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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA). • Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.
		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.	• 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. • Stage "0" projects in grazed areas may require exclusion and/or dedicated watering areas to promote natural stream processes while preserving the ranching operation. • Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA). • Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.
		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. https://doi.org/10.1002/rra.3378	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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • Consult OWRD regarding implications for streamflow. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA).
		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. https://digitalcommons.usu.edu/etd/4417	This Masters Thesis describes large woody debris projects that resulted in channel aggradation. See also the technical references for large woody debris below.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA). • Projects should consider the presence of downstream infrastructure (bridges, culverts) in design decisions for securing materials versus allowing flow manipulation of material placement.

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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA).
Draining of natural wetlands	Natural wetland restoration	Carpenter KD, Snyder DT, Duff JH, Triska FJ, Lee KK, Avanzino RJ, Sobieszczyk 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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information.
		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.	• 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. • 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. • Grazing management changes should be evaluated with the landowner to determine feasibility and impacts to the operation.
		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 may 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.	• Construction specifications may exist relative to the funding source (e.g. NRCS), and if applicable, supersede referenced guidelines. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • 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.
		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.	• 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. • 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. • Depending on the funding source, native plants may be required, or suitable, non-invasive introduced species may be acceptable. • 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. • Plants may need protection from livestock or wild animals (deer, elk, voles, etc.) as well as competition control (pulling/cutting of nearby vegetation). • Site disturbance and irrigation may encourage development of noxious weeds in planted areas; a planting plan should including monitoring for and treatment of weeds.
		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.	
		https://www.energytrust.org/solutions/agriculture-irrigation-improvements/	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.	
	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.	• Projects may require 1 year (or more) of water quality monitoring to inform design so project managers should plan their timeline accordingly • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Loss of production acreage and impacts to the operation due to construction of DSTWs should be evaluated with the landowner during the planning phase.
		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. https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/577c8f60c534a5bc31221f68/1467781084671/Handbook+Combined.pdf	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.	• Coordinate closely with OWRD before and during transfer process. • Project will require a Certified Water Rights Examiner, and may require legal council. • Flow restoration projects funded with public dollars typically require a quantified and permanent instream water rights transfer
		OWRD's Allocation of Conserved Water program website (https://www.oregon.gov/owrd/programs/WaterRights/Conservation/Pages/AOCW.aspx)	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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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 • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • 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. • Projects may need to report any calculated changes to the base flood elevation (County, FEMA) • Follow ODF guidelines, including Notification of Operations and a written plan if in a forested area; otherwise follow ODFW guidelines.
		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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Follow ODF guidelines, including Notification of Operations and a written plan if in a forested area.
		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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • See the ODFW Fish Screening webpage (https://www.dfw.state.or.us/fish/screening/index.asp) for information regarding screen technologies and maintenance needs, and resources such as cost-share programs. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • 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. • 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 (https://www.noaa.gov/sites/default/files/atoms/files/07354626823.pdf) • Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.
		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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF.
		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	See additional considerations 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.	• Follow ODFW in-water work period or obtain variance approval from ODFW. • 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. • Project may require Section 6 or 7 (ESA) consultation. Contact local USFWS office for additional information. • Project may require Section 106 (National Historic Preservation Act) compliance. Contact federal project partner or State Historic Preservation Officer (SHPO) for additional information. • Projects may require fish passage approval to ensure fish passage is not negatively impacted. Contact ODFW for approval and more information. • Projects involving heavy machinery in a forested area require a Permit to use Power-Driven Machinery through ODF. • Specialized equipment, such as a conveyor truck, may be used to direct placement of spawning gravel while minimizing stream disturbance.

U.S. Fish & Wildlife Service

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

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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.

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Contents

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 19th 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.

<u>Riparian Grazing or Exclusion?</u>

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[‡]. 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

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[‡] 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.

<u>Additional Considerations for Grazing Management</u>

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.

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September 2020

U.S. Fish & Wildlife Service

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

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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.

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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.

<u>Dissolved nutrients</u>

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 mangers 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.

<u>Oregon spotted frog</u>

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 luteiveatris*; 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.

<u>Beavers</u>

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).

<u>BDAs, natural beaver dams, and climate change</u>

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

<u>Site selection</u>

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.

<u>BDA complexes</u>

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[§].

[§] 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.

<u>BDA lifespan</u>

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.

<u>Cost</u>

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 porousness 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.

Project Objectives	Monitoring technique	Technical resources
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, contintuous 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.

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July 2020

Appendix B- Monitoring Framework

Impairment	Action	Quantifiable effects	Type of effect and scale	Conceptual model category (see Chapter 3 of the UKBWAP)	Monitoring method	References
Channelization	Channel reconstruction, methods to achieve Stage 0 restoration	Sinuosity	Direct, local	Channel morphology	Sinuosity ratio	Fitzpatrick et al. 1998
		Channel profile (width, depth)	Direct, local	Channel morphology	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
		Channel gradient	Direct, local	Channel morphology	Longitudinal channel profile	Harrelson et al. 1994
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Fish habitat types (e.g., pools, riffles, etc.)	Indirect, local	Native fish needs	Cross sections, longitudinal channel profile	Harrelson et al. 1994
		Streambed elevation relative to floodplain	Indirect, local	Riverine process and function	Cross sections	Harrelson et al. 1994
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Nutrient and sediment loads	Indirect, local (and watershed-scale)	Riverine process and function	Discrete point sampling, continutous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, Schenk et al. 2016
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
Channel incision	Actions to aggrade the stream channel	Water surface elevation	Direct, local	Local channel process	Stage measurements	Fitzpatrick et al. 1998
		Stream velocity	Direct (and indirect), local	Local channel process (direct), Riverine process and function (indirect)	Stream velocity measurements	Fitzpatrick et al. 1998
		Sediment deposition	Direct, local	Local channel process	Cross sections	Harrelson et al. 1994
		Streambed elevation relative to floodplain	Indirect, local	Floodplain-river connection, Riverine process and function (indirect)	Cross sections	Harrelson et al. 1994
		Changes in magnitude and duration of floodplain inundation	Direct, local	Floodplain-river connection	Hydraulic modeling, photopoints during high water periods	Opperman et al. 2009
		Riparian plant abundance/density	Indirect, local	Floodplain condition	Riparian canopy closure, dominant riparian land use/land cover, bank vegetative cover, bank erosion	Fitzpatrick et al. 1998
		Size of floodplain	Indirect, local	Floodplain condition	Hydraulic modeling	Opperman et al. 2009
		Number of LWD	Indirect, local	Native fish needs	LWD Survey	Schuett-Hames et al. 1999
		Fish prey abundance and diversity	Indirect, local	Native fish needs	Benthic macroinvertebrate surveys	Hayslip 2007, Brittonand Greeson 1987
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Presence of overhanging vegetation	Indirect, local	Native fish needs	Survey of habitat cover features	Fitzpatrick et al. 1998
		Beaver activity	Indirect, local	Biological response	Presence, survival, density, aerial photography surveys	Pollock et al. 2014, Pollock et al. 2018
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Nutrient and sediment loads	Indirect, local (and watershed-scale)	Riverine process and function	Discrete point sampling, continutous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, Schenk et al. 2016
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999

Impairment	Action	Quantifiable effects	Type of effect and scale	Conceptual model category (see Chapter 3 of the UKBWAP)	Monitoring method	References
Levees and berms in the floodplain	Levee removal, breaching, or setback	Changes in magnitude and duration of floodplain inundation	Direct, local	Floodplain-river connection	Hydraulic modeling, photopoints during high water periods	Opperman et al. 2009
		Riparian plant abundance/density	Indirect, local	Floodplain condition	Riparian canopy closure, dominant riparian land use/land cover, bank vegetative cover, bank erosion	Fitzpatrick et al. 1998
		Size of floodplain	Indirect, local	Floodplain condition	Hydraulic modeling	Opperman et al. 2009
		Number of LWD	Indirect, local	Native fish needs	LWD Survey	Schuett-Hames et al. 1999
		Fish prey abundance and diversity	Indirect, local	Native fish needs	Benthic macroinvertebrate surveys	Hayslip 2007, Britton and Greeson 1987
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Presence of overhanging vegetation	Indirect, local	Native fish needs	Survey of habitat cover features	Fitzpatrick et al. 1998
		Beaver activity	Indirect, local	Biological response	Presence, survival, density, aerial photography surveys	Pollock et al. 2014, Pollock et al. 2018
		Stream velocity	Indirect, local	Riverine process and function	Velocity measurements	Fitzpatrick et al. 1998
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Streambed elevation relative to floodplain	Iindirect, local	Riverine process and function	Cross sections	Harrelson et al. 1994
		Nutrient and sediment loads	Indirect, local (and watershed-scale)	Riverine process and function	Discrete point sampling, continuous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, Schenk et al. 2016
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
Wetland drainage	Restoration of natural wetlands	Soil moisture	Direct, local	Wetland condition	Soil moisture analyses	NRCS 1998, Schmugge et al. 1980
		Inundation depth	Direct, local	Wetland condition	Depth measurements, hydraulic modeling	Opperman et al. 2009
		Wetland plant abundance/density	Indirect, local	Wetland condition	Aerial surveys, vegetative cover	EPA 2002, adaptation of Fitzpatrick et al. 1998
		Groundwater elevation	Indirect, local	Wetland process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Instream cover	Indirect, local	Native fish needs	Habitat cover features	Fitzpatrick et al. 1998
		Fish prey abundance and diversity	Indirect, local	Native fish needs	Benthic macroinvertebrate surveys	Hayslip 2007, Britton and Greeson 1987
		LRS and SNS rearing habitat	Indirect, local	Native fish needs	Emergent wetland plant surveys	EPA 2002, adaptation of Fitzpatrick et al. 1998
		Sediment nutrient dynamics	Indirect, local	Bacterial response	Laboratory studies	Aldous et al. 2007
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Nutrient and sediment loads	Indirect, local (and watershed-scale)	Water quality	Discrete point sampling, continuous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, Schenk et al. 2016
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999

Impairment	Action	Quantifiable effects	Type of effect and scale	Conceptual model category (see Chapter 3 of the UKBWAP)	Monitoring method	References
Unmanaged (or improperly managed) riparian and floodplain grazing	Riparian and floodplain grazing management, fencing, and planting (if appropriate)	Riparian plant abundance/density	Direct, local	Riparian/floodplain condition	Riparian canopy closure, dominant riparian land use/land cover, bank vegetative cover, bank erosion, utilization (if grazing is occurring)	Fitzpatrick et al. 1998, Winward 2000, Scasta 2010
		Bank cover	Direct, local	Riparian/floodplain condition	Bank vegetative cover	Fitzpatrick et al. 1998
		Soil compaction	Direct, local	Riparian/floodplain condition	Soil compaction analyses	Soil Science Division Staff 2017
		Root strength and abundance	Indirect, local	Riparian/floodplain process	Bank erosion	Fitzpatrick et al. 1998
		Beaver activity	Indirect, local	Biological response	Presence, survival, density, aerial photography surveys	Pollock et al. 2014, Pollock et al. 2018
		Stream shading	Indirect, local	Riparian/floodplain process	Riparian canopy closure	Fitzpatrick et al. 1998
		Number of LWD	Indirect, local	Native fish needs	LWD Survey	Schuett-Hames et al. 1999
		Fish prey abundance and diversity	Indirect, local	Native fish needs	Benthic macroinvertebrate surveys	Hayslip 2007, Britton and Greeson 1987
		Presence of overhanging vegetation	Indirect, local	Native fish needs	Survey of habitat cover features	Fitzpatrick et al. 1998
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Streambed elevation relative to floodplain	Indirect, local	Riverine process and function	Cross sections	Harrelson et al. 1994
		Channel profile (width, depth)	Indirect, local	Riverine process and function	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
Irrigation tailwater returns	Diffuse Source Treatment Wetlands	Hydraulic residence time	Direct, local	Wetland process and function	Before and after comparison using hydraulic modelling	Stillwater Sciences 2020
		Groundwater elevation	Direct, local, site-dependent	Wetland process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and David 2017
		Nutrient and sediment loads	Indirect, local	Water qualtiy	Before and after comparison of nutrient and suspended sediment loads via discrete point sampling, continutous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, USGS, Fitzpatrick et al. 1998
		Thermal load	Indirect, local	Water quality	Before and after comparison of water temperature via discrete or continuous sensor measurements ; must include discharge measurement	ODEQ 2009, Turk and Water Dipper 2001, Fitzpatrick et al. 1998
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Algal productivity	Indirect, watershed-scale	Algal response	Phytoplankton abundance and presence, chlorophyll-*a* concentrations, secchi disk measurements	Wetzel and Likens 1991
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
	Irrigation efficiency/modernization	Decreased tailwater returns	Direct, local	N/A	Before and after comparison of discharge measurements	Fitzpatrick et al. 1998
		Nutrient and sediment loads	Indirect, local	Water qualtiy	Before and after comparison of nutrient and suspended sediment loads via discrete point sampling, continutous sensor measurements (for turbidity); must include discharge measurement	ODEQ 2009, USGS, Fitzpatrick et al. 1998
		Thermal load	Indirect, local	Water quality	Before and after comparison of water temperature via discrete or continuous sensor measurements ; must include discharge measurement	ODEQ 2009, Turk and Water Dipper 2001, Fitzpatrick et al. 1998
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, local (and watershed-scale)	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999

Impairment	Action	Quantifiable effects	Type of effect and scale	Conceptual model category (see Chapter 3 of the UKBWAP)	Monitoring method	References
Disconnection of off-channel springs from mainstem rivers and tributaries	Restored connection of off-channel springs to mainstem rivers and tributaries	Fish access to coldwater refugia	Direct, local	Native fish needs	Velocity, depth, discharge measurements (fish passage assessment)	ODFW 2006
		Groundwater contribution to streamflow	Direct, local	Riverine process and function	Discharge measurements (of spring contribution)	Fitzpatrick et al. 1998
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
Fish passage barriers	Mitigation or removal of fish passage barriers	Fish passage	Direct, local	Native fish needs	Velocity, depth, discharge measurements (fish passage assessment)	ODFW 2006, Ross Taylor and Associates 2015
		Channel gradient	Direct, local	Channel morphology	Longitudinal channel profile	Harrelson et al. 1994
		Channel profile (width, depth)	Direct, local	Channel morphology	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
		Local hydraulics (velocity, water surface elevation, etc.)	Indirect, local	Riverine process and function	Velocity, stage measurements	Fitzpatrick et al. 1998
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, local, watershed-scale	Water quality (local), Ecosystem response (watershed-scale)	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, local, watershed-scale	Riverine process and function (local), Ecosystem response (watershed-scale)	Suspended sediment load	Edwards and Glysson 1999
Roads and culverts	Road decommissioning (including removal or replacement of culverts)	Presence of impermeable surfaces, non-native materials (associated with road bed)	Direct, local	Upland condition	Survey extent of impermeable surfaces/non-native materials	N/A
		Soil compaction	Direct, local	Upland condition	Soil compaction analyses	Soil Science Division Staff 2017
		Fish passage	Direct, local	Native fish needs	Velocity, depth, discharge measurements (fish passage assessment)	ODFW 2006
		Channel gradient	Direct, local	Channel morphology	Longitudinal channel profile	Harrelson et al. 1994
		Channel profile (width, depth)	Direct, local	Channel morphology	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and David 2017
		Streambed elevation relative to floodplain	Indirect, local	Riverine process and function	Cross sections	Harrelson et al. 1994
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999

Impairment	Action	Quantifiable effects	Type of effect and scale	Conceptual model category (see Chapter 3 of the UKBWAP)	Monitoring method	References
Unscreened irrigation diversions	Installation of fish screens	Entrained fish	Direct, local	N/A	Electro-fishing, snorkel surveys, netting; occur behind (downstream of) fish screen	Johnson et al. 2007, Simpson and Ostrand 2012
		Fish populations	Indirect, watershed-scale	Ecosystem response	Electro-fishing, snorkel surveys, netting, PIT tags, rotary screw traps	Johnson et al. 2007, Simpson and Ostrand 2012
Lack of LWD	LWD placement, other actions that increase LWD recruitment	Channel profile (width, depth)	Direct, local	Channel morphology	Bankfull width-to-depth ratio, cross sections	Rosgen 1996; Harrelson et al. 1994
		Longitudinal channel profile	Direct, local	Channel morphology	Longitudinal channel profile	Harrelson et al. 1994
		Instream cover/habitat	Direct, local	Native fish needs	Habitat cover features	Fitzpatrick et al. 1998
		Substrate composition	Indirect, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Fish prey abundance and diversity	Indirect, local	Native fish needs	Benthic macroinvertebrate surveys	Hayslip 2007, Britton and Greeson 1987
		Streambed elevation relative to floodplain	Indirect, local	Riverine process and function	Cross sections	Harrelson et al. 1994
		Groundwater elevation	Indirect, local	Riverine process and function	Groundwater elevation survey	Nielsen 1991, USFS 2007, Cooper and Merritt 2012
		Hydrology (baseflow, hydrograph, magnitude of high and low flows)	Indirect, watershed-scale	Ecosystem response	Continuous stream discharge measurements	Turnipseed and Sauer 2010
		Water quality (nutrients, water temperature, DO concentrations, pH, etc.)	Indirect, watershed-scale	Ecosystem response	Discrete point sampling, continuous sensor measurements, load calculations	ODEQ 2009
		Geomorphology (sediment transport)	Indirect, watershed-scale	Ecosystem response	Suspended sediment load	Edwards and Glysson 1999
Lack or loss of spawning substrate	Gravel additions or other actions that affect substrate composition	Substrate composition	Direct, local	Native fish needs	Facies mapping, pebble counts	Buffington and Montgomery 1999, Wolman 1954, Kondolf 1997
		Fish populations	Indirect, watershed-scale	Ecosystem response	Electro-fishing, snorkel surveys, netting, PIT tags, rotary screw traps	Johnson et al. 2007, Simpson and Ostrand 2012

Appendix C- Stakeholder Outreach and Engagement Plan

Stakeholder Outreach and Engagement Plan

Appendix C to the Upper Klamath Basin Watershed Action Plan

Prepared by Klamath Watershed Partnership and Trout Unlimited
July 2022

Upper Klamath Basin Watershed Action Plan Overview

The purpose of the Upper Klamath Basin Watershed Action Plan (UKBWAP) is to inform effective and prioritized voluntary restoration activities in the UKB to restore riverine and riparian process and function; improve water quality; and restore habitat for native, endemic, and endangered species. Several past collaborative efforts between agencies, organizations, landowners, and Tribal governments, including the Upper Klamath Basin (UKB) Comprehensive Agreement, Total Maximum Daily Load (TMDL) documents, and Endangered Species Act (ESA) recovery plans, have identified the need for a plan to prioritize and implement restoration actions to support fish population recovery, water quality improvements, and recovery of wetland, floodplain, riparian, and riverine process and function in the UKB. Subsequent efforts identified lists of appropriate restoration projects, but the UKB restoration community has recognized the need for a cohesive, collaborative voluntary restoration strategy. The UKBWAP focuses on cooperative and voluntary restoration that benefits both the local rural economy and the ecosystem. Actions that require regulatory or management agency support for implementation, or are a result of legal, policy, or regulatory mandates (e.g., invasive fish removal, UKL lake level management), are not within the scope of the UKBWAP. Refer to the UKBWAP itself for additional information.

