cattle in the Northwestern Great Basin. *Environmental Management* 55:930-942.
- Binford MW, Buchenau MJ. 1993. Riparian greenways and water resources. In: Smith DS, Cawood P, eds. *Ecology of greenways*. University of Minnesota Press: Minneapolis, MN.
- Boyd CS, Svejcar TJ. 2004. Regrowth and production of herbaceous riparian vegetation following defoliation. *Journal of Range Management* 57(5):448-454.
- Bravard JP, Amoros C, Pautou G, Bornette G, Bournaud, Creuze des Chatelliers M, Gibert J, Peiry JL, Perrin JF, Tachet H. 1997. River incision in south-east France: morphological phenomena and ecological effects. *Regulated Rivers: Research and Management* 13:75-90.
- Buffler S, Johnson C, Nicholson J, Mesner N. 2005. Synthesis of design guidelines and experimental data for water quality function in agricultural landscapes in the

- Intermountain West. USDA Forest Service and University of Nebraska Lincoln: Lincoln, NB.
- Bukaveckas PA. 2007. Effects of channel restoration on water velocity, transient storage, and nutrient uptake in a channelized stream. *Environmental Science and Technology* 41(5):1570-1576.
- Carter J, Catlin JC, Hurwitz N, Jones AL, Ratner J. 2017. Upland water and deferred rotation effects on cattle use in riparian and upland areas. *Rangelands*: 1-7. doi 10.1016/j.rala.2017.06.003.
- Castelle AJ, Johnson AW, Conolly C. 1994. Wetland and stream buffer size requirements – A review. *Journal of Environmental Quality* 23:878-882.
- Castelli RM, Chambers JC, Tausch RJ. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. *Wetlands* 20(2):250-266.
- Chaubey I, Edwards DR, Daniels TC, Moore PA, Nichols DJ. 1994. Effectiveness of vegetated filter strips in retaining surface-applied swine manure constituents. *Transactions of the ASAE* 37(3):845-850.
- Clary WP. 1995. Vegetation and soil responses to grazing simulation on riparian meadows. *Journal of Range Management* 48:18-25.
- Clary WP. 1999. Stream channel and vegetation responses to late spring cattle grazing. *Journal of Range Management* 52(3):210-227.
- Clary WP, Thornton CI, Abt SR. 1996. Riparian stubble height and recovery of degraded streambanks. *Rangelands* 18(4):137-140.
- Clary WP, Webster BF. 1990. Riparian grazing guidelines for the Intermountain Region. *Rangelands* 12(4):209-212.
- Crowe EA, Kovalchik BL, Kerr MJ. 2004. Riparian and Wetland Vegetation of Central and Eastern Oregon. Oregon State University, Portland, OR. 473 pp.
- Del Rosario RB, Betts EA, Resh VH. 2002. Cow manure in headwater streams: tracing aquatic insect responses to organic enrichment. *Journal of the North American Benthological Society* 21(2):278-289.
- Dillaha TA, Reneau RB, Mostaghimi S, Lee D. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Transactions of the ASAE* 32:513-519.
- Dillaha TA, Sherrard JH, Lee D, Mostaghimi S, Shanholtz VO. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. *Journal of the Water Pollution Control Federation* 60:1231-1238.
- Dosskey M, Schultz D, Isenhardt T. 1997. How to design a riparian buffer for agricultural land. *Agroforestry Notes (AFN-4)*, National Agroforestry Center, USDA Forest Service and USDA Natural Resources Conservation Service.
- Fischer RA, Fischenich JC. 2000. Design recommendations for riparian corridors and vegetated buffer strips. EMRRP Technical Notes Collection, ERDC TN-EMRRP-SR-24. U.S. Army Engineer Waterways Experiment Station: Vicksburg, MS.
- Ghaffarzadeh M, Robinson CA, Cruse RM. 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. *Journal of Soil and Water Conservation* 51(3):227-230.
- Gilliam JW, Parsons JE, Mikkelsen RL. 1997. Nitrogen dynamics and buffer zones. *Journal of Environmental Quality* 23:917-922.
- Herbst DB, Bogan MT, Roll SK, Safford HD. 2012. Effects of livestock exclusion on in-stream habitat and benthic invertebrate assemblages in montane streams. *Freshwater Biology* 57:204-217.

- Higson JL, Singer MB. 2015. The impact of the streamflow hydrograph on sediment supply from terrace erosion. *Geomorphology* 248:475-488.
- Hill AR. 1996. Nitrate Removal in Stream Riparian Zones. *Journal of Environmental Quality* 25:743-755.
- Hupp CR, Rinaldi M. 2007. Riparian vegetation patterns in relation to fluvial landforms and channel evolution along selected rivers of Tuscany (Central Italy). *Annals of the Association of American Geographers* 97(1):12-30.
- Kauffman JB, Beschta RL, Otting N, D Lytjen. 1997. An ecological perspective of riparian and stream restoration in the Western United States. *Fisheries* 22(5):13-24
- Kauffman JB, Krueger WC, Vavra M. 1983. Riparian plant communities. *Journal of Range Management* 36(6): 685-691.
- Kauffman JB, Thorpe AS, Brookshire ENJ. 2004. Livestock exclusion and belowground ecosystem responses in riparian meadows of eastern Oregon. *Ecological Applications* 14(6):1671-1679.
- Keller CR, Burnham KP. 1982. Riparian fencing, grazing, and trout habitat preference on Summit Creek, Idaho. *North American Journal of Fisheries Management* 2:53-59.
- Kidd SA, Yeakley JA. 2015. Riparian wetland plant response to livestock exclusion in the Lower Columbia River Basin. *Natural Areas Journal* 35(4):504-514.
- Kroes DE, Hupp CR. 2010. The effect of channelization on floodplain sediment deposition and subsidence along the Pocomoke River, Maryland. *Journal of the American Water Resources Association* 46(4):686-699.
- Lee KH, Isenhardt TM, Schultz RC, Michelson SK. 2000. Multispecies riparian buffers trap sediment and nutrients during rainfall simulations. *Journal of Environmental Quality* 29:1200-1205.
- Lowrance R, Altier LS, Newbold JD, Schnabel RR, Groffman PM, Denver JM, Correll DL, Gilliam JW, Robinson JL, Brinsfield RB, Staver KW, Lucas W, Todd AH. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. *Environment Management* 21(5):687-712.
- Lucas RW, Baker TT, Wood MK, Allison CD, Vanleeuwen DM. 2004. Riparian vegetation response to different intensities and seasons of grazing. *Journal of Range Management* 57(5):466-474.
- Magette WL, Brinsfield RB, Palmer RE, Wood JD. 1989. Nutrient and sediment removal by vegetated filter strips. *Transactions of the ASAE* 32:663-667.
- Mander U, Kuusemets V, Lohmus K, Muring T. 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. *Ecological Engineering* 8:299-324.
- Marlow CB, Olson-Rutz K, Atchley J. 1989. Response of a southwest Montana riparian system to four grazing management alternatives. *Environmental Science*.
- Marlow CB, Pogacnik TM, Quinsey SD. 1987. Streambank stability and cattle grazing in southwestern Montana. *Journal of Soil and Water Conservation* 42(4):291-296.
- Masters L, Swanson S, Burkhardt W. 1996a. Riparian grazing management that worked: II. Rotation with and without rest and riparian pastures. *Rangelands* 18(5):196-200.
- Masters L, Swanson S, Burkhardt W. 1996b. Riparian grazing management that worked: I. Introduction and winter grazing. *Rangelands* 18(5):192-195.
- McIver J, Starr L. 2001. Restoration of degraded lands in the interior Columbia River basin: passive vs. active approaches. *Forest Ecology and Management*. 153: 15-28
- Molles MC. 2008. *Ecology: concepts and applications*, 4<sup>th</sup> Ed. McGraw Hill: New York, NY.



- Mosley JC, Cook PS, Griffis AJ, O’Laughlin J. 1999. Guidelines for managing cattle grazing in riparian areas to protect water quality: review of research and best management practices policy. Idaho Foest, Wildlife, and Range Policy Analysis Group, Idaho Forest, Wildlife, and Range Experiment Station, University of Idaho: Moscow, ID.
- Murphy C. 2012. Riparian and wetland restoration planting guide for the Boise and Payette River Basins, Idaho. Prepared for Idaho Department of Lands and U.S. Forest Service. Idaho Department of Fish and Game: Boise, ID.
- Myers TJ, Swanson S. 1995. Impact of deferred rotation grazing on stream characteristics in Central Nevada: a case study. *North American Journal of Fisheries Management* 15:428-439.
- National Research Council 2002. *Riparian Areas: Functions and Strategies for Management*. Washington, DC: The National Academies Press.
- [ODEQ] Oregon Department of Environmental Quality. 2002. Upper Klamath Lake drainage total maximum daily load (TMDL) and water quality management plan (WQMP). <https://www.oregon.gov/deq/FilterDocs/UKtmdlwqmp.pdf>
- Omernik JM, Abernathy AR, Male LM. 1981. Stream nutrient levels and proximity of agriculture and forest land to streams: some relationships. *Journal of Soil and Water Conservation* 36(4):227-231.
- Opperman JJ, Merenlender AM. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. *North American Journal of Fisheries Management* 24:822-834.
- Osborne LL, Kovacic DA. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology* 29:243-258.
- Peterjohn WT, Correll DL. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* 65:1466-1475.
- Platts WS, Nelson RL. 1985. Impacts of rest-rotation grazing on stream banks in forested watersheds in Idaho. *North American Journal of Fisheries Management* 5:547-556.
- Pollock MM, Beechie TJ, Wheaton JM, Jordan CE, Bouwes N, Weber N, Volk C. 2014. Using beaver dams to restore incised stream ecosystems. *BioScience* 64(4):279–290.
- Popolizio CA, Goetz H, Chapman PL. 1994. Short-term response of riparian vegetation to 4 grazing treatments. *Society for Range Management* 47(1):48-53.
- Powell DC. 2012. A stage is a stage is a stage...or is it? Successional stages, structural stages, seral stages. Whate paper F14-SO-WP-Silv-10. Umatilla National Forest, Pacific Northwest Region, USDA Forest Service.
- Shisler JK, Jordan RA, Wargo RN. 1987. Coastal wetland buffer delineation. Mosquito Research and Control, New Jersey Agricultural Experiment Station and Rutgers University: New Brunswick, NJ.
- Sholtes JS, Doyle MW. 2011. Effect of channel restoration on flood wave attenuation. *Journal of Hydraulic Engineering* 137(2):196-208.
- Skarpich V, Horacek M, Galia T, Kapustova V, Sala V. 2016. The effects of river patterns on riparian vegetation: a comparison of anabranching and single-thread incised channels. *Moravian Geographical Reports* 24(3):24-31.
- Stephenson GR, Rychert RC. 1982. Bottom sediment: a reservoir of *Escherichia coli* in rangeland streams. *Journal of Rangeland Management*. 35:119-123.
- Swanson S, Wyman S, Evans C. 2015. Practical grazing management to maintain or restore riparian functions and values on rangelands. *Journal of Rangeland Applications* 2:1-28.

