THE UPPER KLAMATH BASIN WATERSHED ACTION PLAN


Looking north from the south end of Upper Klamath Lake. Photo credit: Megan Skinner.

The Upper Klamath Basin Watershed Action Plan

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Developed by
The Upper Klamath Basin Watershed Action Plan Team[*]

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ABSTRACT

The Upper Klamath Basin (UKB) is home to numerous native fish species of conservation, cultural, and economic importance. A number of factors related to land use practices and a changing climate have led to a decline in water quality, fish populations, and riparian and aquatic habitat in the UKB. Several past efforts, including the UKB Comprehensive Agreement, Total Maximum Daily Loads developed by regulatory entities, water quality management plans and Endangered Species Act recovery plans, have identified the need for a coordinated plan or strategy to prioritize and implement restoration actions to support fish population recovery, water quality improvements, and restoration of riparian and riverine process and function in the UKB. The UKB Watershed Action Plan (UKBWAP) provides science-based guidance regarding types of restoration projects necessary to address specific impairments to riverine and riparian process and function, and develop monitoring regimes tied to quantifiable restoration objectives at multiple scales. The UKBWAP includes a reach-scale watershed condition assessment that prioritizes reaches (based on degree of impairment) for landowner engagement and subsequent implementation of voluntary restoration activities and guidelines for implementation of specific voluntary restoration activities, such as riparian fencing and riparian grazing management. Additionally, the UKBWAP outlines a process of adaptive management to refine condition assessments, recommended restoration actions, and monitoring approaches as new information becomes available. The UKBWAP was developed and will continue to be refined by a team of local restoration professionals representing the U.S. Fish and Wildlife Service, Trout Unlimited, Klamath Watershed Partnership, The Klamath Tribes, Oregon Department of Environmental Quality, The Nature Conservancy, and the North Coast Regional Water Quality Control Board of California.

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ACRONYMS AND ABBREVIATIONS

AFA	*Aphanizomenon flos-aquae* (a cyanobacteria species)
BACI	Before-after-control-impact (a type of study design relevant for restoration project monitoring)
BDA	Beaver Dam Analog
DO	Dissolved oxygen (a water quality metric)
DSTW	Diffuse source treatment wetland
EPA	U. S. Environmental Protection Agency
ESA	Endangered Species Act
IFRMP	Integrated Fisheries Restoration and Monitoring Plan
IRPT	Interactive Reach Prioritization Tool; accessed here
KTAP	Klamath Tracking and Accounting Program
LWD	Large woody debris
NAIP	National Agriculture Imagery Program (aerial imagery)
NDVI	Normalized Difference Vegetation Index (a geospatial data source)
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Water Resources Department
OWRI	Oregon Watershed Restoration Inventory
OWRIO	Oregon Watershed Restoration Inventory Online
PLP	Priority List of Projects (a restoration prioritization effort funded by PacifiCorp)
RCAT	Riparian Condition Assessment Tool (a geospatial tool developed by researchers at Utah State University)
TMDL	Total Maximum Daily Load
TP	Total phosphorus (a water quality metric)
UKB	Upper Klamath Basin
UKL	Upper Klamath Lake
USDA	U. S. Department of Agriculture
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey
UKBWAP	Upper Klamath Basin Watershed Action Plan
UKBWAP Team	The team developing the Upper Klamath Basin Watershed Action Plan

EXECUTIVE SUMMARY

WATERSHED ACTION PLAN PURPOSE AND GOALS

The purpose of the Upper Klamath Basin (UKB) Watershed Action Plan (UKBWAP) is to inform effective and prioritized voluntary restoration activities in the UKB, with the goals of improving water quality, and habitat for fish, wildlife, and water birds through restoration of floodplain, riparian, wetland, and riverine process and function at reach and watershed scales. Many of these goals, particularly those related to water quality, require large-scale coordinated restoration within the watershed. The UKBWAP focuses on cooperative and voluntary restoration that benefit 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.

Note that the focus of the UKBWAP is generally on current conditions and how they may be improved to meet these goals, rather than current conditions relative to historical conditions.

WATERSHED ACTION PLAN COMPONENTS AND LAYOUT

The UKBWAP is designed to provide context and a technical foundation to inform restoration approaches addressing specific impairments, prioritize reaches for restoration implementation, and develop monitoring regimes tied to specific quantifiable objectives at multiple scales.

The UKBWAP includes:

- An overview of the ecosystem and land use in the UKB, as well as some geographical and hydrological context.
- Conceptual models that describe twelve key impairments (channelization, channel incision, levees and berms, wetlands, riparian areas and floodplains, irrigation practices, springs, fish passage, roads, fish entrainment, large woody debris, and spawning substrate) and effects of restoration to address these impairments.
- A description of the web-based Interactive Reach Prioritization Tool (IRPT) and how it is intended to guide and inform strategic landowner engagement efforts and restoration implementation.
- The Restoration Guide (Appendix A), which includes technical resources and literature reviews to offer project implementation guidance for restoration professionals.
- The Monitoring Framework (Appendix B), including a discussion of multi-scale monitoring regimes and how this framework is intended for use by restoration professionals and others.

- Description and identification of data, knowledge gaps, and suggested next steps for restoration prioritization and implementation in the UKB.
- The Stakeholder Outreach and Engagement Plan (Appendix C, *in prep.*), which describes strategies and efforts to identify, contact, and recruit private landowners for voluntary restoration.

HOW TO USE THE WATERSHED ACTION PLAN

Although the UKBWAP includes extensive narrative, conceptual models, and appendices as described above, the primary component of interest to restoration professionals is the IRPT, which provides a web-based interactive map identifying priority areas for restoration based on degree of impairment. The IRPT is intended to be the most accessible, and frequently accessed, portion of the UKBWAP, while the narrative and appendices offer additional guidance and information. The section titled "How to Use the Watershed Action Plan" in Chapter 1 provides additional detail on an example workflow for the UKBWAP.

The UKBWAP is not intended to be read cover-to-cover as many sections (particularly Chapter 3) are repetitive and highly technical, to ensure that accurate and scientifically-sound information is presented for each impairment and project. Rather, the narrative of the UKBWAP exists to provide additional support and documentation for the critical components (IRPT, appendices) of the UKBWAP, as needed by restoration professionals.

WATERSHED ACTION PLAN TEAM

The UKBWAP Team is composed of key members of the UKB restoration implementation and planning community, representing the U.S. Fish and Wildlife Service (USFWS), Trout Unlimited, Klamath Watershed Partnership, The Klamath Tribes, Oregon Department of Environmental Quality (ODEQ), The Nature Conservancy, and the North Coast Regional Water Quality Control Board of California.

STAKEHOLDER OUTREACH

Stakeholder outreach to support development and implementation of the UKBWAP is approached in two phases, as described below. More detailed information will be provided in the Stakeholder Engagement and Outreach Plan (Appendix C, *in prep.*).

Phase I: Watershed Action Plan Development

To ensure the UKBWAP has broad buy-in and applicability within the UKB, it was critically important to solicit stakeholder involvement and feedback during the development of the UKBWAP. Stakeholders were kept informed and/or offered opportunities to provide feedback during UKBWAP development. These stakeholders included federal, state, county, and city agencies, Tribal entities, private landowners and managers, non-profit groups, funding agencies, politicians, educational institutions, and private consultants and companies.

Phase II: Watershed Action Plan Implementation

To ensure widespread awareness, understanding, and support of the UKBWAP in both the technical and non-technical communities of the Klamath Basin, additional outreach and engagement is necessary. These activities will include developing a website to house the UKBWAP, attending local and regional technical meetings and conferences to present information about the UKBWAP, identifying and contacting landowners in IRPT priority areas, and continuing to collaborate with partners to identify potential incentives to encourage restoration implementation.

UPPER KLAMATH BASIN OVERVIEW

The UKB as defined for the UKBWAP is comprised of Upper Klamath and Agency lakes (together, UKL), the Sprague, Williamson, and Wood rivers, and tributaries to UKL originating in the foothills of the Cascade Range (termed the Cascade Tributaries) (Figure 1).

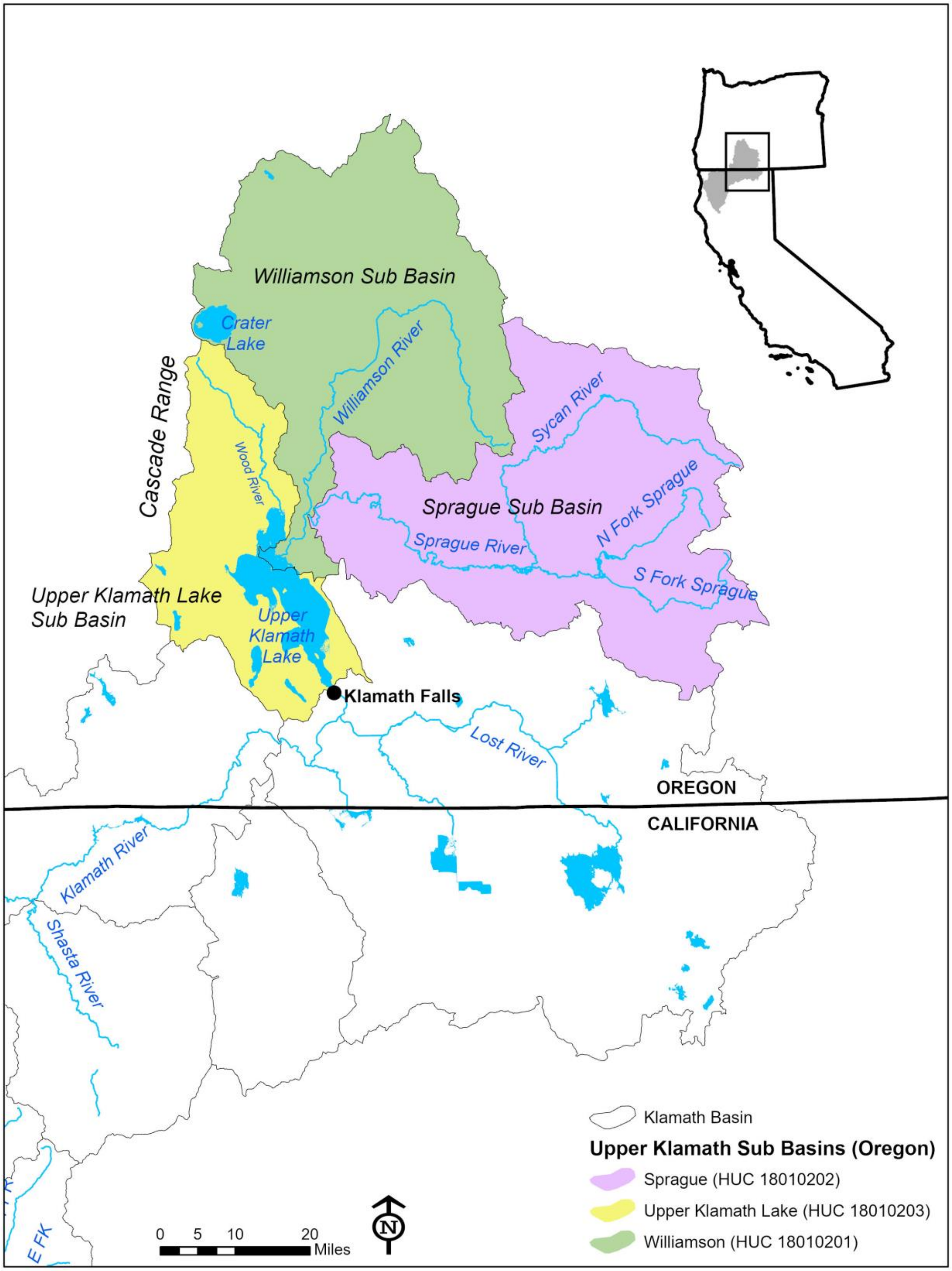

Figure 1. Geographic scope of Upper Klamath Basin, as defined in the Upper Klamath Basin Watershed Action Plan.

The UKL watershed covers 3,786 square miles of south-central Oregon, ranging in elevation from 4,143 feet to over 9,000 feet. Hydrologic characteristics of these systems range from predominantly low-gradient, groundwater-dominated streams (e.g., the Wood and Williamson rivers) to more dynamic snowmelt-runoff-dominated systems (e.g., the Sprague and Sycan rivers and the Cascade Tributaries). A majority of the UKL watershed is owned by federal or state agencies, although extensive private land exists in lower elevation valley bottom areas. Primary land use activities include commercial timber harvest and agriculture (predominantly ranching and pasture production).

UKL is a large, shallow, hypereutrophic lake system. UKL surface elevation can vary by up to five feet in a single water year due to regulation of lake levels at Link River Dam to support agricultural irrigation and Klamath River flows. Historically, extensive wetlands occurred along UKL, however, in the late 1800s and early 1900s farmers were encouraged by the federal government to settle in the upper basin. They began constructing dikes for draining the fringe wetlands to reduce flooding and increase agricultural acres and yield (Snyder and Morace 1997). In all, over half of UKL fringe wetlands have been drained since 1889 (Snyder and Morace 1997), though restoration of fringe wetlands is now ongoing.

The climate of the Klamath River basin is considered sub-humid to semi-arid, depending on elevation. Growing seasons are typically dry in the UKB, but average annual precipitation ranges from 14 inches) in Klamath Falls to 65 inches at Crater Lake.

The UKB lies within the northern extent of the Basin and Range Province, which includes portions of the Cascade Range and the Modoc Plateau. The geology of the UKB is characterized by complex assemblages of lava flows, volcanic vents, pyroclastic deposits, and sedimentary deposits derived from volcanic source materials. Present-day landforms, including broad areas of nearly flat basalt plains, were created by volcanic and tectonic processes and were subsequently modified by glaciation, runoff, and weathering (ODEQ 2002).

The people of The Klamath Tribes (the Klamath, Modoc, and Yahooskin Tribes) have lived in the UKB for thousands of years and historically relied primarily on fishing, hunting, and gathering to acquire food resources. However, the landscape was altered significantly in the latter part of the 19th and early 20th centuries as transportation, flood protection, and irrigation infrastructure was constructed throughout the UKB. Specifically, the Klamath Project, initiated in 1905 by the U.S. Bureau of Reclamation, drew farmers and ranchers to the region. Conflict over water supply for endangered species, migratory waterfowl, public lands, agriculture, commercial fishing, Tribal uses, and hydroelectric power generation has persisted in the UKB throughout the 20th century and into the 21st century. Climate change impacts further stress water availability in the UKB, as warmer winter temperatures and reductions in snowpack alter the timing and magnitude of snowmelt runoff and reduce groundwater recharge throughout the west (McCabe and Clark 2005).

The UKB has numerous water quality and fisheries issues. Of note are two sucker species (Lost River *Deltistes luxatus* and Shortnose suckers *Chasmistes brevirostris*) endemic to the Klamath Basin that are currently ESA-listed and near extinction. Factors likely contributing to the decline of these sucker species include deteriorating water quality and habitat in UKL and tributaries, predation by and competition with invasive fish species, and fish disease (USFWS 2012). Other aquatic species of note include Oregon Spotted Frog (*Rana pretiosa*), Redband Trout (*Oncorhynchus mykiss newberryi),* Bull Trout (*Salvelinus confluentus)*, several lamprey species, and anadromous salmon (which are expected to recolonize the UKB pending removal of four dams on the mainstem Klamath River).

The following sections describe the primary components of the UKBWAP.

CONCEPTUAL MODELS

The UKBWAP conceptual models illustrate process and function as a result of specific anthropogenic activities and/or depict impairments associated with multiple land use activities. These models also reflect the best available information regarding physical and biological processes and linkages (i.e., direct and indirect relationships as illustrated in the conceptual models) in the UKB and provide an adaptive basis from which to plan, design, and monitor restoration projects. The conceptual models are organized such that the reader can navigate to the model (and associated narrative) of interest and access all necessary information.

Specifically, the conceptual models are organized into two types of models per impairment or anthropogenic activity; the "impaired conditions" models illustrate process and function in an impaired state prior to restoration, while the "restored conditions" models depict restoration of process and function as a result of specific restoration actions. The impairments illustrated in these conceptual models are those most common to the UKB, as determined by numerous previous efforts and the expert opinion and professional judgement of the members of the UKBWAP Team. Similarly, the restoration actions illustrated in the "restored conditions" models are those that have been recommended for the UKB by numerous previous restoration planning efforts that address the impairments illustrated in the "impaired conditions" models (see also Appendix A for more comprehensive guidance on restoration actions). The conceptual models are structured to first illustrate the direct effects of an impairment/anthropogenic activity ("impaired conditions" models) or specific restoration action ("restored conditions" models). Second, the models depict how direct effects lead to numerous indirect effects. Ultimately, the models illustrate linkages between indirect and watershed-scale effects. The "restored conditions" models also describe how watershed-scale effects of specific restoration actions are linked to achieving the overall goals of the UKBWAP. These conceptual models are intended to improve understanding of the critical processes and linkages responsible for current ecosystem conditions and potential restored conditions. These models are intended to inform restoration actions to address specific impairments and can be used to develop realistic restoration and monitoring objectives.

The linkages and mechanisms described in the conceptual model narrative and figures, especially those associated with the "restored conditions" models, are theoretical and conceptual, and based on the best available information. Additionally, the UKBWAP does not attempt to define the temporal scale necessary to achieve specific restoration objectives. Indeed, it may take several years (to decades, in some cases) to observe some of the indirect effects of restoration actions described in these models, but this concept is commonly acknowledged in the field of ecosystem restoration.

There are many locations within the UKB where it is necessary to assess multiple stressors for an individual site, and application of more than one conceptual model may be required. The conceptual models, when combined with the condition metrics, can help practitioners to assess the breadth of stressors contributing to impaired conditions and to evaluate the scale, scope, and sequencing of restoration actions.

Finally, the conceptual models also form the technical basis for IRPT (Chapter 4), the Restoration Guide (Chapter 5, Appendix A), and the Monitoring Framework (Chapter 6, Appendix B).

INTERACTIVE REACH PRIORITIZATION TOOL

The IRPT is a web-based geospatial tool that prioritizes stream reaches and UKL shoreline segments based on a condition assessment (described below). The IRPT can be used in a number of ways, including (but not limited to):

- To identify a priority reach for a specific restoration project.
- To identify highest priority reaches for restoration of any kind.
- To understand impairments and priority restoration actions in a pre-selected reach.

The IRPT identifies the most impaired reaches within the UKB based on a score of 1 – 4 (with higher scores indicating poorer condition and therefore higher priority for restoration) for both individual condition metrics (described in Chapter 4 and Appendix D, and listed below), and for an averaged metric score. The IRPT webpage includes metadata for each reach listing the reach number, averaged condition metric score, and the score for each individual condition metric. The IRPT also includes additional layers that can be added to the web map, including designated critical habitat for Oregon Spotted Frog, Lost River Sucker, Shortnose Sucker, and Bull Trout; a beaver dam suitability index; and the fish barriers point file described in Chapter 4 and Appendix D. These additional layers are provided for reference only, and have not been incorporated into reach scoring.

The IRPT is designed to be used in concert with the Restoration Guide (Appendix A) to identify highest priority impairments and restoration options to address those impairments.

Although the IRPT offers a basin-scale assessment of reach-specific condition and reach prioritization for restoration, ground-truthing and professional/expert judgement are critical in determining if specific locations and/or potential project sites within prioritized reaches are indeed high priorities for restoration based on observations. *The IRPT provides guidance, but is not intended to replace professional opinion and judgement and/or ground-truthing, nor is it intended to be binding in any way, as all restoration actions on private land are voluntary.* Site visits, thorough ground-truthing, and pre-project monitoring to better understand site conditions are critical elements in any restoration program and are strongly encouraged. No model or geospatial analysis will ever be fully accurate, so it is expected that as additional information becomes available (through site visits or otherwise), reach condition scores may change.

The IRPT webpage is designed to guide restoration professionals and members of the public. Although the IRPT allows restoration professionals and others to better understand degree of impairment (and priority restoration actions in conjunction with Appendix A) at a reach scale, the IRPT relies on geospatial data that may not always accurately represent current conditions at a fine scale. As such, the IRPT is meant to guide efforts at a landscape scale, but site visits and professional opinion are critical in determining what is most appropriate and the highest priority at a given project site.

The condition metrics used in the IRPT were developed using expert opinion and geospatial methods. Specifically, these condition metrics, identify wetland, riparian, and riverine conditions at a reach scale for each impairment/anthropogenic activity described in the "impaired conditions" conceptual models in Chapter 3. Although the UKBWAP assumes that the highest priority reaches for restoration are those with poorest condition, restoration professionals can prioritize reaches in whatever way best meets their needs (e.g., if preservation is of interest, restoration professionals can use the IRPT to identify and prioritize for preservation reaches in "good" condition).