Stakeholder Outreach and Engagement Plan Purpose

Many of the areas in the UKB with the greatest restoration potential are on private lands. To achieve the goals of the UKBWAP, it is therefore critical that we develop collaborative relationships with private landowners to implement voluntary restoration on private lands. The UKBWAP Team[1] seeks opportunities to build landowner relationships, to provide technical assistance necessary to improve management practices, and to expand awareness of the work necessary to realize ecosystem and economic benefit throughout the watershed. The UKBWAP Team recognizes the need for coordinated education and outreach to reach identified conservation goals on private lands. This includes a coordinated outreach plan, with multiple messaging avenues, that will help move this community effort forward. The UKBWAP Team also plans to collaborate closely with other agencies and organizations in the UKB who were not

[1]Local restoration professionals including U.S. Fish and Wildlife Service, The Klamath Tribes, Trout Unlimited, Oregon Department of Environmental Quality, Klamath Watershed Partnership, The Nature Conservancy, and the North Coast Regional Water Quality Control Board.

a core part of UKBWAP development but play a critical role in outreach, planning, and implementation of restoration.

The collaborative nature of the UKBWAP and a coordinated outreach effort can overcome many obstacles by providing a service and a benefit to those landowners that might consider restoration on their land. The social, community, and environmental benefits of improved water quality, aquatic habitat, and water savings must be communicated in our restoration outreach efforts. The Stakeholder Outreach and Engagement Plan identifies the outreach actions necessary to implement the UKBWAP and realize economic and ecosystem benefits for the watershed, rural communities, and individual landowners.

Stakeholder Outreach and Engagement Actions

A successful and effective outreach and engagement effort must include a combination of broad and targeted outreach strategies. We also include here a list of specific action items and estimated completion dates; these are subject to change, particularly depending on the trajectory of the pandemic in 2022 and beyond.

Broad Marketing

Website: The UKBWAP Team developed a website in spring 2022 (www.ukbwap.com). This website provides access to the latest version of the UKBWAP, a brief summary of the UKBWAP, a link to the Interactive Reach Prioritization Tool (IRPT), and answers to frequently asked questions. The website will be maintained and updated as needed.

Outreach Events: Starting in 2022, the UKBWAP Team will participate in Producer Listening Sessions organized by our partners (primarily Sustainable Northwest). These outreach events will provide an opportunity to understand landowner needs and provide information about restoration opportunities in the UKB. These outreach events will occur approximately every 2 months.

Targeted Marketing

To facilitate targeted marketing, the UKBWAP Team developed the Restoration Priority List using publicly available data such as taxlot and water rights information, county records, and ecosystem conditions data in the IRPT. The Restoration Priority List allows the UKBWAP Team and other interested restoration professionals to prioritize targeted outreach efforts to landowners in areas with the greatest restoration potential and need. This tool is primarily a database but may also include a map component in the future.

The Restoration Priority List prioritizes private landowners with at least 1.0 miles of riverfront property in areas scoring a 4 for the “riparian and floodplain vegetation condition” metric. This metric can be used as a proxy for impairments to river process and function, which are arguably the impairments of greatest concern for water quality and habitat. The limitations of using this metric to prioritize landowners is that it does not directly reflect priority areas for large woody debris and spawning gravel placement, may not reflect the prevalence of disconnected springs, and does not include information about fish passage concerns. Regardless, the purpose of using these criteria (i.e., private land with at least 1.0 miles of river frontage in areas scoring a 4 for the "riparian and floodplain vegetation condition" metric) is simply to provide coherent and relevant means by which to distill a list of several hundred landowners in the UKB. This criteria is in no way binding or meant to limit outreach efforts; rather, it helps us strategically engage key landowners in high priority areas for restoration.

In-Person Meetings: One of the most effective ways to share information with landowners is through in-person meetings and site visits discussing and identifying opportunities for restoration and partnership. This type of outreach prioritizes landowners identified in the Restoration Priority List, and requires clear and frequent communication between UKBWAP Team members to ensure consistent messaging and approach.

Targeted Site Visits/Presentations: Working with landowners that have previously implemented restoration projects on their property, the UKBWAP Team will use the Restoration Priority List to identify others in the vicinity that may benefit from, or otherwise be interested in, restoration. There are numerous examples of successful and effective restoration projects on private lands in the UKB, and landowners are often excited to showcase restoration work completed on their properties. Providing opportunities for landowners to discuss their restoration work with neighbors is an effective method for generating interest in restoration, leading to collaborative relationships between restoration professionals and private landowners. Additionally, it allows neighbors that are interested but potentially hesitant about restoration on their properties to see how these projects are implemented and how they look once completed, and to meet local restoration professionals.

Action Items (2022 and beyond)

1. Develop the UKBWAP website – January 2022 (COMPLETED)
    - Web address: www.ukbwap.com

2. Restoration Priority List– May 2022 (COMPLETED)
    - Funding secured through OWEB
    - Identify points of contact from the restoration community (this will include UKBWAP Team members, and potentially external partners such as Natural Resources Conservation Service, Klamath County Soil and Water Conservation District, Sustainable Northwest, etc.) for each priority landowner identified in the Restoration Priority List.
    - Delegate outreach activities to these points of contact

3. Begin outreach per the Restoration Priority List – May 2022

4. Host three targeted site visits/presentations – no later than December 31, 2022

In addition to the specific action items to be completed in 2022, the UKBWAP Team will implement on-going efforts related to outreach and engagement. These include:

- Preparing materials, presentations, and contacts, and engaging landowners identified in the Restoration Priority List. We will request follow up and feedback from any landowners we engage with.

- Updating the UKBWAP website as new information is available, and as we receive feedback on the format and contents of the website. The UKBWAP Team will be responsible for website updates.

- Updating the Restoration Priority List as new information and data become available.

- Identifying funding sources for on-going UKBWAP-related work (maintaining and updating the UKBWAP website, IRPT, and Restoration Priority List).

- Tracking community response to our outreach and engagement efforts. Specifically, we will solicit feedback from landowners contacted as part of the targeted outreach effort.

- Following up with landowners, as deemed appropriate, with outreach mailings, emails, and site visits.

Additional Considerations

In addition to private landowners (the primary audience for outreach efforts described here), there are other stakeholders that may be interested in learning more about restoration implementation in the UKB. The UKBWAP Team will continue engaging funders and organizations not directly represented on the UKBWAP Team; this will be particularly effective once the website and outreach materials are developed.

Finally, restoration improvements can increase property value, improve efficiencies, and simplify management making farms and ranches more profitable. We also acknowledge that some projects may create challenges for landowners (e.g., capital costs, changes in agricultural operations, etc.). As such, communication and transparency about proposed restoration work, funding requirements, and potential changes to operations are critical. The UKBWAP Team seeks to incentivize restoration opportunities where policy allows but projects require long-term commitment on many levels. Strong, collaborative, and trusting relationships with private landowners are necessary to create sustainable projects that ultimately achieve the goals of the UKBWAP.

Appendix D- Interactive Reach Prioritization Tool Methods Development

Interactive Reach Prioritization Tool Methods Development

Overview

This document outlines the GIS geoprocessing steps used to generate the stream and shoreline reach-scale impairment metrics (and supporting information) used within the Interactive Reach Prioritization Tool described in Chapter 4 of the Upper Klamath Basin Watershed Action Plan (UKBWAP). The intent of this document is to enable replication of the methods applied by GIS specialists and is written for a technical audience. Users interested in the general analytical approach and rationale behind the impairment metrics are encouraged to consult the UKBWAP.

The first section of this document describes analyses conducted by Trout Unlimited (TU) GIS staff in 2020 to update or generate new impairment metrics and supporting information for the UKBWAP. In many cases, those metrics rely on data generated for earlier versions of the UKBWAP by FlowWest staff in 2017. FlowWest methods are provided in Attachment A, in the second portion of this document.

2020 Impairment Metrics Methods

Trout Unlimited GIS staff developed stream and shoreline impairment metrics using a mix of FlowWest data from 2017, expert opinion, and new analyses. GIS methods for calculating the metrics are described below. Unless otherwise noted, TU used ArcGIS Pro software (version 2.6; ESRI, Redlands, California) to conduct the analyses and created Toolbox Models to facilitate repetition and update of the methods. A file geodatabase containing those Models is available for download here.

Channelization

TU used a shapefile representing known channel alignment modifications provided by FlowWest to generate the channelization metric. In late 2021, TU updated the Channelization metric in Brown Creek and Paradise Creek by digitizing channelized reaches from available 1956 aerial imagery. TU used the following general geoprocessing steps.

1. Buffer stream reaches by 100 meters on each side.
2. Sum the lengths of channel alignment modification features for each buffered reach in meters.
3. Divide the total length of alignment modifications by the total length of each reach.
4. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model “channelization”.

Channel Incision

TU used ArcGIS Pro and Lidar data to generate the channel incision metrics. TU used the following general geoprocessing steps.

1. Download individual Lidar datasets from State of Oregon Department of Geology and Mineral Industries Lidar viewer.
2. Import the individual datasets into a raster mosaic for 3 portions of the UKBWAP assessment area (Wood, Sycan, and Sprague rivers). Three separate datasets are required to accommodate the file size of the Lidar data and differences in acquisition characteristics, such as timing and horizontal/vertical value units (foot vs. meter). In late 2021, TU updated the Channel Incision metric and created a new mosaic for areas in the Upper Sprague and adjacent to Upper Klamath Lake where Lidar data was newly available.
3. Use the raster mosaic to generate a slope raster (percent rise).
4. Identify those portions of the slope raster with values greater than 35%, convert to polygons representing high slope areas, and calculate area of the polygons.
5. Select those high slope polygons with an area greater than 400 square meters and extract the elevational range within those polygons (i.e., the incision depth, or the maximum elevation minus minimum elevation) from the Lidar data.
6. Calculate the area within a variable width buffer of each stream reach that overlaps with a high slope polygon and the average incision depth within the portions of the high slope polygons that overlap the stream buffer. A standard 25 meter buffer was applied to all reaches except higher order portions of the Williamson, Sprague, and Wood rivers, where 50 meter buffers were applied (Fourmilecanal segments 3 - 6; sevenmilecanal segment 3; Sprague segments 33 - 78; sycan segments 3 - 6; Williamson segments 21 - 24) or 75 meter buffers were applied (Sprague segments 3 - 30; Williamson segments 3 – 18; Williamsonsidechannel segment 3).
7. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Models "Area_incised_Sprague_Lidar_in_meters", Area_incised_Sycan_Lidar_in_feet", and Area_incised_Wood_Lidar_in_feet".

Levees and Berms

TU used a shapefile representing levees and berms, or 'flow obstructions' provided by FlowWest to generate the channelization metric. In late 2021, TU updated the Levees and Berms metric by digitizing features from newly available Lidar for areas in the Upper Sprague and adjacent to Upper Klamath Lake. TU used the following general geoprocessing steps.

1. Buffer stream reaches by 250 meters on each side.
2. Sum the length of levees and berms in meters within each buffered stream reach, for each side.
3. Divide total length of levees and berms on each side by total reach length in meters.

4. Calculate minimum distance in meters from levees and berms to stream channel on each side.
5. Calculate average distance in meters from stream channel to far edge of floodplain on each side.
6. Sum distance for each side from levees and berms to stream channel.
7. Sum distance for each side from stream channel to far edge of floodplain.
8. Divide summed distance from levees and berms to stream channel by summed distance from stream channel to far edge of floodplain.
9. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model "levees and berms".

Wetlands

TU applied expert opinion scores for UKL shoreline segments to generate the wetlands metric. A panel of four experts provided scores 1 (good) to 4 (poor) for each reach and those scores were averaged by reach.

Riparian and Floodplain Vegetation

TU used Google Earth Engine to calculate the vegetation type within floodplains. Floodplains were defined based on a variable width buffer of the stream reach centerline, with a standard 25 meter buffer applied to all reaches except higher order portions of the Williamson, Sprague, and Wood rivers, where 50 meter buffers were applied (Fourmilecanal segments 3 - 6; sevenmilecanal segment 3; Sprague segments 33 - 78; sycan segments 3 - 6; Williamson segments 21 - 24) or 75 meter buffers were applied (Sprague segments 3 - 30; Williamson segments 3 – 18; Williamsonsidechannel segment 3). TU originally evaluated a number of Landsat-derived land cover classification products, including the National Land Cover Dataset, Landfire, and Oregon's Statewide Habitat map, but determined that the spatial resolution of those products (30 x 30 meter pixels) was too coarse for identifying the conditions of interest in the riparian areas. To address the need for a higher spatial resolution, TU used USDA National Agricultural Imagery Program (NAIP) aerial photographs, which have a 1 x 1 meter spatial resolution (pixel size) in conjunction with the Google Earth Engine analytical platform. Google Earth Engine is a cloud-based remote sensing tool well suited for analyzing large datasets. At the time of analysis, the most recent NAIP imagery available in Google Earth Engine were from 2016.

Within Google Earth Engine, TU used the following JavaScript code to reclassify USDA NAIP imagery as mesic vegetation, xeric vegetation, bare ground, or open water based on NDVI or infrared band values. Output from this analysis was summarized within each buffer as the percentage of mesic vegetation within the terrestrial portions of the buffer (i.e., excluding open water from the calculation).

```
//Load buffered reaches
```

```
var fc = ee.FeatureCollection("users/kurtfesenmyer/KlamReal");

//Load NAIP imagery and select 2016
var collection = ee.ImageCollection('USDA/NAIP/DOQQ');
var collection_nrg = collection
  .filter(ee.Filter.listContains('system:band_names', 'N'));
var date = 2016

//Reduce NAIP collection to a single image with the max and add to map
var coll_nrg = collection_nrg.filterDate(date + '-01-01', date + '-12-31').max();
//Calculate NDVI
var naip_ndvi = coll_nrg.normalizedDifference(['N', 'R']);

//Classify:
//Mesic = 2 = NDVI > 0.3;
//Xeric = 0 = NDVI <= 0.3 and >= 0.05
//Bare = 10 = NDVI < 0.05
//Water = 11, 1 = IR (infrared) < 65
var ndvi_t = ee.Image(2).where(naip_ndvi.lte(0.30),0);
//NDVI threshold 0.05 both years
var bare_t = ee.Image(10).where(naip_ndvi.gte(0.05),0);
// IR water threshold for 2009: 100 ; for 2013: 65;
var ir = coll_nrg.select('N');
var water_t = ee.Image(1).where(ir.gte(65),0);
var output = (water_t.add(ndvi_t).add(bare_t));

// calculate count of pixels by type within each buffer
var count = fc.map(function(feature) {
  var cnt = output.reduceRegion(ee.Reducer.frequencyHistogram().unweighted(),
feature.geometry(),1);
  return feature.set ({'mean': cnt});
});

//export counts to a csv
print(ee.FeatureCollection(count)
 .getDownloadURL('csv', ['segmentID','mean'],'naip'));
```

Irrigation Practices

TU applied expert opinion scores for UKL shoreline segments to generate the irrigation practices metric. A panel of five experts provided scores 1 (good) to 4 (poor) for each reach and those scores were averaged by reach.

For stream reaches, this metric currently only accounts for the density of return points within each stream reach and does not include other information about irrigation practices. TU used a shapefile representing irrigation returns provided by FlowWest (covering the Williamson and Sprague sub-basins), supplemented by a shapefiles developed by TU representing irrigation returns in the Wood River valley to generate the irrigation practices metric for UKB stream reaches. TU used the following general geoprocessing steps.

1. Select only irrigation returns from the FlowWest shapefile, which also included diversions.
2. Merge FlowWest irrigation returns with TU Wood River valley irrigation returns.
3. Sum the count of irrigation returns by UKB stream reaches.
4. Divide the count of irrigation returns by total length in meters of each reach.
5. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model "irrigation practices".

SPRINGS

TU applied expert opinion scores for UKB stream reaches to generate the springs metric. A panel of four experts provided scores 1 (good) to 4 (poor) for each reach and those scores were averaged by reach.

FISH PASSAGE

TU used a shapefile representing known fish passage barriers developed by TU staff to generate the fish passage metric. TU used the following general geoprocessing steps.

1. Sum count of fish passage barriers by stream reach.
2. Assign a multiplier to each stream reach based on National Hydrography Dataset Plus stream level to more heavily weight larger, more downstream reaches.
    a. Stream level 1 multiplier: 3
    b. Stream level 2 multiplier: 2
    c. Stream level 3+ multiplier: 1
3. Multiply count of fish passage barriers by stream level multiplier.
4. Divide weighted count of fish passage barriers by stream reach length in meters.
5. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model "fish passage".

ROADS

TU used a geodatabase feature class representing roads provided by Oregon Department of Transportation to generate the roads metric. TU used the following general geoprocessing steps.