- Sweeney BW, Newbold JD. 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. *Journal of the American Water Resources Association* 50(3): 560-584.
- The Watershed Action Plan Team. *In preparation*. The Upper Klamath Basin Watershed Action Plan. Prepared by U.S. Fish and Wildlife Service, Trout Unlimited, Klamath Watershed Partnership, The Klamath Tribes, Oregon Department of Environmental Quality, The Nature Conservancy, and the North Coast Regional Water Quality Control Board of California.
- Tiedemann AR, Higgins DA. 1989. Effects of management strategies on water resources. p.56-91. *In: Quigley TM, Sanderson HR, Tiedemann AR, Managing interior Northwest rangelands: The Oregon Range Evaluation Project*. USDA Forest Service General Technical Report PNW-GTR-238.
- Trimble SW. 1994. Erosional effects of cattle on streambanks in Tennessee, U.S.A. *Earth Surface Processes and Landforms* 19(5):451-464.
- [USDA NASS] U.S. Department of Agriculture. 2020. National Agricultural Statistics Service. [https://www.nass.usda.gov/Statistics\\_by\\_State/Oregon/Publications/Livestock\\_Report/2020/CE\\_CAT.pdf](https://www.nass.usda.gov/Statistics_by_State/Oregon/Publications/Livestock_Report/2020/CE_CAT.pdf).
- [USDI] U.S. Department of the Interior. 2015. Riparian area management: Proper functioning condition assessment for lotic areas. Technical Reference 1737-15. Bureau of Land Management, National Operations Center, Denver, CO.
- Vidon P, Allan C, Burns D, Duval TP, Gurwick N, Inamdar S, Lowrance R, Okay J, Scott D, Sebestyen S. 2010. Hot spots and hot moments in riparian zones: potential for improved water quality management. *Journal of the American Water Resources Association* 46(2):278-298.
- Walker JD, Kann J, Walker WW. 2015. Spatial and temporal nutrient loading dynamics in the Sprague River Basin, Oregon. Prepared for the Klamath Tribes Natural Resources Department. [https://s3.amazonaws.com/walkerenvres.com/reports/klamath/2015-sprague-nutrient-dynamics/Sprague\\_River\\_Nutrient\\_Dynamics\\_20151229\\_final.pdf](https://s3.amazonaws.com/walkerenvres.com/reports/klamath/2015-sprague-nutrient-dynamics/Sprague_River_Nutrient_Dynamics_20151229_final.pdf)
- Weber N, Bouwes N, Pollock MM, Volk C, Wheaton JM, Wathen G, Wirtz J, Jordan CE. 2017. Alteration of stream temperature by natural and artificial beaver dams. *PLoS ONE* 12(5):e0176313.
- Wenger S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia: Athens, GA.
- Winward AH. 1989. Appendix III: calculating ecological status and resource value ratings in riparian areas. p. 12-13. *In: Clary WP, Webster BF, Managing grazing of riparian areas in the Intermountain Region*. USDA Forest Service General Technical Report INT-263.
- Winward AH. 2000. Monitoring the vegetation resources in riparian areas. Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.
- Yeo JJ. 2005. Effects of grazing exclusion on rangeland vegetation and soils, east central Idaho. *Western North American Naturalist* 65(1):91-102.
- Young RA, Huntrods T, Anderson W. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. *Journal of Environmental Quality* 9:483-487.

**U.S. Fish and Wildlife Service  
Klamath Falls Fish and Wildlife Office  
1936 California Ave  
Klamath Falls, OR 97601**

**<http://www.fws.gov>**



**September 2020**

# Considerations for implementation of beaver dam analogs and similar structures in the Upper Klamath Basin of Oregon, USA

---

## *Literature Review*



Christie Nichols, USFWS

# Considerations for implementation of beaver dam analogs and similar structures in the Upper Klamath Basin of Oregon, USA

July 2020

Prepared by

Megan Skinner, Ph.D.\*; Charlie Erdman†; and Olivia Stoken‡

Recommended citation:

Skinner M, Erdman C, Stoken O. 2020. Considerations for implementation of beaver dam analogs and similar structures in the Upper Klamath Basin of Oregon, USA. Klamath Falls Fish and Wildlife Office, U.S. Fish and Wildlife Service and Trout Unlimited: Klamath Falls, OR.

---

\* U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Klamath Falls, OR

† Trout Unlimited, Klamath Falls, OR

‡ Current affiliation: Oregon Department of Environmental Quality, Klamath Falls, OR

# Table of Contents

<i>Introduction</i> .....	1
<i>Beaver dam analog overview</i> .....	1
<i>Effects of BDAs on abiotic and biotic riverine and riparian components</i> .....	2
Sediment and particulate nutrient load, channel incision, and channel morphology .....	3
Groundwater-surface water interactions and water temperature.....	4
Dissolved nutrients.....	5
Riparian vegetation .....	6
Fish.....	7
Oregon spotted frog .....	9
Beavers.....	9
Other fauna.....	10
BDAs, natural beaver dams, and climate change.....	11
<i>Considerations for design and implementation</i> .....	11
Site selection .....	11
BDA complexes .....	12
BDA components.....	13
BDA lifespan .....	14
Cost .....	14
Construction sequence for individual BDAs .....	15
<i>Other considerations</i> .....	15
Permitting.....	15
Monitoring .....	16
Social implications.....	17
<i>Implementation sequence</i> .....	14
<i>Conclusion</i> .....	14
<i>Acknowledgments</i> .....	15
<i>References</i> .....	16

## *Introduction*

Channel incision, floodplain disconnection, channelization or channel simplification, and riparian impairment are critical issues contributing to increases in sediment, nutrient, and thermal load, and a loss of quality riparian and aquatic habitat in the Upper Klamath Basin (UKB) (ODEQ 2002). Together, these impairments lead to a reduction in suitable habitat for native fish and other aquatic organisms (Brooker 1985, Sedell et al. 1990, ODEQ 2002, Lau et al. 2006, Pollock et al. 2014); facilitate nuisance algal blooms in Upper Klamath Lake that have implications for human health, fish and wildlife, and aesthetics (ODEQ 2002); and potentially reduce surface water availability to fish, wildlife, and humans (Tague et al. 2008, Hardison et al. 2009, Cluer and Thorne 2014). While there are many possible causes for these impairments, the extirpation or reduction in beaver populations across the west has likely facilitated a general decrease in stream condition, negatively affecting aquatic biota and other valuable resources (e.g., groundwater, forage, summer baseflow) (as summarized in Davee et al. 2019 and Charnley 2018). As such, mimicking conditions created by beavers and/or facilitating their return to the landscape is likely to achieve common stream and riparian restoration objectives. Specifically, installation of beaver dam analogs (BDAs) and similar structures is an increasingly popular restoration technique to reverse and/or mitigate channel incision, floodplain disconnection, channelization or channel simplification, and riparian impairment (Pollock et al. 2014). Additionally, it is now widely acknowledged that techniques to restore riverine process and function (such as BDAs and other beaver-related restoration actions) are typically more effective in creating resilient and diverse river ecosystems than a focus on stabilization and the creation of specific geomorphic features, which may limit the restoration potential of a system over the long-term (Cluer and Thorne 2013, Powers et al. 2018, Wheaton et al. 2019). While the body of literature describing beaver-related restoration and the potential ecological and social effects (e.g., landowner support, effects to agricultural operations) is quickly growing, a summary of quantitative data, implementation guidance, and considerations specific to the UKB does not currently exist.

The purpose of this review is to provide guidance for restoration decisions involving BDA installation to reverse channel incision, reconnect rivers and floodplains, improve riparian condition, and increase channel complexity and habitat quality in the UKB in support of numerous restoration goals and objectives (e.g., those goals identified in ODEQ 2002 and USFWS 2012). This review is intended for use by restoration professionals and natural resource managers.

## *Beaver dam analog overview*

Although the term BDA has been used to describe structures made of wood, fencing material (e.g., metal T-posts), and rock (Pilliod et al. 2018), BDA as defined in this review refers to structures made of wood or other vegetative materials. The terms post-assisted wood or log structures (PAWS or PALS, respectively) are often used to describe BDAs; however, there are distinctions between the two types of structures, specifically in their explicit goals. Post-assisted wood or log structures are non-channel spanning and typically used to simulate and enhance natural wood accumulations or achieve objectives related to lateral channel migration, whereas

BDAs are channel-spanning and intended to imitate natural beaver dams (Wheaton et al. 2019). This review focuses primarily on BDAs.

A BDA often includes vertically-placed wood posts pounded into the streambed and/or floodplain soil and may also include willow or other shrub or tree branches woven through the vertical posts to create a porous dam-like structure. In smaller streams with low stream power, it may be possible to build BDAs with large wood complexes instead of vertical posts for support. Regardless, fill material is often placed upstream of the BDA to assist in sealing the structure, and rock or gravel is placed downstream to reduce erosion. In some cases, only the vertical wood posts are installed in anticipation of beavers building a dam from this foundation. BDAs are channel-spanning and may extend from the channel into the floodplain. See “Design considerations” below for additional information regarding specific BDA components.

BDAs are porous, allowing passage of some water and aquatic biota through the dam face. Additionally, BDAs are intended to be transient (i.e., with a lifespan of a few years) rather than permanent structures, and projects involving BDAs often assume or hope that installation of BDAs will promote beaver recolonization and establishment. BDAs can be the first step in a dynamic process that enlists wild beavers to facilitate changes in stream velocity, sediment load, riparian condition, groundwater-surface water interactions, aquatic habitat availability, and to reverse channel incision and floodplain disconnection (Pollock et al. 2007, Beechie et al. 2010, Pollock et al. 2012, Pollock et al. 2014), although these system benefits may also be observed when BDAs are used in the absence of beaver colonization (Wheaton et al. 2019).

BDAs have been installed in a variety of different climates and hydrologic environments including historically ephemeral stream systems in the Great Basin (Pilliod et al. 2018), low-order streams influenced by snowmelt run-off (Pollock et al. 2014), and in fluvial reaches of “flashy” high order systems (Charnley 2018). BDAs have been installed on both public and private lands managed for a variety of different land uses (Charnley 2018, Pilliod et al. 2018, Davee et al. 2019).

Finally, BDAs are meant to mimic natural beaver dams, but there are relatively few studies that compare the effectiveness of BDAs to that of natural beaver dams in achieving restoration goals associated with these projects. Additionally, many of the studies available (e.g., Pollock et al. 2007, 2012, Bouwes et al. 2016, Weber et al. 2017, Silverman et al. 2019) examine the effects of a combination of BDAs and natural beaver dams. Regardless, there are a few studies that have examined the effects of BDAs alone (Charnley 2018, Orr et al. 2019, Pollock et al. 2019), and have provided evidence that BDAs, even in the absence of natural beaver dams, are effective in achieving restoration goals associated with these projects. Given that most studies combine the effects of the two and that there are studies that demonstrate the effectiveness of BDAs alone, this literature review includes information for BDAs, natural beaver dams, and a combination of the two, with the assumption that the findings of any of these individual studies can be applied across all three scenarios.