River reaches for condition metrics were defined uniformly as 3 miles long, regardless of stream size and length, and with the first reach beginning at the mouth of the river or stream of interest. In some cases, shorter reaches are present near headwater areas. UKL shoreline segments were defined uniformly as 3 miles long with the first segment beginning at the mouth of the Williamson River and moving clockwise around the lake. The justification for 3-mile long reaches was that this length allows for a finer-scale conditions assessment, but also protects the privacy of local landowners. In total, this reach designation method resulted in 268 stream reaches and 41 UKL shoreline segments.

Specific condition metrics applied to the IRPT include:

- Channelization (applied to stream reaches)
- Channel incision (applied to stream reaches)
- Levees and berms (applied to stream reaches)
- Wetlands (applied to UKL shoreline segments)
- Riparian and floodplain vegetation (applied to stream reaches)
- Irrigation practices (applied to both stream reaches and UKL shoreline segments)
- Springs (applied to stream reaches)
- Fish passage (applied to stream reaches)
- Roads (applied to stream reaches)
- Fish entrainment (applied to stream reaches)
- Large woody debris (applied to both stream reaches and UKL shoreline segments)
- Spawning substrate (applied to both stream reaches and UKL shoreline segments)

To ensure consistency across metrics, the reach-level scores for each metric were determined based on the quantile values of the metric results relative to all other reaches assessed.

Condition metrics are applied using a scoring system that adds points for factors that increase impairment. In other words, higher metric scores indicate a more impaired condition, while lower metric scores indicate a less impaired condition. Each condition score has been scaled to the same 1 – 4 scoring scale to allow relative comparison. Finally, individual metric scores were averaged to obtain an "averaged condition metric score" for each reach. As with the individual condition metric scores, the combined score is from 1 – 4, with a score of 4 indicating poorest condition. We chose to use an unweighted average for the averaged condition metric score in order to avoid subjectively prioritizing and weighting some impairments over others. There is likely a great number of different weighted combinations restoration professionals may be interested in. This approach was meant to provide a simple and straightforward guide including information that allows individual restoration professionals to further refine reach prioritization based on their expertise and priorities, rather than the UKBWAP Team's own set of priorities. Chapter 4 includes a summary of methods used to develop each metric, but more detail is provided in Appendix D.

RESTORATION GUIDE

The Restoration Guide (Appendix A) is composed of a table providing suggested restoration actions (within the categories presented in the conceptual models) to reverse or mitigate the impairments illustrated in the conceptual models, technical resources regarding implementation of these actions, and other considerations such as permitting, legal criteria, and associated governing agencies. This table is not intended to be an exhaustive list, but rather a starting place that provides current and/or locally relevant technical information that can guide restoration planning.

Appendix A also includes literature reviews and reports offering more specific information about implementation, monitoring, and potential outcomes of restoration actions such as riparian restoration (fencing, grazing management, and planting) and beaver restoration (Beaver Dam Analogs [BDAs] and other actions that facilitate beaver re-establishment).

The Restoration Guide (Appendix A) is meant to be used by restoration professionals to guide restoration implementation after priority reaches and restoration activities have been identified, and this information has been confirmed with a site visit.

MONITORING FRAMEWORK

The conceptual models described in Chapter 3 form the technical basis for the Monitoring Framework (Appendix B). The Monitoring Framework is organized by impairment, restoration project type necessary to correct each impairment, the quantifiable indirect and direct effects at both the local (near the project site) and watershed scales associated with each impairment/restoration action model pair, and finally the appropriate monitoring methods to measure each quantifiable effect.

The Monitoring Framework is intended to inform both project and watershed-scale monitoring regimes based on objectives associated with specific restoration project types. Targeted and effective monitoring is a critical component of adaptive management, specifically aimed at strengthening technical understanding of ecosystem processes and functions and improving and adjusting restoration implementation methods to achieve desired objectives. The UKBWAP will utilize new information from voluntary monitoring to validate and refine the conceptual models (Chapter 3) and the restoration actions recommended in the Restoration Guide (Appendix A), and to improve the effectiveness of future restoration actions in the UKB. To answer both watershed and project-scale questions, simultaneous multi-scale monitoring is often necessary, and the UKBWAP therefore considers monitoring at multiple scales.

Finally, while the Monitoring Framework serves as a guideline for development of monitoring regimes associated with specific restoration project types, there is an expectation that restoration professionals will assess site-specific conditions and make adjustments as appropriate and based on expert judgement.

The UKBWAP envisions the following workflow for the Monitoring Framework:

1. The restoration professional can identify an appropriate restoration action based on the Restoration Guide (Appendix A) or through previous efforts (such as identifying a single restoration project type and pursuing funding to implement this type of project throughout the watershed; see Workflow subsection in Chapter 4 for specific discussion).

2. The restoration professional can then review the list of quantifiable effects associated with the restoration project type of interest, focusing first on the direct and local effects. These quantifiable effects correspond to quantifiable project objectives, thereby allowing the user to select specific project objectives that can be evaluated through monitoring.

3. Once the restoration professional has identified specific project objectives, they can determine the appropriate monitoring method and review associated documents for further information about monitoring implementation.

4. After monitoring methods are selected, the restoration professional would ideally begin pre-implementation monitoring to quantify the baseline condition prior to project implementation. Additional sampling is necessary (using the same methods to measure the same parameters as for pre-implementation monitoring) after project implementation to quantify the effects of the project.

The Monitoring Framework is not intended to replace expert judgement and local expert opinion. The Monitoring Framework is a guideline for restoration and monitoring and there is an expectation that restoration professionals will assess conditions at potential project sites to validate (and revise, when appropriate) UKBWAP recommendations.

DATA GAPS AND NEXT STEPS

The development of the IRPT identified several key data and knowledge gaps essential for making well-informed prioritization of restoration activities at the UKB-scale. Specific needs to enhance and expand the IRPT include:

- Channel bathymetry
- Flood control infrastructure (to evaluate constraints of any proposed channel realignment)
- Detailed, field-verified irrigation infrastructure data
- Hydrodynamic model output (e.g., to better gage the amount of floodplain made accessible by levee removal)
- Status of fish passage barriers currently characterized as "unknown status"
- Impact of passage barriers on specific fish life stages
- Impact of passage barriers during specific seasonal flow conditions
- Fish screen status in areas currently labelled "unknown status"
- Stream velocity and depth information
- Fish habitat mapping
- More spatially resolved grazing and farming data and management practices
- Vegetation maps with species, wetland indicator status, soil stabilizer properties, diversity and age
- Updated LiDAR covering the geographic scope of the UKBWAP

Additionally, while restoration project cost estimates are not critical for ecological prioritization of restoration activities, information regarding project cost is critical for restoration planning. Future cost estimates for project types should be confirmed by pilot projects that are currently on-going and should also include reflections on the efficacy of pilot projects and projected maintenance estimates. Relative to past projects, it would be valuable to future restoration activities to attribute data from USFWS, USDA Resource Advisory Committees, the Natural Resources Conservation Service, U.S. Bureau of Reclamation, Oregon Watershed Enhancement Board, and the Bureau of Land Management with cost information, when possible.

Relative to next steps, the UKBWAP is envisioned as a multi-phase project that, in this first phase, produced a draft IRPT and Monitoring Framework. The UKBWAP uses an adaptive management framework such that as additional data become available, the IRPT can be enhanced with additional data and updated.

Specific next steps include:

- Updating the fish passage metric to include information in the 2019 ODFW fish passage barrier update and the 2020 ground-truthing project, and adding known barriers not currently included.
- Developing a wetlands metric for stream and river reaches.
- Developing springs and fish entrainment metrics for UKL shoreline segments.
- Investigating metrics for upland areas.

- Exploring options to prioritize reaches or systems for instream water rights transfers.
- Developing the Stakeholder Engagement Plan (Appendix C, *in prep*.) and completing the associated activities identified therein and summarized in Chapter 1.
- Continuing to assess new information and data, and revising the UKBWAP accordingly.
- Continuing to engage with the restoration community, local landowners, technical experts, Tribes, and other interested parties to ensure that the UKBWAP meets the needs of the community and remains a technically-sound document.
- Continuing to investigate methods to incentivize voluntary restoration, particularly that on private lands.

In the interim period, interested parties are encouraged to contact any of the UKBWAP Team members to provide input and recommendations for future iterations of the UKBWAP. Additionally, the UKBWAP Team welcomes the participation by other interested parties for development of future phases of the UKBWAP.

ACKNOWLEDGMENTS

The UKBWAP Team acknowledges the contributions of past team members, including Christie Nichols (USFWS), Heather Hendrixson and Eric Wold (The Nature Conservancy), and Tim Burnett (The Klamath Tribes). We also thank the Trout Unlimited Geospatial Team for developing and refining condition metrics and developing the IRPT webmap, and the local experts (including personnel from USFWS, Klamath Watershed Partnership, Oregon Department of Agriculture, Trout Unlimited, ODFW, and The Klamath Tribes) for contributing information to the condition metrics that relied on expert opinion. Ag Innovations provided facilitation services during early development of the UKBWAP. The consulting firm FlowWest also contributed substantial geospatial information to this effort. Finally, we acknowledge the tremendous contributions of numerous reviewers that have provided valuable feedback on UKBWAP drafts.

Development of the UKBWAP was funded by the U.S. Bureau of Reclamation, PacifiCorp, USFWS, OWEB, and through in-kind contributions from the UKBWAP Team member organizations.

FEEDBACK AND QUESTIONS

As outlined above, the UKBWAP Team plans to update the UKBWAP at least annually and any time new information becomes available. To provide feedback or obtain additional information about the UKBWAP, please contact Megan Skinner at megan_skinner@fws.gov.

CHAPTER 1: PLAN OVERVIEW

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 (ODEQ 2002, O'Connor et al. 2015, CH2M Hill 2018, Klamath Tribal Water Quality Consortium 2018) 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 benefit both the local rural economy and the ecosystem, and 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.

Identifying a desired state, while common in many restoration plans, was intentionally not addressed here. Specifically, there is a diversity of hydrology, geomorphology, habitat, and even climate in the UKB[2], so the UKB Watershed Action Plan (UKBWAP) instead focuses on synthesizing the findings of past efforts to identify the degree of impairment at a reach level and then provide information and guidance to restoration professionals to reverse those impairments. Similarly, much previous work has been done to assess historical conditions (e.g., O'Connor et al. 2015). Although a return to historical conditions may be warranted in some cases[3], the UKBWAP seeks to generally improve wetland, riverine, riparian, and floodplain process and function to benefit numerous species and achieve water quality goals; as such, **the focus is generally on current conditions and how they may be improved to meet these goals, rather than current conditions relative to historical conditions.** The UKBWAP seeks to restore process and function to the greatest extent by identifying and reversing impairments. This approach has developed over decades of conversations with the restoration community, natural resource managers, regulatory agencies, and landowners and therefore represents what these groups see as most needed and beneficial to the UKB restoration community.

Finally, the UKBWAP in general (and Chapter 2 in particular) is not meant to comprehensively summarize historical conditions or events, or other contextual details that are provided in numerous other documents (particularly ESSA 2017). Rather, the focus of this plan is, as described below, to provide tools and guidance to restoration professionals to achieve various goals related to water quality, species needs, and restoration of process and function. For a comprehensive synthesis of historical and contextual information, see ESSA (2017).

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[2] The Watershed Action Plan defines the UKB as the portion of the Klamath River watershed upstream of Link River Dam.

[3] Understanding historical conditions is therefore important in cases where a return to historical conditions may be warranted. Restoration professionals have the option to include this in their assessment of conditions and restoration options as part of a site visit.

WATERSHED ACTION PLAN PURPOSE AND GOALS

The purpose of the UKBWAP is to inform effective and prioritized voluntary restoration activities in the UKB, with the goals of improving the following through restoration of floodplain, riparian, wetland, and riverine process and function:

- Water quality, as addressed in the Upper Klamath Lake (UKL) Drainage TMDL (ODEQ 2002) and the U.S. Fish and Wildlife Service (USFWS) "Recovery Plan for the Lost River suckers and Shortnose suckers (*Deltistes luxatus* and *Chasmistes brevirostris*) (USFWS 2012)"

- Habitat for Lost River and Shortnose suckers, as addressed in the USFWS Sucker Recovery Plan (USFWS 2012)

- Habitat for Bull Trout (*Salvelinus confluentus*), as addressed in the USFWS Klamath Recovery Unit Implementation Plan for bull trout (USFWS 2002)

- Habitat for adfluvial/resident Redband Trout (*Oncorhynchus mykiss newberrii*), a Federal species of concern, an Oregon state sensitive vulnerable species, and a cultural and subsistence resource for The Klamath Tribes

- Habitat for returning anadromous salmon and lamprey after the pending removal of four mainstem Klamath River dams, as addressed in the "Implementation Plan for the Reintroduction of Anadromous Fishes into the Oregon Portion of the Upper Klamath Basin" (ODFW and The Klamath Tribes 2020)

- Open water wetland habitat for Oregon Spotted Frog (*Rana pretiosa*), an ESA-listed amphibian native to parts of the UKB

Owing to the complexity of anthropogenic influences on the biotic and abiotic factors across a watershed, the UKBWAP attempts to tease out discrete and scientifically-sound linkages (i.e., direct and indirect relationships as illustrated in the conceptual models) presented in existing management guidelines in the UKB as the basis for addressing impairments with landscape applicability and relevance. In other words, the diversity of needs in time and space for the species listed above are such that achieving these goals, combined with those of the UKL drainage TMDL, result in a focus on ecosystem restoration, primarily restoration of wetland, riverine, floodplain, and riparian process and function.

To meet the goals described above, the UKBWAP provides the following:

- Identification of specific impairments to floodplain, wetland, riverine, and riparian process and function

- A reach[4]-scale watershed condition assessment that prioritizes reaches based on degree of impairment for landowner recruitment and subsequent implementation of restoration activities
- Science-based guidance regarding the selection and implementation of restoration projects necessary to address impairments
- Monitoring regimes tied to quantifiable restoration objectives at multiple scales
- A process of adaptive management to refine condition assessments, restoration actions, and monitoring as new information becomes available

Finally, many of the goals of the UKBWAP, particularly those related to water quality, require large-scale coordinated restoration within the watershed.

WATERSHED ACTION PLAN COMPONENTS AND LAYOUT

The UKBWAP is designed to first provide context and a technical foundation to inform subsequent discussion of restoration project types to address specific impairments, prioritized reaches for restoration implementation, and development of monitoring regimes tied to specific quantifiable restoration objectives at multiple scales. Specifically, Chapter 2 of this document provides an overview of the ecosystem and land use in the UKB, as well as some geographical and hydrological context. Chapter 3 outlines conceptual models that form the technical basis for the UKBWAP. Chapter 4 describes the map-based Interactive Reach Prioritization Tool (IRPT), how it is intended to guide and inform strategic landowner recruitment efforts and restoration implementation, and how condition metrics (which are used to characterize condition at a reach scale) were developed. Chapter 5 describes the Restoration Guide (Appendix A), which includes technical resources and literature reviews to offer project implementation guidance for restoration professionals. Chapter 6 describes the Monitoring Framework (Appendix B), including a discussion of multi-scale monitoring regimes and how this framework is intended for use by restoration professionals and others. Chapter 7 identifies data and knowledge gaps and suggests next steps for the UKBWAP and restoration prioritization and implementation in the UKB. Finally, the Stakeholder Outreach and Engagement Plan (Appendix C, *in prep.*; describes strategies and efforts to identify, contact, and recruit private landowners for voluntary restoration) is currently under development.

HOW TO USE THE WATERSHED ACTION PLAN

Although the UKBWAP includes extensive narrative, conceptual models, and appendices as described above, the primary component of interest to restoration professionals is likely the IRPT, which provides a web-based interactive map identifying priority areas for restoration based on degree of impairment (as described above). The IRPT is intended to be the most accessible and frequently accessed portion of the UKBWAP, while the narrative and appendices offer additional guidance and information. An example workflow for the UKBWAP is:

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[4] Condition assessment and prioritization occurs at the river/stream reach and UKL shoreline segment level to balance the geographic specificity necessary to accurately identify the most impaired areas in the watershed and concerns around landowner privacy.

1. Accessing the IRPT to identify a priority area for restoration, which may include reviewing Chapter 4 to learn more about the IRPT

2. Proceeding with a site visit or landowner outreach (possibly using strategies outlined in the Stakeholder Outreach and Engagement Plan [Appendix C, *in prep.*]), depending on relationships with landowners in the identified project area

3. Project planning, which may include:
    a. Reviewing the Restoration Guide (Appendix A) to inform restoration project selection.
    b. Reviewing the conceptual models and associated narrative (Chapter 3) for the impairment/restoration action pair of interest to better understand direct and indirect effects (particularly useful when developing grant proposals for project funding).
    c. Reviewing the Monitoring Framework (Appendix B) to inform development of quantifiable project objectives and an associated monitoring regime.

4. Proceeding with project implementation

The UKBWAP is not intended to be read cover-to-cover as many sections (particularly Chapter 3) are repetitive and highly technical, to ensure that accurate and scientifically-sound information is presented for each impairment and project type. Rather, the narrative of the UKBWAP exists to provide additional support and documentation for the critical components (IRPT, appendices) of the UKBWAP, as needed by restoration professionals.

WATERSHED ACTION PLAN TEAM

Key members of the UKB restoration implementation and planning community, including USFWS, Trout Unlimited, Klamath Watershed Partnership, The Klamath Tribes, Oregon Department of Environmental Quality (ODEQ), The Nature Conservancy, and the North Coast Regional Water Quality Control Board of California, came together with common goal of developing a restoration strategy with a clearly defined process for implementation.

Watershed Action Plan Team members are also currently working together on other larger-scale voluntary restoration planning projects within the Klamath Basin. The USFWS is sponsoring the development of the Klamath Basin Integrated Fisheries Restoration and Monitoring Plan (IFRMP) and the Klamath Hydroelectric Settlement Agreement Interim Measure 11 Water Quality Improvement Measures for the Klamath Basin - Priority List of Projects (PLP). These projects are consistent with and supportive of the UKBWAP, but focus on more coarse spatial resolution and may not include the network of local partners that compose the UKBWAP and UKBWAP Team. The IFRMP and PLP are referenced here because they provide foundational information and data for the UKBWAP and may provide funding opportunities for voluntary projects.

STAKEHOLDER OUTREACH

Stakeholder outreach to support development and implementation of the UKBWAP is approached in two phases, as described below.

Phase I: Watershed Action Plan Development

To ensure the UKBWAP has broad buy-in and applicability within the UKB, it was critically important to solicit stakeholder involvement and feedback during the development of the UKBWAP. Stakeholders were kept informed and/or provided feedback during UKBWAP development. These stakeholders included federal, state, county, and city agencies, Tribal entities, private landowners and irrigators, non-profit groups, funding agencies, politicians, educational institutions, and private consultants and companies. This diverse list of stakeholders was split into four categories to facilitate appropriate outreach and communication:

1. UKBWAP Team: As defined above, the UKBWAP Team consists of the organizations committed to writing and producing the UKBWAP

2. Technical Reviewers: This group consists of individuals considered experts in a specific field. These reviewers provided technical oversight and comments on the draft UKBWAP

3. Landowner Reviewers: This group consists of private landowners who provided feedback on the draft UKBWAP. UKBWAP Team representatives reached out to members of this group individually during the plan development process to keep them informed about progress and to solicit their feedback

4. Informed Stakeholders: This group was kept informed about the process and received the web address for the UKBWAP website

Phase II: Watershed Action Plan Implementation

To ensure widespread awareness, understanding, and support of the UKBWAP in both the technical and non-technical communities of the Klamath Basin, additional outreach and engagement is necessary. Specific strategies for this phase of stakeholder outreach will be further outlined in Appendix C (The Stakeholder Outreach and Engagement Plan, *in prep.*), but are described briefly below.

First, the UKBWAP Team will develop a website (*in prep*.) to house the UKBWAP narrative and other components to provide user-friendly access to the most recent version of the UKBWAP.

Second, members of the UKBWAP Team will attend several local and regional technical meetings and conferences, presenting information about the UKBWAP to ensure these technical communities (i.e., resource management agencies, conservation groups, and funding entities) have an understanding of the UKBWAP's status, components, purpose, and can access the

UKBWAP for restoration planning and implementation purposes. UKBWAP Team members will also reach out directly to other relevant entities that are not represented at these meetings and conferences to provide this information and solicit feedback.

Third, the UKBWAP Team will identify landowners in priority areas using reach priority findings in the IRPT, combined with publicly available property ownership information. This allows the UKBWAP Team and other members of the restoration community to focus outreach and engagement on landowners in areas with the highest potential for recovery, rather than engaging in a watershed-wide effort.

Fourth, the UKBWAP Team and other restoration partners, such as the Klamath County Soil and Water Conservation District, will use strategies outlined in the Stakeholder Outreach and Engagement Plan (Appendix C, *in prep.*) to contact and engage landowners in priority restoration areas, with the goal of stimulating landowner interest and collaboration for voluntary restoration on their private lands. This engagement includes providing landowners with the web address for the UKBWAP (and physical copies, when appropriate), a brief "tutorial" demonstrating how the UKBWAP, and the IRPT in particular, work, and technical assistance regarding restoration implementation and best management practices when warranted. This approach will provide several opportunities for landowners to learn about the UKBWAP and connect with restoration professionals interested in implementing priority restoration projects in priority reaches.