1. Buffer stream reaches by 100 meters on each side.
2. Select all roads except federal and state highways.
3. Sum length of selected roads in miles within 100-meter buffer by reach.
4. Divide summed length of roads within each buffered stream reach by the area in square miles of each buffered stream reach.
5. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model "roads".

Fish Entrainment

TU used a shapefile of diversions in the Wood River valley developed by TU staff as well as a table of diversion locations in the remainder of the UKB developed by FlowWest to generate the fish entrainment metric. TU used the following general geoprocessing steps.

1. Merge TU and FlowWest diversion datasets.
2. Apply an entrainment score to each diversion according to the presence of a screen on the diversion.
    a. Screeened: 0
    b. Unknown: 1
    c. Unscreened: 2
3. Sum the scored screens by stream reach.
4. Divide the summed screen scores by reach length in meters.
5. Attribute reaches with this information.

These steps are additionally documented in the Toolbox Model "fish entrainment".

Large Woody Debris

TU applied expert opinion scores for UKB stream reaches and UKL shoreline reaches to generate the large woody debris metric. Experts provided scores 1 (good) to 4 (poor) for each reach. The same three experts provided scores for UKB stream reaches and UKL shoreline segments. The UKL scores were averaged by shoreline segment.

Spawning substrate

TU applied expert opinion scores for UKB stream reaches and UKL shoreline reaches to generate the spawning substrate metric. Experts provided scores 1 (good) to 4 (poor) for each reach. Three experts provided scores for UKB stream reaches, and four experts provided scores for UKL shoreline segments. The UKL scores were averaged by segment.

2020 Beaver Dam Suitability Methods

TU created a beaver dam suitability layer for all National Hydrography Dataset Plus HR stream reaches in the UKB. This layer is not integrated into the impairment metrics scoring schema, rather is intended to serve as a reference layer to help inform restoration activities identified by the UKBWAP.

To create the beaver dam suitability layer, TU adapted the general modeling framework presented in Macfarlane et al. (2017), which predicts where and at what densities beaver dams can be built within riverscapes based on immutable factors (i.e., stream slope and stream power) and factors subject to land management (i.e., vegetation). For the UKB, TU focused solely on immutable factors for beaver dam suitability in acknowledgement of restoration approaches that do not require beaver to create stream habitat enhancements provided by beaver dams (e.g., beaver dam analogues [BDAs], post-assisted log structures [PALSs]).

TU characterized stream reaches based on the following rulesets:

- Stream slope as % (National Hydrography Dataset Plus HR attribute): 0 – 0.55 (Really flat); 0.5 – 15% (Can build dam); 15 – 23% (Probably can build dam); > 23% (Cannot build a dam)

- Drainage area in square kilometers (National Hydrography Dataset Plus HR attribute): 0 – 10000 (Can build a dam); > 10000 (Cannot build a dam)

- Baseflow stream power in watts/m: 0 – 175 (Can build a dam); 175 – 190 (Probably can build a dam); > 190 (Cannot build a dam). Baseflow stream power in watts/m is calculated based on this formula: (Reach drainage area/Gage drainage area) * Gage August 80% base flow. Gage drainage area and baseflow values are available via USGS StreamStats (https://streamstats.usgs.gov/ss/)

- Q2 (2-year interval flood) stream power in watts/m: 0 – 1000 (Dam persists); 1000 – 1200 (Occasional breach); 1200 – 2000 (Occasional blowout); > 2000 (Blowout). Q2 stream power in watts/m is calculated based on this formula: (Reach drainage area/Gage drainage area) * Gage Q2 flow. Gage drainage area and Q2 values are available via USGS StreamStats (https://streamstats.usgs.gov/ss/)

- Dam suitability:

Slope category	Drainage area category	Baseflow category	Q2 flow category	Beaver dam suitability
No dam	-	-	-	None
-	No dam	-	-	None

-	-	No dam	-	None
-	-	-	blowout	None
can build	can build	can build	dam persists	High
probably build	can build	can build	dam persists	Moderate
flat	can build	can build	dam persists	High
can build	can build	can build	occasional breach	Moderate
probably build	can build	can build	occasional breach	Low
flat	can build	can build	occasional breach	Moderate
can build	can build	can build	occasional blowout	Low
probably build	can build	can build	occasional blowout	Very low
flat	can build	can build	occasional blowout	Low
can build	can build	probably build	dam persists	Moderate
probably build	can build	probably build	dam persists	Low
flat	can build	probably build	dam persists	Moderate
can build	can build	probably build	occasional breach	Low
probably build	can build	probably build	occasional breach	Very low
flat	can build	probably build	occasional breach	Low
can build	can build	probably build	occasional blowout	Very low
probably build	can build	probably build	occasional blowout	Very low
flat	can build	probably build	occasional blowout	Very low

Below is the Python code TU used to map beaver dam suitability for National Hydrography Dataset Plus HR reaches.

```
#Purpose: Generate BRAT-like attributes rapidly using NHDPlus HR attributes

import arcpy
arcpy.env.overwriteOutput = True

# Variables - NHD Plus HR Flowline and FlowlineVAA table; reference basin drainage
#area in sqkm, Aug 80% low flow, Q2 flood flow from USGS StreamStats
BRAT_flowlines = r"C:\Users\kurt.fesenmyer\OneDrive - Trout
Unlimited\Kurt_GIS\Else\Klamath_watershed_plan\Klamath_WAP.gdb\BRAT_flowline
s"
NHDPlusFlowlineVAA =
r"H:\Reference_datasets\NHDPlus_HR\NHDPLUS_H_1801_HU4_GDB\NHDPLUS_H
_1801_HU4_GDB.gdb\NHDPlusFlowlineVAA"

# Process: use Join Fields to add Drainage Area and Slope attributes from FlowlineVAA
table to NHD Plus HR Flowline
```

```
#BRAT_flowlines_3_ = arcpy.management.JoinField(in_data=BRAT_flowlines,
in_field="NHDPlusID", join_table=NHDPlusFlowlineVAA, join_field="NHDPlusID",
fields=["TotDASqKm", "DivDASqKm", "Slope"])[0]

# Process: add and calculate slope field with no 0 values
codeblock0 = """
def Reclass(Slope):
    if Slope < 0.001:
        return 0.001
    else:
        return float(Slope)"""

BRAT_flowlines_9_ = arcpy.management.CalculateField(in_table=BRAT_flowlines,
field="Geo_slope", expression="Reclass(!Slope!)", expression_type="PYTHON_9.3",
code_block=codeblock0)[0]

# Process: add and calculate low flow in CFS using reference basin drainage area in
sqkm, Aug 80% low flow from USGS StreamStats
BRAT_flowlines_8_ = arcpy.management.CalculateField(in_table=BRAT_flowlines_9_,
field="Hyd_QLow", expression="(!TotDASqKm!/157.471392)*6",
expression_type="PYTHON_9.3", code_block="")[0]

# Process: add and calculate Q2 flow in CFS using reference basin drainage area in sqkm,
Q2 flood flow from USGS StreamStats
BRAT_flowlines_4_ = arcpy.management.CalculateField(in_table=BRAT_flowlines_8_,
field="Hyd_Q2", expression="(!TotDASqKm!/157.471392)*183",
expression_type="PYTHON_9.3", code_block="")[0]

# Process: add and calculate low flow stream power in Watts/m
BRAT_flowlines_5_ = arcpy.management.CalculateField(in_table=BRAT_flowlines_4_,
field="Hyd_SPLow",
expression="(1000*9.80665)*!Geo_slope!*!Hyd_QLow!*0.028316846592",
expression_type="PYTHON_9.3", code_block="")[0]

# Process: add and calculate Q2 stream power in Watts/m
BRAT_flowlines_7_ = arcpy.management.CalculateField(in_table=BRAT_flowlines_5_,
field="Hyd_SPQ2",
expression="(1000*9.80665)*!Geo_slope!*!Hyd_Q2!*0.028316846592",
expression_type="PYTHON_9.3", code_block="")[0]

# Process: add and calculate slope categorical score
codeblock = """
def Reclass(Geo_slope):
    if Geo_slope < 0.05:
        return 'flat'
    elif (Geo_slope >=0.05 and Geo_slope <15):
```

```
        return 'can build'
    elif (Geo_slope >= 15 and Geo_slope <= 23):
        return 'probably build'
    elif Geo_slope > 23:
        return 'no dam'
    else:
        return 'missing'"""
BRAT_flowlines_10_ =
arcpy.management.CalculateField(in_table=BRAT_flowlines_7_, field="Cat_Slope",
expression="Reclass(!Geo_slope!)", expression_type="PYTHON_9.3", code_block =
codeblock)[0]

# Process: add and calculate drainage area categorical score
codeblock1 = """
def Reclass(TotDASqKm):
    if TotDASqKm <= 10000:
        return "can build"
    elif TotDASqKm > 10000:
        return 'no dam'
    else:
        return 'missing'"""
BRAT_flowlines_11_ =
arcpy.management.CalculateField(in_table=BRAT_flowlines_10_, field="Cat_DA",
expression="Reclass(!TotDASqKm!)", expression_type="PYTHON_9.3", code_block =
codeblock1)[0]

# Process: calculate low flow stream power score
codeblock2 = """
def Reclass(Hyd_SPLow):
    if Hyd_SPLow < 175:
        return 'can build'
    elif (Hyd_SPLow >= 175 and Hyd_SPLow < 190):
        return 'probably build'
    elif Hyd_SPLow >= 190:
        return 'no dam'
    else:
        return 'missing'"""
BRAT_flowlines_12_ =
arcpy.management.CalculateField(in_table=BRAT_flowlines_11_, field="Cat_QLow",
expression="Reclass(!Hyd_SPLow!)", expression_type="PYTHON_9.3", code_block =
codeblock2)[0]

# Process: add and calculate SP2 flow stream power score
codeblock3 = """
def Reclass(Hyd_SPQ2):
    if Hyd_SPQ2 < 1000:
```

```
        return 'dam persists'
    elif (Hyd_SPQ2 >= 1000 and Hyd_SPQ2 < 1200):
        return 'occasional breach'
    elif (Hyd_SPQ2 >= 1200 and Hyd_SPQ2 < 2000):
        return 'occasional blowout'
    elif Hyd_SPQ2 >= 2000:
        return 'blowout'
    else:
        return 'missing'"""
BRAT_flowlines_13_ =
arcpy.management.CalculateField(in_table=BRAT_flowlines_12_, field="Cat_Q2",
expression="Reclass(!Hyd_SPQ2!)", expression_type="PYTHON_9.3", code_block =
codeblock3)[0]

# Process: add and calculate combined final score but without consideration of vegetation
factors
codeblock8 = """
def Reclass(Cat_DA,Cat_Slope,Cat_QLow,Cat_Q2):
    if (Cat_QLow == 'no dam'):
        return "None"
    elif (Cat_Slope == 'no dam'):
        return "None"
    elif (Cat_DA == 'no dam'):
        return "None"
    elif (Cat_Q2 =='blowout'):
        return "None"
    elif (Cat_QLow =='can build' and Cat_Q2 =='dam persists' and Cat_Slope=='can
build'):
        return 'High'
    elif (Cat_QLow =='can build' and Cat_Q2 =='dam persists' and Cat_Slope=='probably
build'):
        return 'Moderate'
    elif (Cat_QLow =='can build' and Cat_Q2 =='dam persists' and Cat_Slope=='flat'):
        return 'High'
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional breach' and Cat_Slope=='can
build'):
        return 'Moderate'
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional breach' and
Cat_Slope=='probably build'):
        return 'Low'
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional breach' and
Cat_Slope=='flat'):
        return 'Moderate'
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='can build'):
        return 'Low'
```

```
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='probably build'):
        return 'Very low'
    elif (Cat_QLow =='can build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='flat'):
        return 'Low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='dam persists' and Cat_Slope=='can
build'):
        return 'Moderate'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='dam persists' and
Cat_Slope=='probably build'):
        return 'Low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='dam persists' and
Cat_Slope=='flat'):
        return 'Moderate'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional breach' and
Cat_Slope=='can build'):
        return 'Low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional breach' and
Cat_Slope=='probably build'):
        return 'Very Low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional breach' and
Cat_Slope=='flat'):
        return 'Low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='can build'):
        return 'Very low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='probably build'):
        return 'Very low'
    elif (Cat_QLow =='probably build' and Cat_Q2 =='occasional blowout' and
Cat_Slope=='flat'):
        return 'Very low'
    else:
        return 'missing'"""
BRAT_flowlines_17_ =
arcpy.management.CalculateField(in_table=BRAT_flowlines_16_,
field="Cat_DamCapNV",
expression="Reclass(!Cat_DA!,!Cat_Slope!,!Cat_QLow!,!Cat_Q2!)",
expression_type="PYTHON_9.3", code_block = codeblock8)[0]
```

ATTACHMENT A – 2017 IMPAIRMENT METRICS METHODS

Restoration Opportunities Analysis (ROA): Task III

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DATE:	8/24/2017

THE SOUTH FORK SPRAGUE RIVER AT IVORY PINE ROAD.

CONTENTS

PURPOSE

The Restoration Opportunities Analysis (ROA) is the first step in identifying site-specific restoration actions and is part of concurrent planning efforts in the Upper Klamath Basin. The ROA is a component of the larger Sprague Basin Aquatic Adaptive Restoration Guide (AARG) and Upper Klamath Basin Watershed Action Plan, which are intended to inform restoration actions in the Upper Klamath Basin. ROAs will identify specific locations for restoration actions in the Upper Klamath Basin. These sites will provide significant opportunities to address key restoration goals in the watershed, specifically: improving instream water quality, restoring in-channel flow, increasing groundwater supply, and restoring plant diversity in riparian habitat. ROA Task I identified flow obstructions along the Sprague River where the channel is disconnected from the floodplain. ROA Task II built on the data collected for the flow obstructions analysis and identified restoration opportunities on the Sprague River, North Fork Sprague, South Fork Sprague, and Sycan River through (1) locating of irrigation diversion and return points, (2) identification of upland areas converted to juniper dominated communities, and (3) identification of stream reaches with straightened channels.

ROA Task III further builds on the geospatial analyses completed in Tasks I and II, and incorporates the following into GIS data layers:

- Canal and irrigation ditch networks in the Sprague River Tributaries and Williamson River basins;
- Location of direct irrigation returns to streams in the Sprague River tributaries (excluding the North and South Fork Sprague River and the Sycan River) and Williamson River basin;
- Location of water diversions in the Williamson River basin and Sprague River tributaries (excluding the North and South Fork Sprague River and the Sycan River), which would be candidates for screening designed to reduce fish entrainment;
- Location of berms, levees, and dikes that may be candidates for removal/set-back/breaching to facilitate floodplain reconnection in the Wood River Valley, Williamson River basin, and Sprague River tributaries (excluding the North and South Fork Sprague River and the Sycan River); and,
- Stream reaches with straightened channels that may be candidates for channel reconfiguration projects in the Wood River Valley, Williamson River basin, and Sprague River tributaries (excluding the North and South Fork Sprague River and the Sycan River).

Table 1 describes each water body within the spatial scope of the study, and the associated analyses completed for the water body. The ROA Task III spatial scope includes the additional rivers and creeks within the watersheds shown in Figure 1.

TABLE 1: MAPPING TASKS COMPLETED PER WATER BODY FOR ROA TASK III.

Watershed	Creek	Extent (from confluence to extent boundary in River Miles)	Canal and Irrigation Network Mapping	Direct Irrigation Returns Mapping	Water Diversion Mapping	Berm, Levee, and Dike Mapping	Historical Channel Change Mapping
Sprague	Blue Creek	0.9	ROA III	ROA III	ROA III	ROA III	ROA III
	Brown Creek	6.8	ROA III	ROA III	ROA III	ROA III	ROA III
	Brown Spring Creek	Entire reach (1.2)	ROA III	ROA III	ROA III	ROA III	ROA III
	Copperfield Creek	2.0	ROA III	ROA III	ROA III	ROA III	ROA III
	Deming Creek	2.1	ROA III	ROA III	ROA III	ROA III	ROA III
	Fishhole Creek	12.0	ROA III	ROA III	ROA III	ROA III	ROA III
	Fivemile Creek	9.0	ROA II/III	ROA II/III	ROA II/III	ROA I/II/III	ROA III
	Ish Tish Creek	0.9	ROA III	ROA III	ROA III	ROA III	ROA III
	Meryl Creek	3.7	ROA III	ROA III	ROA III	ROA III	ROA III
	North Fork Sprague	11.0	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III*
	Paradise Creek	4.7	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III
	Pole Creek	1.1	ROA III	ROA III	ROA III	ROA III	ROA III
	Snake Creek	1.9	ROA III	ROA III	ROA III	ROA III	ROA III
	South Fork Sprague	12.6	ROA I/II	ROA I/II	ROA I/II	ROA I/II	ROA I/II
	Sprague River	Entire reach (108.2)	ROA I/II	ROA I/II	ROA I/II	ROA I/II	ROA I/II
	Sycan River	12.9	ROA I/II	ROA I/II	ROA I/II	ROA I/II	ROA I/II*
	Trout Creek	12.0	ROA III	ROA III	ROA III	ROA III	ROA III
	Whisky Creek	9.2	ROA III	ROA III	ROA III	ROA III	ROA III
	Whitehorse Spring Creek	1.9	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III	ROA I/II/III
Williamson	Larkin Creek	2.9	ROA III	ROA III	ROA III	ROA III	ROA III
	Williamson	46.7	ROA III	ROA III	ROA III	ROA III	ROA III
	Spring Creek	2.5	ROA III	ROA III	ROA III	ROA III	ROA III
	Sunnybrook Creek	0.6	ROA III	ROA III	ROA III	ROA III	ROA III

Watershed	Creek	Extent (from confluence to extent boundary in River Miles)	Canal and Irrigation Network Mapping	Direct Irrigation Returns Mapping	Water Diversion Mapping	Berm, Levee, and Dike Mapping	Historical Channel Change Mapping
	Upper Williamson	41.8	ROA III	ROA III	ROA III	ROA III	ROA III*
Wood River Valley	Agency Creek	0.8		**	**	ROA III	ROA III
	Annie Creek	6.7		**	**	ROA III	ROA III
	Crane Creek	4.3		**	**	ROA III	ROA III
	Crooked Creek	12.0		**	**	ROA III	ROA III
	Fort Creek	4.3		**	**	ROA III	ROA III
	Fourmile Creek	13.4		**	**	ROA III	ROA III
	Larkin Creek	2.9		**	**	ROA III	ROA III
	Sevenmile Creek	23.0		**	**	ROA III	ROA III
	Sun Creek	0.5		**	**	ROA III	ROA III
	Wood River	23.7		**	**	ROA III	ROA III*

Notes: * Analysis extends past project boundary; **Analysis completed by Trout Unlimited.