*Effects of BDAs on abiotic and biotic riverine and riparian components*



### Sediment and particulate nutrient load, channel incision, and channel morphology

The direct result of BDA installation is typically a decrease in stream velocity due to a reduction in channel slope and an increase in channel roughness and width, followed by an increase in sediment deposition within the stream channel (Pollock et al. 2014). A decrease in stream velocity and increase in sediment deposition can indirectly result in a restored connection between the floodplain and river, and increased periods of floodplain inundation, due to channel aggradation (Pollock et al. 2014). Interestingly, the heterogeneous nature of sediment deposits upstream of BDAs and natural beaver dams decrease the likelihood of future incision if BDAs fail or the natural beaver dam complex is abandoned (Pollock et al. 2014); this sediment is also likely to be recolonized by riparian vegetation if BDAs and beaver dams are breached or abandoned, further decreasing the likelihood that sediment deposited behind BDAs and natural beaver dams will be fully remobilized (Pollock et al. 2014, 2018).

Although BDAs are a relatively new restoration technique, there are several case studies that support using BDAs to reverse channel incision and reduce suspended sediment concentrations and sediment loads. Allred (1980) reported that ten beaver ponds in the South Fork Snake River, ID retained 63 percent of the sediment load associated with a high flow event. Pollock et al. (2007) estimated 0.47 meters (1.5 feet) of vertical channel aggradation behind BDAs within the first few years after installation in Bridge Creek, OR. Bridge Creek is considered to have a relatively high sediment load (35,000 to 53,000 cubic meters per year [1.2 to 1.9 million cubic feet] at the project site), indicating that this type of sediment deposition and channel aggradation may be possible in streams with similar, or greater, sediment loads. Similarly, Orr et al. (2019) estimated 33.7 cubic meters (1,190 cubic feet) of sediment deposition behind BDAs in the South Fork Crooked River, OR though the authors noted that this was largely limited to the most upstream BDA, suggesting that the upstream structure may have limited sediment load for deposition behind downstream structures.

In addition to facilitating channel aggradation, BDAs can also result in an increase in channel sinuosity and complexity. Specifically, BDAs or natural beaver dams constructed in incised reaches with very little, if any, floodplain available to disperse high flows may breach or fail due to concentrated stream power; however, these dams often deflect stream flow against banks, which then erode to widen the incision trench, increase sinuosity, and promote development of inset floodplains (Demmer and Beschta 2008). Constructing PALS or PAWS that span only a portion of a channel can facilitate lateral channel migration and an increase in channel sinuosity, while also reducing the likelihood of downstream BDA breach and/or failure (Pollock et al. 2012, Wheaton and Shahverdian 2018). Over time, an increase in sinuosity results in a greater capacity to intercept and retain nutrients and sediment (Bukaveckas 2007, Kroes and Hupp 2010), and an increased capacity to attenuate high flows (Sholtes and Doyle 2010) which can then promote construction and maintenance of natural beaver dams (Pollock et al. 2014). Conversely, angled PALS or PAWS could also be used to direct flow away from eroding banks if there is nearby infrastructure or other concerns that limit the scope of natural lateral channel migration (Pollock et al. 2012).

In the UKB, groundwater-dominated streams (e.g., Wood River, Williamson River above the confluence with the Sprague River) tend to have lower sediment loads (Walker et al. 2012) and less channel incision, suggesting that BDAs in these systems have less potential for sediment

deposition, and thus channel aggradation (or facilitation of lateral migration) may be less of priority for these types of projects in those areas. Conversely, the Sprague River and tributaries (especially the Sycan River) and snowmelt run-off dominated streams on the west side of the UKB can convey substantial sediment loads (e.g., approximately 812,000 cubic meters [2.9 million cubic feet] per year for the Sycan River [calculated using total suspended solids data reported in Walker et al. 2015]), which could facilitate channel aggradation if BDAs were implemented in incised reaches in these systems. Furthermore, stream reaches in the UKB often lack complexity, and implementing BDAs can assist in restoring more dynamic geomorphic processes. Finally, due to the relatively high phosphorus content of UKB soils (ODEQ 2002, Walker et al. 2015), actions to increase deposition of sediment within the watershed (rather than continued conveyance of sediment loads into higher order rivers and Upper Klamath Lake) have the potential to reduce total phosphorus load to impaired waterbodies in the UKB. A 40 percent reduction in total phosphorus load is an explicit goal of the Upper Klamath Lake Drainage Total Maximum Daily Load document (ODEQ 2002), and BDAs and natural beaver dams could assist in achieving these goals through a reduction in particulate phosphorus associated with sediment loads.

#### Groundwater-surface water interactions and water temperature

Reversal of channel incision and the associated rise in water surface elevation within the stream channel typically results in an increase in the water table elevation within the riparian corridor and floodplain (Tague et al. 2008, Hardison et al. 2009; see The Watershed Action Plan Team *In prep.* for a detailed summary and discussion of this topic). Indeed, Orr et al. (2019) reported an 18 to 30-centimeter (7.1 to 11.8-inch) rise in water table elevation up to 135 meters (443 feet) upstream of BDAs and 12 meters (39.4 feet) into the floodplain along the South Fork Crooked River. Bouwes et al. (2016) reported a 0.25-meter (9.8-inch) increase in water table elevations downstream of BDAs, relative to control reaches in Bridge Creek. Similarly, Charnley (2018) and Davee et al. (2019) noted increased water table elevations associated with BDA installation in Oregon and California, but did not provide specific information about the magnitude of change. Weber et al. (2017) reported a general increase in groundwater upwelling zones within beaver dam and BDA complexes in Bridge Creek, providing further evidence of the positive effect on groundwater-surface water interactions and water table elevations associated with BDAs and natural beaver dams.

Although BDAs can increase wetted channel widths substantially (Bouwes et al. 2016, Weber et al. 2017), which reduces the shading effect from riparian vegetation and thereby potentially increases the exposure of streams to solar radiation, numerous studies (Bouwes et al. 2016, Weber et al. 2017, Charnley 2018, Orr et al. 2019) reported reductions in stream temperature after installation of BDAs, or a combination of declines in temperature and no change in stream temperature, depending on study site. Specifically, Bouwes et al. (2016) determined that in Bridge Creek, maximum stream temperatures were on average 1.47°C cooler in reaches with BDAs and natural beaver dams, relative to those without. Additionally, sites with BDAs and natural beaver dams had substantially more cool-water refugia and stream temperatures were generally cooler during both the day and night, relative to reaches without BDAs and natural beaver dams (Bouwes et al. 2016). Similarly, Weber et al. (2017) found that Bridge Creek beaver dam density (whether BDAs or natural beaver dams) was negatively correlated with summer maximum stream temperature. These studies attributed the above described changes in

water temperature to increased groundwater-surface water interactions associated with BDAs and natural beaver dams. Interestingly, it also appeared that the presence of BDAs and natural beaver dams was associated with average reductions in summertime diel temperature fluctuations of 2.6°C (meaning that maximum temperature decreased and minimum temperature increased), which the authors attributed to the buffering effect of increased water volume associated with ponds behind BDAs and beaver dams (Weber et al. 2017). Finally, Pollock et al. (2007) observed pockets of cool water averaging 4.1°C below ambient stream temperatures downstream of BDAs and beaver dams in Bridge Creek in late summer. These effects on temperature combined with the increase in groundwater upwelling within beaver dam complexes led Bouwes et al. (2016) and Weber et al. (2017) to conclude that BDAs and natural beaver dams resulted in increased coldwater fish habitat in Bridge Creek. This was further supported by increases in salmonid density and production in Bridge Creek (Bouwes et al. 2016) as described in detail below.

Many areas of the Upper Klamath Basin have the potential for increased groundwater-surface water interactions (e.g., if channel incision is reversed and water table elevations increase), due to local geology (O'Connor et al. 2015). As such, BDA installation may provide substantial additional groundwater-surface water interaction within formerly incised stream channels, which could result in additional coldwater fish habitat (and potentially baseflow), as demonstrated in the studies cited above. Based on the case studies described above, this effect could be observed as soon as water table elevations increase with increasing water surface elevation behind BDAs and natural beaver dams.

#### Dissolved nutrients

Generally, there is very limited information about the role BDAs and natural beaver dams play in nutrient dynamics, beyond the effect on particulate nutrients described above. As such, this section is largely theoretical and further study on this topic is recommended.

As described above, natural beaver dams and BDAs create shallow ponds and wetland riparian areas in riverine systems. The primary mechanisms by which wetlands, shallow lakes, and ponds can result in removal of dissolved nitrogen include uptake by aquatic plants, macrophytes, and algae; denitrification; and volatilization of ammonia (Wetzel 2001). Typically, uptake by photosynthesizing organisms plays a minimal role in nitrogen removal given the cycle of senescence and growth that recycles nutrients annually. When anoxia (low oxygen conditions) dominates in wetland ecosystems, denitrification facilitated by heterotrophic bacteria becomes an important mechanism for the removal of nitrogen from the system (Wetzel 2001).

Dissolved phosphorus is removed from the water column of wetlands, shallow lakes, and ponds via sorption to metal hydroxides-oxides; uptake by aquatic plants, algae, and macrophytes; and accretion in the sediments as a result of incomplete decomposition and subsequent burial of plant biomass (Kadlec 1997). Sorption is often a temporary mechanism (e.g., hours to weeks) for phosphorus sequestration, with fluctuations between sorption and desorption occurring frequently when oxic sediment conditions are not consistently maintained (Mortimer 1941). Biomass uptake can effectively sequester phosphorus during the growing season, but phosphorus is often released during senescence in the fall (Walbridge and Struthers 1993, Mayer et al. 1999). And finally, accretion typically results in long-term sequestration of phosphorus assuming that

the conditions under which plant tissues are only partially decomposed (e.g., anoxic sediment conditions and relatively low pH, as observed in peat wetlands) are maintained (Kadlec 1997, Graham et al. 2005, Juston et al. 2013). See Skinner (2016) for a detailed technical discussion regarding the specific mechanisms associated with these processes.

Ponds created behind BDAs and natural beaver dams can act as a sink for dissolved nutrients such as phosphorus and nitrogen given that beaver pond sediment is often anoxic (as discussed in Pollock et al. 2018). Anoxic sediment facilitates denitrification and nitrogen release, as discussed above, and often stymies decomposition of organic material (e.g., organic detritus, woody debris), which effectively sequesters phosphorus through accretion (Kadlec 1997, Graham et al. 2005, Juston et al. 2013). However, it is also possible that anoxic conditions in the sediment may facilitate release of phosphorus bound to metal hydroxide-oxides (Mortimer 1941). Regardless, the potential for denitrification and accretion, combined with the potential to reduce particulate nutrient loads through reductions in suspended sediment as described above, may lead to reductions in nutrient loads downstream of BDAs and natural beaver dams. Demonstrating that natural beaver dams can be a sink for phosphorus in particular, Muskopf (2007) reported an approximately 240 percent increase in total phosphorus concentrations downstream of areas where beaver dams were removed in the Lake Tahoe, CA watershed.

In the UKB, many water bodies do not meet water quality standards for nutrients, dissolved oxygen, temperature, and pH, often due to excessive nutrient loading (ODEQ 2002). Using BDAs as a tool to reduce both particulate and dissolved nutrient loads may therefore help reduce external nutrient load to Upper Klamath Lake, though as mentioned above, more research regarding the ability of BDAs and natural beaver dams to sequester dissolved nutrients (particularly phosphorus) is warranted.