Finally, the UKBWAP Team will continue to collaborate with all of our partners to identify potential incentives to encourage restoration implementation. The UKBWAP Team will also continue to advocate for an accessible and robust restoration tracking inventory that can help practitioners, funding entities, landowners, and other interested parties quantify and understand what and where restoration that has occurred in the UKB.

ADAPTIVE MANAGEMENT

The UKBWAP is intended to be adaptive in nature to accommodate new information and data relevant to the UKB. It is critical that the components of the UKBWAP can adapt to incorporate new information to ensure that prioritization, implementation, and monitoring are as effective as possible and based on the best available science and information.

The adaptive management framework is a six-step process, as described below with UKBWAP-specific examples:

1. *Build partnerships and define goals*- The UKBWAP Team consists of key restoration implementation and planning entities in the UKB; the UKBWAP Team will continue to evaluate team membership and UKBWAP goals and will also develop the Stakeholder Outreach and Engagement Plan to identify additional restoration partners.

2. *Characterize current conditions*- The UKBWAP assesses and characterizes the current conditions in the UKB and will continue to do so as conditions change and/or new information becomes available.

3. *Identify problems and develop solutions*- The UKBWAP characterizes specific ecosystem impairments and linkages, identifies reaches with the greatest level of impairment, and recommends project types to address these impairments through the conceptual models, the IRPT, and the Restoration Guide (Appendix A), respectively.

4. *Implement solutions*- The UKBWAP provides guidelines and technical references for specific restoration practices along with potential permitting and regulatory authorities as applicable via the Restoration Guide (Appendix A).

5. *Measure and evaluate progress*- The UKBWAP identifies specific monitoring regimes that help the restoration community evaluate progress towards quantifiable restoration objectives via the Monitoring Framework (Appendix B).

6. *Make adjustments*- The UKBWAP describes how monitoring and outreach will be used to adjust and adapt restoration practices and geographic prioritization to ensure restoration activities are both strategic and effective. Similarly, the UKBWAP describes how information collected through monitoring efforts can inform revision of the conceptual models and Monitoring Framework (Appendix B).

CHAPTER 2: UPPER KLAMATH BASIN OVERVIEW

LOCATION AND OVERVIEW OF HYDROLOGY

The UKB, as defined for the UKBWAP, includes Upper Klamath Lake (UKL), the Sprague, Williamson, and Wood rivers, and tributaries to UKL originating in the foothills of the Cascade Range (termed the Cascade Tributaries) (Figure 1).

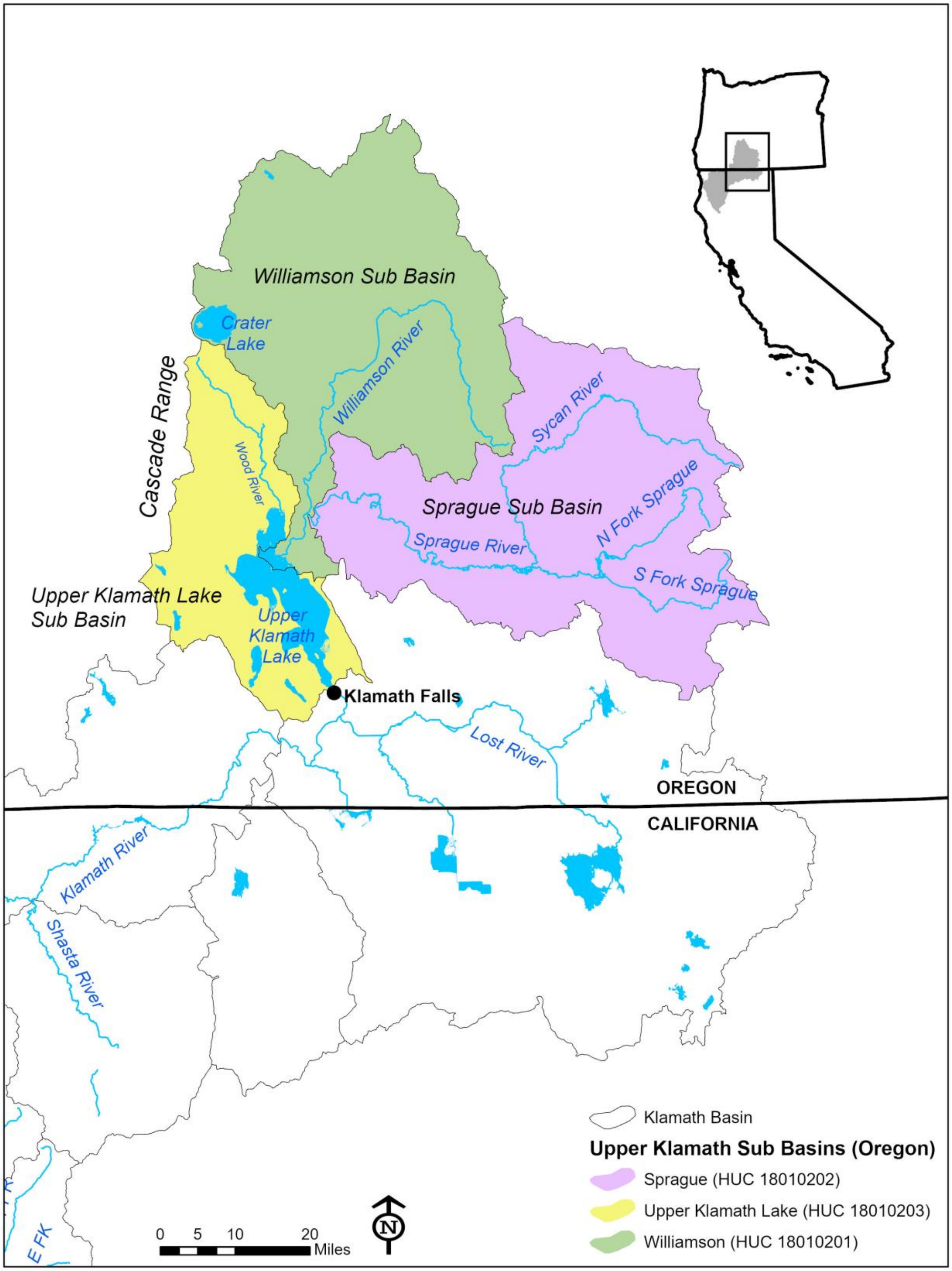

Figure 1. Geographic scope of Upper Klamath Basin, as defined in the Upper Klamath Basin Watershed Action Plan.

Williamson River Watershed

The Williamson River watershed is approximately 1,420 square miles and ranges in elevation from 9,182 feet in the Cascade Range to 4,143 feet at the Williamson River delta (on the northeast shore of UKL). The Williamson River flows north from the headwaters, curves west and then south through the Klamath Marsh National Wildlife Refuge, and then flows south to UKL. The Williamson River is relatively low gradient with a majority of the watershed having a slope less than 8 percent (David Evans and Associates 2005). Surface flow downstream of Klamath Marsh National Wildlife Refuge is controlled by Kirk Reef, a natural basalt formation. During periods of low flow, typically in mid-summer to late fall, approximately a half mile of the river channel is dewatered in the vicinity of the reef.

The geology of the Williamson River sub-basin is primarily volcanic in origin. Due to the porous geology, many tributaries on the west side of the watershed are subject to subsurface flow before reaching the Williamson River as springs (David Evans and Associates 2005).

A majority of the Williamson River watershed is owned by federal or state agencies, while the remaining land is privately owned and managed primarily for commercial timber and agricultural activities. Overall, approximately 81 percent of the watershed is characterized as timber; 6 percent as farms; and 13 percent as range, water, and urban areas (primarily Chiloquin, OR) (Risley and Laenen 1999).

Sprague River Watershed

The Sprague River watershed is 1,580 square miles. The river originates in the Fremont-Winema National Forest at approximately 7,000 feet in elevation and flows south and west towards the confluence with the Sycan River near the town of Beatty, OR. The Sycan River originates at Winter Ridge (6,700 feet) and flows northwest into Sycan Marsh and then south to the confluence with the Sprague River. From the confluence with the Sycan, the Sprague River flows west to the confluence with the Williamson River.

A majority of the Sprague River watershed is owned by federal or state agencies, while the remaining land is privately owned and managed primarily for commercial timber and/or grazing and other agricultural activities. The private agricultural lands are primarily located in the alluvial valleys along the mainstem Sprague River and portions of the south and north forks of the river (O'Connor et al. 2015).

Wood River and Cascade Tributaries

The Wood River begins just south of Crater Lake National Park flows to Agency Lake (the northern lobe of UKL) near Chiloquin, OR. The Wood River meanders through agricultural lands consisting of irrigated pasture and is largely groundwater dominated. Historically, much of the Wood River Valley was comprised of wetlands, 79 percent of which have been converted to agricultural land (ONRCS 2010).

The Wood River watershed is considered part of the UKL hydrologic unit (HUC 18010203). Additional tributaries to UKL include Sevenmile Creek/Canal and Fourmile Creek/Canal, which originate in the foothills of the Cascade Range and are characterized by snowmelt runoff and precipitation-dominated hydrology. These canals also function as conveyance structures for agricultural runoff and tailwater returns in the Wood River Valley (Walker et al. 2012).

Upper Klamath and Agency Lakes

Upper Klamath and Agency lakes (together, UKL) compromise a large, shallow, hypereutrophic lake system. The northern lobe of UKL, Agency Lake, is shallow and hypereutrophic. Levee breeching in the Williamson River delta in 2007 and 2008 has increased connectivity between the two lobes of UKL (Wood et al. 2014). Additional future wetland restoration efforts just north of Agency Lake will likely further expand lake surface area.

UKL surface elevation can vary by up to five feet in a single water year due to diversion of water at Link River Dam to support agricultural irrigation, releases downstream to support Klamath River flows, and lake elevation regulation for flood control. Historically, extensive wetlands occurred along UKL, however, in the late 1800s and early 1900s farmers were encouraged by the federal government to settle in the UKB. Farmers began constructing dikes for draining the fringe wetlands to reduce flooding and increase agricultural acres and yield (Snyder and Morace 1997). In all, over half of UKL fringe wetlands have been drained since 1889 (Snyder and Morace 1997), though restoration of fringe wetlands is now ongoing.

CLIMATE

The following excerpt from USFWS (2015) summarizes UKB climate:

> “The climate of the Klamath River basin, the product of wind from the west and the Cascade rain shadow, varies from sub-humid to semi-arid depending on elevation (NRC 2004). Average annual precipitation ranges from 36 centimeters (14 inches) in Klamath Falls to 165 centimeters (65 inches) at Crater Lake; precipitation comes primarily as winter snow, with little rainfall during the growing season (Gannett et al. 2007). While precipitation is generally greater in the higher elevations, much of the surface water for perennial streams is supplied by springs below 2,042 meters (6,700 feet). Runoff primarily consists of a base-level perennial discharge from springs and seasonal (mid spring) discharge from snowmelt. Rare rain-on-snow events may also occur in early fall or during spring snowmelt. Growing seasons are typically dry with localized thunderstorms. Temperatures vary widely both diurnally and seasonally. Summer temperatures are generally warm with a mean July maximum of 29° Celsius [C] (85° Fahrenheit [F]) at Klamath Falls and 20° C (68° F) at Crater Lake. Winter temperatures are generally cold with a mean January minimum of -7° C (20° F) at Klamath Falls and -8° C (18° F) at Crater Lake (Gannett et al. 2007).”

For additional information about UKB climate, please refer to ESSA (2017).

GEOLOGY

The UKB lies within the Basin and Range Province (NRC 2004), which includes portions of the Cascade Range and the Modoc Plateau. The geology of the UKB is characterized by complex assemblages of lava flows, volcanic vents, pyroclastic deposits, and sedimentary deposits derived from volcanic source materials (Gannett et al. 2007). Present-day landforms, including broad areas of nearly flat basalt plains (NRC 2004), were created by volcanic and tectonic processes and were subsequently modified by glaciation, runoff, and weathering (Gannett et al. 2007).

A massive eruption from Mount Mazama at the northern end of the UKB occurred about 7,700 years ago. During the eruption, Mount Mazama collapsed, forming Crater Lake, and generated pumice and ash deposits over much of the UKL watershed, altering channel dynamics and sediment transport (O'Connor et al. 2015). The Williamson River watershed, just east of the former Mount Mazama, was subject to pyroclastic flows and ash fall measuring in the tens of meters (Cummings and Conaway 2009). A pyroclastic debris dam formed in the Williamson River canyon downstream of the modern-day community of Kirk and contributed to the formation of a lake in the area that is now Klamath Marsh (Cummings and Conaway 2009). A subsequent outburst flood event scoured the canyon and deposited boulders from the mouth of the canyon downstream (Cummings and Conaway 2009). Post-eruption and flood evolution of the Williamson River tributaries in the Cascade Mountains and Antelope Desert saw the conversion of perched streams into losing (influent) streams and the loss of perennial flow in many tributaries that persists today (Cummings and Conaway 2009). The Sycan watershed received the greatest level of tephra deposits, and subsequent flood and deposition events resulted in a dynamic, migrating channel that continues to be a source of pumiceous sand to the Sycan and Sprague rivers (O'Connor et al. 2015). Subsequent to the eruption, but prior to human intervention, evidence suggests that the Sprague River watershed was a slowly aggrading system (O'Connor et al. 2015). The Wood River Valley consists of fine-grained alluvial deposits of low permeability overlaying high permeability sand and pumice (Gannett et al. 2007). Head pressure generated by steep gradients and groundwater flows from the west (Cascade Mountains) and north (Crater Lake) creates artesian conditions across most of the valley (Gannett et al. 2007).

GROUNDWATER HYDROLOGY

Transmissivity and permeability in the UKB are generally highest in the late Tertiary to Quaternary volcanic soil layers. The primary water-producing aquifer system in the UKB is comprised of interconnected late Tertiary to Quaternary volcanic rock layers. Late Tertiary sedimentary deposits interbedded among the volcanic rocks are composed of fine-grained lake sediments and basin fill and are generally low permeability deposits that restrict groundwater movement. Beneath the primary regional aquifer system, and bounding it to the east and the west, are older Tertiary volcanic rocks with very low permeability and transmissivity (Gannett et al. 2007).

The UKB, especially south of Crater Lake, has dozens of mapped faults that are generally oriented north-northwest. These geologic structures likely have localized impacts to groundwater flow directions by juxtaposing rocks with different permeabilities or creating structural basins that were subsequently filled with high permeability volcanic deposits or low permeability basin fill sediments. This is true of the Sprague River, which flows in a westerly direction through narrow canyons created by fault-bounded uplifts, alternating with broad alluvial valleys (O'Connor et al. 2015).

Groundwater in the basin moves from higher-elevation recharge areas, especially in the Cascade Mountains, towards discharge areas in tributary floodplains and UKL. Streams and rivers in the UKB are heavily influenced by groundwater; in the Wood River and Spring Creek, groundwater contribution to mean annual flow is about 93 and nearly 100 percent, respectively (Cummings and Conaway 2009). When summer surface discharge through Klamath Marsh is limited, groundwater discharged in the Williamson River canyon and via Spring Creek supplies most of the flow in the lower Williamson River (Cummings and Conaway 2009). However, there are runoff-dominated streams in the basin, including the Sycan River, for which groundwater contribution is only about 15 percent of mean annual flow. The Sprague River is another example of a runoff-dominated river. Regardless, well over 60 percent of the water flowing into UKL originates as groundwater discharge in the Wood River sub-basin, springs in the lower Sprague River drainage, and the Williamson River (Cummings and Conaway 2009).

LAND USE

The people of The Klamath Tribes (the Klamath, Modoc, and Yahooskin) have lived in the UKB for thousands of years, and historically relied primarily on fishing, hunting, and gathering (Hamilton et al. 2016) to acquire food resources. Fur traders began accessing tribal lands in 1826, and through the middle of the 19th century, European-American immigration increased (The Klamath Tribes 2019). Ranching was one of the earliest and most widespread agricultural practices in the UKB (KBEF and KBREC 2007). With construction of the first railroad in 1909, timber harvest also became a major industry in the area (KBEF and KBREC 2007). European-American settlers sought to protect the economy and the expanding population through forest management practices, in particular the exclusion of fire.

The landscape was altered significantly in the latter part of the 19th and early 20th centuries as transportation, flood protection, and irrigation infrastructure was constructed throughout the UKB. This time period included the installation of several dams on the Klamath River downstream from the UKB: Keno Dam (1967), J.C. Boyle (1958), Copco 1 Dam (1918), Copco 2 Dam (1925) and Iron Gate Dam (1962). These dams eliminated anadromous access to hundreds of stream miles (Hamilton et al., 2016).

The Klamath Project, initiated in 1905 by the U.S. Bureau of Reclamation, drew farmers and ranchers to the region with the promise of irrigation for agricultural production (Gosnell and Clover Kelly 2010). European-American immigrants claimed water rights in the UKB under Oregon State's prior appropriation doctrine, however the 2013 adjudication determined that The Klamath Tribes' water rights are senior to all other water rights in the UKB. Tribal instream water rights include claims for physical and riparian habitat flows (OWRD 2013).

Conflict over water supply for endangered species, migratory waterfowl, public lands, agriculture, commercial fishing, Tribal uses, and hydroelectric power generation has persisted in the UKB throughout the 20th century and into the 21st century. Recent federal efforts to address water supply challenges include support for water conservation infrastructure (the 2002 Farm Bill), incentivizing crop-idling, promoting groundwater supplementation, and other financial assistance for farmers and commercial fisheries (Gosnell and Clover Kelly 2010). In addition, the federal government has also recently provided considerable funds to support wetland migratory bird and threatened and endangered aquatic species habitat restoration. Climate change impacts further stress water availability in the UKB, as warmer winter temperatures and reductions in snowpack alter the timing and magnitude of snowmelt runoff and reduce groundwater recharge (Mayer and Naman 2011). The rate and consistency of groundwater discharge to streams or as springs in the UKB is dependent upon recharge and changes in storage. Recharge is a function of climate and is influenced by timing and magnitude of precipitation and snowmelt, frequency of drought, and oscillations in long-term climate trends (Gannett and Breen 2015). Variations in recharge within the UKB primarily occur in the Cascade Mountains (Gannett et al. 2007). Groundwater storage, which is often reflected in groundwater elevation or water table levels, is affected by groundwater pumping and withdrawal. Irrigation and public supply uses are the main groundwater withdrawals in the UKB and have the greatest long-term impact on groundwater storage in valley-bottom areas within the basin (Gannett et al. 2007). Groundwater discharge in streams or as springs will continue to decline as groundwater is developed in the basin. Ongoing conflict over water management, combined with the effects of climate change, create a particularly challenging environment for riparian and riverine restoration in the UKB.

Note that the effects of changes in land use in the UKB are described in detail in Chapter 3.

WATER QUALITY

Upper Klamath Lake is considered a naturally eutrophic lake (Sanville et al. 1974, Johnson 1985, Eilers et al. 2004), but anecdotal and quantified changes in algal communities, fish populations, and water quality since the early 1900s suggest that nutrient enrichment following European-American settlement has contributed to the current hypereutrophic conditions (Bortleson and Fretwell 1993). Land and water use practices have exacerbated nutrient issues, and a combination of external (watershed) and internal (lake sediment) sources, the latter of which is a legacy of historical external loading, now drive water quality issues in UKL (ODEQ 2002). In 1998, ODEQ in compliance with the Clean Water Act Section 303(d) placed UKL and its tributaries on the list of impaired waters not meeting water quality standards for beneficial uses (ODEQ 1998), citing location and seasonal deviations from standards for chlorophyll-*a*, dissolved oxygen, pH, and/or temperature. Subsequently, ODEQ prepared the UKL Drainage TMDL and Water Quality Management Plan, approved by the EPA in 2002, which set in-stream pollutant levels necessary to meet water quality standards (ODEQ 2002). The TMDL determined that "…total phosphorus [TP] load reduction is the primary and most practical mechanism to reduce algal biomass and attain water quality standards for pH and dissolved oxygen…" (ODEQ 2002). To meet TP goals, the TMDL calls for a 40 percent reduction in external loading of TP to UKL, and sets targets for average annual inflow concentrations (66 µg TP/L), and average annual (110 µg TP/L) and spring (30 µg TP/L) lake concentrations (ODEQ 2002). Recent modelling work has corroborated the targets set in the TMDL, indicating that 40 percent reductions in external TP loading will result in reductions in water column TP and algal biomass within a few decades (Wherry and Wood 2018).