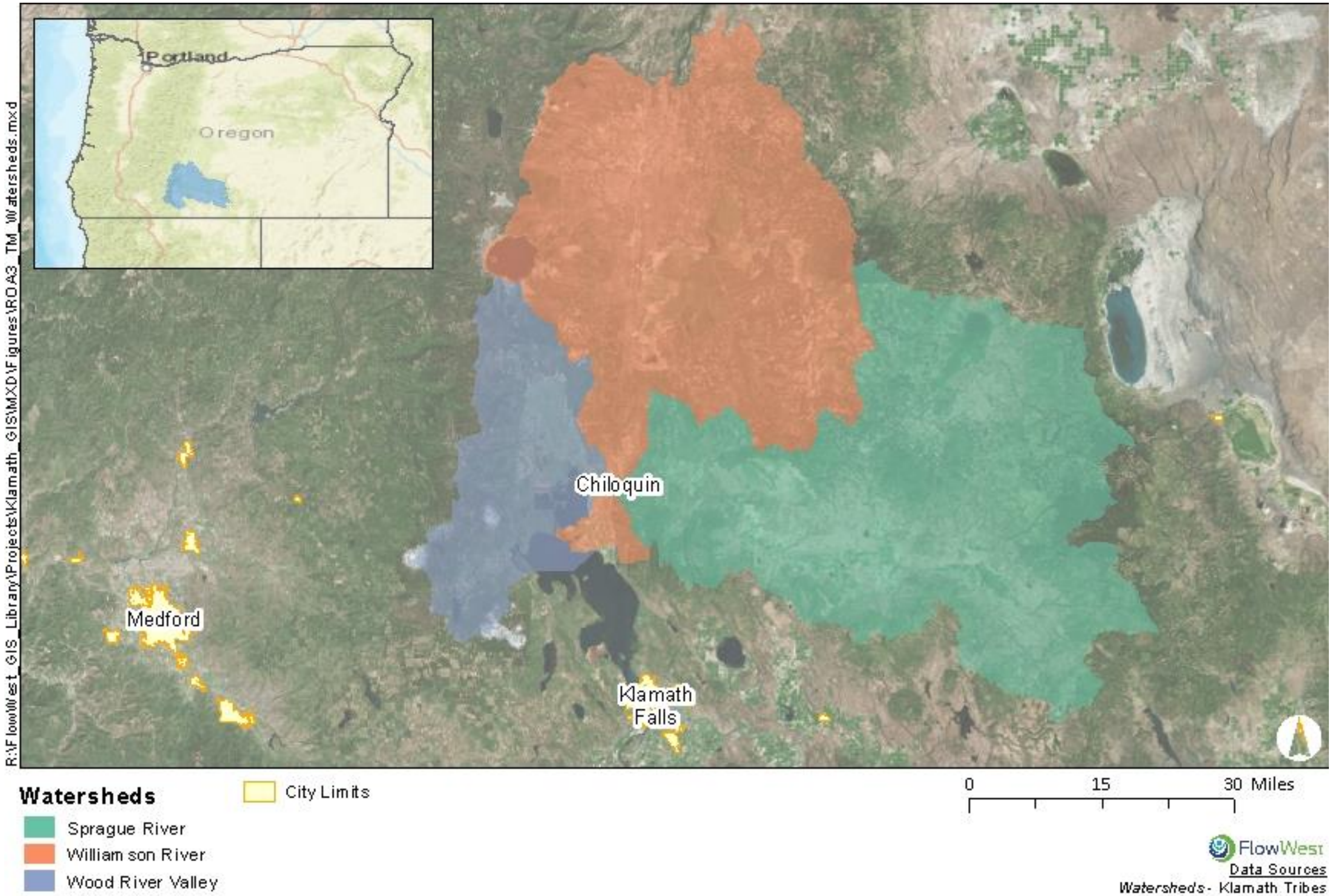

FIGURE 1: STUDY AREA WATERSHEDS.

As the Klamath Tribes assess and prioritize potential restoration actions in the Upper Klamath Basin, identifying locations where channel alignment has changed over time provides important context for future restoration actions. In our analysis we identified changes in alignment for flood control, irrigation, and agricultural production. These locations are high priority sites for restoration to restore geomorphic processes. We also identified many meander cutoffs that require additional analysis to determine why wide spread channel simplification has occurred. By understanding these changes, restoration mangers can design more sustainable restoration projects. Reduction of channel erosion and incision is important for both riparian and aquatic habitat for species of concern and to improve water quality. The soils in the Upper Klamath Basin are naturally rich in phosphorus and channel erosion contributes to the phosphorus load into Upper Klamath and Agency Lakes. This dataset of provides the first step in identification and prioritization of channel related restoration sites in the basin.

Flow obstructions were initially collected into a geospatial database in ROA Task I. These polyline features are defined as an artificial embankment or structure constructed in the floodplain or along the channel banks that prevents floodwaters from spreading out onto the floodplain. Initially, the focus of the flow obstruction identification was predominately levees, but our analysis shows that many other floodplain features direct, confine, and/or obstruct flow. These structures include levees, berms, canals, ditches, irrigation structures, paved and dirt roads (active and abandoned), railroad beds (active and abandoned), and residential or agricultural development. The geodatabase flow obstruction feature class identifies and geolocates each obstruction, and contains attribute information of the physical characteristics of each obstruction. This information can be used by restoration managers to identify areas to implement restoration projects, and the breadth of attribution within the database can be used to filter the obstructions in various ways to aid in prioritization of restoration activities.

The identification of irrigation diversion and return points has been a critical aspect of the ROA analysis, as many agricultural and ranching operations are located near the creeks of the Sprague, Upper and Lower Williamson River basins, in addition to the mainstems. These points are of interest for restoration purposes for several reasons. Untreated agricultural return flows increase the phosphorus and other nutrient loading into Upper Klamath Lake, and increase instream water temperatures—negatively impacting water quality for aquatic species. Unscreened diversions can result in juvenile and adult trout and sucker species entrainment in irrigation canals. Furthermore, these points are often associated with structures that interrupt and modify natural geomorphic and hydrologic processes by limiting overbank flow and floodplain deposition. The associated polyline structures are identified in the companion database of flow obstruction features. Irrigation diversion and return points in the Wood River Valley were excluded from this work, as the identification of those features was completed by a collaborator (Trout Unlimited). Identification of these features will aid in planning restoration actions targeting issues imposed by agricultural return flows and irrigation diversion infrastructure.

DATA ACQUISITION & INTEGRATION

Straightened Channel Identification

We used the USGS EarthExplorer website to identify and download single frame aerial photography for the Williamson River, Sprague River Tributaries, and Wood River Valley regions. We downloaded the oldest aerial imagery datasets available for the project reaches. In addition to the historical aerial images we also downloaded and rectified historical topographic maps from 1897 and 1965. We georeferenced the historical images using the ESRI Georeferencing tool in ArcMap 10.5. The fit of the control points is determined by observing changes in the residual for each point given the influence of the other control points, and by the root mean square (RMS) of all control points. Although the residuals were kept under 2.0 meters and the RMS was kept below 1.5 meters, the current channel centerline rarely fit the creeks in the historical images over the entire extent of each image. We were unable to completely correct the distortion of the historical images, but were able to use the georeferenced images to identify changes in channel alignment based on the pattern of the current channel centerline and the georeferenced images. In images where a project creek only covered a portion of the historical image, we georeferenced only the portion of the historical images near the project creek. This often resulted in the further distorting the historical image at the opposite side of the image. We used National Agriculture Imagery Program (NAIP) imagery from 2014 to georeference the historical images. We also used channel centerlines digitized by the Klamath Tribes from the NAIP (2014) imagery during the georeferencing process. A summary of the historical images used in this analysis and the spatial extent of each by river is shown in Table 2.

TABLE 2: SPATIAL EXTENT FOR HISTORIC CHANNEL DATA.

River/Creek	Format	Month	Year	Scale	Source	Extent
Western Wood River Valley	Map		1897	1:250,000	USGS TopoView	Entire area
	Map		1955	1:62,000	USGS TopoView	Entire area
	Aerial Photo	July	1953	1:37,400	USGS Earth Explorer	Western portion of Annie Creek, Seven and Four Mile Creek
Eastern Wood River Valley	Map		1897	1:250,000	USGS TopoView	Entire area
	Map		1955	1:62,000	USGS TopoView	Entire area
	Aerial Photo	July	1955	1:37,400	USGS Earth Explorer	Eastern portion of Seven and Four Mile Creek, Agency Creek, Annie Creek, Crane Creek, Crooked Creek, Fort Creek, and Sun Creek
Williamson River	Map		1889	1:250,000	USGS TopoView	Entire area
	Map		1957 & 1960	1:62,000	USGS TopoView	Entire area
	Aerial Photo	July	1955	1:37,400	USGS Earth Explorer	Klamath Marsh to confluence with Upper Klamath Lake
	Aerial Photo	Sept. & Oct.	1953	1:54,000	USGS Earth Explorer	Headwater to Klamath Marsh
Sprague River Tributaries	Map		1889	1:250,000	USGS TopoView	Entire area to just east of Bly
	Map		1957 & 1960	1:62,000	USGS TopoView	Entire area
	Aerial Photo	July	1955	1:37,400	USGS Earth Explorer	Sprague River Tributaries

We were unable to obtain historical aerial imagery prior to levee construction and channel straightening conducted on the South Fork Sprague in the late 1940s and early 1950s by the U.S. Army Corps of Engineers (USACE). The straightened channels in the South Fork are present in the aerial imagery from 1955. Unfortunately, the 1889 topographic map does not extend over the South Fork Reach past Bly and is of poor accuracy for comparison with the 1955 historical aerial photographs. However, the channel alignment clearly shows that channels near the South Fork Sprague River were straightened between the 1955 historical aerial photographs and the 1889 historical topographic map. Lastly, we were unable to obtain information on the levee construction in the South Fork; the projects were completed as an emergency flood protection effort and the USACE was not required to document these modifications (KBEF, 2007).

Flow Obstruction & Irrigation Diversion/Return point Identification

Numerous data sources were acquired and used during the ROA analysis to identify and map flow obstructions and irrigation diversion and return points in the study area, and are presented in Table 3. Data include: flow line features from the National Hydrography Dataset (NHD); aerial imagery, lidar-derived elevation data; a fish passage barrier database created by the Oregon Department of Fish and Wildlife (ODFW); a restoration project database from Oregon Watershed Restoration Inventory (OWRI); and an aerial thermal infrared (TIR) imagery analysis. Flow obstructions include both levee and berm features, as well as irrigation canal and ditch networks.

TABLE 3: DATA USED FOR FEATURE IDENTIFICATION.

Data Layer	Reference	Data Type	Attributes	Spatial Extent
Geomorphology and Flood-plain Vegetation of the Sprague and Lower Sycan Rivers	O'Connor et al 2013	Line	Built features (bridge, building, dam, irrigation ditch, levee, other built feature, railroad, road)	Mainstem Sprague River and lower reaches of major tributaries
Agency Lake, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Chiloquin, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Chiloquin, USGS 62,500 quad	USGS 1957	Raster	None	Quad. map
S'Ocholis Canyon, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Buttes of the Gods, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Sprague River West, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Sprague River East, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Beatty, USGS 1:24k quad	USGS 1998	Raster	None	Quad. map
Ferguson Mountain, USGS 1:24k quad	USGS 2004	Raster	None	Quad. map
Bly, USGS 1:24k quad	USGS 2004	Raster	None	Quad. map
Bly, USGS 62,500 quad	USGS 1960	Raster	None	Quad map
Campbell Reservoir, USGS 1:24k quad	USGS 2004	Raster	None	Quad. map
Yamsay Mountain, USGS 1:62,500 quad	USGS 1960	Raster	None	Quad map
Swan Lake, USGS 1:62,500 quad	USGS 1957	Raster	None	Quad map
Riverbed Butte, USGS 62,500 quad	USGS 1960	Raster	None	Quad map
Modoc Point, USGS 62,500 quad	USGS 1957	Raster	None	Quad map
Lenz, USGS 62,500 quad	USGS 1957	Raster	None	Quad map
Lake O Woods, USGS 62,500 quad	USGS 1955	Raster	None	Quad map
Klamath Marsh, USGS 62,500 quad	USGS 1957	Raster	None	Quad map
Fuego Mountain, USGS 62,500 quad	USGS 1960	Raster	None	Quad map
Fishhole Mountain, USGS 62,500 quad	USGS 1960	Raster	None	Quad map
Calimus Butte, USGS 62,500 quad	USGS 1956	Raster	None	Quad map
Beatty, USGS 62,500 quad	USGS 1960	Raster	None	Quad map
Pelican Butte, USGS 62,500 quad	USGS 1955	Raster	None	Quad map
Klamath, USGS 1:250k quad	USGS 1889	Raster	None	Quad map
Ashland, USGS 1:250k quad	USGS 1897	Raster	None	Quad map
National Hydrography Dataset	USGS 2007-2014	Vector	Name, feature type, ID, direction	National (clipped to the watershed)

Data Layer	Reference	Data Type	Attributes	Spatial Extent
The Sprague River Streambank Assessment Report	KWP 2010	Point	Name, feature type, description	River Mile (RM) 1 - 10 of the S. Fork Sprague River
2004 Sprague Lidar	Watershed Sciences 2004	Raster/ points	Bare earth elevations as 1 m grids and points	Mainstem Sprague and lower reaches of tributaries
2007 True Color Ortho-Photos: Sprague Watershed	Watershed Sciences 2008	Raster	Imagery	1,500 ft corridor centered on the mainstem Sprague and major tributaries
2010 0.3m	Microsoft 2010	Raster	Imagery	Watershed
NAIP 2012	USDA 2012	Raster	Imagery	Watershed
NAIP 2014	USDA 2014	Raster	Imagery	Watershed
National Elevation Dataset (NED)	USGS 2010	Raster	Elevation	Upper and Lower Williamson River
Oregon Department of Fish and Wildlife (ODFW) Fish Passage Database	ODFW 2015	Vector	Fish passage barriers	Watershed
Oregon Water Resources Department (OWRD) water rights point of diversion (POD) database	OWRD 2015	Vector	POD	Watershed
Aerial thermal infrared (TIR) imagery analysis data	Watershed Sciences 2008	Raster	Water temperature	Watershed

Klamath ROA III DEM Coverage

We used a combination of three DEMs to complete this analysis. No single DEM dataset with less than 10 meter resolution covers the entire study area. We used the following three DEM datasets with resolutions between 1 and 2.5 meters that cover the study extent:

- USGS 2010 DEM
- Klamath Tribes 2004 Sprague DEM
- Klamath Basin Rangeland Trust 2004 Wood DEM

The date of collection and resolution of each of the DEM data sets is listed in Table 4.

TABLE 4: DEM DATASETS, RESOLUTIONS, AND EXTENTS USED IN THIS ANALYSIS.

Name	Date	Resolution (meters)	Extent
USGS 2010 DEM	9/14/2010	2.5	Williamson Basin, Wood Basin (excluding Wood Valley)
Klamath Tribes 2004 Sprague DEM	November, 2004	1.0	Sprague River corridor
Klamath Basin Rangeland Trust 2004 Wood DEM	9/26-27, 2004	1.0	Wood Valley

The following three figures show the extents of the different DEM datasets and the Upper Klamath River basin ROA III project area (Figure 2). The USGS DEM covers the entire Williamson River basin, but does not cover the Sprague River basin. The USGS DEM also covers the forested portion of the Wood River basin outside of the area covered by the Klamath Basin Rangeland Trust DEM. The Klamath Tribes DEM covers the mainstem Sprague River corridor from the confluence with the Williamson River, and includes the non-forested portions of the Sprague River, South Fork Sprague River, North Fork Sprague River, and a portion of the Sycan River (Figure 3). Major tributaries to the Sprague are also included in this dataset. Lastly, the Klamath Basin Rangeland Trust DEM covers the irrigated portion of the Wood River Valley (Figure 4).

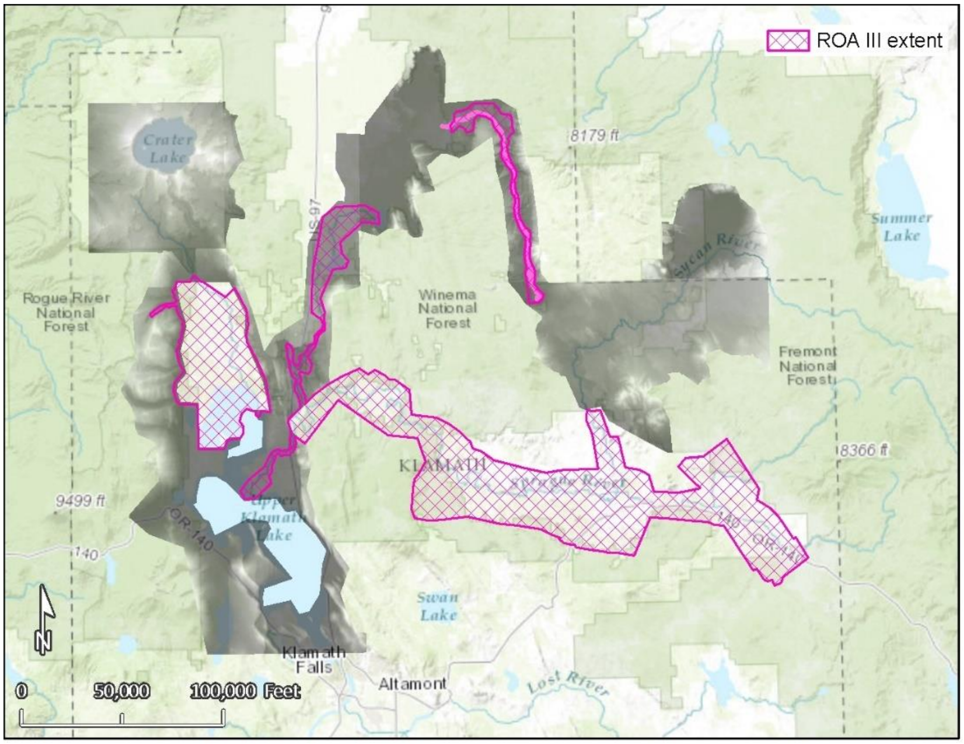

FIGURE 2: USGS 2010 DEM EXTENT.