### Riparian vegetation

The increase in water table elevation associated with channel aggradation and improved river-floodplain connection, as described above, typically results in increased functioning size of the floodplain, and restoration of site-appropriate riparian and floodplain plant communities (Bravard et al. 1997, Lite et al. 2005, Hupp and Rinaldi 2007, Skarpich et al. 2016). Several studies support this theoretical evidence, reporting increases in riparian condition (Charnley 2018, Davees et al. 2019, Silverman et al. 2019; defined variously as an increase in riparian vegetation growth, productivity, density, diversity, and cover) associated with BDA installation or presence of beaver dams. Specifically, Silverman et al. (2019) determined that after construction of BDAs and reestablishment of wild beaver in Bridge Creek, riparian productivity (determined via normalized difference vegetation index, which is a proxy for riparian plant condition and spatial extent of riparian zones) increased by 20 percent, and this change was statistically significant, relative to that prior to restoration at the site. Additionally, BDA and beaver restoration extended the growing season with a 276 percent increase in riparian productivity in November, relative to that observed prior to restoration (Silverman et al. 2019).

Although there is both empirical and theoretical evidence that BDAs and natural beaver dams improve riparian condition, it is worth considering riparian planting in addition to BDA implementation and other beaver-related restoration actions. Specifically, when beaver recolonization is a specific project objective and riparian vegetation is sparse or in poor

condition, it may take several years for recovery to the point that sufficient riparian vegetation is available as a food source to encourage wild beaver recolonization (Orr et al. 2019); as such it may be necessary to implement riparian planting. Conversely, BDAs and natural beaver dams have the potential to dramatically change channel morphology and floodplain topography (as described above and below; could result in riparian planting losses), and it may therefore be advisable to delay any planned planting activities until channel and floodplain changes begin to materialize. The cost-benefit ratio of actively planting versus allowing volitional colonization should be assessed for each project site.

### Fish

An increase in channel and floodplain complexity, as a direct result of BDA structures or an indirect result of channel aggradation and floodplain reconnection, typically leads to a greater diversity of fish habitat features and substrate types (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010), which in turn provides higher quality fish habitat for a variety of species and life history stages.

Pollock et al. (2019) reported that a complex of four BDAs on a tributary to the Scott River, CA, created approximately 1.7 acres (0.7 hectares) of slow water and wetland habitat critical for rearing juvenile Coho salmon (*Oncorhynchus kisutch*). Indeed, this habitat is estimated to have supported over 6,700 juvenile Coho in a single year (Pollock et al. 2019). Similarly, in Bridge Creek, Bouwes et al. (2016) reported an increase in the number and depth of pools and a 228 percent increase in overall wetted channel area in areas with BDAs and natural beaver dams. Additionally, side channel habitat increased by 1,216 percent relative to the “pre-restoration condition,” while reference reaches showed no significant change (Bouwes et al. 2016). These changes in physical habitat, along with changes in water temperatures described above, appear to have led to a 52 percent increase in juvenile steelhead survival, a 175 percent increase in juvenile steelhead (*O. mykiss* ssp.) production, and an 81 fish per 100 meter increase in juvenile steelhead density associated with reaches containing BDAs and natural beaver dams, relative to areas without these features (Bouwes et al. 2016).

In addition to physical habitat, another important consideration associated with BDAs and natural beaver dams is fish passage. There are numerous studies (Lokteff et al. 2013, Bouwes et al. 2016, Pollock et al. 2019) supporting the idea that BDAs and natural beaver dams do not block fish passage, particularly for salmonids and trout. Lokteff et al. (2013) concluded that natural beaver dams were not passage barriers to native and invasive trout and that trout used the diversity of flow paths (over, through, under, and around) associated with natural beaver dams to pass both up and downstream of the structures. Similarly, Pollock et al. (2019) found that both Coho and steelhead juveniles had little difficulty passing BDAs in a tributary of the Scott River; passage was possible by jumping over a 40 centimeter (15.7 inch) waterfall or swimming up a short side channel (which in some cases were specifically constructed to facilitate fish passage, but that certainly occur naturally, as discussed throughout this review) with an 8 to 11 percent gradient. Charnley (2018) also noted that juvenile salmonids traveling upstream in tributaries of the Scott River were more likely to pass around, rather than jumping over, BDAs and Pollock et al. (2018) further supported this observation by suggesting that in most studies, it appears fish rarely pass BDAs and beaver dams by jumping over the face of the dam. Bouwes et al. (2016) observed that BDAs and natural beaver dams did not hinder juvenile or adult salmonid passage

even noting that several sexually mature adult steelhead passed over two hundred BDAs and natural beaver dams en route to spawning grounds. Finally, Kemp et al. (2012) noted that 78 percent of studies reviewed that cite BDAs and natural beaver dams as negatively impacting fish passage did not support this claim with data, but relied on speculation instead (Kemp et al. 2012). Of the remaining 22 percent of studies reviewed indicating negative effects of BDAs and natural beaver dams on fish passage, several determined that passage issues were often associated with low flows (e.g., Mitchell and Cunjak 2007) or below-average flows (e.g., Taylor et al. 2010). Kemp et al. (2012) concluded that fish passage limitations were very difficult to predict in both time and space, indicating further research and monitoring is necessary to determine when, where, and if BDAs and natural beaver dams limit fish passage. Regardless, experts surveyed by Kemp et al. (2012) indicated that BDAs and natural beaver dams were overwhelmingly beneficial to fish populations through increases in production and community diversity (as highlighted by case studies cited above), even if and when passage was temporarily limited.

Although numerous studies have assessed the ability of salmonids and trout to pass BDAs and natural beaver dams, there is limited information about how these features affect other fish species. Of particular concern in the UKB is passage for Endangered Species Act-listed Lost River and shortnose suckers and other native, but unlisted, catostomids such as the Klamath largescale Sucker (*Catostomus snyderi*). The primary concern is that these species will be unable to pass BDAs if jumping is the only means of passage. However, no empirical evidence exists regarding the jumping ability of these three species. Gardunio (2014) observed white sucker (*Catostomus commersonii*) ascending fall heights of up to 250 millimeters (9.8 inches) in a laboratory-focused study, and the highest fall ascended was 85.6 percent of the total length of the individual fish ascending the fall. In Washington, Salish sucker (*Catostomus catostomus*) were rarely observed crossing natural beaver dams, but the greatest number of suckers were found in beaver pond complexes (Garrett and Spinelli 2017). Note that this species of sucker is generally much smaller in total body length compared to those of concern in the UKB, which means these observations may not apply to UKB species at certain life history stages (e.g., mature adults). These studies indicate that some catostomids can jump over or otherwise pass small barriers, though careful consideration of the interaction between the waterfall height and plunge pool depth associated with a BDA is necessary (e.g., plunge pools should be deep enough to allow for jumping). Regardless, the diversity of flow paths associated with BDAs likely provide numerous passage opportunities for sucker species present in the UKB, as demonstrated for salmonids and trout (as described above). Directed studies are necessary to assess the ability of UKB catostomids, and other native fish species, to pass BDAs given that it is often difficult to predict if, when, and where BDAs and natural beaver dams may limit fish passage (Kemp et al. 2012).

Aside from concerns regarding the ability of fish to pass BDAs and natural beaver dams, other potential negative impacts to native fish should be considered when developing BDA projects. In watersheds with existing non-native fish populations, the ponds associated with BDAs could alter the composition of fish assemblages within a river system. In a semi-arid stream in Arizona, non-native species dominated the fish assemblage to a greater extent within natural beaver ponds than within lotic (riverine) sites (Gibson et al. 2014). Given that non-native fish can pose a threat to aquatic ecosystems (Cucherousset and Olden 2011), restoration practitioners and managers should consider how BDAs may influence native fishes differently than they do

non-native fishes prior to implementing a project using BDAs. BDA-mediated changes to the macroinvertebrate community, a major food source of salmonids and trout, could also impact fish feeding and growth. In the Logan River, UT, macroinvertebrate taxa richness, density, and biomass were lower within beaver ponds compared to lotic reaches (Washko et al. 2020), and native Bonneville cutthroat trout (*O. clarkii utah*) were larger in the lotic reaches compared to the pond habitat (Washko 2018). However, numerous other studies (e.g., Gard 1961; McDowell and Naiman 1986; Anderson and Rosemond 2010) have reported higher biomass and densities of macroinvertebrates in beaver ponds compared to lotic reaches. Because differences in macroinvertebrate community structure is likely site-dependent, a monitoring program to assess changes associated with BDAs will be beneficial to understanding an observed growth response in native fishes. Furthermore, complex interactions between fish community structure, hydrology, prey availability, and environmental conditions at a site combine to influence native fish populations targeted for conservation through BDA implementation. Developing testable hypotheses prior to implementation is critical in realizing project goals and adaptively managing a BDA projects.

#### Oregon spotted frog

Oregon spotted frog (*Rana pretiosa*) is an amphibian that requires perennial wetland habitat, including areas of open water, for numerous life history stages (USFWS 2020). The Oregon spotted frog was listed as threatened under the Endangered Species Act in 2014 (USFWS 2014). Due to habitat loss, in many cases associated with beaver removal (USFWS 2014), it is estimated that this species has been extirpated from at least 78 percent of its historical range (USFWS 2020). Beaver removal from the historical range of the Oregon spotted frog was identified as one of six threats to the features critical for the conservation of this species, and beaver-related restoration and management is considered essential in ensuring that suitable wetland habitat exists for species survival and recovery, particularly within designated critical habitat in the UKB (USFWS 2013, 2016). Specifically, Pollock et al. (2018) notes that beaver pond characteristics such as cover associated with emergent vegetation and slightly warmer surface water in the spring months compared to upstream and downstream areas may provide preferred habitat for egg survival and embryo development. Pearl et al. (2018) also reported that areas with beaver activity were important wintering habitats for the species. Furthermore, Columbia spotted frog (*Rana luteiventris*; a very closely related species with similar habitat requirements) populations were found to be greater in areas with beavers, relative to those without (USFWS 2014), further suggesting that beaver-related restoration is likely to aid in the survival and recovery of existing Oregon spotted frog populations, and facilitate re-establishment of populations in newly created habitat.

As mentioned above, portions of the UKB basin such as the Wood River Valley and areas near the foothills of the Cascade Mountains contain designated critical Oregon spotted frog habitat. As such, BDA installation in these areas of the UKB is likely to benefit the survival and recovery of Oregon spotted frog.

#### Beavers

Many BDAs are installed with the ultimate goal of facilitating reestablishment of wild beaver populations that can maintain BDAs and/or build additional natural beaver dams (Pollock et al. 2014). Several studies (Bouwes et al. 2016, Weber et al. 2017, Orr et al. 2019) indicate that

when multiple BDAs (i.e., three or more) are installed, wild beavers readily colonize the project site, and that the project site may even become a source of beaver for adjacent reaches (Bouwes et al. 2016). Specifically, Weber et al. (2017) noted that beaver actively maintained and added additional material to BDAs in Bridge Creek, resulting in increased BDA crest elevation, increased lateral BDA extent, and decreased BDA permeability. Weber et al. (2017) also reported an increase of nearly one hundred natural beaver dams in 34 kilometers (21 miles) of Bridge Creek from 2009 to 2014, which the authors attributed to the presence of BDAs and the effect these had on stream conditions and riparian vegetation. Reporting results from the same project area, Bouwes et al. (2016) found that after 2009 (the first year of BDA installation in Bridge Creek), the total number of natural beaver dams was eight times greater than that prior to BDA installation, while no natural beaver dams were built in control reaches during the same time period. Interestingly, many of the natural beaver dams were built either directly up- or downstream of reaches with BDAs, suggesting that BDA installation created “a source of beavers” to colonize adjacent areas (Bouwes et al. 2016). Similarly, Orr et al. (2019) noted that beaver repaired damaged BDAs and were attempting to build natural beaver dams at the project site using available upland vegetation; the authors expect successful natural beaver dam construction will occur once riparian vegetation has reestablished at the project site. Finally, Beechie et al. (2010) found that beavers traveled more than 5 kilometers (3 miles) from the nearest beaver colony to populate BDA sites within a few months of installation in Bridge Creek.