Phosphorus occurs in relatively high levels in the local geology of the UKB, and agricultural application of P amendments is minimal (ODEQ 2002, Walker et al. 2015). Phosphorus-rich sediment is mobilized in the watershed through anthropogenic activities that increase erosion (Walker et al. 2012, Walker et al. 2015), a process that is compounded by the diminishment of riparian and fringe wetland areas that function in filtering and processing sediments and nutrients (ODEQ 2002). The major rivers in the UKB contribute approximately two thirds of the external TP load to UKL (Williamson- 21 percent, Sprague- 23 percent, and Wood- 21 percent), while Sevenmile Creek/Canal (9 percent) and direct pumping of irrigation tail water to UKL (13 percent) are also major contributors (Walker et al. 2012). Measured TP is comprised of natural/background levels and inputs from anthropogenic activities, with the latter estimated to account for 37 percent of the external TP load to UKL from 1992 through 2010 (Walker et al. 2012).

Phosphorus leads to exceedance of water quality standards in UKL by promoting the rapid and widespread production of algae, specifically the nitrogen-fixing cyanobacterium *Aphanizomenon flos-aquae* (AFA) (ODEQ 2002). For more than 70 years, AFA has dominated the phytoplankton community during spatially and temporally extensive blooms in UKL (Bortleson and Fretwell 1993). These seasonal blooms lead to extreme diel fluctuations in dissolved oxygen (DO) and pH, followed by toxic levels of un-ionized ammonia during AFA die-off, and proliferation of another cyanobacterium, *Microcystis aeruginosa* (ODEQ 2002, Eldridge et al. 2013). *M. aeruginosa* produces hepatotoxic microcystins, which pose a threat to humans and other animals and have been cited by the Oregon Health Authority in recreational use health advisories for UKL each summer since 2015 (OHA 2020). These water quality conditions, alone and in combination, can create a stressful environment for aquatic biota, and contribute to increased disease and mortality (Perkins et al. 2000a, Burdick et al. 2020). Water quality during and following AFA blooms has been associated with re-distribution of ESA-listed Lost River and shortnose suckers (Buettner and Scoppettone 1991, Banish et al. 2007, Banish et al. 2009), and was linked to population declines and fish kills in recent decades (Perkins et al. 2000a).

FISH POPULATIONS

Lost River and Shortnose Suckers are species endemic to the Klamath River Basin. Historical accounts estimate tribal harvests of these species in the tens of thousands (NCRWQCB 2008). Both species were listed as endangered under the ESA in 1988. Current factors limiting sucker recovery include high mortality of larvae and juveniles due to reduced rearing habitat and forage quality, disease, entrainment in water management structures, poor water quality, and negative interactions with introduced species (USFWS 2012). Lost River and Shortnose sucker populations associated with UKL have declined by as much as 50 and 75 percent, respectively, between 2001 and 2015 (Hewitt et al. 2017), and have continued to decline since 2015 (D. Hewitt, pers. comm.). Note that these sucker species, and the challenges associated with their decline, also occur in the Lost River sub-basin and other areas of the Klamath River Basin. As described above, the current geographic scope of the UKBWAP is limited to the UKB, however, there is interest in including the Lost River sub-basin in the UKBWAP in the future. The Lost River sub-basin is also of critical importance to the recovery of these sucker species, and inclusion of this sub-basin in the UKBWAP would facilitate additional prioritization and restoration guidance for sucker recovery.

The prominence of salmon in the culture and oral tradition of The Klamath Tribes combined with empirical evidence indicate that salmon, predominantly Chinook (*O. tshawytscha*) and steelhead (*O. mykiss* ssp.), were historically present in the tributaries to UKL (Hamilton et al. 2005). There is evidence that anadromous Pacific Lamprey (*Entosphenus tridentatus*) were present within the Klamath River as far upstream as the confluence with Spencer Creek (downstream of Keno Dam), however, it is unclear if Pacific Lamprey occurred in UKL and tributaries in the UKB prior to the construction of Klamath River dams (Hamilton et al. 2005).[5]

According to historical accounts from European-Americans in the mid-19th century, anecdotal estimates of salmon runs vary from the thousands to millions (Hamilton et al. 2016). Historical observations of salmon runs in the UKB prior to 1918 (when upstream migration was prevented by the completion of Copco 1 Dam) were seasonally diverse and reported several salmon species and different life stages (Hamilton et al. 2016). Currently, there is an effort underway to remove four dams on the mainstem Klamath River, with the goal (among many) of improving anadromous fish passage to the UKB. Anticipating removal of four mainstem Klamath River dams and restored access to hundreds of miles of aquatic habitat in the UKB, ODFW and The Klamath Tribes are developing the “Implementation Plan for the Reintroduction of Anadromous Fishes into the Oregon Portion of the Upper Klamath Basin.” The reintroduction implementation plan intends to guide the reintroduction of Chinook, Coho (*O. kisutch*), Steelhead, and Pacific Lamprey in the portion of the Klamath Basin in Oregon, with the goal of restoring naturally reproducing and self-sustaining populations in suitable historical habitats. For the basin upstream of Link River Dam (the area defined as the UKB in the UKBWAP), the reintroduction plan specifically supports volitional recolonization of fall-run Chinook, Steelhead, and Pacific Lamprey; and active reintroduction of spring-run Chinook (necessitated by a lack of a source population in the upper Klamath River).

ODFW (2008) summarizes the distribution of Redband Trout in the UKB as follows:

> “Redband trout are widely distributed throughout the upper Klamath basin. Resident and/or migratory redband trout are present in Klamath River, the major tributaries of Upper Klamath and Agency Lakes, and headwater streams of the Gearhart and Cascade mountains.”

Additionally, connectivity between most populations is likely with suitable water conditions in UKL and adequate flow over irrigation diversions in the lower reaches of many rivers (ODFW 2008). However, a portion of the historical Redband Trout habitat in the UKB is either inaccessible due to the presence of passage barriers, or of suboptimal quality (ODFW 2008). Redband Trout are a Federal species of concern, an Oregon state sensitive vulnerable species, and a cultural and subsistence resource for The Klamath Tribes.

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[5] Numerous resident (non-anadromous) Lamprey species are present in UKL and the UKB including Pit-Klamath Brook Lamprey (*Entosphenus lethophagus*, Miller Lake lamprey (*Entosphenus minimus*), and two other species of the subgenus *Entosphenus*, about which little information is known (ODFW 2002).

Bull Trout in the UKB are part of the Klamath Recovery Unit, which includes three Bull Trout core areas (UKL, Sycan River, and upper Sprague River) (USFWS 2008). USFWS (2008) summarizes the status of Bull Trout in the UKB as follows:

> “Bull Trout in the Klamath Recovery Unit have been isolated from other Bull Trout populations for the past 10,000 years and are recognized as evolutionarily and genetically distinct…. As such, there is no opportunity for Bull Trout in another recovery unit to naturally recolonize the Klamath Recovery Unit if it were to become extirpated. The Klamath Recovery Unit lies at the southern edge of the species range and occurs in an arid portion of the range of Bull Trout. Bull Trout were once widespread within the Klamath River basin…but habitat degradation and fragmentation, past and present land use practices, agricultural water diversions, and past fisheries management practices have greatly reduced their distribution. Bull Trout abundance also has been severely reduced, and the remaining populations are highly fragmented and vulnerable to natural or manmade factors that place them at a high risk of extirpation....The presence of nonnative Brook Trout (*Salvelinus fontinalis*), which compete and hybridize with bull trout, is a particular threat to Bull Trout persistence throughout the Klamath Recovery Unit.

CHAPTER 3: CONCEPTUAL MODELS TO DESCRIBE ECOSYSTEM PROCESS AND FUNCTION

OVERVIEW

The UKBWAP conceptual models are intended to improve understanding of the critical processes and relationships responsible for current ecosystem conditions and potential restored conditions. These models are intended to inform restoration actions to address specific impairments and can be used to develop realistic restoration and monitoring objectives.

The conceptual models reflect the best available information regarding physical and biological processes and linkages in the UKB and provide an adaptive basis from which to plan, design, and monitor restoration projects. The conceptual models illustrate process and function as a result of specific anthropogenic activities and/or depict impairments associated with multiple land use activities. This chapter includes both graphical representations of the conceptual models and narrative descriptions of conceptual models to discuss caveats, specific mechanisms, and other information that is not clearly illustrated by the graphical format of the conceptual models. This chapter is organized such that the reader can turn to the section of interest and access all necessary information; as such, each subsection includes a complete narrative description of the associated conceptual models even if similar linkages have been fully described in a previous subsection.

The conceptual models are organized into two types of models per impairment or anthropogenic activity; the "impaired conditions" models illustrate process and function in an impaired state prior to restoration, while the "restored conditions" models depict restoration of process and function as a result of restoration actions. The impairments illustrated in these conceptual models are those most common to the UKB, as determined by numerous previous efforts (e.g., ODEQ 2002, USFWS 2012, Klamath Tribal Water Quality Consortium 2018) and the expert opinion and professional judgement of the members of the UKBWAP Team. Similarly, the restoration actions illustrated in the "restored conditions" models are those that have been recommended for the UKB by numerous previous restoration planning efforts (e.g., ODEQ 2002, CH2M Hill 2018, Klamath Tribal Water Quality Consortium 2018) and that address the impairments illustrated in the "impaired conditions" models[6].

The conceptual models are structured to first illustrate the direct effects of an impairment/anthropogenic activity ("impaired conditions" models) or restoration action ("restored conditions" models). Second, the models depict how direct effects lead to numerous indirect effects. Ultimately, the models illustrate linkages between indirect and watershed-scale

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[6] Although the "restored conditions" conceptual models consider restoration project types that may be used to address a particular impairment, specific and prescriptive practices are outside of the scope of this watershed-level tool, although some guidance is provided in Appendix A (the Restoration Guide). Landowners and practitioners are encouraged to approach each project with a thorough understanding of the site conditions using accepted standards and criteria for practice design. To aid in this process, Appendix A provides a table of technical references and literature reviews.

effects. The “restored conditions” models also describe how watershed-scale effects of restoration actions are linked to achieving the overall goals of the UKBWAP. Finally, terms such as “restored” in the narrative descriptions of the “restored conditions” models indicate restoration of conditions appropriate to each individual site has (theoretically) been achieved.

The linkages and mechanisms described in the conceptual model narrative and figures, especially those associated with the “restored conditions” models, are theoretical and conceptual, and based on the best available information. Additionally, the UKBWAP does not attempt to define the temporal scale necessary to achieve specific restoration objectives. Indeed, it may take several years (to decades, in some cases) to observe some of the indirect effects of restoration actions described in these models, but this concept is commonly acknowledged in the field of ecosystem restoration. Overall, these models assume that restoration activities have been implemented at the appropriate location and scale, that these projects are effective as implemented, and that recovery of process and function has occurred (i.e., has not been hindered by some other unforeseen impairment or issue), which may not always be the case in reality.

There are many locations within the UKB where it is necessary to assess multiple stressors for an individual site, and application of more than one conceptual model may be required. For example, nuisance water quality conditions can exist due to the interaction of watershed inputs, poor riparian cover, degraded channel conditions, low flows, and high temperature (Butcher 2006). The conceptual models, when combined with the condition metrics, can help practitioners to assess the breadth of stressors contributing to impaired conditions and to evaluate the scale, scope, and sequencing of restoration actions.

Finally, the conceptual models also form the technical basis for the IRPT (Chapter 4), the Restoration Guide (Chapter 5, Appendix A), and the Monitoring Framework (Chapter 6, Appendix B).

CHANNELIZATION

Channelization is an engineered channel realignment practice, typically to straighten a channel for land development and flood control. Anthropogenic channel modifications began in the late 19th century in the UKB to support burgeoning industries, such as agriculture and timber harvesting, as well as for flood protection, water supply and delivery, and to accommodate construction of transportation infrastructure (O’Connor et al. 2015). Channelization occurred extensively throughout the Sprague River basin beginning in the 1950s, as a result of the U.S. Army Corps of Engineers channelization program (Rabe and Calonje 2009).

Impaired Conditions

The impaired conditions conceptual model for channelization represents impairments resulting from a single specific anthropogenic activity (channelizing rivers and streams).

The direct result of channelization is changes in channel morphology, including decreased sinuosity, changes in channel profile (e.g., channel width and depth), and changes in channel gradient (Figure 2; Brooker 1985, Bukaveckas 2007, Kroes and Hupp 2010).

Changes in channel morphology affect geomorphic process and function including a decreased capacity to intercept and retain nutrients and sediment (Bukaveckas 2007, Kroes and Hupp 2010), and a decreased capacity to attenuate high flows (Sholtes and Doyle 2010). The mechanisms supporting these linkages are primarily a loss of channel complexity (e.g., sinuosity and site-appropriate channel profile) (Brooker 1985, Lau et al. 2006) including features that slow stream velocity (particularly during high flows that convey the greatest sediment and nutrient loads) and facilitate deposition of sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010).

Additionally, changes in channel morphology lead to decreased diversity in native fish habitat (e.g., pools, riffles, etc.) (Brooker 1985, Lau et al. 2006) and indirectly to changes in substrate composition (as described below; Lau et al. 2006). As with changes in geomorphic process and function described above, the mechanisms supporting these linkages are primarily a loss of channel complexity (e.g., sinuosity and site-appropriate channel profile) that act to slow stream velocity and affect sediment transport dynamics.

Changes in geomorphic process and function also affect riverine process and function, leading to:

- Increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010) (which affects water quality and substrate composition).
- Increased channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[7].
- Decreased groundwater elevation, recharge, and contribution to baseflow (Bravard et al. 1997, Tague et al. 2008, Hardison et al. 2009) (which affects water quality and hydrology).

The mechanisms driving these linkages include a change in capacity to retain sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effect of increased sediment and nutrient load on UKL algal response (i.e., increased nutrient concentrations/loads lead to increased UKL algal productivity [ODEQ 2002]), which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies.

Under the “impaired conditions” model for channelization, there are no linkages to the overall goals of the UKBWAP.

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[7] This affects hydrology, sediment and nutrient load, and groundwater characteristics by lowering the groundwater elevation; see the “Channel Incision” subsection that follows for a detailed description of the effects of channel incision.

Restored Conditions

The specific restoration action recommended in the UKBWAP to address channelization and associated impairments is channel reconstruction[8] and methods to achieve "Stage 0" restoration[9].

The direct result of channel reconstruction and Stage 0 restoration is restoration of channel morphology, including site-appropriate sinuosity, channel profile (e.g., channel width and depth), and channel gradient (Figure 3).

Restoration of channel morphology affects geomorphic process and function including an increased 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). The mechanisms supporting these linkages are primarily restoration of channel complexity (e.g., sinuosity and site-appropriate channel profile) (Keller 1978, Lau et al. 2006) including features that slow stream velocity (particularly during high flows that convey the greatest sediment and nutrient loads) and facilitate deposition of sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010).

Additionally, restoration of channel morphology leads to increased diversity in native fish habitat (e.g., pools, riffles, etc.) (Lau et al. 2006) and indirectly to restoration of site-appropriate substrate composition (as described below). As with improvements in geomorphic process and function described above, the mechanisms supporting these linkages are primarily restoration of channel complexity (e.g., sinuosity and site-appropriate channel profile) and other features that slow stream velocity and facilitate restoration of sediment transport dynamics.

Improvements in geomorphic process and function also affect riverine process and function, leading to:

- Site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010) (which affects water quality and substrate composition).
- Decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010)[10].
- Increased groundwater elevation, recharge, and contribution to baseflow (Bravard et al. 1997, Tague et al. 2008, Hardison et al. 2009) (which affects water quality and hydrology).

The main mechanisms driving these effects include restoration of the capacity to retain sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow.

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[8] In some cases, levee removal, set-back, or breaching (among other actions, such as those to correct channel incision) may be effective in increasing channel complexity and sinuosity, but in the UKB and in this conceptual model in particular, channelization is the result of channel reconstruction by the U.S. Army Corps of Engineers, rather than other processes that may be responsive to less intensive restoration actions.

[9] Stage 0 restoration typically entails raising the elevation of the channel or relocating the channel to the floodplain utilizing a variety of techniques, including those considered "low-tech process-based." Powers et al. (2019) provides a technical summary of this type of restoration and associated goals and objectives.

[10] This affects hydrology, sediment and nutrient load, and groundwater characteristics.

Additional linkages within this conceptual model include the effect of site-appropriate sediment and nutrient load on UKL algal response[11], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies.

Finally, channel reconstruction, “stage 0” restoration, or other similar actions, implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 3).

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[11] I.e., impairment is no longer contributing additional concentrations/loads that lead to increased UKL algal productivity (ODEQ 2002).

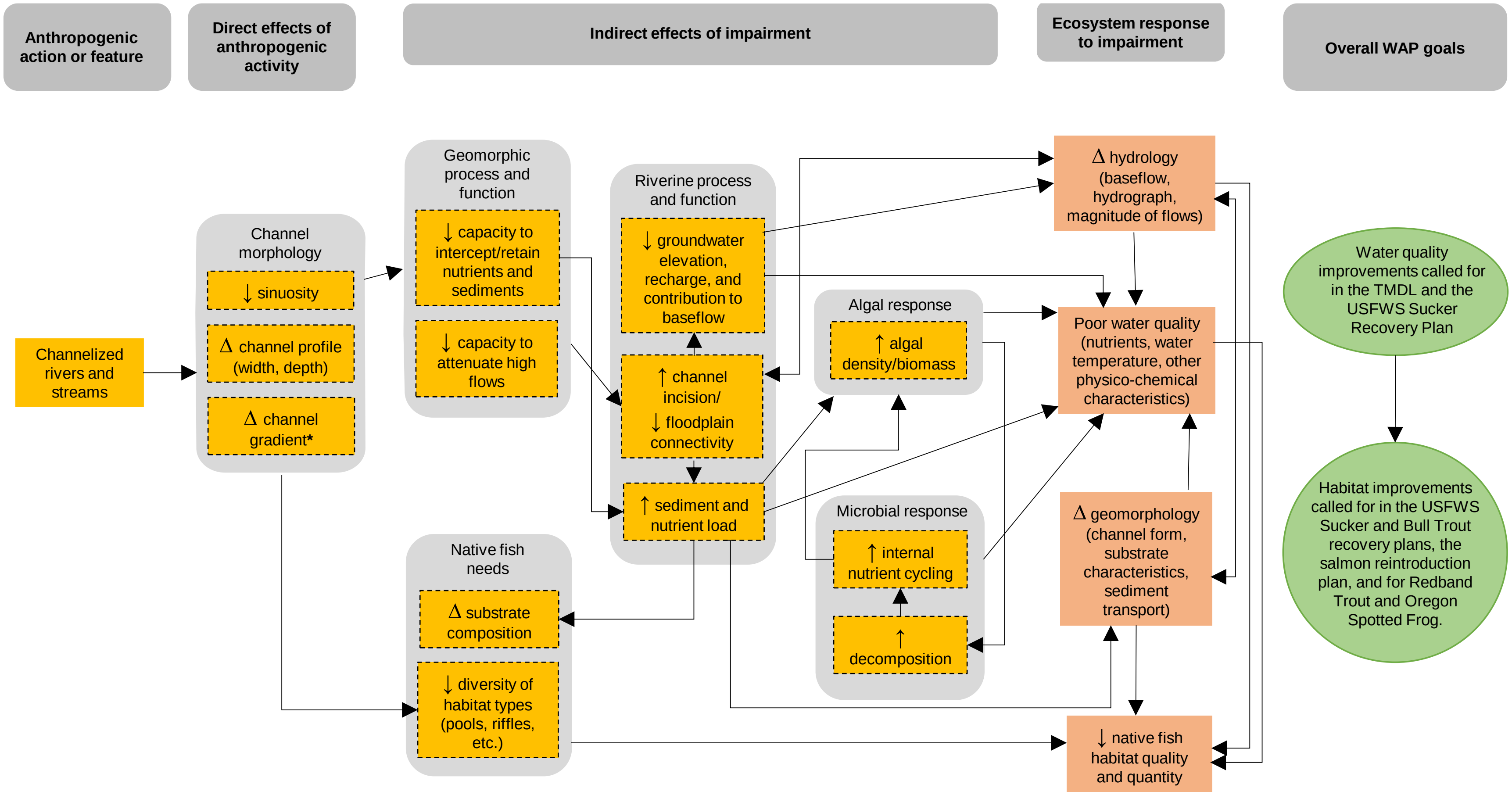

Figure 2. Channelization "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

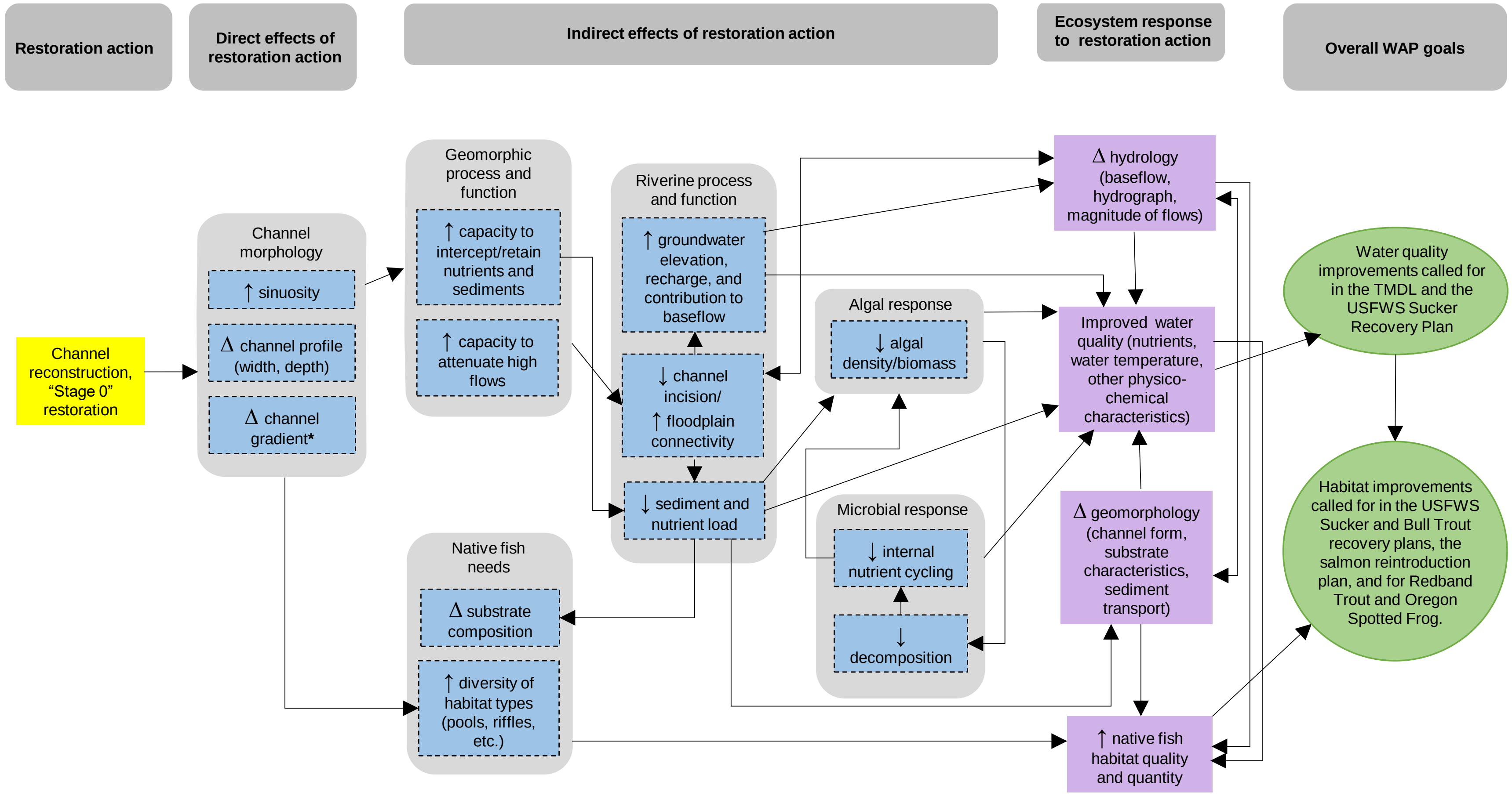

Figure 3. Channelization "restored conditions" conceptual model illustrating response to channel reconstruction or "Stage 0" methods implemented to correct and repair impairments associated with channelization. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