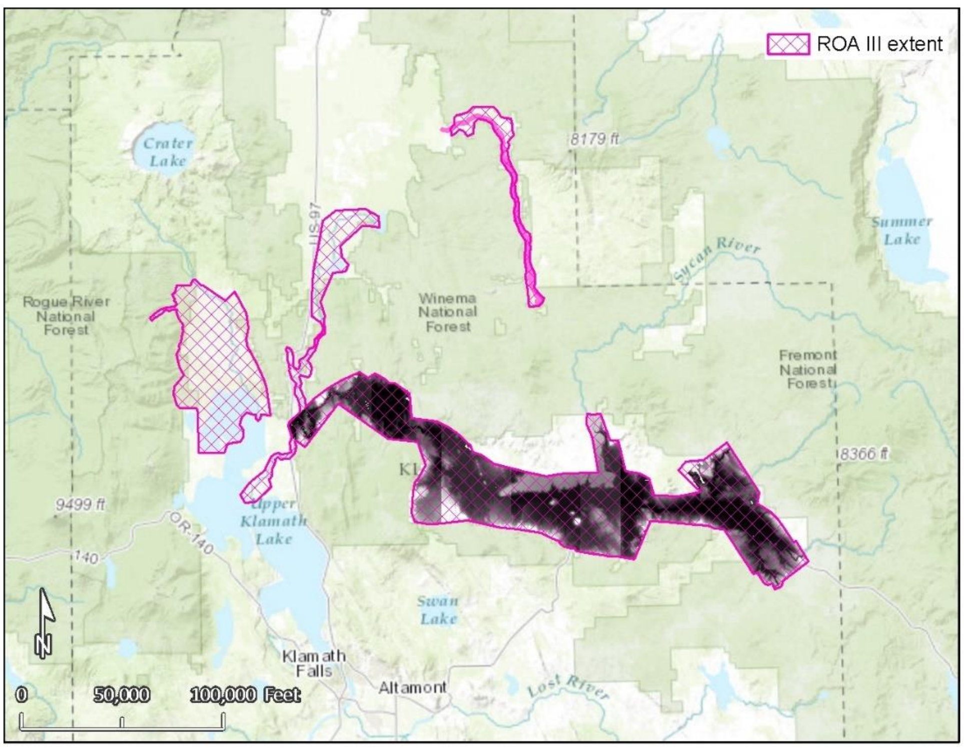

FIGURE 3: KLAMATH TRIBES 2004 SPRAGUE DEM EXTENT.

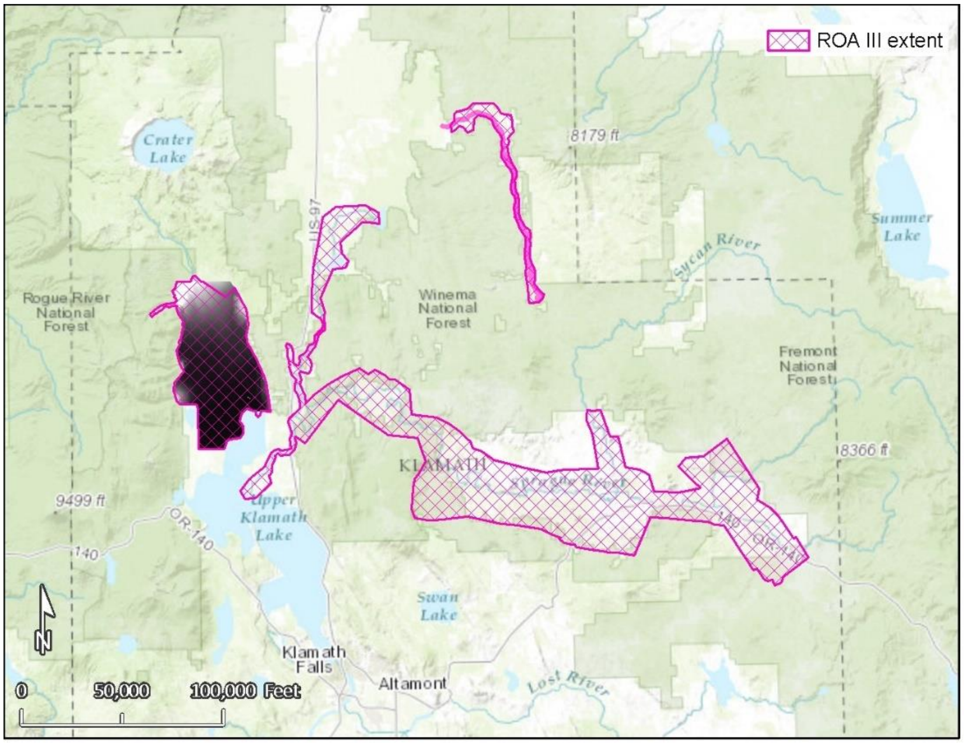

FIGURE 4: KLAMATH BASIN RANGELAND TRUST 2004 WOOD DEM EXTENT.

Analysis

Straightened Channel Identification

We incorporated the 2014 centerline from the Klamath Tribes into the project GIS to compare with the geolocated historical aerial photographs and historical topographic maps. To ascertain whether channel planform changes had occurred, we reviewed the rivers from downstream to upstream, and created a point shapefile to delineate changes in channel alignment. At each identified channel change location, the change type was attributed as avulsion, meander cutoff, or channel straightening. Avulsions result from natural geomorphological changes, whereas channel straightening locations indicate anthropogenic influence on channel alignment. We attributed each point with the years in which the change had occurred based on the available datasets.

Next, this point shapefile of channel alignment changes was reviewed and cross-checked with two datasets: a polyline shapefile of infrastructure features that FlowWest mapped including levees, canals, dams, plugs, etc., and several point shapefiles denoting restoration project locations and information. Restorations projects cross-referenced included those managed by the US Fish and Wildlife (USFWS), OWEB, and the Bureau of Reclamation (BOR). The original point shapefile of channel alignment change locations was then expanded to attribute whether there was an existing restoration project near the channel change site and details about the restoration project if available. We included information on the infrastructure features near the channel alignment change in the attribute field *Structures*—particularly if they were likely to have influenced channel migration or confinement. Restoration projects near channel alignment change locations were documented in several attribute fields: project type, year, and funding source. Lastly, we created a polyline shapefile that delineates the length of the channel alignment change at each site.

We summarized the attributes for channel alignment changes documented as a point shapefile (Table 5). We placed a point near the center of each area of channel alignment change, i.e. at the center of a meander (Figure 5). In some cases if there were several channel path changes within a relatively short length of stream (e.g. < 0.5 miles), we added one point to indicate the changes in that location. We describe the attributes for our representation of channel alignment changes as a polyline shapefile in Table 6 below. The attributes for the polyline shapefile are the same as the point shapefile except for an additional attribute for the length of the channel segment.

TABLE 5: ATTRIBUTE TABLE FIELDS FOR CHANNEL ALIGNMENT CHANGE POINT SHAPEFILE.

Field	Description	Values	Field Type
FID	Object ID	0,1,2,3,…	Integer
ChangeType	Type of channel alignment change	Avulsion, straightened channel, meander cutoff, channel cutoff	Text
ChangeYear	Years over which change occurred	Typically between two years from available datasets (e.g. 1953 and 1968)	Text
Structures	Type/s of structures present near alignment change	Varies	Text
ExistingRP	Binary field indicating whether there is an existing restoration project reported near the channel alignment change	Y, N	Text
RP_Type	Restoration project type description, if available	Varies	Text
RP_Agency	Restoration project agency, if available	USFWS, OWEB, BOR	Text
RP_Year	Restoration project year	Varies	Text
Notes	Additional notes about channel alignment change	Varies	Text
Reach	Geomorphic reach from O'Conner et al., 2013	Reach, creek, or river name	Text
Geomorph	Geomorphic characteristics of each reach (for the Sprague River)	Sinuosity, secondary channels, channel cut off, anabranching, bedload sediment transport	Text
Multistem	Assessment of multistem channel form based on aerial photos from 1968, 2000, and 2014 and 1:24k topographic maps	Y, N	Text
Link_ID	ID to link the point and polyline shapefiles	1, 2, 3, …	Integer
Infrastructure	Was infrastructure a potential cause for channel change	Y, N	Text

TABLE 6: ATTRIBUTE TABLE FIELDS FOR CHANNEL ALIGNMENT CHANGE POLYLINE SHAPEFILE.

Field	Description	Values	Field Type
FID	Object ID	0,1,2,3,…	Integer
ChangeType	Type of channel alignment change	Avulsion, straightened channel, meander cutoff, channel cutoff	Text
ChangeYear	Years over which change occurred	Typically between two years from available datasets (e.g. 1953 and 1968)	Text
Structures	Type/s of structures present near alignment change	Varies	Text
ExistingRP	Binary field indicating whether there is an existing restoration project reported near the channel alignment change	Y, N	Text
RP_Type	Restoration project type description, if available	Varies	Text
RP_Agency	Restoration project agency, if available	USFWS, OWEB, BOR	Text
RP_Year	Restoration project year	Varies	Text
Notes	Additional notes about channel alignment change	Varies	Text
Reach	Geomorphic reach from O'Conner et al., 2013	Reach, creek, or river name	Text
Geomorph	Geomorphic characteristics of each reach (for the Sprague River)	Sinuosity, secondary channels, channel cut off, anabranching, bedload sediment transport	Text
Multistem	Assessment of multistem channel form based on aerial photos from 1968, 2000, and 2014 and 1:24k topographic maps	Y, N	Text
Infrastructure	Was infrastructure a potential cause for channel change	Y, N	Text
Link_ID	ID to link the point and polyline shapefiles	1, 2, 3, …	Integer
Length_ft	Length of channel where the alignment changed	Length (feet)	Integer

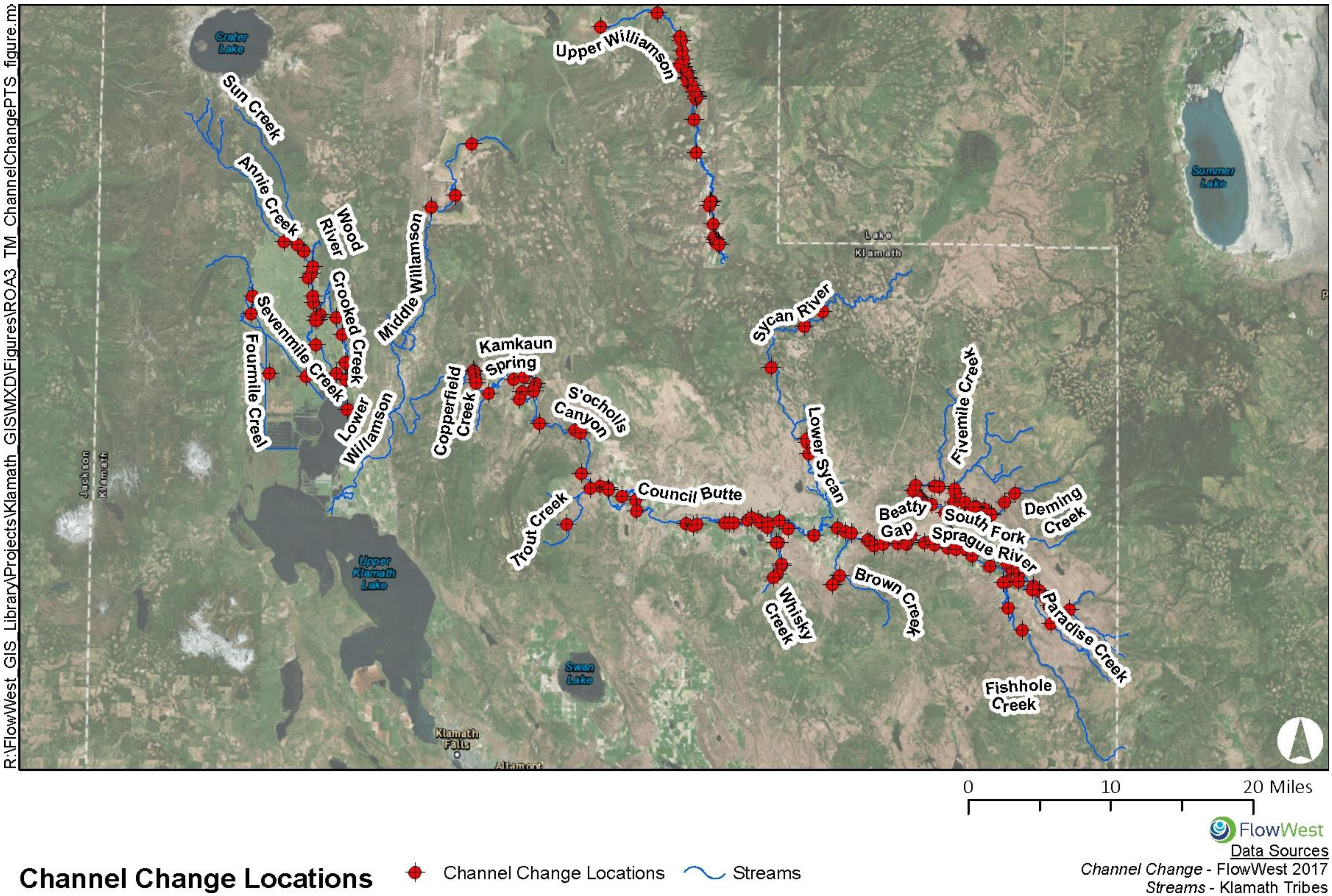

FIGURE 5: LOCATION OF CHANNEL CHANGE FEATURES.

Flow Obstruction Identification

When we first started this analysis we assumed that flow obstructions were predominately levees, but further investigation showed that many other floodplain features direct or confine flows in the Sprague and Williamson River watersheds. In addition to levees, other flow obstructions include: paved and dirt roads (active and abandoned), railroad beds (active and abandoned), canals, drainage ditches, irrigation structures, and residential or agricultural development. We defined flow obstruction as an artificial embankment or structure constructed in the floodplain or along the channel banks that prevents floodwaters from spreading out onto the floodplain. Obstructions were not necessary constructed with the purpose of diverting floodwater flow paths, but nonetheless, these obstructions do confine or direct unimpeded flow. In ROA Task II, irrigation canals and ditches were mapped within an approximately 1000-ft buffer of streams; in this analysis that spatial extent was expanded and all identifiable components of the irrigation networks were mapped within the study extent (see pink ROA III boundaries in Figure 2-Figure 4). Flow obstructions were categorized into classes and types (Table 7) and attributed as such in the accompanying shapefile. A discussion of each flow obstruction follows.

Flow Obstruction Classes and Types

TABLE 7: FLOW OBSTRUCTION CLASSES AND TYPES.

Class	Type
Berm	Berm
Development	Building pad
	Grading
Irrigation	Canal
	Canal bermed
	Dam
	Ditch
	Ditch bermed
	Weir
Levee	Levee
Restoration	Berm
	Plug
	Wetland
Transportation	Railroad
	Road
	Road / bridge

Berm

We defined a berm as a small (in comparison to levees) artificial ridge or bank used to confine or direct flow (Figure 6). Berms are defined here as having less than two feet of relief from the surrounding ground surface. We tried to distinguish berms from natural levees, which we excluded from our analysis.

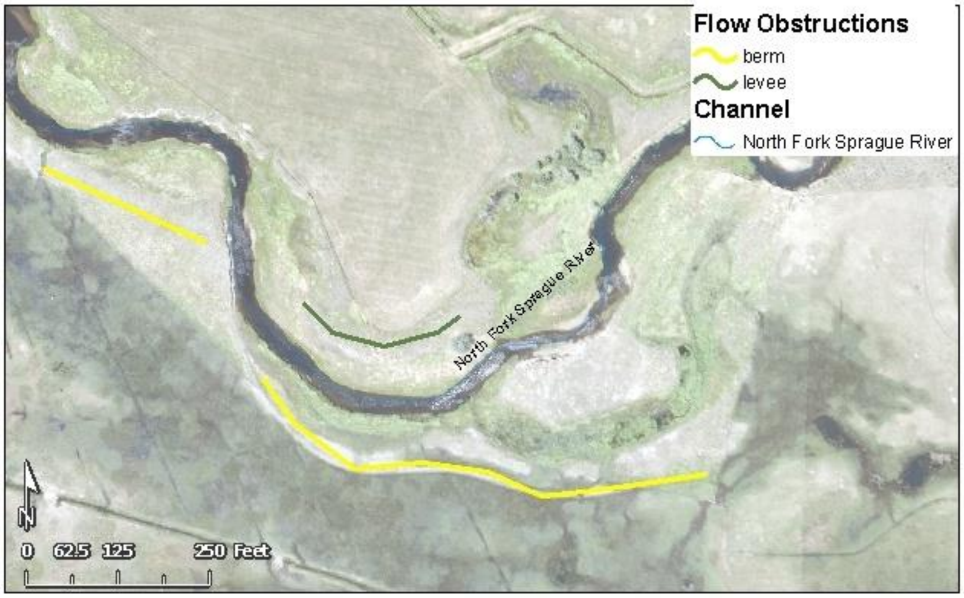

FIGURE 6: EXAMPLE OF BERM AND LEVEE FEATURES DELINEATED ALONG THE NORTH FORK SPRAGUE RIVER.