Although there may be some interest in actively relocating beaver to areas with BDAs to speed the recolonization process, Pilliod et al. (2018) and Davee et al. (2019) indicate that less than 50 percent of relocated beaver survive, though survival may be higher in locations with abundant suitable habitat. Given that beavers generally return within a relatively short period of time (e.g., months) after BDA installation (as described above), it appears prudent to allow for volitional recolonization rather than engaging in active relocation. If volitional recolonization does not occur, riparian planting or other actions to increase food and dam-building resources for wild beavers are recommended (Orr et al. 2019). Similarly, if natural beaver recolonization is a project goal, BDA installation sites should not only be chosen based on physical (hydrology, geomorphology) and social criteria (e.g., where landowner support for structures and beaver recolonization exists), but also based on proximity to (e.g., 5 kilometers [3 miles] or less from) natural beaver populations (per observations in Beechie et al. 2010).

Beaver are present in the UKB, suggesting that beavers are likely to colonize BDAs if structures are sited appropriately for recolonization (as described above). Note that many observations of beaver in the UKB are of “bank beaver,” or those that build lodges and burrows in river and streambanks. Numerous studies reviewed in Pollock et al. (2018) suggest that beavers build lodges and burrows in streambanks when suitable habitat and sufficient materials for dams and “water lodges” are not available. Pollock et al. (2018) also explicitly note that bank-dwelling beavers can be a source population for establishing natural beaver dam complexes, suggesting that “bank beaver” observed in the UKB may build dams if and when appropriate conditions exist.

#### Other fauna

There is abundant evidence that BDAs and natural beaver dams create conditions beneficial to a variety of other animals including benthic macroinvertebrates (as discussed briefly in the “Fish”



section above), reptiles, and birds. For a comprehensive review of studies reporting these benefits, see Pollock et al. (2018).

### BDAs, natural beaver dams, and climate change

Water storage associated with BDAs and natural beaver dams will become increasingly important, especially during low flow conditions, given the predicted decrease in snowmelt runoff and increase in drought conditions in the future (Pollock et al. 2018). As described above, the hydraulic head created by BDAs and natural beaver dams typically results in increased groundwater inputs, particularly during baseflow periods when the hydraulic gradient is most pronounced. Additionally, the increase in groundwater elevation can help mitigate the effects of drought on riparian vegetation (Bravard et al. 1997, Lite et al. 2005, Hupp and Rinaldi 2007, Skarpich et al. 2016). These considerations, combined with the effect that increased surface water-groundwater interactions have on stream temperature, mean that BDAs and natural beaver dams are critically important tools in restoring and maintaining resilient riparian and riverine habitat in the face of climate change (Pollock et al. 2018).

### *Considerations for design and implementation*

#### Site selection

Generally, perennial streams with a gradient less than 6 percent, an unconfined valley or incision trench, and bankfull stream power less than 2,000 watts per meter (610 watts per foot) can physically support BDAs and natural beaver dams (Pollock et al. 2014). Researchers at Utah State University have developed a geospatial analysis tool (the Beaver Restoration Assessment Tool [BRAT; Macfarlane et al. 2017]) that can identify suitable sites for beaver-related restoration efforts. BRAT is open-source, meaning that anyone can access the tool and implement it using geospatial software combined with publicly-available geospatial source datasets (Macfarlane et al. 2017) and it is therefore a useful restoration planning tool. However, this geospatial tool is not required for site selection and most sites that meet the criteria generally described above are likely suitable, particularly if the project includes measures to decrease stream power. For instance (and as described above), BDAs or natural beaver dams constructed in incision trenches may breach or fail due to concentrated stream power (Demmer and Beschta 2008). However, constructing PALS or PAWS that span only a portion of a channel in such areas can facilitate lateral channel migration and an increase in channel sinuosity, while also reducing the likelihood of downstream BDA breach and/or failure (Pollock et al. 2012, Wheaton and Shahverdian 2018). Over time, an increase in sinuosity, and associated effects on stream power, can allow for construction of channel-spanning BDAs or promote construction and maintenance of natural beaver dams (Pollock et al. 2014, 2018).

Additionally, it is critical to consider social and infrastructure constraints when identifying a site for BDA implementation. Specifically, landowner support for BDAs and beaver recolonization, perspectives of upstream and downstream neighbors, vulnerability of nearby land-use activities to flooding, and the presence of infrastructure such as culverts or irrigation diversions that may be affected by beaver activity should be assessed prior to implementing BDAs at a given site (Charnley 2018, Pollock et al. 2018, Davee et al. 2019).

Once a general site is selected, Orr et al. (2019) recommend building BDAs in areas with a steep bank slope on one side and a floodplain on the other side of the channel, which allows high flows to dissipate over the floodplain. Additionally, Orr et al. (2019) advise building 2 to 10 meters (7 to 33 feet) downstream of riffle crests. Given that posts (for BDAs that include support posts) should be driven 50 centimeters to 1 meter (1.6 to 3.3 feet) into the channel substrate (see below for additional detail), it may also be necessary to test substrate within the specific BDA site to determine where to place posts (methods described below). Finally, site selection will vary depending on the specific goals and objectives associated with BDA installation.

### BDA complexes

Generally, natural beaver dams occur as part of a complex (as summarized in Pollock et al. 2018), which includes a primary dam that provides inundation for the main beaver lodge and space for a food cache, and between one to fifteen secondary dams that extend beaver forage range and provide redundancy such that if a single dam fails, there is not a dramatic change in local hydraulics, habitat, water surface elevation, etc. (as summarized in Pollock et al. 2018, Wheaton and Shahverdian 2018). Numerous studies and documents (Pollock et al. 2012, 2018, Wheaton and Shahverdian 2018) recommend multiple BDA structures both upstream, to reduce stream power, and downstream, to reduce the likelihood of excessive scour and initiation of headcutting, of a larger central “primary” BDA structure. Note that regulatory agencies often seek to limit the number of channel-spanning structures installed in order to address perceived BDA fish passage issues (Charnley 2018). As a result, numerous projects have included PALS or PAWS that are not fully channel-spanning (as illustrated in Wheaton and Shahverdian 2018) upstream of the primary channel-spanning structure in order to still reduce stream power above the primary structure, while also addressing regulatory agency concern regarding fish passage. Similarly, if a specific project objective is to facilitate meander development and lateral channel migration, inclusion of angled non-channel-spanning PALS or PAWS is warranted (Pollock et al. 2012, Wheaton and Shahverdian 2018), as described above. Regardless, structures downstream of the primary BDA should be channel-spanning BDAs to effectively prevent excessive scour and headcut development (Pollock et al. 2012, Wheaton and Shahverdian 2018).

Finally, restoration practitioners must consider distance between individual BDA structures within the BDA complex. In Bridge Creek, researchers and restoration practitioners installed individual structures consistent with spacing observed in natural beaver dam complexes (which is a function of channel slope), but also such that water ponded behind a downstream structure backed up to the base of the next upstream structure during average discharge conditions (Pollock et al. 2012, Bouwes et al. 2016). Conversely, Orr et al. (2019) constructed BDAs 0.13 to 1 river kilometers (427 feet to 0.6 miles) apart, noting that this resulted in BDAs that were farther apart than in Bridge Creek<sup>§</sup>.

---

<sup>§</sup> Note that Orr et al. (2019) ultimately had to adjust the design of individual BDAs to increase resistance to stream power, which would likely not have been necessary if individual BDAs were installed as part of a complex. Charnley et al. (2019) highlights a similar issue with failures of single structures on the mainstem Scott River. Given these two examples, this wider spacing should only be attempted if a BDA complex is not possible and designs of individual BDAs can be adjusted accordingly.

### BDA components

It may be possible to install BDAs without posts in some systems, however, in areas with relatively high stream power, including posts in the BDA design helps ensure structural integrity during high flow events (Wheaton and Shahverdian 2018). Specifically, most BDA projects use 2 meter-long (6.6 foot-long) posts (often of lodgepole pine [*Pinus contorta*], stripped of bark, with a point cut into the end to be pounded into the channel), 6 to 11 centimeters (2.4 to 4.3 inches) in diameter, to act as the structural foundation for BDAs (Pollock et al. 2012, Weber et al. 2017, Orr et al. 2019). Posts are typically pounded 30 centimeters to 1 meter (11.8 inches to 3.3 feet) apart with a hydraulic post pounder to a depth of 50 centimeters to over 1 meter (1.6 to over 3.3 feet) into the active channel sediment (Pollock et al. 2012, Weber et al. 2017, Orr et al. 2019). Orr et al. (2019) used a penetrometer to identify specific locations within their project site with substrate conducive to secure post placement. Depending on site conditions and project objectives, posts can be placed solely within the active channel (i.e., spanning bankfull width), or extend into the floodplain (Pollock et al. 2012, Weber et al. 2017, Orr et al. 2019).

In terms of planform design, posts can be placed:

- In a straight line across the active channel perpendicular to flow (facilitates channel widening, which is desirable in deep and narrow incision trenches [Pollock et al. 2014]);
- Convex downstream such that the middle post in the structure is the most downstream post (this promotes divergent flow, avoids concentrating flow in the thalweg downstream of the BDA, and prevents excessive downstream scour [Pollock et al. 2012]); or
- Angled, to force flow towards (increases sinuosity) or away (to protect infrastructure from erosion) from specific areas of streambank (Wheaton and Shahverdian 2018).

Any of these designs can also include 5 to 10-meter-long (16 to 33-foot-long) “bank wraps” at either end of the BDA that angle upstream, to help reduce bank scour (Pollock et al. 2018 and figures therein). Pollock et al. (2018) recommend that posts (and weave) for bank wraps be taller than that of the in-channel BDA to force water into floodplain rather than through highly erodible bank material.

Once placed, posts are trimmed to achieve the desired dam crest height, which is often to bankfull height or slightly higher, depending on site conditions and project objectives (Wheaton and Shahverdian 2018). Crest height can also be based on that of natural beaver dams in the vicinity (Bouwes et al. 2016).

After placing posts and adjusting post height, most practitioners weave willow (Pollock et al. 2012, Bouwes et al. 2016, Weber et al. 2017, Orr et al. 2019) and/or other materials, such as juniper (Orr et al. 2019) through posts to create a porous dam structure. Weave often extends to bankfull height but should be adjusted based on site conditions and project objectives (Pollock et al. 2012). Generally, higher weave increases pond size, but also may increase the likelihood of dam failure (Pollock et al. 2012). In addition to weave, bed sediment, vegetative material, and other fine-grained materials are used to “patch” the upstream side of the weave to increase water retention of the BDA (Bouwes et al. 2016, Pollock et al. 2018, Orr et al. 2019); it is possible to construct BDAs without this additional material, though the BDAs will be more permeable and therefore not be capable of creating upstream ponds as quickly or effectively (Pollock et al.