CHANNEL INCISION

Channel incision is defined as a reduction in the elevation of a streambed that leads to an imbalance in flow energy and sediment load within the stream. Channel incision typically results in disconnection of the stream from the floodplain at all but the highest flows. As a result of incision, streams convey greater discharge within the deepened channel, and there is a lack of floodplain connectivity to attenuate the energy associated with high flows (Sholtes and Doyle 2010). This increase in stream power within the stream channel promotes conveyance of additional sediment downstream (Bukaveckas 2007, Kroes and Hupp 2010, Pollock et al. 2014) and also leads to continued channel incision (Bravard et al. 1997, Kroes and Hupp 2010, Pollock et al. 2014).

Impaired Conditions

The "impaired conditions" channel incision conceptual model represents an impairment associated with multiple anthropogenic activities within the UKB, rather than a single specific activity.

The direct results of channel incision are a decrease in water surface elevation, an increase in water velocity, and a decrease in sediment deposition as a result of the increase in water velocity (Cluer and Thorne 2014) (Figure 4). A decrease in water surface elevation leads to a decrease in groundwater elevation, recharge, and contribution to baseflow (Cluer and Thorne 2014), the effects of which are described in more detail below. Additionally, these direct effects result indirectly in decreased connection between floodplain and river and decreased periods, or complete lack of, floodplain inundation (Kroes and Hupp 2010, Sholtes and Doyle 2011, Skarpich et al. 2016).

Decreased connection between the floodplain and the river or stream results in impairments to floodplain condition, namely decreased functioning size of the floodplain (e.g., it may not be as wide) and changes in the riparian and floodplain plant communities (Bravard et al. 1997, Lite et al. 2005, Hupp and Rinaldi 2007, Pollock et al. 2014, Skarpich et al. 2016). This indirect effect is largely due to a lack of surface water and/or groundwater that is typically available within functioning floodplains to support riparian and floodplain vegetation[12] (Dawson and Ehleringer 1991, Lite et al. 2005, Pollock et al. 2014, Skarpich et al. 2016). Additionally, decreased floodplain connection results in decreased high flow refugia and/or rearing habitat typically associated with functioning and connected floodplains (Sedell et al. 1990).

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[12] The term riparian and floodplain vegetation is used to represent the vegetative community that would be found at a given site based on abiotic factors such as geomorphology, climate, hydrology, and soils. In the riparian area, stabilizing characteristics, such strong rhizomes, extensive and fibrous roots, and durable leaves or stems, serve to protect streambanks against erosion, and are necessary among plant communities in the restoration and/or maintenance of most lotic systems (USDOI 2015). It can be assumed that native species are preferred over non-natives, but not at the loss of function to the system.

The effect of changes in floodplain condition include changes in floodplain processes and native fish habitat due primarily to the association between native riparian and floodplain vegetation, fish habitat components, beaver activity, and the capacity to intercept suspended sediment and particulate nutrient sources during high flows.

Change in floodplain processes resulting from changes in floodplain condition includes:

- Decreased capacity to intercept and retain nutrients and sediment[13] (Bukaveckas 2007, Kroes and Hupp 2010).
- A decrease in beaver habitat and activity[14] due to a reduction in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990)[15].
- Decreased capacity to attenuate high flows (Sholtes and Doyle 2010)[16].

Change in native fish habitat resulting from changes in floodplain condition includes:

- Decreased large woody debris (LWD) recruitment[17] (which affects the capacity to attenuate high flows) due to a lack of riparian and floodplain vegetation (Bragg et al. 2000, Opperman and Merenlender 2004).
- Decreased prey abundance due to a lack of food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Changes in substrate composition due to a lack of plant matter and floodplain/riparian roughness necessary for appropriate sediment transport dynamics (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Decreased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990).
- Decreased cover associated with overhanging vegetation.

Taken together, these changes in native fish habitat may affect habitat quality and quantity at the ecosystem scale.

Changes in riverine process and function, driven by linkages described above, include increased stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which affects hydrology); decreased groundwater elevation, recharge, and contribution to baseflow

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[13] This leads to changes in riverine process and function, including additional channel incision and decreased floodplain connectivity as sediment loads are conveyed through the watershed rather than deposited within.

[14] Note that the effects relative to beaver activity may not be relevant in areas that do not support beaver based on physical (stream gradient, valley confinement, stream power) and biological (riparian vegetation available as a food source and for dam-building materials) conditions (Pollock et al. 2018). Careful assessment of project sites is necessary to determine if efforts to relocate or attract beavers to an area are appropriate. Pollock et al. (2018), Appendix A, and the beaver dam suitability layer included in the IRPT provide additional information and guidance.

[15] This leads to changes in riverine process and function, hydrology, and geomorphology (Pollock et al. 2014).

[16] This leads to changes in riverine process and function, and hydrology.

[17] Similar to the caveats regarding beaver activity above, LWD may not have been present historically in some portions of the UKB. It should be acknowledged that riparian and floodplain restoration alone may not result in additional LWD recruitment in areas that don’t support woody vegetation. Additionally, careful thought should be given to LWD additions in areas where LWD was scarce historically.

(Tague et al. 2008, Hardison et al. 2009)[18]; additional channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[19]; and increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[20]. The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019). Similarly, the components of riverine process and function affect native fish habitat quality and quantity, as described above.

Additional linkages within this conceptual model include the effect of increased sediment and nutrient load on UKL algal response[21], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies.[22].

Under the "impaired conditions" model for channel incision, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration actions to address channel incision and associated impairments include facilitating beaver recolonization and establishment, constructing structures such as beaver dam analogs, "Stage 0" restoration, or other actions to aggrade stream channels (Harvey and Watson 1986, Shields et al. 1995a, Shields et al. 1995b, Pollock et al. 2014, Pollock et al. 2018). Appendix A provides additional information regarding implementation of beaver dam analogs, specifically.

The direct result of these restoration activities is a decrease in stream velocity, followed by an increase in sediment deposition within the stream channel due to a reduction in channel slope and increase in channel roughness and width, and an increase in water surface elevation (Pollock et al. 2014) (Figure 5). An increase in water surface elevation leads to a decrease in groundwater elevation, recharge, and contribution to baseflow (Cluer and Thorne 2014, Pollock et al. 2014), the effects of which are described in more detail below. A decrease in stream velocity and increase in sediment deposition indirectly leads to increased connection between the floodplain and river and increased periods of floodplain inundation due to a restoration of the site-appropriate difference in elevation between the streambed and floodplain through aggradation processes (Pollock et al. 2014).

Increased connection between the floodplain and the river or stream results in improvements in floodplain condition, namely 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). These indirect effects are largely due to the increased availability of surface water and/or groundwater within the floodplain to support riparian and floodplain vegetation (Dawson and Ehleringer 1991, Lite et al. 2005, Skarpich et al.

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[18] This affects hydrology and water quality, and floodplain condition, as described above.

[19] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.

[20] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

[21] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

[22] This subsequently affects water quality parameters such as pH and DO.

2016). Additionally, increased floodplain connection results in increased high flow refugia and/or rearing habitat associated with the functioning and connected floodplain (Sedell et al. 1990).

The effect of improvements in floodplain condition include restoration of floodplain processes, and improvements in native fish habitat due primarily to the association between riparian and floodplain vegetation, fish habitat components, beaver activity, and the capacity to intercept suspended sediment and particulate nutrient sources during high flows.

Restoration of floodplain processes resulting from improvements in floodplain condition includes:

- Increased capacity to intercept and retain nutrients and sediment[23] (Bukaveckas 2007, Kroes and Hupp 2010).
- An increase in beaver habitat and activity due to an increase in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990)[24].
- Increased capacity to attenuate high flows (Sholtes and Doyle 2010)[25].

Improvement in native fish habitat resulting from improvements in floodplain condition includes:

- Increased LWD recruitment[26] due to an increase in riparian and floodplain vegetation (Bragg et al. 2000).
- Increased prey abundance due to an increase in food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Site-appropriate substrate composition due to increased plant matter and floodplain/riparian roughness necessary to restore site-appropriate sediment transport processes (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Increased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990).
- Increased cover associated with overhanging vegetation.

Taken together, these improvements in native fish habitat increase habitat quality and quantity at the ecosystem scale.

Restoration of riverine process and function, driven by linkages described above, include restoration of site-appropriate stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which affects hydrology); increased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[27]; decreased channel incision

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[23] This leads to improvements in riverine process and function including decreased channel incision and increased floodplain connectivity as sediment loads are deposited within the watershed.
[24] This leads to improvements in riverine process and function (Pollock et al. 2014).
[25] This leads to improvements in riverine process and function, and restoration of site-appropriate hydrology.
[26] This directly increases the capacity to attenuate high flows.
[27] This affects hydrology and water quality, and floodplain condition, as described above.

and increased floodplain connectivity (Kroes and Hupp 2010)[28]; and restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[29]. The main mechanisms driving these effects include an improvement in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019). Similarly, the components of riverine process and function affect native fish habitat quality and quantity, as described above.

Additional linkages within this conceptual model include the effect of site-appropriate sediment and nutrient load on UKL algal response[30], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[31]. Finally, actions to aggrade stream channels, implemented effectively and at the appropriate scale throughout the watershed, indirectly result in achievement of the overall goals of the UKBWAP (Figure 5).

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[28] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.

[29] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

[30] I.e., impairments are no longer a source of additional nutrient loads leading to increased UKL algal productivity.

[31] This subsequently affects water quality parameters such as pH and DO.

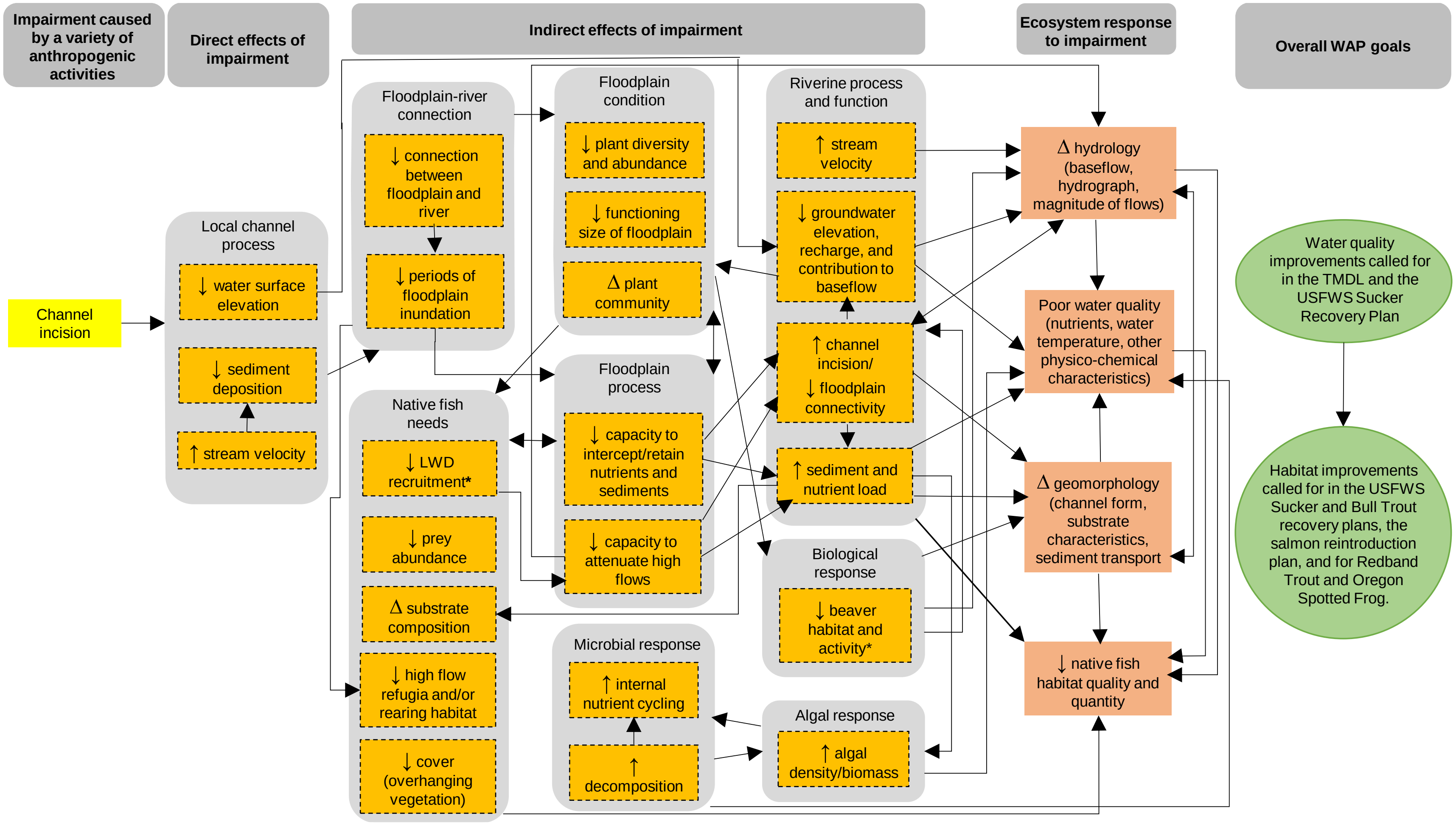

Figure 4. Channel incision “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

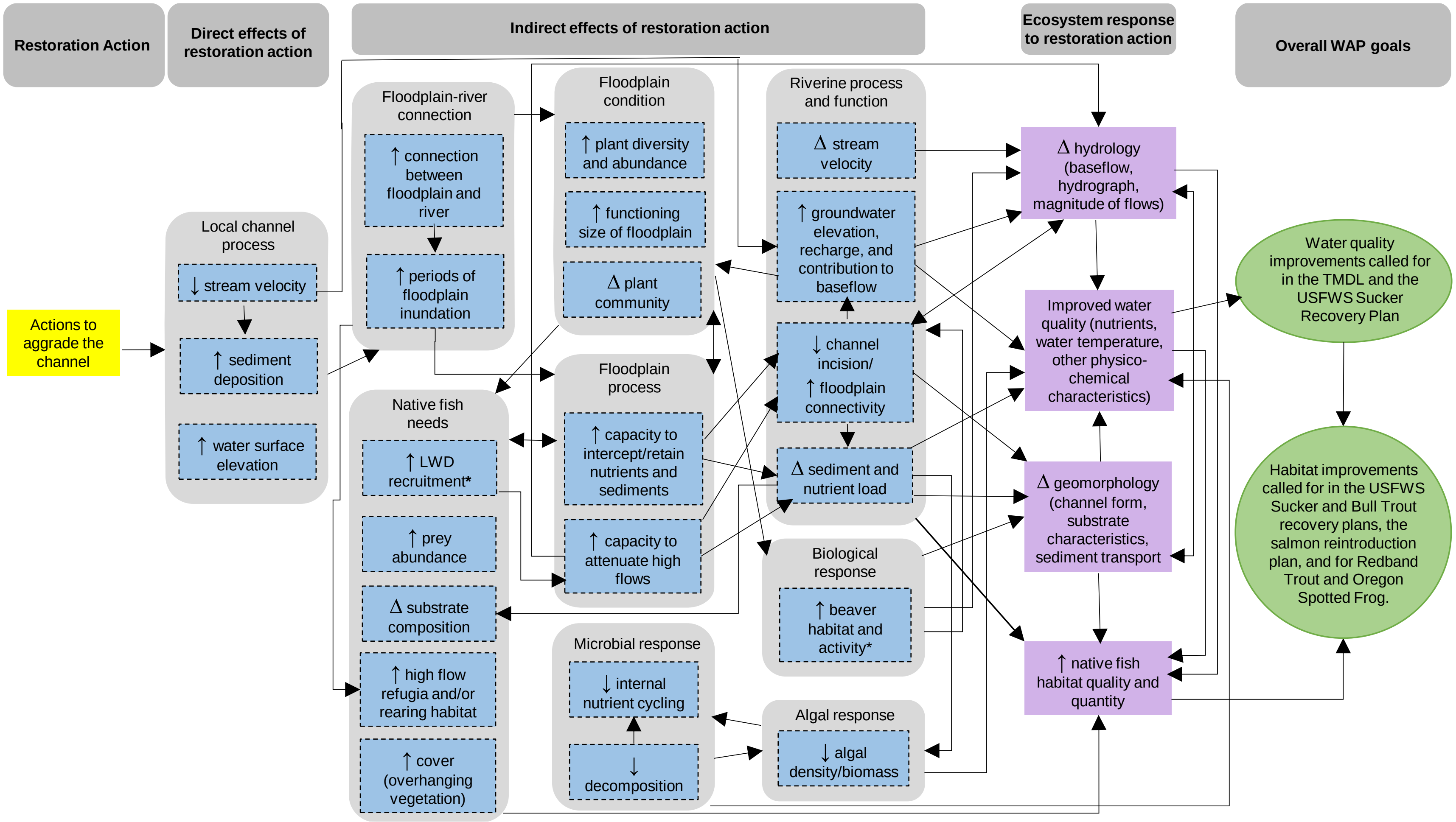

Figure 5. Channel incision "restored conditions" conceptual model illustrating response to projects that promote channel aggradation, implemented to correct and repair impairments associated with channel incision. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

LEVEES AND BERMS

The U.S. Army Corps of Engineers began constructing levees in the UKB after major flooding events in 1950 and 1964 (KBEF and KBREC 2007). Although these structures are intended to protect against flooding, levees also lead to disconnection of floodplains from river and stream systems (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010), which in turn leads to a loss of valuable habitat and ecosystem process and function (including flood attenuation), as described in subsections above.

The UKBWAP focuses on levees and berms constructed by humans, rather than natural levees or berms, per analysis of historical photographs (further described in Chapter 4 and Appendix D). In areas such as UKL, artificial levees may play an important role (such as reducing wave action associated with strong winds on UKL), so careful assessment of the costs and benefits of each levee is warranted and considered part of the assessment using professional opinion that occurs during a site visit.