Development

The development classification includes modified bank or floodplain topography related to residential, agricultural, and/or commercial land use. We identified grading areas where fill has been placed on the floodplain and building pads where structures have been built in the floodplain (Figure 7).

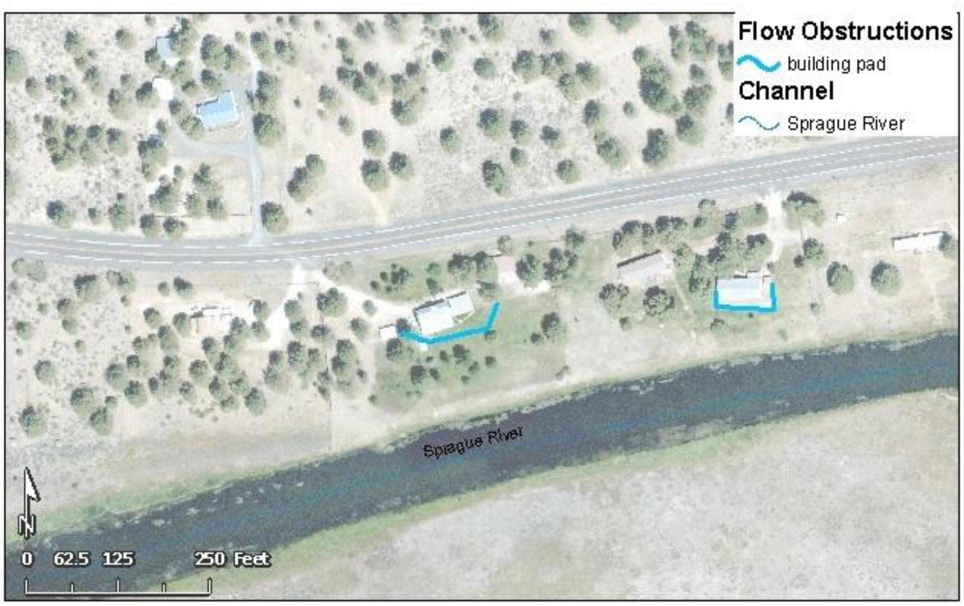

FIGURE 7: EXAMPLE OF BUILDING PAD FEATURES DELINEATED ALONG THE SPRAGUE RIVER.

Irrigation

The irrigation classification has the most sub-types of the features that we identified. In general, irrigation features include structures that convey irrigation or return flow (Figure 8). Irrigation structures include dams and weirs. Canals and ditches are features dug into the ground surface and flush with the surround topography. We used the labels from existing data sources for canals and ditches and when we were able to identify a flow direction from aerial photographs, we associated canals with diversions and ditches with drainage or return flow. Canals and ditches with material mounded next to them were classified as "bermed." We included canals and ditches without a berm in our analysis as they can direct floodplain flows through the existing channel network. Many levees also have barrow trenches directly in front or behind them that makes the delineation between levee and canal/ditch difficult, and is one potential source of error in our analysis.

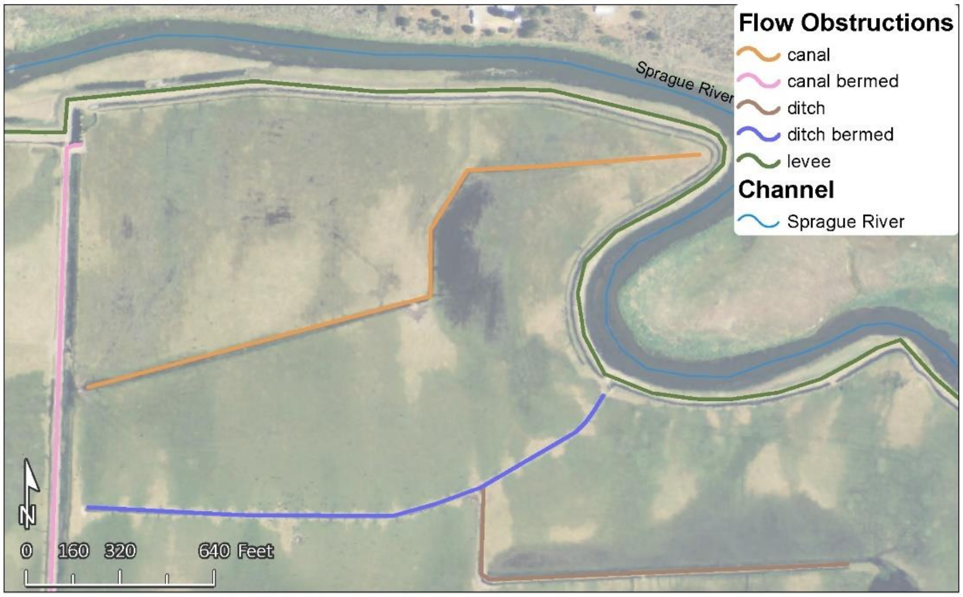

FIGURE 8: EXAMPLE OF CANAL, CANAL BERMED, DITCH, DITCH BERMED, AND LEVEE FEATURES DELINEATED ALONG THE SPRAGUE RIVER.

Levee

For this analysis we defined levees as artificial embankments two feet higher than the surrounding surface along a stream to protect land from flooding or to direct flood flows (Figure 9). Levees often have an adjacent canal or ditch, and in the case of numerous flow obstructions we mapped the dominate feature (based on height or proximity to the channel). Natural levees are geomorphic features found on floodplains and are formed when flood waters spread out onto the floodplain and overbank flows deposit sediment at the top of the bank. We used the two-feet height threshold based on the 2004 lidar data to differentiate artificial levees from berms, natural levees, and natural topographic features. Levee features were characterized as parallel, offset, or perpendicular. A parallel levee follows the top of bank of the channel, an offset levee is set back from the top of bank and typically confines the river corridor from meander bend to meander bend. Lastly, perpendicular levees concentrate floodplain flows into the channel and extend from the top of bank across the floodplain. We define the front of the levee as the side facing floodwaters (typically towards the channel or facing upstream for floodplain levees perpendicular to the channel).

FIGURE 9: EXAMPLE OF THE LEVEE FEATURES DELINEATED ALONG THE SOUTH FORK SPRAGUE RIVER.

Restoration

We identified restoration features that impact flood flows at identified restoration sites (Figure 10). We classified restoration features as built structures intended to restore the riparian zone. We identified plugs, constructed wetlands, and berms. Our analysis may have missed restoration projects or additional restoration features that have limited impacts on flow concentration or direction.

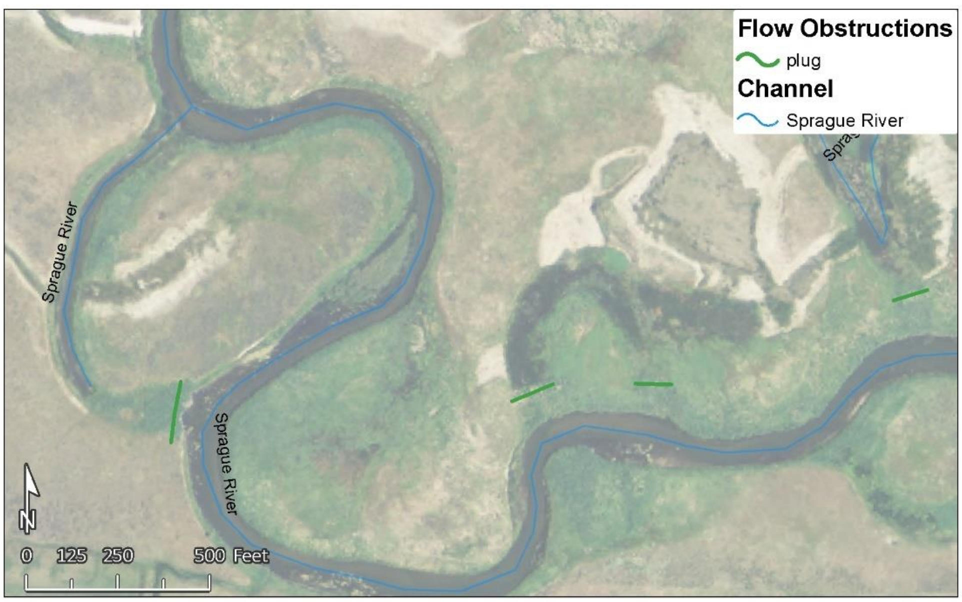

FIGURE 10: EXAMPLE OF PLUG FEATURES DELINEATED AT A RESTORATION SITE ALONG THE SPRAGUE RIVER.

Transportation

We delineated transportation features related to recreational, rail, and vehicular traffic networks. We classified transportation features as road, railroad, and road / bridge (Figure 11). The road category includes dirt roads, paved roads, and highways that are active or abandoned. The railroad category includes both active rail lines and the Oregon, California and Eastern (OC&E) Woods Line State Trail.

Lastly, the road / bridge category includes both bridges and elevated road segments on the approach or abutment for the bridge and includes both active and abandoned features.

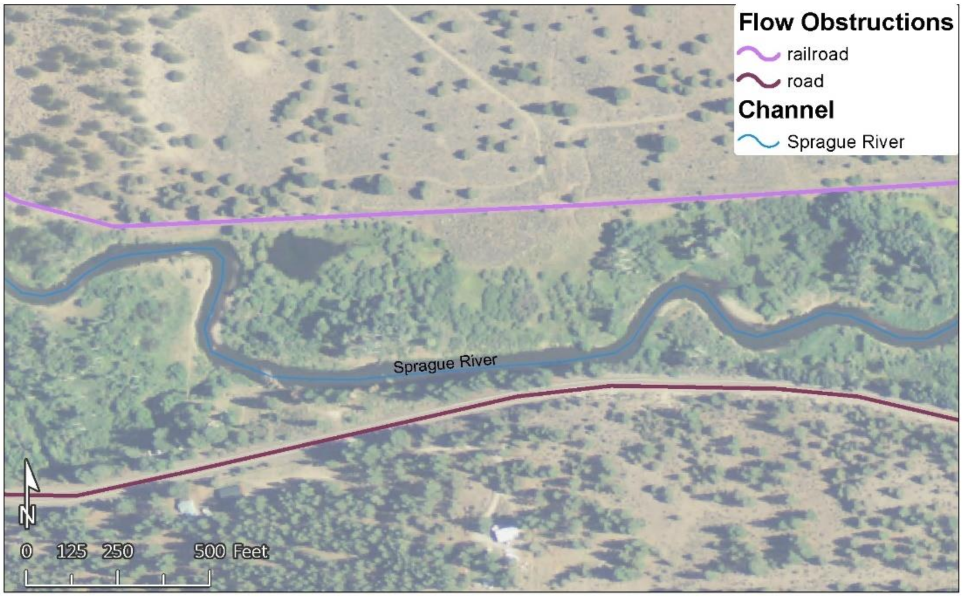

FIGURE 11: EXAMPLE OF RAILROAD AND ROAD FEATURES DELINEATED ALONG SPRAGUE RIVER.

Mapping

We conducted flow obstruction mapping in two phases. In the first phase, we incorporated the existing data layers and delineated levees from maps and aerial photographs. In the second phase we created a slope map, hillshade map, and generated contours from the 2004 lidar data. Next we systematically reviewed the Sprague River and major tributaries to identify flow obstruction features from the slope map, hillshade map, contours, and aerial photographs. Lastly, we attributed mapped features and added attribute data.

Existing Data

First, we integrated the levees delineated in Geomorphology and Flood-plain Vegetation of the Sprague and Lower Sycan Rivers (O'Connor et al 2013) and used this layer as our base shapefile that we modified as we added features. Each digitized feature was attributed with the primary source. Next, we digitized levees delineated on USGS 1:24,000 topographic maps and reviewed the National Hydrography Dataset (USGS 2007-2014) for levees. We did not find any levees in the National Hydrography Dataset (USGS 2007-2014) in the Sprague Watershed, but we utilized the flow network and canals and ditches during our systematic review in the second phase of the levee mapping. Point data from The Sprague River Streambank Assessment Report (KWP 2010) was added to the associated levees digitized from aerial photographs. Lastly, we digitized features that we interpreted as levees or flow obstructions on aerial imagery from 2007 (Watershed Science 2008), 2010 (Microsoft 2010), and 2012 (USDA 2012).

Lidar-based Identification of Flow Obstructions

In the second phase of the flow obstruction mapping, we incorporated the 2004 lidar (Watershed Sciences 2004) raster data processed as 1 meter grids and generated a slope map and 2 foot contours. The 2 foot contours were created to give us a general understanding of the floodplain and channel geometry above the water surface and to verify the areas highlighted in the slope map. Using the 3D Analyst Extension in ArcMap 10.2, we created a slope map and symbolized the resulting slope map by categories. We used yellow for slopes of 16-22 degrees for approximately 3:1 slope, orange for 22-34 degrees for approximately 2:1 slope, and red for greater than 34 for 1:1 slopes. This method allowed us to identify high slope areas that are likely from manmade structures compared to the natural terrain. For each orange to red area (slopes greater than 16 degrees), we reviewed the contours and then looked at the 2007, 2010, and 2012 imagery to help identify flow obstruction features. We also created a hillshade layer using 3D Analyst to help identify flow obstruction features. We cut cross sections from the 2004 lidar derived grids to identify flow obstructions. We also used the cross sections to differentiate between steep channel banks and levees.

Flow Obstruction Attributes

For each flow obstruction feature delineated we compiled attributes for the source of the data used to delineate the feature, the type of flow obstruction, the distance from the channel, alignment, confinement on one or both sides of the channel, the length of the obstruction, the class of obstruction, stream, reach, and elevation and height attributes for the an example cross section of the flow obstruction (Table 8). The attributes allow users of the shapefile to prioritize and categorize flow obstructions within the Upper Klamath Basin.

TABLE 8: FLOW OBSTRUCTION SHAPEFILE FIELD AND ATTRIBUTES.

Field	Description	Values	Field
Id	Unique feature identifier	Numeric	Integer
Type	Type of levee or flow obstruction	berm, building pad, canal, canal bermed, dam, ditch, ditch bermed, grading, levee, OCE trail, plug, pond, pond bermed, road, road / bridge, weir, wetland	Text
Align	Alignment of the flow obstruction to the channel	parallel, perpendicular, parallel / perpendicular	Text
Banks	Obstructions on one or both banks	1, 2	Number
Length_ft	Length of the obstruction	Distance calculated in GIS in meters and converted to feet	Number (ft)
LevType*	Levee or berm location with respect to the channel	Channel, channel / setback, floodplain, offset, perpendicular, setback	Text
Source1	Primary data layer used to identify feature	2004 lidar, 2007 aerial imagery, 2010 lidar, 2014 aerial imagery	Text
hWSE04_ft*	Height from the 2004 lidar Water Surface Elevation to the crest of the levee	Height	Number (ft)
h_BANK_ft*	Height from the base of the levee facing flow to the Water Surface Elevation	Height	Number (ft)
h_LEVft_ft*	Height of the levee facing the floodwaters from the toe to the crest	Height	Number (ft)
h_LEVbk_ft*	Height of the opposite side of the levee to floodwaters from the toe to the crest	Height	Number (ft)
SUB_ft*	Subsidence- difference between the front point and back point elevation	Height	Number (ft)
OFFSET_ft*	Distance from the 2012 NAIP edge of water to the toe of the levee/obstruction	Distance	Number (ft)
NOTE	Notes about features and/or how they were measured		Text
Channel	Name of main channel obstruction is nearest to	Creek or river name	Text
Reach	Name of reach obstruction is nearest to	Reach, creek, or river name	Text
TypeClass	Flow obstruction class	Berm, Development, Irrigation, Levee, Restoration, Transportation	Text
WSEpt_ft*	Water Surface Elevation at levee cross section	Elevation	Number (ft)
Front_pt*	Elevation at the base of the levee facing flow	Elevation	Number (ft)
Back_pt*	Elevation at the base of the levee facing floodplain (backside of levee)	Elevation	Number (ft)
Crest_pt*	Elevation at top of levee	Elevation	Number (ft)
Status	Feature status		Text
Notes_1	Notes from Klamath Tribes staff		Text

**Attributed to levee and berm features only.*

Irrigation Diversion and Agricultural Return Flow Identification

We cross-referenced several datasets to identify return and diversion features. The flow obstructions feature class layer was used to examine the canal network per agricultural operations, and locate areas where flow was likely to be diverted or returned to the rivers and creeks via canals and/or ditches. We also used an analysis of terrain slope from elevation data, and cut cross sections over larger swaths of topography to examine the general direction of gradient. This helped us ascertain whether features were likely to be inflow or outflow canals. We also used satellite imagery to cross-check whether features were diversions or returns, specifically we looked for pumps, piping, and irrigation structures. These features were recorded in a shapefile and relevant descriptions were included in the attribute table.

We reviewed this first cut dataset of return and diversion features, and amended it to include information from several relevant databases. First, we incorporated the flow line directionality of the NHD data into the diversion and return feature data. When a feature overlaid a flow line, we recorded the directionality to help identify whether the diversion feature was likely diverting river flow or returning agricultural discharge into the river channel. The NHD data was also helpful in understanding the general flow directions in canals and ditches near the Sprague River; often if a flowline did not overlay a feature we were able to estimate the likely flow direction based on nearby canals in the same irrigation system. However, the NHD data was not complete in the Sprague Basin and many channels were not included in the NHD dataset and errors were discovered in the dataset. Next, we compared the fish passage barrier database (ODFW) and the restoration project database (OWRI) with the diversion and return flow features we mapped. Any barriers or restoration projects we found in proximity to or overlapping the diversions were used to add to the diversion feature attribution. These datasets helped to identify some diversion features that have been screened and we eliminated these from our diversion feature shapefile.