2018). This material is often placed in the shape of a ramp on the upstream side of the BDA weave (Orr et al. 2019, as illustrated in Pollock et al. 2018). It is also necessary to add cobble (5 to 20 centimeters [2.0 to 7.9 inches] in diameter) to the upstream side of the BDA weave to prevent headcutting and excessive scour beneath the structure, which could cause BDA failure and breaching (Pollock et al. 2012, Pollock et al. 2018, Orr et al. 2019); interestingly, beaver often add cobble upstream of natural dams in a similar manner to prevent scour (Pollock et al. 2012). Finally, a “mattress” of material (oriented parallel with flow) and gravel or cobble are often placed on the downstream side of the BDA to dissipate the energy of water flowing over the crest of the BDA and to prevent excessive downstream scour (Wheaton and Shahverdian 2018, Orr et al. 2019).

Both Pollock et al. (2018) and Wheaton and Shahverdian (2018) provide numerous figures and photographs that visually illustrate these design components.

### BDA lifespan

Natural beaver dams are typically temporary structures that are often abandoned as beavers relocate up- or downstream or build dams in different areas of the same reach (Pollock et al. 2018). As such, BDAs are meant to be ephemeral, rather than permanent, structures.

Specifically, a two-year BDA lifespan from the point that beavers begin occupying the project site is thought to be sufficient to establish viable beaver colonies given beaver reproduction cycles and other life history timelines (Pollock et al. 2018). If beaver recolonization is not a specific project objective, shorter or longer lifespans can be considered based on site conditions and project objectives.

One of the primary concerns with BDAs is the potential for dam failure or breaching during high flows. Orr et al. (2019) note that three of their five BDAs failed during high flows that included ice floes. The authors attributed failure to post breakage and/or scour and addressed these issues by building wider (longitudinally) BDAs and added juniper and willow boles and branches parallel to flow against the streambanks to prevent side cutting and scour (Orr et al. 2019). Similarly, Charnley (2018) reports that several BDAs built on the mainstem Scott River failed during high flow events. In both cases, these BDAs were individual structures not built as part of the typical BDA complex (Charnley 2018, Orr et al. 2019), thus not only was failure more likely to alter local hydraulics and geomorphology because redundancy didn't exist, but there was a lack of channel complexity present upstream of these BDAs to reduce stream power and downstream of the BDAs to reduce the likelihood of excessive scour and headcut development. These cases further support the notion that constructing individual BDAs as part of a complex is necessary to achieve the desired BDA lifespan, but that there are also options to strengthen individual BDAs (as described above and in Orr et al. [2019]) that can further reduce the likelihood of dam failure, particularly when BDAs are not built as part of complexes.

### Cost

One of the many reasons that restoration using BDAs is becoming increasingly popular is the relatively low implementation and maintenance costs, particularly relative to other actions (such as channel reconstruction) often employed to achieve similar objectives. Specifically, BDAs typically cost \$1,000 to \$5,000 per structure, including cost of design and permitting (Davee et al. 2019). Note that a need for detailed designs of each structure (e.g., for permit acquisition)

and monitoring adds to the cost of implementation; similarly, building BDAs individually rather than within a complex is likely to increase implementation and maintenance costs.

#### Construction sequence for individual BDAs

Below is a suggested sequence for constructing individual BDAs based on review of design components and recommendations in the literature. This sequence assumes that a site has already been identified, ideally using the guidance provided above. This list and the specifics included therein are meant to provide guidance and contextual information; expert opinion and judgement of restoration professionals should determine what is necessary for a given site and project. Finally, note that BDAs only including posts (but not weave) will not require steps 2 through 4.

1. Pound posts, spaced 30 centimeters to 1 meter apart (11.8 inches to 3.3 feet), 50 centimeters to 1 meter (1.6 to 3.3 feet) deep within the channel substrate using a hydraulic post-pounder, and adjust height of posts to 30 centimeters (11.8 inches) above bankfull height or less, depending on site conditions and project objectives;
2. Weave willow whips or other branches in between posts to approximately bankfull height or less (depending on site conditions and project objectives) to create a porous dam;
3. Line the upstream base of the dam with cobble and other large material;
4. Add finer-grained material and vegetation to the upstream face of the dam until desired porosity is achieved (note that secondary dams downstream of the central primary dam often do not include this step [Pollock et al. 2018], but this step is likely necessary for the primary dam); and
5. Place branches or other material oriented parallel with flow across the top of the dam (to create a “mattress” as described in Orr et al. 2019) and gravel and cobble directly downstream of the dam, both to prevent excessive downstream scour.

#### *Other considerations*

This section includes information regarding BDA implementation and other considerations based on review of design components, recommendations, and lessons learned described in the literature.

#### Permitting

Permitting requirements for BDAs are largely dependent on the geographic location (e.g., areas with anadromy, which state the project site is located in), landownership of the project site (e.g., public or private), and project objectives (e.g., projects with channel-spanning structures will likely require permits that projects without will not). In particular, given that regulatory agencies have relatively limited experience with BDAs, permitting currently requires persistence and, ideally, proponents within regulatory agencies that understand the potential ecological benefits of BDA projects (Charnley 2018). Of particular relevance to permitting within the state of Oregon is a legacy of structures similar to BDAs (or structures called BDAs, but not necessarily designed to resemble natural beaver dams) being implemented to increase water surface elevation primarily to ease water diversion for agricultural purposes (rather than implementation to achieve ecological restoration objectives). This has created a great deal of concern among regulatory

agencies and additional permitting requirements as a result (Pilliod et al. 2018, Davee et al. 2019).

Regardless, at a minimum, it appears that a US Army Corps of Engineers 4345 permit for work on private land or a US Army Corps of Engineers regional general permit (RGP-04) for public lands is often required (Davee et al. 2019). In the state of Oregon, a Department of State Lands removal-fill permit is required for work on both private and public land when moving more than 38 cubic meters (1,342 cubic feet) of material in a wetland or waterway (ORS 196.795-990; Davee et al. 2019). Additionally, it is necessary to obtain written approval from the Oregon Department of Fish and Wildlife for any work done instream where migratory fish are present, and additional fish passage plans approved by this agency may be necessary for BDA projects as well (Davee et al. 2019). Specific to fish passage, in the state of California, practitioners in the Scott River Valley were able to obtain a categorical exclusion by classifying their project as a research project with a specific research question about, and plans to monitor, fish passage (Charnley 2018). In Oregon, keeping the Oregon Department of Water Resources apprised of project plans and status is also recommended; planning to construct BDAs prior to or at the end of the irrigation season is likely to allay any water rights concerns such agencies may have regarding BDA projects (Charnley 2018). Note that permitting requirements for BDAs in Oregon may change in the future. The Oregon state legislature is currently working on several bills (SB 1511 and HB3132) that would exempt “environmental restoration weirs” (which would include BDAs, as defined in this literature review) from certain permits. Finally, depending on project location and jurisdiction, additional permits and regulatory processes such as those called for under the Endangered Species Act and the National Environmental Protection Act may be necessary.

### Monitoring

Of particular importance for any restoration project is developing specific and quantifiable project objectives (Pollock et al. 2018) and then designing a monitoring regime that can assess to what degree these objectives have been achieved (Table 1); including pre-treatment monitoring and a before-after-control-impact (BACI) monitoring design is necessary to determine with any certainty the effects of BDAs (Pollock et al. 2012, Bouwes et al. 2016, Weber et al. 2017). An example of this study design would include sites in a reach unaffected by the BDAs with monitoring data from the period before and after BDA construction, and sites that will be affected by BDAs with monitoring data for the same time period.

Monitoring of BDAs is particularly important at this time given that this is an increasingly popular restoration method, but there is only a handful of case studies that have quantified the effects of BDAs on specific ecological and biological variables (Pilliod et al. 2018). In particular, additional information about the general effects of BDAs in larger streams, and the effects of BDAs on fish passage and dissolved nutrients are warranted. Table 1 provides examples of quantifiable project objectives and potential monitoring methods to be considered for BDA projects. Additionally, given the importance of monitoring or directed studies in increasing our understanding of the impact of these structures in restoring ecological processes and native fish populations, restoration practitioners should seek funding specifically for monitoring, rather than solely for implementation. Given the potential benefits and impacts of

BDAs on river ecology, managers and resource agencies should be committed to providing funding for these programs.

### Social implications

Although BDAs clearly provide ecological benefit, there is also evidence that these benefits may extend to agricultural operations in the vicinity of BDA projects. For instance, it appears that private landowners, once suspicious of beaver and associated activity, are increasingly viewing BDAs and other beaver-related restoration work more positively as they observe increases in water table elevation and riparian forage production in areas with BDAs (Charnley 2018, Goldfarb 2018). However, private landowners are still concerned that wild beaver will tamper with irrigation infrastructure and flood pasture and croplands (Charnley 2018, Davee et al. 2019); as such, transparency and addressing landowner concerns is necessary for BDA project success (Charnley 2018).

**Table 1.** Examples of BDA project objectives and monitoring techniques to assess progress towards achieving objectives.

<b>Project Objectives</b>	<b>Monitoring technique</b>	<b>Technical resources</b>
Decreased stream velocity	Stream velocity measurements	Fitzpatrick et al. 1998
Increased sediment deposition	Cross sections	Harrelson et al. 1994
Channel aggradation	Cross sections	Harrelson et al. 1994
Changes in magnitude and duration of floodplain inundation	Hydraulic modeling, photopoints (with a staff gage) during high water periods	Opperman et al. 2009
Increased riparian plant abundance/density	Riparian canopy closure, dominant riparian land use/land cover, bank vegetative cover, bank erosion	Fitzpatrick et al. 1998
Increased fish prey abundance and diversity	Benthic macroinvertebrate surveys	Hayslip 2007, Britton and Greeson 1987
Changes in substrate composition	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
Increased beaver activity	Presence, survival, density, aerial photography surveys	Pollock et al. 2014, Pollock et al. 2018
Increased groundwater elevation	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
Changes in nutrient and sediment loads	Discrete point sampling, continuous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, Schenk et al. 2016
Changes in water chemistry (water temperature, DO concentrations, pH, etc.)	Discrete point sampling, continuous sensor measurements	ODEQ 2009
Increased sinuosity	Sinuosity ratio	Fitzpatrick et al. 1998
Changes in channel profile (width, depth)	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
Decreased channel gradient	Longitudinal channel profile	Harrelson et al. 1994
Increased diversity in fish habitat types (e.g., pools, riffles, etc.)	Cross sections, longitudinal channel profile	Harrelson et al. 1994



### *Implementation sequence*

Below is a suggested sequence for implementation of projects including BDAs based on recommendations currently available in the literature:

1. Establish project goals (broad desired outcomes) and objectives (quantifiable steps necessary to achieve goals; see Table 1 and above narrative for additional details);
2. Identify a project site considering valley confinement, stream gradient, stream power (consider utilizing a geospatial tool such as BRAT), and project goals and objectives;
3. Complete design work:
  - a. Identify a specific site for the BDA complex within the project site, considering channel profile, bank dimensions and profile, locations of pools and riffles, and substrate;
  - b. Determine number of individual dams within the BDA complex;
  - c. Determine BDA planform shape (e.g., angled, perpendicular to flow, convex) and planform width (e.g., partially channel-spanning, fully channel-spanning, channel-spanning and into a portion of the floodplain); and
  - d. Draft designs for individual BDAs, if necessary (note that this typically increases the time, effort, and cost to implement BDAs and minimizes the ability to adaptively manage the project, which is generally antithetical to the benefits and attractiveness of using BDAs as a restoration tool);
4. Identify and obtain necessary permits:
  - a. Oregon Department of State Lands fill permit;
  - b. U.S. Army Corps of Engineers fill permit;
  - c. Oregon's State Historic Preservation Office permit;
  - d. Oregon Department of Fish and Wildlife fish passage approval (written);
  - e. Oregon Department of Water Resources approval;
  - f. Oregon Department of Water Quality 401 certification; and
  - g. Other permits (such as Endangered Species Act Section 7 and processes associated with the National Environmental Protection Act) as jurisdiction and property ownership warrant;
5. Develop and begin pre-project monitoring, including monitoring at control and treatment sites, as applicable (see Table 1 for potential monitoring methods);
6. Construct the primary BDA within the complex (see guidelines in "Considerations for design and implementation" section);
7. Determine locations of other BDAs within the complex, including at least one channel-spanning downstream BDA and preferably several upstream structures that are either channel-spanning or angled, considering the distance necessary to ensure that impoundments reach upstream dams;
8. Construct other BDAs within the complex;
9. Begin post-project monitoring using the same sites as established in step 5; and
10. Adjust project design and monitoring as new information becomes available, and maintain BDAs as necessary and consistent with project objectives.

### *Conclusion*

BDAs appear to be a relatively efficient, effective, and inexpensive method to facilitate dramatic beneficial changes in river ecology, geomorphology, and even hydrology. There is clear evidence that BDAs can reverse channel incision, increase groundwater elevation, facilitate reestablishment of robust riparian vegetation, create high quality fish habitat (through creation of physical habitat features and through changes in water temperature), reduce sediment and particulate loads, potentially reduce dissolved nutrient loads, and create habitat for other animals on relatively short timelines, particularly when compared with other restoration actions such as riparian planting and channel reconstruction. Additionally, there are numerous studies indicating that BDAs and natural beaver dams are not barriers to fish passage; however, given the difficulty in predicting if, when, and where BDAs and natural beaver dams may affect fish passage, additional research on this topic is necessary. Regardless, there appears to be widespread consensus among fisheries experts that BDAs and natural beaver dams are overwhelmingly beneficial to fish populations, even if and when fish passage is limited. BDAs may also benefit agricultural operations through increases in groundwater elevation and forage production, which has resulted in a changing opinion of beaver in the rural west. Finally, there are many nuances associated with BDA project planning (site selection in particular), design (shape, number within a complex, placement of individual structures within a complex), construction (finding suitable substrate), and monitoring.

Relative to the UKB, it appears that sediment loads are sufficient in many areas (the Sycan and Sprague rivers in particular) to enable BDAs to facilitate channel aggradation. Similarly, BDAs will likely reduce particulate nutrient loads in support of the goals in ODEQ (2002). Stream reaches in the UKB often lack complexity, and implementing BDAs can assist in restoring more dynamic geomorphic processes. Given that relatively few BDAs have been implemented in the UKB, there may initially be regulatory hurdles and challenges, similar to those experienced in the Scott Valley (as described in Charnley 2018); however, persistence and monitoring can help alleviate concerns of regulatory agencies. A collaborative approach that thoughtfully involves restoration professionals, landowners, and agency staff from project planning through implementation will be necessary to successfully facilitate BDA and beaver-related restoration in the UKB. Finally, because BDAs and other beaver-focused restoration techniques are relatively new; there is a general need for more research regarding some of the effects of BDAs; and that implementation sites differ geomorphically, hydrologically, and ecologically, it is critical to implement a monitoring program to assess progress towards achieving project objectives and to attempt to answer lingering questions about the effects of BDAs.

### *Acknowledgments*

The authors would like to thank the numerous individuals that reviewed and provided feedback on draft forms of this literature review, including Leigh Ann Vradenburg, Nell Scott, Will Natividad, Josh Rasmussen, Adam Johnson, Dan Blake, Akimi King, Nolan Banish, and Jennifer O'Reilly.

Note that the guidance presented in this review was developed by the authors and does not represent the official position of the Oregon Department of Environmental Quality.

## References

- Allred M. 1980. A re-emphasis on the value of the beaver in natural resource conservation. *Journal of the Idaho Academy of Science* 16(1):3-10.
- Anderson CB, Rosemond AD. 2010. Beaver invasion alters terrestrial subsidies to subantarctic stream food webs. *Hydrobiologia* 652:349–361.
- Beechie TJ, Sear DA, Olden JD, Pess GR, Buffington JM, Moir H, Roni P, Pollock MM. 2010. Process-based principles for restoring river ecosystems. *BioScience* 60(3):209-222.
- Bouwes N, Weber N, Jordan CE, Saunders WC, Tattam IA, Volk C, Wheaton JM, Pollock MM. 2016. Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Scientific Reports* 6: 28581, doi:10.1038/srep28581.
- Bravard JP, Amoros C, Pautou G, Bornette G, Bournaud S, Creuze des Chatelliers M, Gibert J, Peiry JL, Perrin JF, Tachet H. 1997. River incision in south-east France: morphological phenomena and ecological effects. *Regulated Rivers: Research and Management* 13:75-90.
- Britton LJ, Greeson PE. 1987. Techniques of water-resources investigations of the United States Geological Survey: Chapter A4: Methods for collection and analysis of aquatic biological and microbiological samples, in: *Techniques of Water-Resources Investigations*. [https://pubs.usgs.gov/twri/twri5a4/pdf/twri\\_5-A4\\_g.pdf](https://pubs.usgs.gov/twri/twri5a4/pdf/twri_5-A4_g.pdf)
- Brooker MP. 1985. The impact of river channelization IV: The ecological effects of channelization. *The Geographical Journal* 151(1):63-69.
- Buffington JM, Montgomery DR. 1999. A procedure for classifying textural facies in gravel-bed rivers. *Water Resources Research*, 35(6): 1903–1914. <https://doi.org/10.1029/1999WR900041>
- Bukaveckas PA. 2007. Effects of channel restoration on water velocity, transient storage, and nutrient uptake in a channelized stream. *Environmental Science and Technology* 41(5):1570-1576.
- Charnley S. 2018. Beavers, landowners, and watershed restoration: experimenting with beaver dam analogues in the Scott River Basin, California. Research Paper PNW-RP-613, Pacific Northwest Research Station, Northwest Climate Hub, U.S. Forest Service.
- Cluer B, Thorne C. 2013. A stream model integrating habitat and ecosystem benefits. *River Research and Applications* 30(2): 135-154.
- Cooper DJ, Merritt DM. 2012. Assessing the water needs of riparian and wetland vegetation in the western United States (General Technical Report No. RMRS-GTR-282). U.S. Forest Service, Rocky Mountain Research Station. [http://www.fs.fed.us/rm/pubs/rmrs\\_gtr282.pdf](http://www.fs.fed.us/rm/pubs/rmrs_gtr282.pdf)
- Cucherousset J, Olden JD. 2011. Ecological impacts of nonnative freshwater fishes. *Fisheries* 36: 215–230.
- Davee R, Gosnell H, Charnley S. 2019. Using beaver dam analogues for fish and wildlife recovery on public and private rangelands in eastern Oregon. Research Paper PNW-RP-612, Pacific Northwest Research Station, Northwest Climate Hub, U.S. Forest Service.
- Demmer R, Beschta RL. 2008. Recent history (1988-2004) of beaver dams along Bridge Creek in central Oregon. *Western North American Naturalist* 32:309-318.
- Fitzpatrick FA, Waite IR, D'Arconte PJ, Meador MR, Maupin MA, Gurtz ME. 1998. Revised methods for characterizing stream habitat in the National Water-Quality Assessment

- Program. Water-Resources Investigations Report 98-4052. U.S. Geological Survey: Raleigh, NC.
- Gard, R. 1961. Effects of beaver on trout in Sagehen Creek, California. *The Journal of Wildlife Management* 25(3):221–242.
- Gardunio E. 2014. Jumping and swimming performance of Burbot and White Sucker: implications for barrier design. Masters Thesis. Colorado State University: Fort Collins, CO.
- Garrett DL, Spinelli J. 2017. The Presence of Salish Sucker and the Native Fish Fauna at Naval Radio Station Jim Creek, Washington. Washington Department of Fish and Wildlife.
- Gibson PP, Olden JD, O'Neill MW. 2015. Beaver dams shift desert fish assemblages toward dominance by non-native species (Verde River, Arizona, USA). *Ecology of Freshwater Fish*, 24: 355-372.
- Goldfarb B. 2018. Beavers, rebooted. *Science* 360(6393):1058-1061.
- Graham SA, Craft CB, McCormick PV, Aldous A. 2005. Forms and accumulation of soil P in natural and recently restored peatlands- Upper Klamath Lake, Oregon, USA. *Wetlands* 25(3):594-606.
- Hardison EC, O'Driscoll MA, DeLoatch JP, Howard RJ, Brinson MM. 2009. Urban land use, channel incision, and water table decline along coastal plain streams, North Carolina. *Journal of the American Water Resources Association* 45(4):1032-1046.
- Harrelson CC, Rawlins CL, Potyondy JP. 1994. Stream channel reference sites: An illustrated guide to field technique. General Technical Report No. RM-245. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.
- Hayslip G. 2007. Methods for the collection and analysis of benthic macroinvertebrate assemblages in wadeable streams of the Pacific Northwest. [http://www.colvilletribes.com/media/files/2007\\_0612PNAMP\\_macroinvert\\_protocol\\_final.pdf](http://www.colvilletribes.com/media/files/2007_0612PNAMP_macroinvert_protocol_final.pdf)
- Hupp CR, Rinaldi M. 2007. Riparian vegetation patterns in relation to fluvial landforms and channel evolution along selected rivers of Tuscany (Central Italy). *Annals of the Association of American Geographers* 97(1):12-30.
- Juston JM, DeBusk TA, Grace KA, Jackson SD. 2013. A model of phosphorus cycling to explore the role of biomass turnover in submerged aquatic vegetation wetlands for Everglades restoration. *Ecological Modelling* 251:135-149.
- Kadlec RH. 1997. An autobiotic wetland phosphorus model. *Ecological Engineering* 8:145-172.
- Kemp PS, Worthington TA, Langford TE, Tree AR, Gaywood MJ. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries* 13:158-181.
- Kondolf GM. 1997. Application of the pebble count notes on purpose, methods, and variants. *Journal of the American Water Resources Association* 33: 79–87. <https://doi.org/10.1111/j.1752-1688.1997.tb04084.x>
- Kroes DE, Hupp CR. 2010. The effect of channelization on floodplain sediment deposition and subsidence along the Pocomoke River, Maryland. *Journal of the American Water Resources Association* 46(4):686-699.
- Lau JK, Lauer TE, Weinman ML. 2006. Impacts of channelization on stream habitats and associated fish assemblages in East Central Indiana. *American Midland Naturalist* 156:319-330.