Many of the linkages and mechanisms described in the conceptual models below are similar to the channel incision conceptual models described above; the justification for keeping these models separate is that these impairments typically require very different restoration actions to reverse or mitigate impacts.

Impaired Conditions

The impaired conditions conceptual model for levees and berms represents impairments resulting from a single specific anthropogenic activity (construction of berms and levees).

The direct results of levees and berms are decreased connection between floodplain and river with decreased periods, or complete lack of, floodplain inundation (Gergel et al. 2002, Opperman et al. 2009, Steinfeld and Kingsford 2013); and changes in channel morphology including a decrease in sinuosity, changes in channel profile, and changes in channel gradient (Brooker 1985, Bukaveckas 2007, Kroes and Hupp 2010) (Figure 6).

Decreased connection between the floodplain and the river or stream results in impairments to floodplain condition, namely decreased functioning size of the floodplain (e.g., it may not be as wide), and changes in the riparian and floodplain plant community (Bravard et al. 1997, Lite et al. 2005, Hupp and Rinaldi 2007, Skarpich et al. 2016). This indirect effect is largely due to a lack of surface water and/or groundwater that is typically available within functioning floodplains to support vegetation (Dawson and Ehleringer 1991, Lite et al. 2005, Skarpich et al. 2016). Additionally, decreased floodplain connection results in decreased high flow refugia and/or rearing habitat typically associated with functioning and connected floodplains (Sedell et al. 1990).

Changes in channel morphology result in changes in riverine process and function, including increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[32]; increased

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[32] This affects water quality and substrate composition.

channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[33]; and decreased groundwater elevation, recharge, and contribution to baseflow (Bravard et al. 1997, Tague et al. 2008, Hardison et al. 2009) (which affects water quality and hydrology).

The effect of changes in floodplain condition include changes in floodplain processes and native fish habitat due primarily to the association between native riparian and floodplain vegetation, fish habitat components, beaver activity, and the capacity to intercept suspended sediment and particulate nutrient sources.

Change in floodplain processes resulting from changes in floodplain condition includes:

- Decreased capacity to intercept and retain nutrients and sediment[34] (Bukaveckas 2007, Kroes and Hupp 2010).
- A decrease in beaver habitat and activity due to a reduction in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990)[35].
- Decreased capacity to attenuate high flows (Sholtes and Doyle 2010)[36].

Change in native fish habitat resulting from changes in floodplain condition includes:

- Decreased LWD recruitment (which directly affects the capacity to attenuate high flows) due to a lack of riparian and floodplain vegetation (Bragg et al. 2000).
- Decreased prey abundance due to a lack of food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Changes in substrate composition due to a lack of plant matter and floodplain/riparian roughness necessary for site-appropriate sediment transport dynamics (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Decreased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990).
- Decreased cover associated with overhanging vegetation

Taken together, these changes in native fish habitat affect habitat quality and quantity at the ecosystem scale.

Changes in riverine process and function, driven by linkages described above, include increased stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which directly affects hydrology); decreased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[37]; channel incision and additional decreases in

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[33] This affects hydrology, sediment and nutrient load, and groundwater characteristics; see the “Channel Incision” subsection above for a detailed description of the effects of channel incision.

[34] This leads to changes in riverine process and function including additional channel incision and decreased floodplain connectivity as sediment loads are conveyed through the watershed rather than deposited within.

[35] This leads to changes in riverine process and function (Pollock et al. 2014).

[36] This leads to changes in riverine process and function, and hydrology.

[37] This affects hydrology and water quality, and floodplain condition, as described above.

floodplain connectivity (Kroes and Hupp 2010)[38]; and increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[39]. The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effect of increased sediment and nutrient load on UKL algal response[40], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[41].

Under the "impaired conditions" model for levees and berms, there are no linkages to the overall goals of the UKBWAP (Figure 6).

It is important to note that levees and berms may provide flood protection and other beneficial functions, and it therefore may be difficult or dangerous to change the placement or structural integrity of some levees. The infrastructure-related benefits of levees or berms should be reviewed on a case by case basis when evaluating potential restoration projects.

Restored Conditions

The specific restoration actions to address impairments associated with levees and berms include levee/berm removal (Bayley 1991), set-back (Dwyer et al. 1997, Gergel et al. 2002), or breaching (Florsheim and Mount 2002, Kroes and Hupp 2010).

The direct results of these restoration activities are increased connection between floodplain and river and increased periods of floodplain inundation due to a restored connection between the river/stream and floodplains (Gergel et al. 2002, Steinfeld and Kingsford 2013), assuming other impairments such as channel incision are not additionally limiting; and changes in channel morphology including a decrease in sinuosity, changes in channel profile, and changes in channel gradient (Brooker 1985, Bukaveckas 2007, Kroes and Hupp 2010) (Figure 7).

Increased connection between the floodplain and the river or stream results in improvements to floodplain condition, namely 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). These indirect effects are largely due to the increased availability of surface water and/or groundwater within the floodplain to support site-appropriate vegetation (Dawson and Ehleringer 1991, Lite et al. 2005, Skarpich et al. 2016). Additionally, increased floodplain connection results in increased high flow refugia and/or rearing habitat associated with the functioning and connected floodplain (Sedell et al. 1990).

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[38] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.

[39] This affects water quality, geomorphology, UKL algal responses, and substrate composition)

[40] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

[41] This subsequently affects water quality parameters such as pH and DO.

Removal of levees and berms results in changes in riverine process and function, including decreased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[42]; decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010)[43]; and increased groundwater elevation, recharge, and contribution to baseflow (Bravard et al. 1997, Tague et al. 2008, Hardison et al. 2009) (which affects water quality and hydrology).

The effect of improvements in floodplain condition include restoration of floodplain processes and improvements in native fish habitat, due primarily to the association between native riparian and floodplain vegetation, fish habitat components, beaver activity, and the capacity to intercept suspended sediment and particulate nutrient sources.

Restoration of floodplain processes resulting from improvements in floodplain condition includes:

- Increased capacity to intercept and retain nutrients and sediment[44]) (Bukaveckas 2007, Kroes and Hupp 2010).
- An increase in beaver habitat and activity due to an increase in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990)[45].
- Increased capacity to attenuate high flows (Sholtes and Doyle 2010)[46].

Improvement in native fish habitat resulting from improvements in floodplain condition includes:

- Increased LWD recruitment (which directly increases the capacity to attenuate high flows) due to an increase in riparian and floodplain vegetation (Bragg et al. 2000).
- Increased prey abundance due to an increase in food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Site-appropriate substrate composition due to increased plant matter and floodplain/riparian roughness necessary to process sediment (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Increased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990).
- Increased cover associated with overhanging vegetation.

Taken together, these changes in native fish habitat increase habitat quality and quantity at the ecosystem scale.

Restoration of riverine process and function, driven by linkages described above, include restoration of site-appropriate stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which affects hydrology); increased groundwater elevation, recharge, and

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[42] This affects water quality and substrate composition.

[43] This affects hydrology, sediment and nutrient load, and groundwater characteristics.

[44] This leads to improvements in riverine process and function including decreased channel incision and increased floodplain connectivity as sediment loads are deposited within the watershed.

[45] This leads to improvements in riverine process and function (Pollock).

[46] This leads to improvements in riverine process and function, and site-appropriate hydrology.

contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[47]; decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010)[48]; and restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[49]. The main mechanisms driving these effects include an improvement in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effect of site-appropriate sediment and nutrient load on UKL algal response[50], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[51].

Finally, levee removal, setback, or breaching, when implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 7).

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[47] This affects hydrology and water quality, and floodplain condition, as described above.

[48] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.

[49] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

[50] I.e., impairments are no longer a source of additional nutrient loads leading to increased UKL algal productivity.

[51] This subsequently affects water quality parameters such as pH and DO.

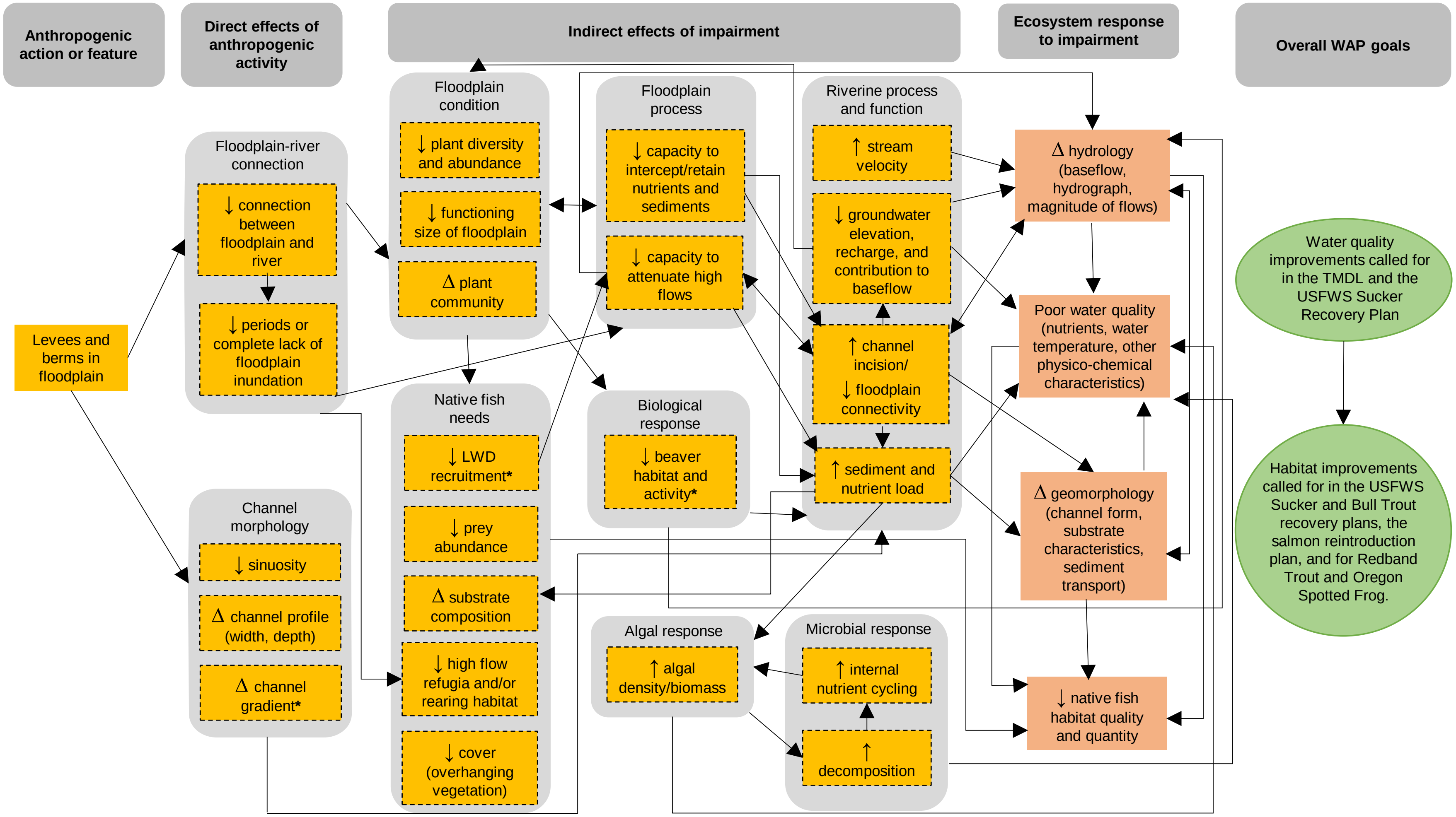

Figure 6. Levees and berms "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

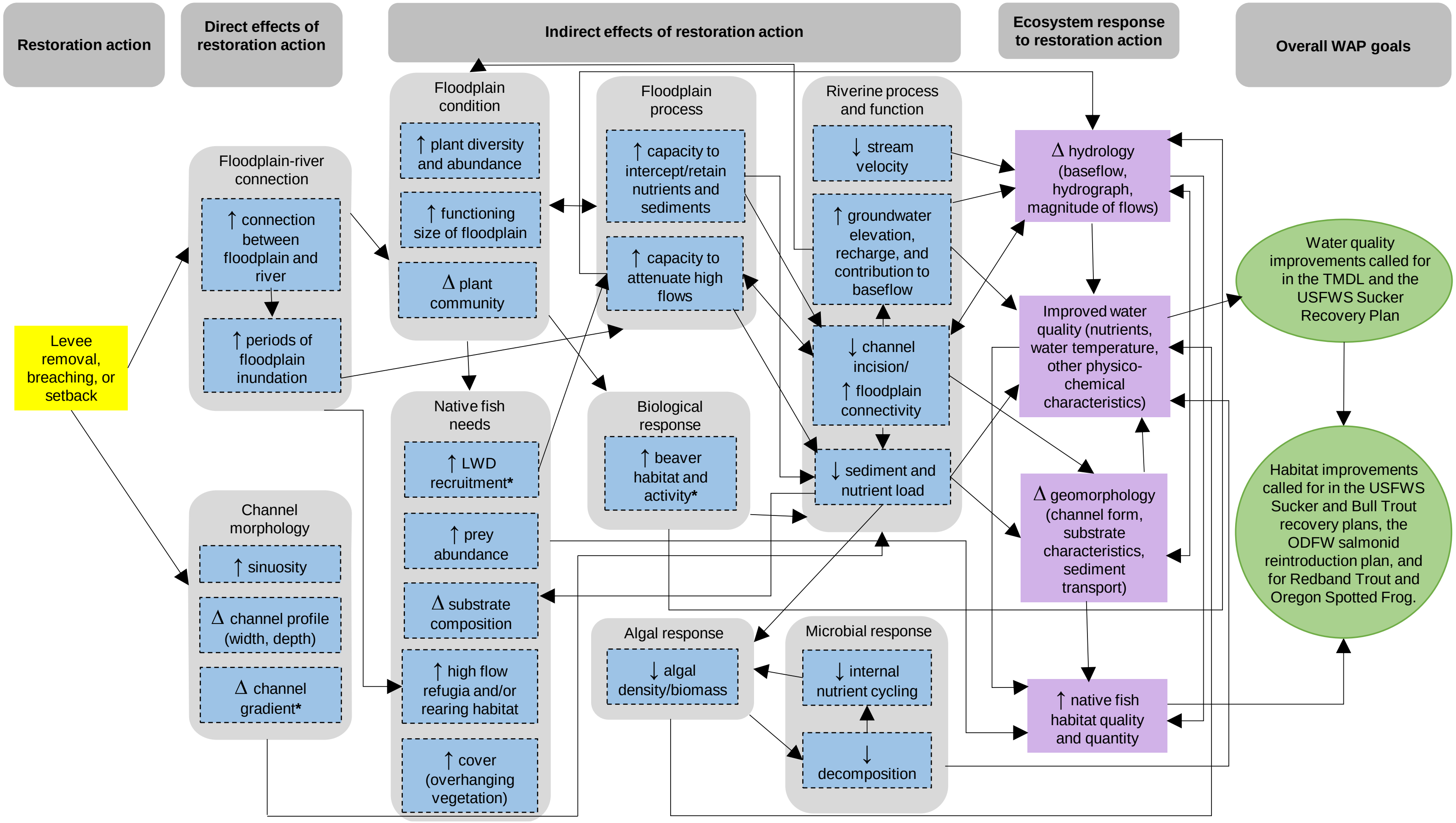

Figure 7. Levees and berms "restored conditions" conceptual model illustrating response to levee removal, set-back, or breaching, implemented to correct and repair impairments associated with levees and berms. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

WETLANDS

Wetlands provide numerous ecosystem functions including habitat for a variety of flora and fauna, water quality enhancement, reductions in the magnitude and frequency of floods, and carbon sequestration (Zedler and Kercher 2005). When wetlands are drained, these important ecological functions are lost. Wetland draining began in the UKB in the late 19th century to support the expansion of agriculture (Platt Bradbury et al. 2004, Snyder and Morace 1997). Over half of the historical lake-fringe wetlands once surrounding UKL have been drained (Snyder and Morace 1997), though some wetland restoration and conservation has occurred recently (namely, the restoration of approximately 5,500 acres of wetlands in the Williamson River delta). Note that this section primarily focuses on peat fringe wetlands along UKL. In the future, the UKBWAP may be expanded to include other types of wetlands.

Impaired Conditions

The wetland "impaired conditions" conceptual model represents impairments resulting from a single specific anthropogenic activity (draining and reclaiming of natural wetlands).

The direct result of wetland draining and reclamation is changes in wetland condition, including exposure of wetland sediment (which leads to increased decomposition within exposed wetland sediment and release of phosphorus and other nutrients [Aldous et al. 2005] and a reduction in the capacity to capture and sequester nutrients and sediments), a decrease in the amount of standing water, and a decrease in the abundance of native wetland vegetation (Figure 8).

Changes in wetland process and function associated with changes in wetland condition include reduced attenuation of high flows (DeLaney 1995, Hillman 1998)[52], reduced capacity to capture and sequester nutrients and sediment (which affects water quality), and reduced groundwater recharge as a result of a loss of standing water (Pollock et al. 2014, Weber et al. 2017) (which affects hydrology). The mechanisms supporting linkages to nutrient dynamics include a loss of complexity and roughness to slow and capture high flows and associated particulate matter (Bukaveckas 2007, Kroes and Hupp 2010), and a decrease in accretion of peat soils, which is the principal pathway for phosphorus sequestration in wetlands over the long-term (Kadlec 1997). Exposure of wetland soils and increased decomposition of existing peat soils result in a reduction in the capacity to capture and store phosphorus over the long-term and increases in terrestrial nutrient availability within the former wetland (Aldous et al. 2005, Graham et al. 2005).

Changes in native fish and amphibian habitat associated with changes in wetland condition include decreased in-water cover, decreased prey abundance, decreased Lost River and Shortnose sucker rearing habitat (specifically associated with drainage of lake-fringe wetlands), and decreased Oregon Spotted Frog habitat (specifically associated with open water wetland areas). The mechanism supporting these linkages is primarily a loss of native vegetation used as both fish and prey habitat (USFWS 2012) and the loss of water to support fish and amphibians. These changes in native fish habitat together affect the quality and quantity of habitat at the ecosystem scale.

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[52] This results in a reduced capacity to capture and sequester nutrients and sediment.

Additional linkages included in this conceptual model are the associations between increased nutrient load, increased UKL algal productivity, and increased decomposition of exposed wetland sediment (which subsequently leads to increased terrestrial nutrient availability, as described above) that ultimately affect water quality at the ecosystem scale. Additionally, decomposition of exposed organic matter can lead to substantial subsidence (Sigua et al. 2009, Aldous et al. 2005, Graham et al. 2005), which in turn may prevent wetland vegetation from establishing if the drained wetland is restored in the future[53].

Under the "impaired conditions" model for wetland drainage and reclamation, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration action addressing impairments associated with drainage and reclamation of natural wetlands is restoration of these wetlands (often via removal or breaching of levees and berms constructed to aid in wetland reclamation during the late 19th and early 20th centuries). It is important to note that the effects of wetland restoration described below assume that wetland vegetation is reestablished and able to reach maturity. In areas where subsidence has occurred and levee breaching or removal results in inundation depths greater than that supportive of wetland plant communities, the results described below are unlikely to be realized. Similarly, where land use activities in drained wetlands contributed to an increase in soil phosphorus concentration prior to restoration and where soil was exposed to air for long periods prior to restoration, an initial release of nutrients, particularly phosphorus, from the sediment is possible (Dunne et al. 2006, Kinsman-Costello et al. 2014, Land et al. 2016). Over time, and as wetland vegetation matures and peat accumulation begins, these wetlands are likely to become net sinks for nutrients (Land et al. 2016) via the mechanisms described below.

The direct result of wetland restoration is improvements in wetland condition, including inundation of sediment[54], an increase in the amount of standing water, and an increase in the abundance of native wetland vegetation (Figure 9).

Improvements in wetland process and function associated with restored wetland condition include increased attenuation of high flows (DeLaney 1995, Hillman 1998)[55], increased capacity to capture and sequester nutrients and sediment (which affects water quality), and increased groundwater recharge associated with increases in standing water (Pollock et al. 2014, Weber et al. 2017) (which affects hydrology). The mechanisms supporting linkages to nutrient dynamics include an increase in complexity and roughness to slow and capture high flows and associated particulate matter (Bukaveckas 2007, Kroes and Hupp 2010), and an increase in accretion of peat soils, which is the principal pathway for phosphorus sequestration in wetlands over the long-term (Kadlec 1997). It is important to note that it may take several years or even decades for restored wetlands to become fully functional (Aldous et al. 2005, Graham et al. 2005). In other words, the ability of wetlands to capture and sequester nutrients may initially be limited until recolonization of wetland vegetation and subsequent accretion of peat soils occur.

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[53] Due to water depths exceeding those suitable for wetland vegetation.

[54] Over time, this leads to decreased decomposition within wetland sediments and increased capacity to capture and sequester nutrients and sediments (Aldous et al. 2005).

[55] This results in an increased capacity to capture and sequester nutrients and sediment.