Finally, we incorporated the 2007 TIR report information (Watershed Sciences 2008a); this report was produced to identify springs and thermal refugia throughout the Sprague watershed. The report also documented diversion and irrigation return canals throughout the Sprague River mainstem, North Fork, South Fork, and Sycan Rivers, as well as several tributaries including Meryl Creek and Fivemile Creek. The irrigation diversion and agricultural return flow canals reported in this document were cross-referenced with the diversion and return features we mapped. We added attributes to indicate whether the 2007 TIR report (Watershed Sciences 2008a) had shown the features to be for return or diversion flows, and also added any features the TIR reported that were not already in our shapefile. Finally, we cross-referenced our identified diversion and return flow features with the NHD data, terrain slope, aerial imagery, and the 2007 TIR report (Watershed Sciences 2008a) and assigned a final category for each feature.

Table 9 describes the attribute fields for the irrigation diversion and return feature point class shapefiles.

TABLE 9: ATTRIBUTE TABLE FIELDS FOR AGRICULTURAL RETURN AND DIVERSION POINT SHAPEFILES.

Field	Description	Values	Field Type
OBJECTID	Object ID	0,1,2,3,…	Integer
Type	Feature type	Canal, canal bermed, pump	Text
Location	Diversion or return feature location in reference to the river channel	Channel, floodplain, setback	Text
Source	Data source from which feature was identified	2004 lidar, 2014 aerial imagery, 2016 aerial imagery 2007 TIR report, NHD, flow obstruction shapefile, ORWD, June 2017 field work	Text
Channel	Name of main channel feature is nearest to	Creek or river name	Text
Reach	Name of reach feature is within	Reach, creek, or river name	Text
OFPBDS	Description of fish barrier present if reported in Oregon Fish Passage Barriers 2015 database	Varies	Text
TIR_report	If reported, classification as return or diversion by TIR report	Return or diversion	Text
Final_Desi	Final classification of feature as diversion or return made by FlowWest based on slope from lidar data, aerial imagery, NHD flow direction, and the TIR report	Return or diversion	Text
Notes	Additional notes about diversion or return feature	Varies	Text
Year		Notes from Klamath Tribes staff	Text
Scrn_stat	Screen status		Text
Pass_bar		Notes from Klamath Tribes staff	Text
Notes_1		Notes from Klamath Tribes staff	Text
Status	Return status		Text

Field Verification

In June 2017, we examined several locations within the study area to validate flow obstruction and irrigation return and diversion point features mapped using remotely-sensed data. We were able to confirm a number of diversion points, return points, canals, levees and berms along the Upper and Lower Williamson River, Spring Creek, the Sprague River mainstem, and Whisky Creek. We also recorded features in the field that were not identifiable in the various datasets used in the ROA analysis, and made revisions and edits to features that were misidentified or not currently present on the landscape. Unfortunately, several areas in the Upper Williamson River and along Fishhole Creek we hoped to evaluate were inaccessible via public property.

The following series of figures highlights several findings from the June 2017 fieldwork. Figures 13 and 14, 15 through 18, and 19 through 21 refer to the Williamson River, Sprague River, and Spring Creek, respectively.

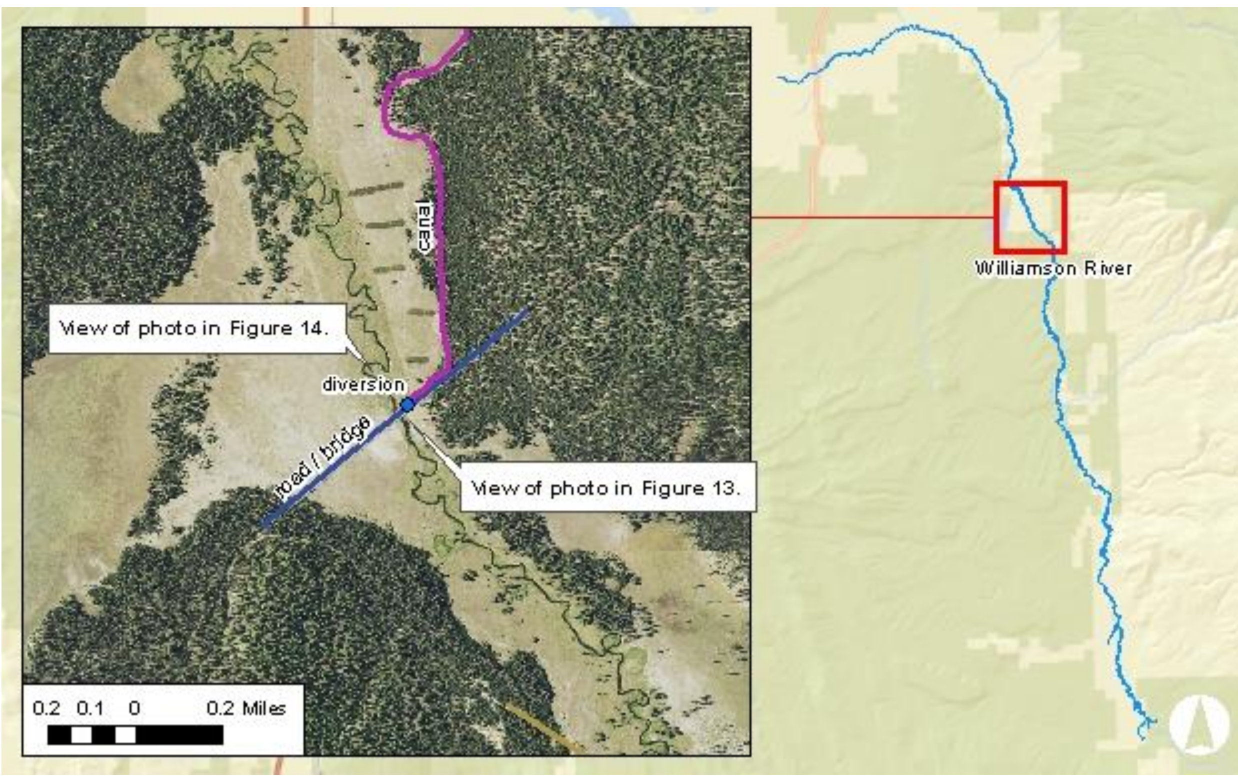

FIGURE 12: REFERENCE MAP FOR FIGURES 13 AND 14

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FIGURE 13: UPSTREAM OF BRIDGE ON THE UPPER WILLIAMSON RIVER. NOTE FENCING ADJACENT TO CHANNEL EDGE AND THE ACCESSIBILITY OF THE RIPARIAN AREA FOR CATTLE.

FIGURE 14: DOWNSTREAM OF BRIDGE ON THE UPPER WILLIAMSON RIVER. NOTE RIPARIAN AREA IS FENCED OFF.

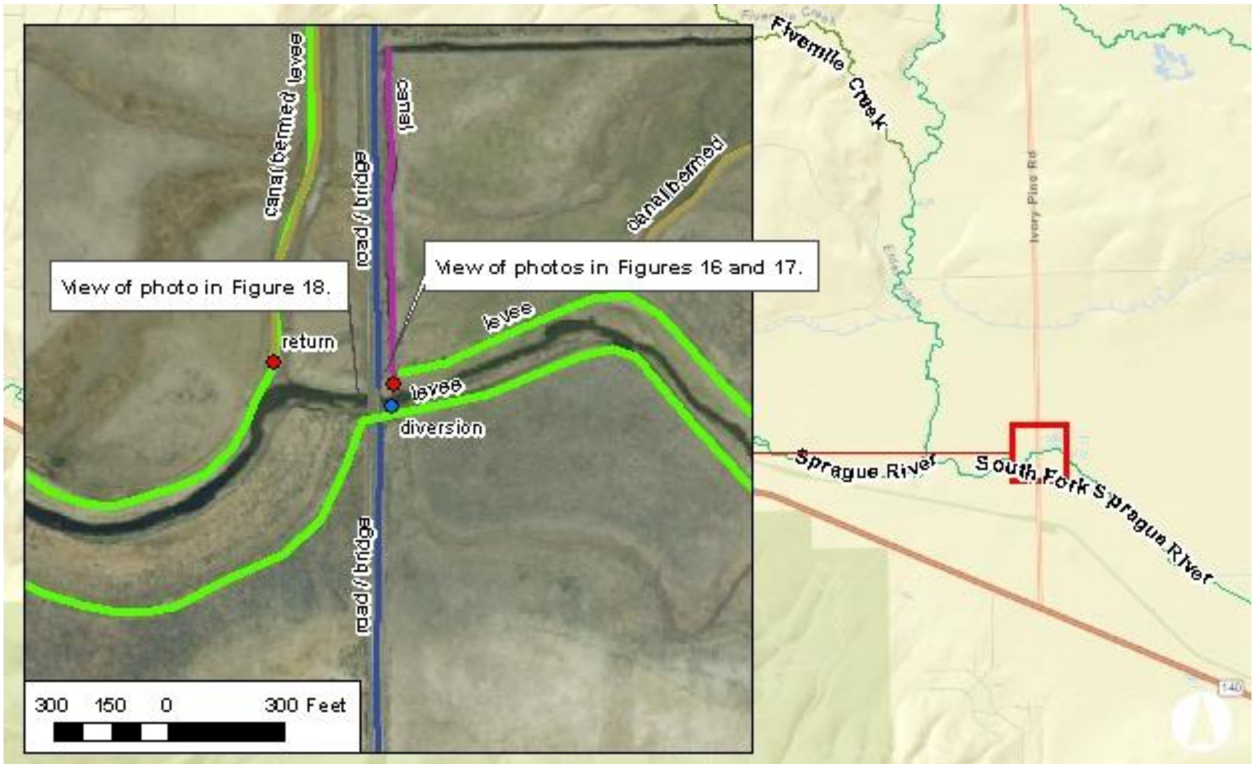

FIGURE 15: REFERENCE MAP FOR FIGURES 16, 17, AND 18.

FIGURE 16: CATTLE NEAR IRRIGATION RETURN CANAL ADJACENT TO IVORY PINE ROAD.

FIGURE 17: RETURN FROM CATTLE AREA INTO SPRAGUE RIVER JUST UPSTREAM OF IVORY PINE ROAD BRIDGE.


FIGURE 18: RETURN AGRICULTURAL FLOW MIXED INTO RIVER DOWNSTREAM OF IVORY PINE ROAD BRIDGE.

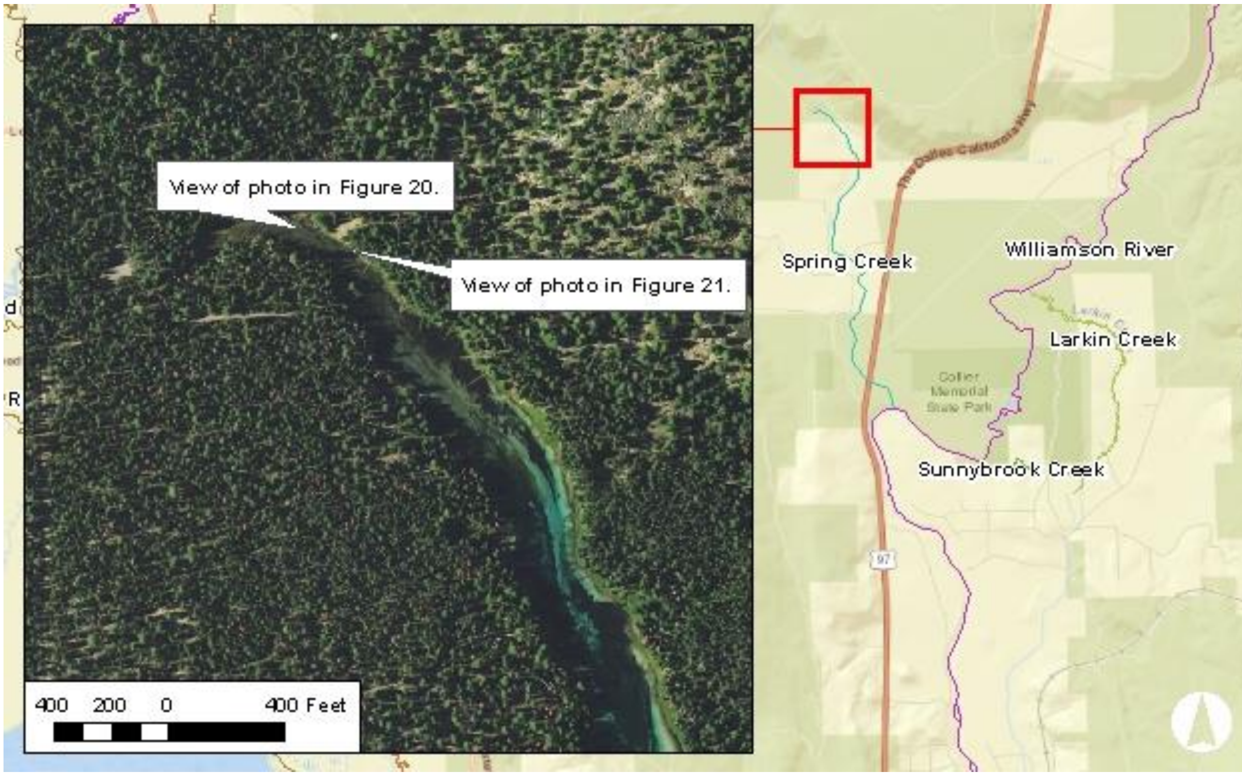

FIGURE 19: REFERENCE MAP FOR FIGURES 20 AND 21.


FIGURE 20: SPRING CREEK (LOOKING UPSTREAM) AT LOCATION WHERE A SMALL DIRT ROAD WAS MISIDENTIFIED AS A CANAL FROM ELEVATION DATA.

FIGURE 21: SPRING CREEK (LOOKING DOWNSTREAM) AT LOCATION WHERE A SMALL DIRT ROAD WAS MISIDENTIFIED AS A CANAL FROM ELEVATION DATA.

RESULTS

Straightened Channel Identification

The following tables and maps summarize the extent of mapped channel change features expanded and refined during the ROA III study. Of the three watersheds investigated in this study, we identified the highest number of channel change location in the Sprague Watershed (Table 10; Table 11). In terms of the cumulative length of features, the Wood River Valley was very close to the Sprague, but the number of features was much smaller. In the Wood River Valley, Fourmile Creek and Sevenmile Creek account for the majority of the length of the mapped features.

TABLE 10: SUMMARY OF CHANNEL CHANGE FEATURES BY WATERSHED.

Watershed	Number of Mapped Features	Length of Mapped Features (mi)
Sprague	118	36.0
Williamson	36	12.4
Wood River Valley	24	28.1

To quickly identify reaches that have experience the most channel change (by length of features) we developed Figure 22. The reaches with the highest length of mapped features are clearly identified as the Upper Williamson, Sevenmile Creek, and Fourmile Creek. The channelized portions of South Fork Sprague River and Fishhole Creek also have long sections of altered channels.

TABLE 11: DETAILED SUMMARY OF CHANNEL CHANGE FEATURES BY WATERSHED, CHANNEL, AND REACH.

Watershed	Channel	Reach	Number of Mapped Features	Length of Mapped Features (mi)
Sprague	Brown Creek	Brown Creek	2	2.2
	Copperfield Creek	Copperfield Creek	1	0.2
	Deming Creek	Deming Creek	2	1.4
	Fishhole Creek	Fishhole Creek	4	5.1
	Fivemile Crek	Fivemile Crek	10	1.3
	Meryl Creek	Meryl Creek	2	1.0
	North Fork Sprague	North Fork Sprague	12	2.6
		Upper Valley	1	0.1
	Paradise Creek	Paradise Creek	3	3.0
	South Fork Sprague	South Fork Sprague	15	7.4
	Sprague	Beatty Gap	8	1.1
		Beatty-Sycan	3	1.5
		Buttes of the Gods	6	0.7
		Council Butte	14	2.2
		KamKaun Spring	12	2.4
		S'choholis Canyon	4	0.6
		Upper Valley	4	0.6
	Sycan River	Lower Sycan	3	0.4
		Sycan River	3	0.3
	Trout Creek	Trout Creek	2	0.2
	Whisky Creek	Whisky Creek	7	1.8
Williamson	Middle Williamson	Middle Williamson	3	1.8
	Upper Williamson	Upper Williamson	33	10.6
Wood River Valley	Agency Creek	Agency Creek	1	0.1
	Annie Creek	Annie Creek	2	0.2
	Crooked Creek	Crooked Creek	5	3.0
	Fourmile Creek	Fourmile Creek	1	12.4
	Sevenmile Creek	Sevenmile Creek	3	10.0
	Sun Creek	Sun Creek	1	0.1
	Wood River	Wood River	12	2.4

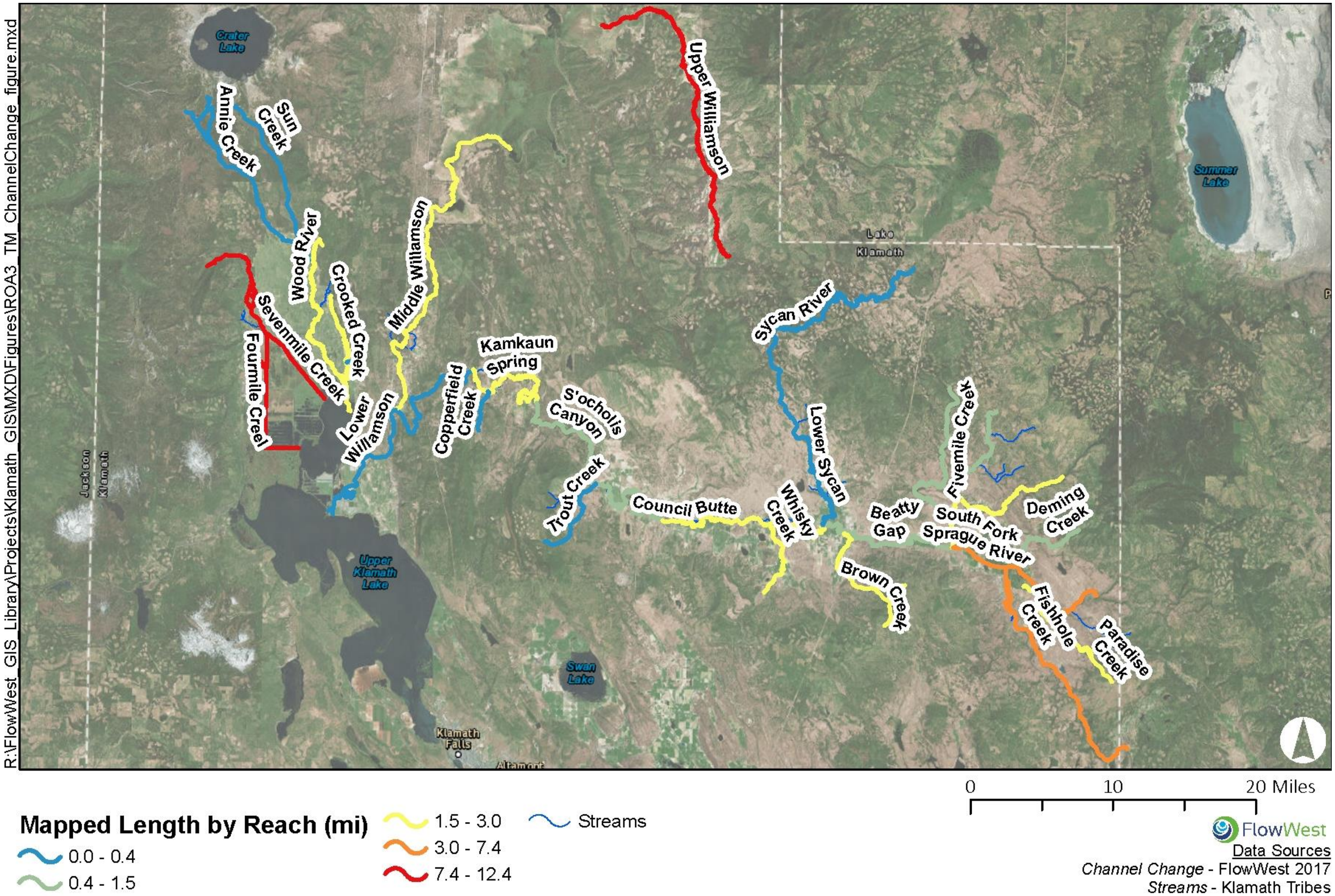

FIGURE 22: CUMMULATIVE LENGTH OF MAPPED CHANNEL CHANGE FEATURES PER REACH IN THE SPRAGUE, WILLIAMSON, AND WOOD RIVER VALLEY WATERSHEDS. THE "STREAMS" LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE CHANNEL CHANGE OR WERE NOT INCLUDED IN THE STUDY SCOPE.