- Lite SJ, Bagstad KJ, Strombery JC. 2005. Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. *Journal of Arid Environments* 63:785-813.
- Lokteff RL, Roper BB, Wheaton JM. 2013. Do beaver dams impede the movement of trout? *Transactions of the American Fisheries Society* 142:1114-1125.
- Macfarlane WW, Wheaton JM, Bouwes N, Jensen ML, Gilbert JT, Hough-Snee N, Shivik JA. 2017. Modeling the capacity of riverscapes to support beaver dams. *Geomorphology* 277:72-99.
- Mayer T, Ptacek C, Zanini L. 1999. Sediments as a source of nutrients to hypereutrophic marshes of Point Pelee, Ontario, Canada. *Water Resources* 33:1460-70.
- McDowell DM, Naiman RJ. 1986. Structure and function of a benthic invertebrate stream community as influenced by beaver (*Castor canadensis*). *Oecologia* 68(4):481-489.
- Mitchell SC, Cunjak RA. 2007. Stream flow, salmon and beaver dams: roles in the structuring of stream fish communities within an anadromous salmon dominated stream. *Journal of Animal Ecology* 76:1062-1074.
- Mortimer CH. 1941. The exchange of dissolved substances between mud and water in lakes. *Journal of Ecology* 29:280-329.
- Muskopf SA. 2007. The effect of beaver (*Castor canadensis*) dam removal on total phosphorus concentration in Taylor Creek and wetland, South Lake Tahoe, California. Humboldt State University.
- Nielson DM. 1991. *Practical handbook of ground-water monitoring*. Lewis Publishers: Chelsea, MI.
- O'Connor JE, McDowell PF, Lind P, Rasmussen CG, Keith MK. 2015. Geomorphology and floodplain vegetation of the Sprague and lower Sycan Rivers, Klamath Basin, Oregon. U.S. Geological Survey Scientific Investigations Report 2014-5223. doi: <http://dx.doi.org/10.3133/sir20145223>.
- [ODEQ] Oregon Department of Environmental Quality. 2002. Upper Klamath Lake drainage total maximum daily load (TMDL) and water quality management plan (WQMP). <https://www.oregon.gov/deq/FilterDocs/UKtmdlwqmp.pdf>
- [ODEQ] Oregon Department of Environmental Quality. 2009. Water monitoring and assessment mode of operations manual (MOMs). No. DEQ03-LAB-0036-SOP: Hillsboro, OR.
- Opperman JJ, Galloway GE, Fargione J, Mount JF, Richter BD, Secchi S. 2009. Sustainable floodplains through large-scale reconnection to rivers. *Science* 326(5959):1487-1488. <https://doi.org/10.1126/science.1178256>.
- Orr MR, Weber NP, Noone WN, Mooney MG, Oakes TM, Broughton HM. 2019. Short-term stream and riparian responses to beaver dam analogs on a low-gradient channel lacking woody riparian vegetation. *Northwest Science* 93:171-184.
- Pearl CA, McCreary B, Rowe JC, Adams MJ. 2018. Late-season movement and habitat use by Oregon Spotted Frog (*Rana pretiosa*) in Oregon, USA. *Copeia* 106(3):539-549.
- Pilliod DS, Rohde AT, Charnley S, Davee RR, Dunham JB, Gosnell H, Grant GE, Hausner MB, Huntington JL, Nash C. 2018. Survey of beaver-related restoration practices in rangeland streams of the western USA. *Environmental Management* 61:58-68.
- Pollock MM, Beechie TJ, Jordan CE. 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream channel in the interior Columbia River basin, eastern Oregon. *Earth Surface Processes and Landforms* 32:1174-1186.

- Pollock MM, Beechie TJ, Wheaton JM, Jordan CE, Bouwes N, Weber N, Volk C. 2014. Using beaver dams to restore incised stream ecosystems. *BioScience* Advanced Access, doi:10.1093/biosci/biu036.
- Pollock MM, Lewallen GM, Woodruff K, Jordan CE, Castro CM. 2018. The beaver restoration guidebook: working with beaver to restore streams, wetlands, and floodplains. Version 2.01. U.S. Fish and Wildlife Service: Portland, OR.
- Pollock MM, Wheaton JM, Bouwes N, Volk C, Weber N, Jordan CE. 2012. Working with beaver to restore salmon habitat in the Bridge Creek intensively monitoring watershed: design rationale and hypotheses. Technical Memo NMFS-NWFSC-120, National Oceanic and Atmospheric Agency.
- Pollock MM, Witmore S, Yokel E. 2019. A field experiment to assess passage of juvenile salmonids across beaver dams during low flow conditions in a tributary to the Klamath River, California, USA. doi:10.1101/856252.
- Powers PD, Helstab M, Niezgodla SL. 2018. A process-based approach to restoring depositional river valleys to stage 0, an anastomosing channel network. *River Research and Applications* 35(1): 3-13.
- Rosgen DL. 1996. Applied river morphology. Wildland Hydrology Books: Pagosa Springs, CO.
- Schenk LN, Anderson CW, Diaz P, Steward MA. 2016. Suspended-sediment loads to Upper Klamath Lake, Oregon using surrogate regressions with real-time turbidity and acoustic backscatter data. Scientific Investigations Report 2016-5167. Prepared by U.S. Geological Survey for the U.S. Bureau of Reclamation and The Klamath Tribes.
- Sedell JR, Reeves GH, Hauer FR, Stanford JA, Hawkins CP. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. *Environmental Management* 14(5):711-724.
- Sholtes JS, Doyle MW. 2011. Effect of channel restoration on flood wave attenuation. *Journal of Hydraulic Engineering* 137(2):196-208.
- Silverman NL, Allred BW, Donnelly JP, Chapman TB, Maestas JD, Wheaton JM, White J, Naugle DE. 2019. Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. *Restoration Ecology* 27(2):269-278.
- Skarpich V, Horacek M, Galia T, Kapustova V, Sala V. 2016. The effects of river patterns on riparian vegetation: a comparison of anabranching and single-thread incised channels. *Moravian Geographical Reports* 24(3):24-31.
- Skinner MM. 2016. *Nuphar lutea* in wetlands and shallow lakes with particular emphasis on the Upper Klamath Basin of Oregon. Aquatics Program, Natural Resources Department, The Klamath Tribes: Chiloquin, OR.
- Tague C, Valentine S, Kotchen M. 2008. Effect of geomorphic channel restoration on streamflow and groundwater in a snowmelt-dominated watershed. *Water Resource Research* 44: W10415. doi:10.1029/2007WR006418.
- Taylor BR, MacInnis C, Floyd TA. 2010. Influence of rainfall and beaver dams on upstream movement of spawning Atlantic salmon in a restored brook in Nova Scotia, Canada. *River Research and Applications* 26:183-193.
- The Watershed Action Plan Team. *In prep*. Upper Klamath Basin Watershed Action Plan. Prepared by U.S. Fish and Wildlife Service, California North Coast Regional Water Quality Control Board, Klamath Watershed Partnership, Oregon Department of

- Environmental Quality, The Klamath Tribes, The Natural Conservancy, and Trout Unlimited.
- [USFS] U.S. Forest Service. 2007. Technical guide to managing ground water resources. Report FS-881.
- [USFWS] U.S. Fish and Wildlife Service. 2012. Revised recovery plan for the Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*). U.S. Fish and Wildlife Service, Pacific Southwest Region: Sacramento, CA.  
[http://www.fs.fed.us/geology/FINAL\\_Ground%20Water%20Technical%20Guide\\_FS-881\\_March2007.pdf](http://www.fs.fed.us/geology/FINAL_Ground%20Water%20Technical%20Guide_FS-881_March2007.pdf)
- [USFWS] U.S. Fish and Wildlife Service. 2013. Endangered and threatened wildlife and plants; designation of critical habitat for the Oregon spotted frog; Proposed Rule. National Archives and Records Administration, Federal Register 78(168).
- [USFWS] U.S. Fish and Wildlife Service. 2014. Endangered and threatened wildlife and plants; threatened status for the Oregon spotted frog; Final Rule. National Archives and Records Administration, Federal Register 79(168).
- [USFWS] U.S. Fish and Wildlife Service. 2016. Final Critical Habitat Map- Oregon spotted frog.  
<https://www.fws.gov/wafwo/articles.cfm?id=149489682>
- [USFWS] U.S. Fish and Wildlife Service. 2020. Oregon spotted frog.  
<https://www.fws.gov/oregonfwo/articles.cfm?id=149489458>
- Walbridge MR, Struthers JP. 1993. Phosphorus retention in non-tidal palustrine forested wetlands of the mid-Atlantic region. *Wetlands* 13:84-94.
- Walker JD, Kann J, Walker WW. 2015. Spatial and temporal nutrient loading dynamics in the Sprague River Basin, Oregon. Prepared for the Klamath Tribes Natural Resources Department. [https://s3.amazonaws.com/walkerenvres.com/reports/klamath/2015-sprague-nutrient-dynamics/Sprague\\_River\\_Nutrient\\_Dynamics\\_20151229\\_final.pdf](https://s3.amazonaws.com/walkerenvres.com/reports/klamath/2015-sprague-nutrient-dynamics/Sprague_River_Nutrient_Dynamics_20151229_final.pdf)
- Walker WW, Walker JD, Kann J. 2012. Evaluation of water and nutrient balances for the Upper Klamath Lake Basin in water years 1992–2010: Technical Report to The Klamath Tribes Natural Resources Department.  
[http://www.walker.net/ukl/klamath\\_nutrientbudget\\_2012\\_final.pdf](http://www.walker.net/ukl/klamath_nutrientbudget_2012_final.pdf)
- Washko S. 2018. The macroinvertebrate and fish communities of in-stream beaver ponds in northeastern Utah. Masters Thesis, University of Utah.
- Washko S, Roper B, Atwood TB. 2020. Beavers alter stream macroinvertebrate communities in north-eastern Utah. *Freshwater Biology* 65:579– 591.
- Weber N, Bouwes N, Pollock MM, Volk C, Wheaton JM, Wathen G, Wirtz J, Jordan CE. 2017. Alteration of stream temperature by natural and artificial beaver dams. *PloS ONE* 12(5):e0176313.
- Wheaton J, Shahverdian S. 2018. Rock Creek- NRCS partnering with beaver in restoration design workshop- pilot/demonstration restoration. Utah State University and The Fluvial Habitats Center. Prepared for: The Nature Conservancy Idaho and the Wood River Land Trust.
- 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.  
<http://lowtechpbr.restoration.usu.edu/manual>
- Wolman MG. 1954. A method of sampling coarse river-bed material. *Eos, Transactions, American Geophysical Union* 35(6):951–956. <https://doi.org/10.1029/TR035i006p00951>

Wetzel RG. 2001. Limnology, 3<sup>rd</sup> Ed. Elsevier: San Diego, CA.



**U.S. Fish and Wildlife Service  
Klamath Falls Fish and Wildlife Office  
1936 California Ave  
Klamath Falls, OR 97601**

**<http://www.fws.gov>**



**July 2020**