Improvements in native fish and amphibian habitat associated with restoration of wetland condition include increased in-water cover, increased prey abundance, increased Lost River and Shortnose sucker rearing habitat (specifically associated with restoration of lake-fringe wetlands), and increased Oregon Spotted Frog habitat (specifically associated with open water wetland areas). Key mechanisms supporting these linkages include an increase in wetland vegetation used as habitat for both fish and prey (USFWS 2012) and water present to support fish and amphibians. These improvements in native fish habitat together increase the quality and quantity of habitat at the ecosystem scale.

Additional linkages included in this conceptual model are the associations between site-appropriate nutrient load, decreased UKL algal productivity, and decreased decomposition in wetland soils (which subsequently leads to decreased terrestrial and aquatic nutrient availability, as described above) that improve water quality at the ecosystem scale. Additionally, decreased decomposition of wetland vegetation leads to soil (peat) accretion (Kadlec 1997), which in turn allows for greater establishment of wetland vegetation[56].

Ancillary benefits associated with natural wetland restoration include creation of new recreation opportunities for the landowner and/or the public (if the area is accessible) and increases in wetland habitat for wildlife and waterfowl (Brown and Smith 1998, Stevens et al. 2003).

Finally, restoration of natural wetlands, implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 9).

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[56] Due to a decrease in water depth to that suitable for wetland vegetation establishment.

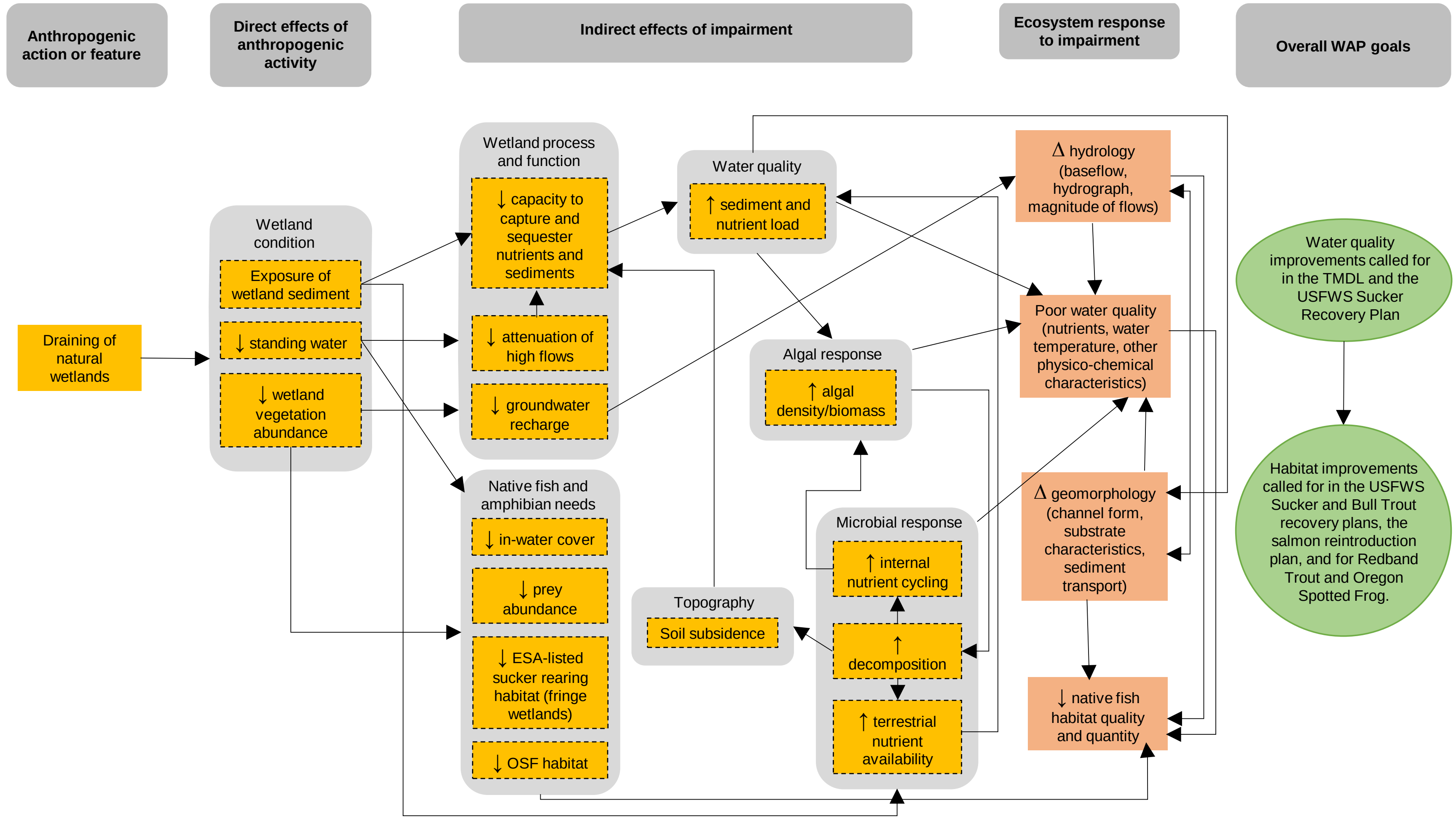

Figure 8. Wetlands "impaired conditions" conceptual model. Δ indicates a change in conditions. "OSF" is an acronym for Oregon Spotted Frog.

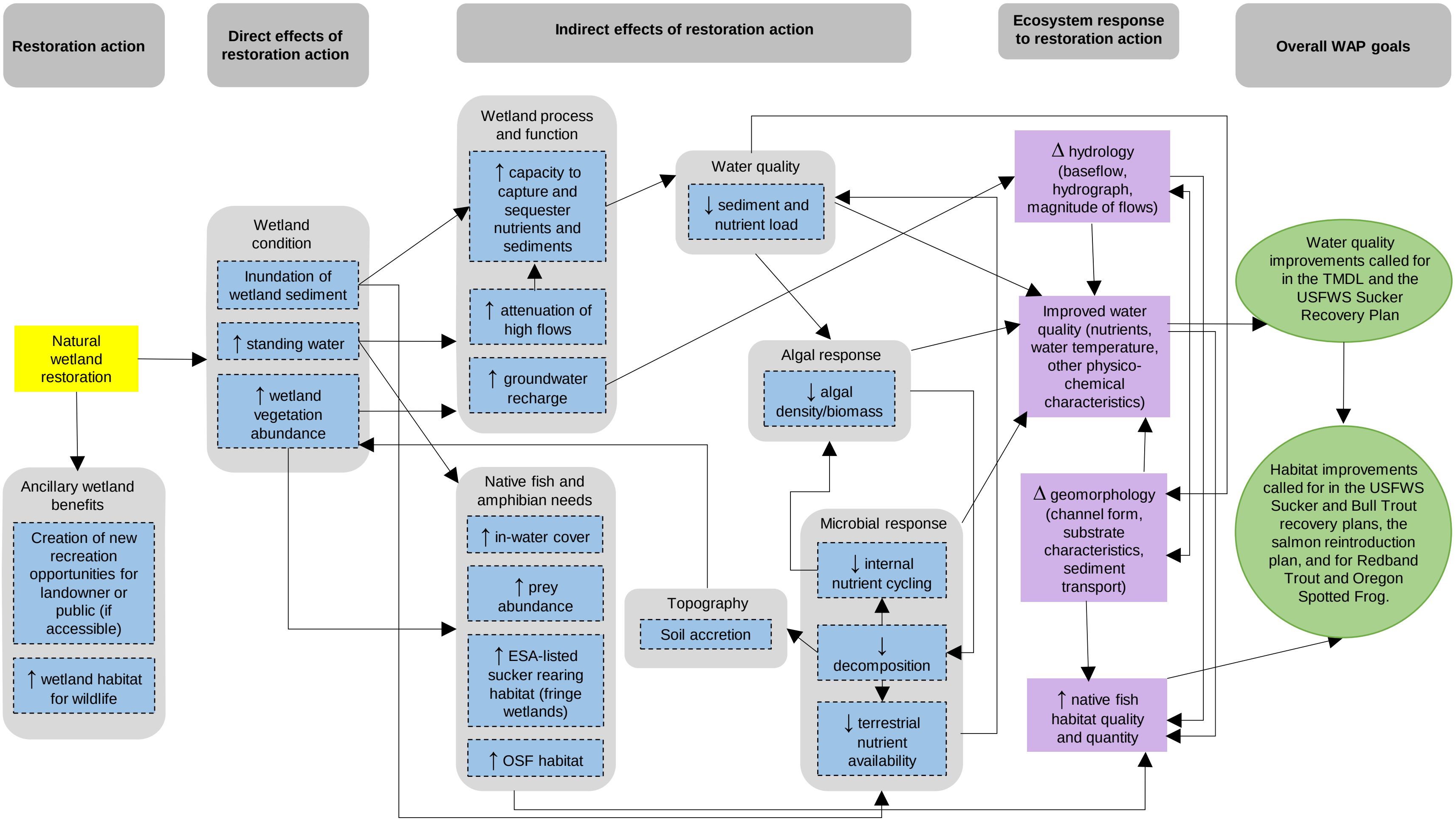

Figure 9. Wetlands "restored conditions" conceptual model illustrating response to wetland restoration implemented to correct and repair impairments associated with wetland drainage. Δ indicates a change in conditions to those considered appropriate for a given site.

RIPARIAN AND FLOODPLAIN VEGETATION

Functioning riparian corridors (including floodplains)[57] are critical 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 terrestrial and aquatic biota (Opperman and Merenlender 2004). Numerous land use practices contribute to impaired riparian function, including (but not limited to):

- Clearing and tilling (for crop and pasture cultivation) of riparian areas and floodplains.
- Residential, commercial, and infrastructure construction in riparian areas and floodplains.
- Road construction in riparian areas and floodplains.
- Construction of levees and berms.
- Unmanaged riparian grazing.

The UKBWAP addresses riparian impairments specifically as a result of unmanaged riparian grazing, as this appears to be the most common contributor to current riparian degradation in the UKB (ODEQ 2002, Walker et al. 2015) However, the conceptual models below also largely apply to any activity or land use practice that results in riparian and floodplain impairments.

Riparian grazing is common throughout the west, especially in areas with limited access to, and/or infrastructure for, off-stream watering areas. In the UKB, ranching operations became common beginning in the late 19th century, reaching a peak of approximately 140,000 head of cattle in Klamath County by the mid-1960s (ODEQ 2002). The number of cattle and calves in Klamath County has decreased in recent decades, from 113,701 in 1997 to 71,020 in 2017 (USDA 2019).

Impaired Conditions

The riparian and floodplain grazing “impaired conditions” conceptual model represents impairments resulting from a single specific anthropogenic activity (grazing in floodplains and riparian areas that is unmanaged or managed inconsistent with restoration objectives). Many of the linkages and mechanisms described in the unmanaged riparian and floodplain grazing conceptual models are similar to the channel incision and levees and berms conceptual models described above. Additionally, the linkages described here also apply to a general degradation in riparian condition that can result from actions other than unmanaged grazing (e.g., cultivation to the edge of surface waterbodies).

The direct results of grazing in floodplains and riparian areas that is unmanaged or managed inconsistent with restoration objectives are changes in riparian and floodplain condition and instream conditions including decreased functional plant community density, diversity, and abundance (Clary 1995, Masters et al. 1996, Clary 1999); decreased bank cover (Clary and Webster 1990, Popolizio et al. 1994, Lucas et al. 2004); soil disturbance and compaction

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[57] The riparian 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 functional riparian corridor, as defined in the UKBWAP, is one that supports the processes described in the conceptual models in this subsection.

(Trimble 1994, Clary 1995); increased direct manure inputs (which affects nutrient load and water quality) (Stephenson and Rychert 1982, Tiedemann and Higgins 1989); and disturbance and compaction of the streambed (which affects substrate composition) (Clary 1999, Del Rosario et al. 2002) (Figure 10).

Changes in riparian and floodplain condition result in changes in riparian and floodplain process, including:

- Decreased capacity to intercept and retain nutrients and sediment[58] 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 stabilization via a decrease in root strength and abundance[59] due to a reduction in site-appropriate vegetation (Opperman and Merenlender 2004, Pollock et al. 2014).
- Decreased beaver habitat and activity[60]due to a reduction in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990).
- Decreased capacity to attenuate high flows[61], as described above.
- Decreased stream shading[62] due to a reduction in vegetation (Opperman and Merenlender 2004, Weber et al. 2017).
-

Change in native fish habitat resulting from changes in riparian and floodplain condition includes:

- Decreased LWD recruitment (which affects the capacity to attenuate high flows) due to a lack of riparian and floodplain vegetation (Bragg et al. 2000, Opperman and Merenlender 2004).
- Decreased prey abundance due to a lack of food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Changes in substrate composition due to a lack of plant matter and floodplain/riparian roughness necessary for appropriate sediment transport dynamics (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).

Taken together, these changes in native fish habitat affect habitat quality and quantity at the ecosystem scale.

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[58] This leads to changes in riverine process and function including additional channel incision and decreased floodplain connectivity as sediment loads are conveyed through the watershed rather than deposited within (Kroes and Hupp 2010).

[59] This leads to additional channel incision and decreased floodplain connectivity as banks become steeper and more erodible.

[60] This leads to changes in riverine process and function and hydrology.

[61] This leads to changes sediment and nutrient load, increased channel incision and decreased floodplain connectivity, and hydrology.

[62] This leads to changes in water quality, namely an increase in water temperature.

Changes in riverine process and function, driven by linkages described above, include decreased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[63]; additional channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[64]; channel widening[65]; and increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[66]. The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effect of increased sediment and nutrient load on UKL algal response[67], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[68].

Under the "impaired conditions" model for riparian and floodplain grazing that is unmanaged or managed inconsistent with restoration objectives, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration actions to address impairments associated with unmanaged riparian and floodplain grazing include riparian fencing, planting, and/or grazing management (see Appendix A for guidance on implementing these actions). Additionally, the linkages described here also apply to restoration of riparian condition that can result from actions to correct impairments other than unmanaged grazing.

The direct results of riparian fencing and/or grazing management are improvements in riparian and floodplain condition and restoration of site-appropriate instream conditions including increased plant community density, diversity, and abundance (Clary 1995, Masters et al. 1996); increased bank cover (Clary and Webster 1990, Popolizio et al. 1994, Lucas et al. 2004); a reduction in soil disturbance and compaction (Trimble 1994, Clary 1995); decreased direct manure inputs (which affects nutrient load and water quality) (Stephenson and Rychert 1982, Tiedemann and Higgins 1989); and reduced disturbance and compaction of the stream channel bed (which affects substrate composition) (Clary 1999, Del Rosario et al. 2002) (Figure 11).

Improvements in riparian and floodplain condition result in restoration of riparian and floodplain process, including:

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[63] This affects hydrology and water quality, and riparian and floodplain condition (Pollock et al. 2014).

[64] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.

[65] Due to increased soil disturbance and a decrease in bank-stabilizing riparian vegetation (Marlow et al. 1989, Myers and Swanson 1995). This leads to changes in water quality, namely an increase in water temperature and sediment load.

[66] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

[67] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

[68] This subsequently affects water quality parameters such as pH and DO.

- Increased capacity to intercept and retain nutrients and sediment[69] (Bukaveckas 2007, Kroes and Hupp 2010).
- Increased bank stabilization via an increase in root strength and abundance[70] (Opperman and Merenlender 2004, Pollock et al. 2014).
- An increase in beaver habitat and activity[71] due to an increase in food sources and key habitat features (Howard and Larson 1985, McComb et al. 1990).
- Increased capacity to attenuate high flows (Sholtes and Doyle 2010)[72].
- Increased stream shading[73] (Opperman and Merenlender 2004, Weber et al. 2017).

Improvement in native fish habitat resulting from restoration of riparian and floodplain condition includes:

- Increased LWD recruitment (which increases the capacity to attenuate high flows) due to increased riparian and floodplain vegetation (Bragg et al. 2000, Opperman and Merenlender 2004).
- Increased prey abundance due to restored food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Restoration of substrate composition due to an increase in plant matter and floodplain/riparian roughness necessary to restore sediment transport dynamics (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Increased cover associated with overhanging vegetation.

Taken together, these changes in native fish habitat increase habitat quality and quantity at the ecosystem scale.

Restoration of riverine process and function, driven by linkages described above, include increased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[74]; decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010) (which affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load); channel narrowing[75]; and restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[76]. The main mechanisms driving these effects include an improvement in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

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[69] This affects riverine process and function including reduced channel incision and increased floodplain connectivity as sediment loads are deposited within the watershed and channel aggradation occurs (Kroes and Hupp 2010).

[70] This leads to a reduction in channel incision and increased floodplain connectivity as banks become more stable.

[71] This leads to changes in riverine process and function and hydrology.

[72] This leads to restoration of site-appropriate sediment and nutrient load, decreased channel incision and increased floodplain connectivity, and restoration of site appropriate hydrology, as described above.

[73] This affects water quality, primarily resulting in a reduction in water temperature.

[74] This affects hydrology and water quality, and riparian and floodplain condition (Pollock et al. 2014).

[75] Due to decreased soil disturbance and an increase in bank-stabilizing riparian vegetation (Marlow et al. 1989, Myers and Swanson 1995). This affects water quality, namely reduced water temperature and sediment load.

[76] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

Additional linkages within this conceptual model include the effect of site-appropriate sediment and nutrient load on UKL algal response[77], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[78].

Finally, riparian fencing, grazing management, or other riparian restoration practices as appropriate, implemented effectively and at the appropriate scale throughout the watershed, indirectly result in achievement of the overall goals of the UKBWAP (Figure 11).

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[77] I.e., impairments are no longer a source of additional nutrient loads leading to increased UKL algal productivity.

[78] This subsequently affects water quality parameters such as pH and DO.

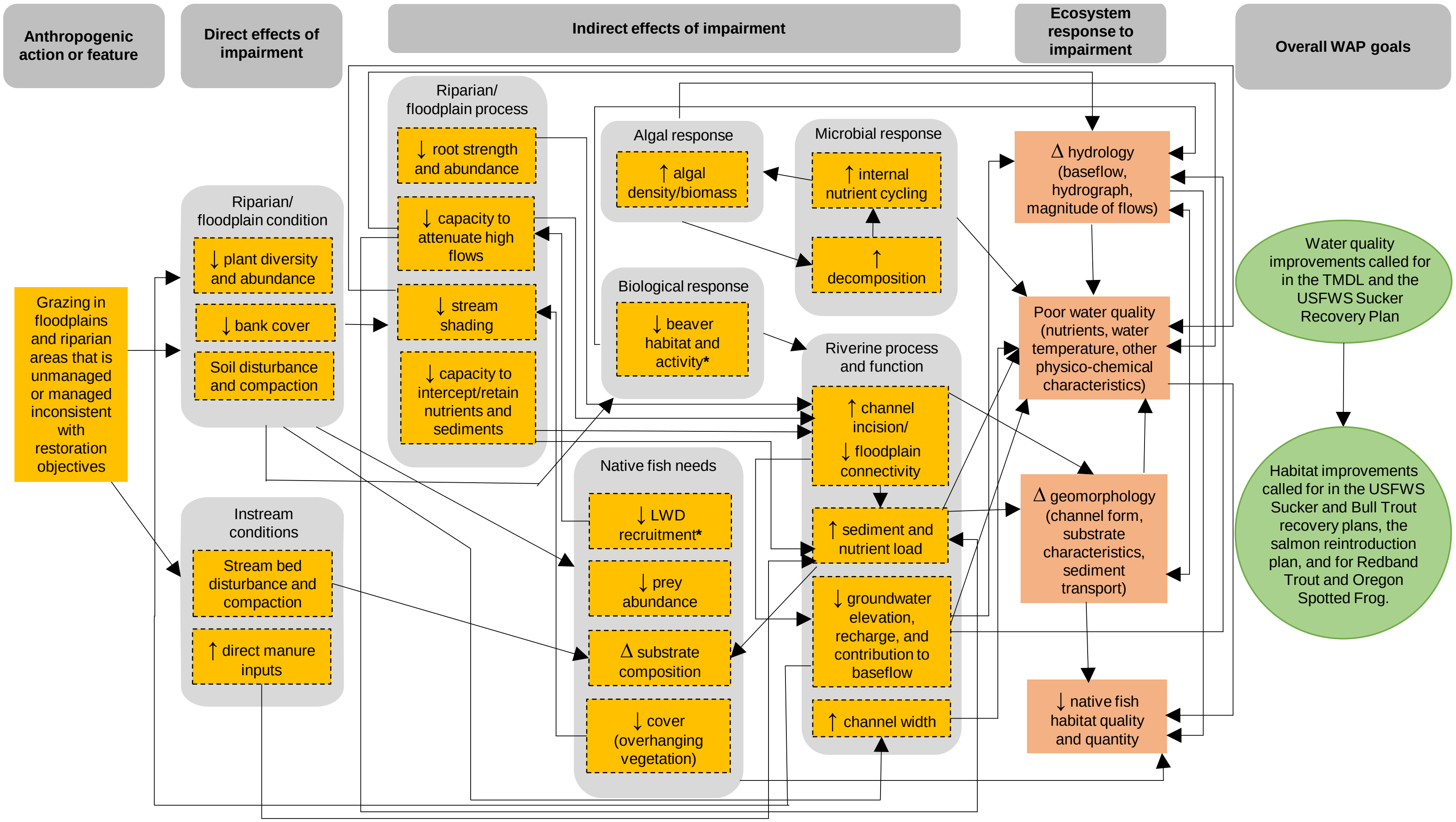

Figure 10. Riparian and floodplain vegetation "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