Flow Obstruction & Irrigation Diversion and Return Point Identification

The following tables and maps summarize the extent of the flow obstructions and irrigation and diversion point locations datasets expanded and refined during the ROA III study.

TABLE 12: COUNTS OF FLOW OBSTRUCTIONS FOR THE WILLIAMSON AND WOOD RIVER VALLEYS.

Channel	Reach	Flow Obstruction Category	Number of Mapped Features	Total
Williamson River	Upper Williamson	Berm	39	**220**
		Irrigation	176	
		Levee	2	
		Transportation	3	
	Middle Williamson	Berm	1	**35**
		Development	1	
		Irrigation	27	
		Levee	2	
		Transportation	4	
	Lower Williamson	Berm	2	**14**
		Irrigation	5	
		Levee	4	
		Transportation	3	
Spring Creek	Spring Creek	Transportation	1	**1**
Wood River	Wood River	Berm	2	**7**
		Levee	5	
Fourmile Creek	Fourmile Creek	Levee	1	**1**
Sevenmile Creek	Sevenmile Creek	Levee	2	**2**
Crooked Creek	Crooked Creek	Berm	1	**2**
		Levee	1	

TABLE 13: COUNTS OF FLOW OBSTRUCTION FEATURES BY REACH FOR THE SPRAGUE RIVER.

Channel	Reach	Flow Obstruction Category	Number of Mapped Features	Total
Sprague River	Beatty-Sycan	Irrigation	9	**15**
		Transportation	6	
	Beatty Gap	Irrigation	5	**12**
		Levee	2	
		Transportation	5	
	Braymill	Irrigation	1	**9**
		Transportation	8	
	Buttes Of The Gods	Berm	4	**74**
		Irrigation	58	
		Levee	8	
		Restoration	2	
		Transportation	2	
	Chiloquin Canyon	Development	5	**20**
		Irrigation	1	
		Transportation	14	
	Council Butte	Berm	2	**104**
		Development	2	
		Irrigation	67	
		Levee	21	
		Restoration	6	
		Transportation	6	
	Kamkaun Spring	Berm	6	**106**
		Irrigation	64	
		Levee	26	
		Restoration	7	
		Transportation	3	
	S'ocholis Canyon	Irrigation	3	**19**
		Transportation	16	
	Upper Valley	Irrigation	7	**8**
		Levee	1	
North Fork Sprague River	North Fork	Berm	5	**49**
		Irrigation	26	
		Levee	10	
		Transportation	8	
	Upper Valley	Irrigation	1	**1**
South Fork Sprague River	South Fork	Irrigation	41	**75**
		Levee	23	
		Transportation	11	

TABLE 14: COUNTS OF FLOW OBSTRUCTIONS FOR CREEKS.

Channel	Flow Obstruction Category	Number of Mapped Features	Total
Brown Creek	Berm	5	**22**
	Irrigation	7	
	Levee	5	
	Transportation	5	
Brown Spring Creek	Irrigation	3	**3**
Copperfield Creek	Berm	4	**17**
	Irrigation	8	
	Levee	4	
	Transportation	1	
Crane Creek	Transportation	1	**1**
Deming Creek	Irrigation	7	**7**
Fishhole Creek	Berm	15	**40**
	Irrigation	9	
	Levee	15	
	Transportation	1	
Five Mile Creek	Irrigation	6	**7**
	Transportation	1	
Meryl Creek	Irrigation	3	**4**
	Levee	1	
Paradise Creek	Irrigation	5	**5**
Sycan River	Irrigation	11	**15**
	Restoration	1	
	Transportation	3	
Trout Creek	Irrigation	3	**4**
	Transportation	1	
Whisky Creek	Berm	9	**69**
	Irrigation	45	
	Levee	8	
	Transportation	7	
Whitehorse Spring Creek	Berm	1	**19**
	Irrigation	17	
	Transportation	1	

TABLE 15: COUNTS OF IRRIGATION DIVERSIONS AND RETURNS BY STREAM AND REACH.

Channel	Reach	Category	Number of Mapped Features
Brown Creek	Brown Creek	**diversion**	**3**
		return	1
Deming Creek	Deming Creek	**diversion**	**1**
Fishhole Creek	Fishhole Creek	**diversion**	**5**
		return	1
Fivemile Creek	Fivemile Creek	**diversion**	**3**
Meryl Creek	Meryl Creek	**diversion**	**3**
		return	1
North Fork Sprague River	North Fork	diversion	5
		return	2
Paradise Creek	Paradise Creek	**diversion**	**2**
South Fork Sprague River	South Fork	**diversion**	**10**
		return	12
Sprague River	Beatty-Sycan	**diversion**	**1**
	Beatty Gap	**diversion**	**2**
		return	3
	Buttes of the Gods	**diversion**	**10**
		return	4
	Chiloquin Canyon	**diversion**	**1**
		return	1
	Council Butte	**diversion**	**10**
		return	19
	Kamkaun Spring	**diversion**	**6**
		return	4
	S'ocholis Canyon	**diversion**	**1**
	Upper Valley	**diversion**	**1**
		return	3
	Council Butte	return	1
Sycan River	Beatty-Sycan	**diversion**	**1**
	Lower Sycan	**diversion**	**7**
		return	5
Trout Creek	Trout Creek	**diversion**	**2**
Whisky Creek	Whisky Creek	**diversion**	**8**
		return	2
Whitehorse Spring Creek	Whitehorse Spring Creek	**diversion**	**5**
		return	1
Williamson River	Upper Williamson	**diversion**	**14**
		return	6
	Middle Williamson	**diversion**	**6**
		return	2

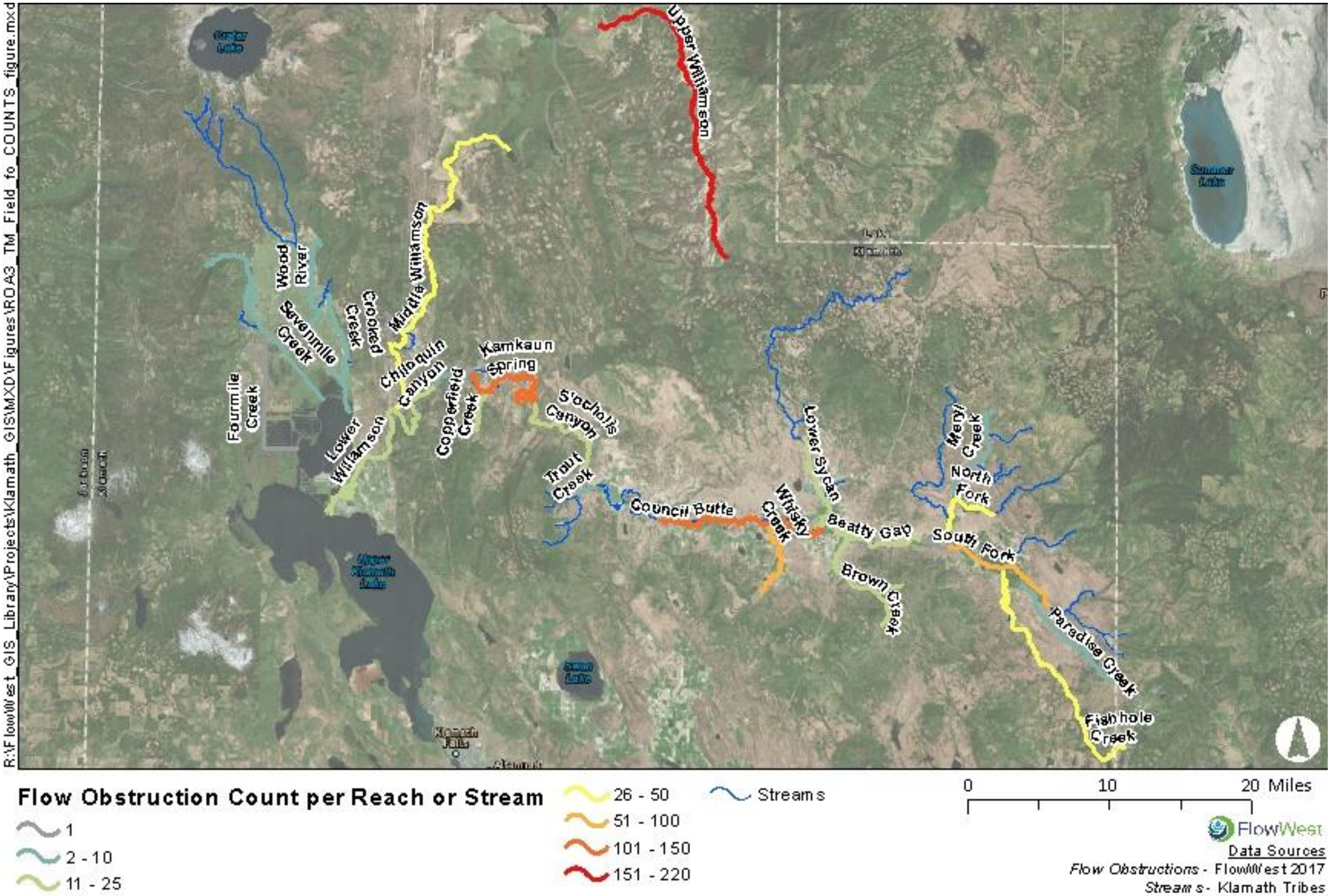

FIGURE 23: FLOW OBSTRUCTIONS PER REACH OR STREAM IN THE SPRAGUE AND WILLIAMSON RIVER WATERSHEDS. THE "STREAMS" LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE FLOW OBSTRUCTIONS OR WERE NOT INCLUDED IN THE STUDY SCOPE.

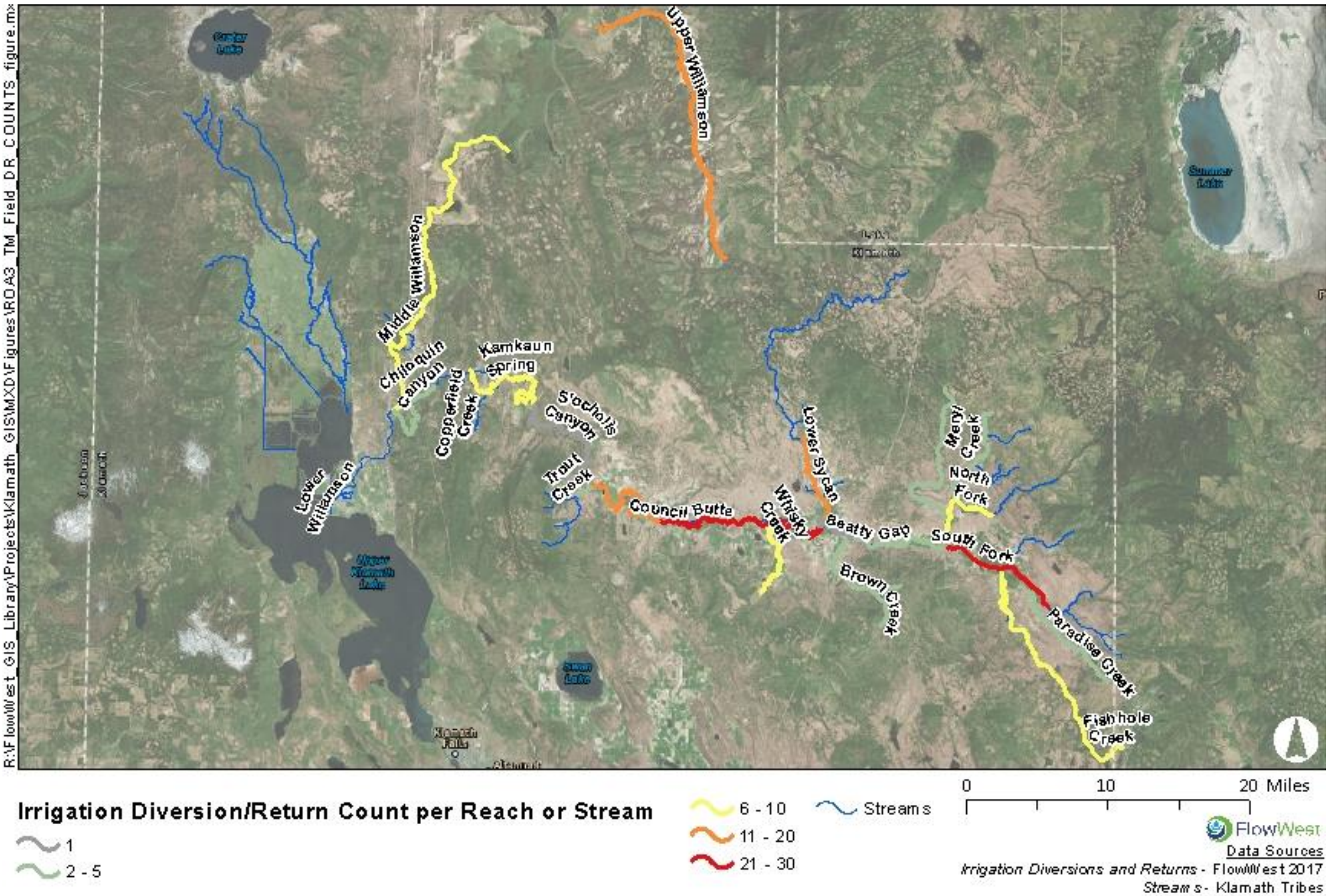

FIGURE 24: IRRIGATION DIVERSION AND RETURN POINTS PER REACH OR STREAM IN THE SPRAGUE AND WILLIAMSON RIVER WATERSHEDS. THE "STREAMS" LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE IRRIGATION DIVERSIONS OR RETURNS, OR WERE NOT INCLUDED IN THE STUDY SCOPE.

DISCUSSION OF RESULTS

Reconnaissance-level field verification was very useful in this analysis, and implementing a systematic field verification process in collaboration with landowners would improve the quality of the data derived from aerial photographs and topography.

To further prioritize channel realignment restoration sites, the provided shapefile can be queried to refine the number of sites. For example, channel change sites related to restoration projects could be queried out of the shapefile. This would reduce 26 potential restoration sites from consideration. Further, channel changes that likely resulted from infrastructure (79 sites) could be selected and prioritized. A detailed study of flood control opportunities in the leveed reach of the South Fork Sprague River should be considered where there is a high concentration of historical channel realignment. There has been significant channel manipulation in the Upper Williamson reach that should be investigated further. Our analysis did not include the Klamath Marsh, but major channel alignment changes are evident from a brief review of the historical aerial images.

The results of the flow obstruction analysis identify several reaches and creeks with high densities of structures (50 or greater) impeding natural flow and morphology: the Upper Williamson, the Kamkaun Spring and Council Butte reaches of the Sprague River, the North Fork Sprague River, the South Fork Sprague River, and Whisky Creek, as shown in Figure 23. Flow obstructions related to irrigation uses (i.e. canals and ditches) are the most predominant in all of these reaches and creeks. The count per reach or creek index provides a summary breakdown of all of the results, however the flow obstruction database can further queried and analyzed to prioritize restoration activities.

Irrigation diversions and returns points are predominant in several reaches and creeks in the study area, consistent with the predominance of flow obstructions related to agricultural irrigation activities. The Council Butte reach of the Sprague River has the most identified diversion and return points at 29. This section of the Sprague River has concentrated agricultural use. The South Fork Sprague River has the second-highest number of these points at 22, while the Upper Williamson—also an area of significant agricultural activity—has 20. The results of this study should be integrated with current efforts undertaken by other stakeholders to map irrigation diversion and returns points in the Wood River Valley to maximize the effectiveness of restoration planning and implementation.

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