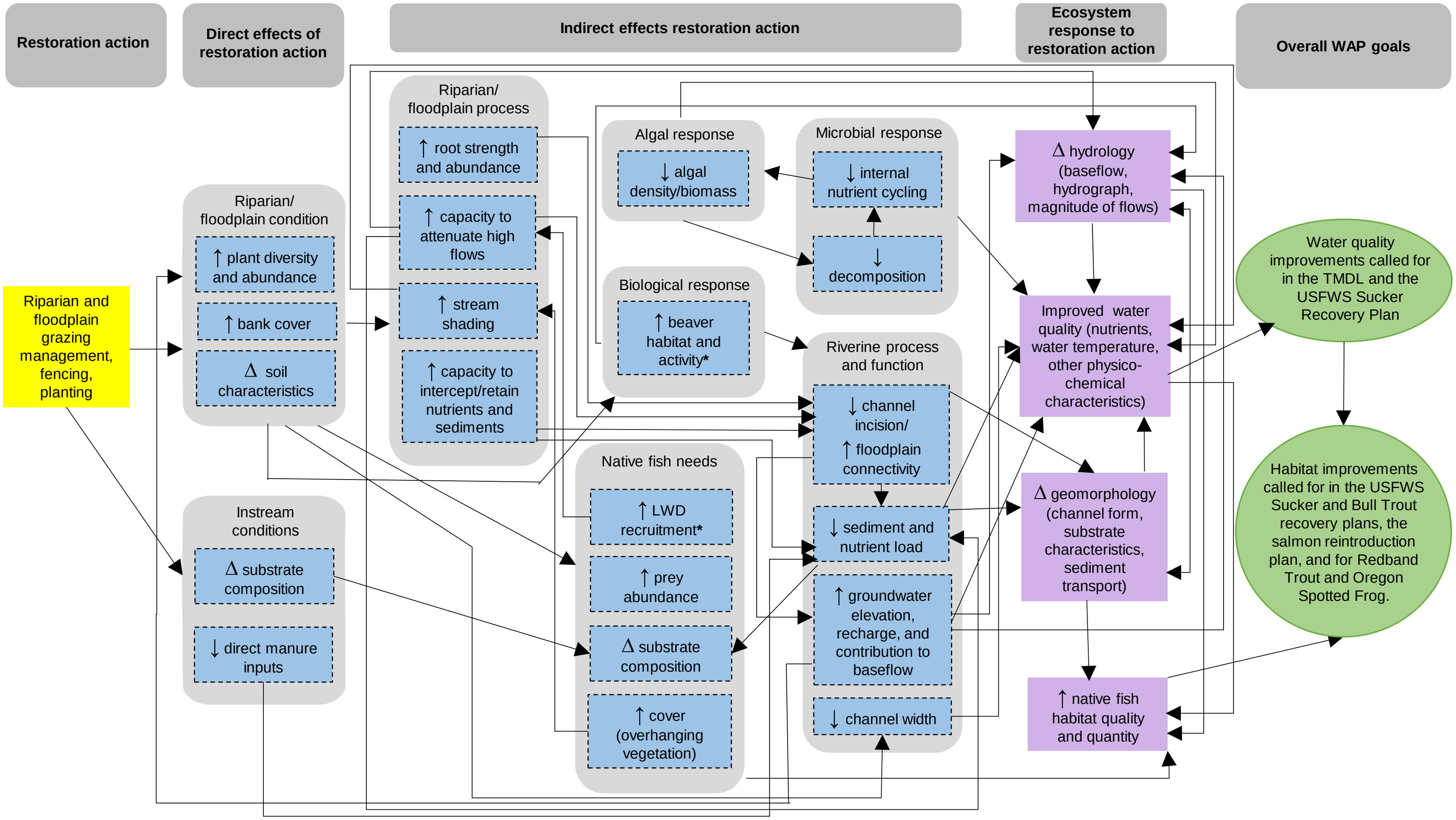

Figure 11. Riparian and floodplain vegetation “restored conditions” conceptual model illustrating response to wetland restoration implemented to correct and repair impairments associated with unmanaged riparian and floodplain grazing. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

IRRIGATION PRACTICES

The earliest irrigation projects in the UKB were privately initiated, principally along the Lost and Klamath rivers. By the 1880s, several thousand acres were under private irrigation in the area near and north of Klamath Falls, OR. In the UKL watershed, approximately 100,000 acres of private land is currently irrigated for pasture and some limited crop production (NRCS 2009, NRCS 2010), though irrigation practices have changed somewhat since the 2013 water rights adjudication in the UKB. In addition to this private land in the UKL watershed (termed the "off-Project area"), the U.S. Bureau of Reclamation's Klamath Project also encompasses several hundred thousand acres near and adjacent to UKL; Project lands near UKL produce crops such as potatoes, and use various methods of irrigation. The majority of the Klamath Project is located downstream of UKL and these areas are therefore not included in the geographic scope of the UKBWAP. Portions of the Klamath Project adjacent to UKL are included in the geographic scope of the UKBWAP.

The primary irrigation method in the UKB is gravity-fed flood irrigation. Water is sourced from direct stream and river withdrawals or from groundwater pumping. Some recent efforts have focused on modernizing irrigation practices, equipment, and conveyance infrastructure in the UKB. These changes to irrigation methods have come about for multiple reasons, including changing landowner objectives and cropping practices; the need to minimize and/or treat excess irrigation water running off of the fields and into waterbodies for water quality purposes; and the need to maximize water efficiency in years when irrigation water supply is limited by drought and/or use by senior water rights holders.

Rates of diversion and water use have been reduced significantly in recent years due to calls by senior water right holders, including calls for instream water rights held by the Klamath Tribes. In locations where water rights are generally unreliable, investment in irrigation modernization may not provide substantial ecological value. Reach or property-specific analyses of water availability are therefore necessary when considering projects to address irrigation practices.

This section includes two separate "impaired conditions" and "restored conditions" conceptual models that represent practices and associated restoration options that fall broadly under the term "irrigation practices."

Finally, while Appendix A provides some additional information on specific techniques to address the impairments described in this section, we rely on the expert opinion of restoration professionals to assess conditions, identify seasonal flow targets, and identify restoration options at a particular project site.

Impaired Conditions

Tailwater Returns

The tailwater returns "impaired conditions" conceptual model represents impairments resulting from a specific anthropogenic activity: tailwater return flows (defined as irrigation water returned from fields to adjacent surface waterbodies) that are unmanaged or managed inconsistent with restoration objectives.

The direct result of tailwater return flows that are unmanaged or managed inconsistent with restoration objectives include an increase in sediment, nutrient, and thermal loads (i.e., tailwater returns often have higher nutrient and sediment concentrations and water temperature relative to receiving waters; ODEQ 2002, NRCS 2009) (Figure 12a). These water quality changes lead to changes in UKL algal responses (due to an increase in nutrient loading to UKL; ODEQ 2002), native fish habitat (due to increases in thermal and sediment load [ODEQ 2002]), and water quality and geomorphology at an ecosystem scale (Walker et al. 2015).

Native fish habitat is affected by changes in water quality through changes in substrate composition (as a result of increased sediment load [ODEQ 2002]) and changes in thermal habitat and stream temperatures (ODEQ 2002). These native fish habitat impairments result in a decrease in the quantity and quality of habitat at the ecosystem scale.

Additional linkages within this conceptual model include increased decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies (which subsequently affect water quality parameters such as pH and DO) as a result of increased algal productivity.

Under the "impaired conditions" model for tailwater returns, there are no linkages to the overall goals of the UKBWAP (Figure 12a).

Water Allocation

The water allocation "impaired conditions" conceptual model represents impairments resulting from a specific anthropogenic activity: over-allocation of water for beneficial use.

The direct result of over-allocation of water is an increase in diversions for irrigation that directly and indirectly impacts and array of conditions (Figure 12b). This leads to changes in the floodplain-river connection (Jenkins and Boulton 2007); changes in hydrology including baseflow, hydrograph, and magnitude of flows (Dewson 2007, Jenkins and Boulton 2007); and decreased wetted channel area and water depth (Goodman et al. 2018). Decreased wetted channel area and water depth may subsequently result in increased stream temperature (Gu et al. 1998, Meier et al. 2003) and effects to native fish habitat and prey (Dewson et al. 2007, Bradford and Heinonen 2008).

Decreased connection between the floodplain and the river or stream results in impairments to floodplain condition, namely decreased functioning size of the floodplain (e.g., it may not be as wide) and changes in the riparian and floodplain plant communities (Bravard et al. 1997, Lite et al. 2005, Hupp and Rinaldi 2007, Pollock et al. 2014, Skarpich et al. 2016). This indirect effect is largely due to a lack of surface water and/or groundwater that is typically available within functioning floodplains to support riparian and floodplain vegetation (Dawson and Ehleringer 1991, Lite et al. 2005, Pollock et al. 2014, Skarpich et al. 2016). Additionally, decreased floodplain connection results in decreased high flow refugia and/or rearing habitat typically associated with functioning and connected floodplains (Sedell et al. 1990).

The effect of changes in floodplain condition include changes in floodplain processes and native fish habitat due primarily to the association between native riparian and floodplain vegetation, fish habitat components, and the capacity to intercept suspended sediment and particulate nutrient sources during high flows.

Change in floodplain processes resulting from changes in floodplain condition includes:

- Decreased capacity to intercept and retain nutrients and sediment[79] (Bukaveckas 2007, Kroes and Hupp 2010).
- Decreased capacity to attenuate high flows (Sholtes and Doyle 2010)[80].

Change in native fish habitat resulting from changes in floodplain condition includes:

- Decreased LWD recruitment (which affects the capacity to attenuate high flows) due to a lack of riparian and floodplain vegetation (Bragg et al. 2000, Opperman and Merenlender 2004).
- Decreased prey abundance due to a lack of food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011).
- Changes in substrate composition due to a lack of plant matter and floodplain/riparian roughness necessary for appropriate sediment transport dynamics (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010).
- Decreased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990).
- Decreased cover associated with overhanging vegetation

Taken together, these changes in native fish habitat may affect habitat quality and quantity at the ecosystem scale.

Changes in riverine process and function, driven by linkages described above, include increased stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which affects hydrology); decreased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[81]; additional channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[82]; and increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[83]. The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

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[79] This leads to changes in riverine process and function including additional channel incision and decreased floodplain connectivity as sediment loads are conveyed through the watershed rather than deposited within.
[80] This leads to changes in riverine process and function, and hydrology.
[81] This affects hydrology and water quality, and floodplain condition, as described above.
[82] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load.
[83] This affects water quality, geomorphology, UKL algal responses, and substrate composition.

Additional linkages within this conceptual model include the effect of increased sediment and nutrient load on UKL algal response[84], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[85].

Under the "impaired conditions" model for water allocation, there are no linkages to the overall goals of the UKBWAP (Figure 12a).

Restored Conditions

Tailwater Returns

The specific restoration actions to address impairments associated with tailwater return flows that are unmanaged or managed inconsistent with restoration objectives include efficiency upgrades; modernization of irrigation infrastructure; modification of irrigation practices such as tailwater recirculation (all to reduce tailwater returns; NRCS 2009); and tailwater treatment options such as diffuse source treatment wetlands (DSTWs)[86] (Stillwater Sciences et al. 2013) (Figure 13a)[87]. The specific objective of this work is to reduce and/or treat tailwater returns; as such, irrigation efficiency and modernization work should include actions that reduce the amount of water returned from the field to nearby surface waterbodies. In areas where reductions are not feasible, desirable, or sufficient, then DSTWs are an option to treat tailwater returns such that thermal, nutrient, and sediment loads to nearby surface waterbodies are reduced.

The direct result of irrigation efficiency/modernization work is a reduction in irrigation tailwater returns (NRCS 2009). The direct result of irrigation tailwater treatment via DSTWs is an increase in hydraulic residence time that facilitates deposition of suspended sediment and particulate nutrients (Diaz et al. 2012, Stillwater et al. 2013); a possible increase in local groundwater elevations (Pollock et al. 2014, Weber et al. 2017), depending on site-specific characteristics; and a possible increase in peat accretion (which traps and sequesters soluble bioavailable nutrients) (Graham et al. 2005), but this is highly site dependent and relies on specific types of wetland vegetation and soil characteristics.

Changes in water quality as a result of reduced irrigation tailwater returns include decreased nutrient/sediment, and thermal loads (NRCS 2009). For irrigation tailwater treatment with DSTWs, changes in water quality are specifically related to a reduction in sediment and nutrient load via processes described above. Together, water quality benefits associated with reduced or

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[84] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

[85] This subsequently affect water quality parameters such as pH and DO.

[86] "Diffuse source treatment wetland" is a term that refers to wetlands constructed specifically with treatment of run-off in mind. DSTWs are intended to provide small-scale treatment of specific run-off (such as tailwater from a limited number of agricultural operations) within the watershed, such that multiple small-scale wetlands can achieve similar water quality objectives as a single large wetland further downstream (Stillwater et al. 2013). In the UKB, DSTWs have been designed to treat sediment and particulate phosphorus loads from irrigation tailwater runoff by increasing hydraulic residence time.

[87] Although irrigation efficiency and modernization work is often presented as an effective action to increase instream flow, in areas of the UKB, it is possible that this work could actually result in a decrease in instream flow, particularly during the baseflow period (NRCS 2009). As such, this action is only recommended specifically to reduce tailwater returns to achieve reductions in sediment, nutrient, and thermal loads to streams and rivers in the UKB.

treated tailwater returns lead to improvements in UKL native fish habitat, algal responses, and water quality and geomorphology at an ecosystem scale.

Native fish habitat is affected by improvements in water quality and water quantity through restoration of site-appropriate substrate composition (as a result of decreased sediment load [ODEQ 2002]), improvements in thermal habitat (ODEQ 2002), and an increase in physical wetted habitat (Goodman et al. 2017). These native fish habitat improvements result in increased quantity and quality of habitat at the ecosystem scale.

Additional linkages within this conceptual model include decreased decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies (which subsequently affect water quality parameters such as pH and DO) as a result of decreased algal productivity.

Finally, note that these restoration actions may include ancillary benefits. Irrigation modernization and efficiency work may decrease the amount of water diverted for irrigation (and thereby increase instream flow) and may also decrease for the landowner the energy cost associated with irrigation operations (assuming modernization and efficiency work is improving equipment in power-driven or pressurized systems, rather than installing equipment where gravity-fed flood irrigation currently exists). There is some indication that modernizing and improving the efficiency of irrigation equipment and practices may result in increased consumptive use through additional evapotranspiration from pasture/crops as a result of more efficient irrigation application and increased pasture/crop production (NRCS 2009), which would not necessarily translate to a reduction in irrigation withdrawals from streams and rivers. Similarly, flood irrigation contributes substantial surface and subsurface return flow to streams and rivers in the UKB; elimination or reductions in the use of flood irrigation may therefore result in reduced instream flow in some areas during the irrigation season (NRCS 2009). As such, the primary objective of irrigation efficiency and modernization work in the UKBWAP is to reduce or eliminate tailwater returns to achieve reductions in sediment, nutrient, and thermal loads to streams and rivers in the UKB.

As for ancillary benefits associated with DSTWs, this restoration technique likely also increases groundwater recharge (site-dependent) (Pollock et al. 2014, Weber et al. 2017); creates new recreation opportunities for the landowner and/or the public (if DSTWs are accessible); and increases wetland habitat for fish (if accessible), wildlife, and waterfowl (Brown and Smith 1998, Stevens et al. 2003).

Irrigation efficiency/modernization work and/or DSTWs, implemented effectively and at the appropriate scale throughout the watershed, indirectly result in achievement of the overall goals of the UKBWAP (Figure 13a).

Water Allocation

The specific restoration action to address over-allocation of irrigation diversion is temporary or permanent transfer of irrigation water rights instream. Temporary transfers can last for one year or many, or can even just be a partial season transfer. The decision to use a temporary or permanent transfer depends on the needs of the producer, the timing of benefits to the ecosystem, and the available funding. The specific objective of this action is to increase instream flow, but it can also have the effect of decreasing or eliminating tailwater return flows (NRCS 2009).

The direct results of instream water rights transfers are a reduction in irrigation tailwater returns (as described in detail above and in Figure 13a) and a reduction in water diversions for irrigation. Note that there is some indication that modernizing and improving the efficiency of irrigation equipment and practices may result in increased consumptive use through additional evapotranspiration from pasture/crops as a result of more efficient irrigation application and increased pasture/crop production (NRCS 2009), which would not necessarily translate to a reduction in irrigation withdrawals from streams and rivers. Similarly, flood irrigation contributes substantial surface and subsurface return flow to streams and rivers in the UKB; elimination or reductions in the use of flood irrigation may therefore result in reduced instream flow in some areas during the irrigation season (NRCS 2009). As such, the primary objective of irrigation efficiency and modernization work in the UKBWAP is to reduce or eliminate tailwater returns to achieve reductions in sediment, nutrient, and thermal loads to streams and rivers in the UKB. Transfer of water rights instream can lead to decreased labor, maintenance, or energy costs for a landowner, and can also result in direct compensation payments (Kendy et al. 2018).

Indirect results of transferring water rights for instream use include increases in the floodplain-river connection (Jenkins and Boulton 2007); changes in hydrology, including baseflow, hydrograph, and magnitude of flows (Dewson 2007, Jenkins and Boulton 2007); and increased wetted channel area and water depth (Goodman et al., 2018) (Figure 13b). Increased wetted channel area and water depth may subsequently result in decreased stream temperature (Gu et al. 1998, Meier et al. 2003) and effects to native fish habitat and prey (Dewson et al. 2007, Bradford and Heinonen 2008).

Increased connection between the floodplain and the river or stream results in improvements in floodplain condition, namely 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). These indirect effects are largely due to the increased availability of surface water and/or groundwater within the floodplain to support riparian and floodplain vegetation (Dawson and Ehleringer 1991, Lite et al. 2005, Skarpich et al. 2016). Additionally, increased floodplain connection results in increased high flow refugia and/or rearing habitat associated with the functioning and connected floodplain (Sedell et al. 1990).

The effect of improvements in floodplain condition include restoration of floodplain processes, and improvements in native fish habitat due primarily to the association between riparian and floodplain vegetation, fish habitat components, and the capacity to intercept suspended sediment and particulate nutrient sources during high flows.

Restoration of floodplain processes resulting from improvements in floodplain condition includes:

- Increased capacity to intercept and retain nutrients and sediment[88] (Bukaveckas 2007, Kroes and Hupp 2010).
- Increased capacity to attenuate high flows (Sholtes and Doyle 2010)[89].

Improvement in native fish habitat resulting from improvements in floodplain condition includes:

- Increased LWD recruitment (which directly increases the capacity to attenuate high flows) due to an increase in riparian and floodplain vegetation (Bragg et al. 2000)
- Increased prey abundance due to an increase in food sources and habitat for prey (Genito et al. 2002, Arnaiz 2011)
- Site-appropriate substrate composition due to increased plant matter and floodplain/riparian roughness necessary to restore site-appropriate sediment transport processes (Lau et al. 2006, Bukaveckas 2007, Kroes and Hupp 2010)
- Increased high flow refugia and/or rearing habitat associated with functioning and connected floodplains (Sedell et al. 1990)
- Increased cover associated with overhanging vegetation

Taken together, these improvements in native fish habitat increase habitat quality and quantity at the ecosystem scale.

Restoration of riverine process and function, driven by linkages described above, include restoration of site-appropriate stream velocity (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010) (which affects hydrology); increased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009)[90]; decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010)[91]; and restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[92]. The main mechanisms driving these effects include an improvement in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effect of site-appropriate sediment and nutrient load on UKL algal response[93], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[94]. Finally, transfer of water rights instream, implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 13b).

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[88] This leads to improvements in riverine process and function including decreased channel incision and increased floodplain connectivity as sediment loads are deposited within the watershed.

[89] This leads to improvements in riverine process and function, and restoration of site-appropriate hydrology.

[90] This affects hydrology and water quality, and floodplain condition, as described above)

[91] This affects hydrology, water quality, the capacity to attenuate high flows, groundwater characteristics, geomorphology, and sediment and nutrient load)

[92] This affects water quality, geomorphology, UKL algal responses, and substrate composition)

[93] I.e., impairments are no longer a source of additional nutrient loads leading to increased UKL algal productivity.

[94] This subsequently affects water quality parameters such as pH and DO.

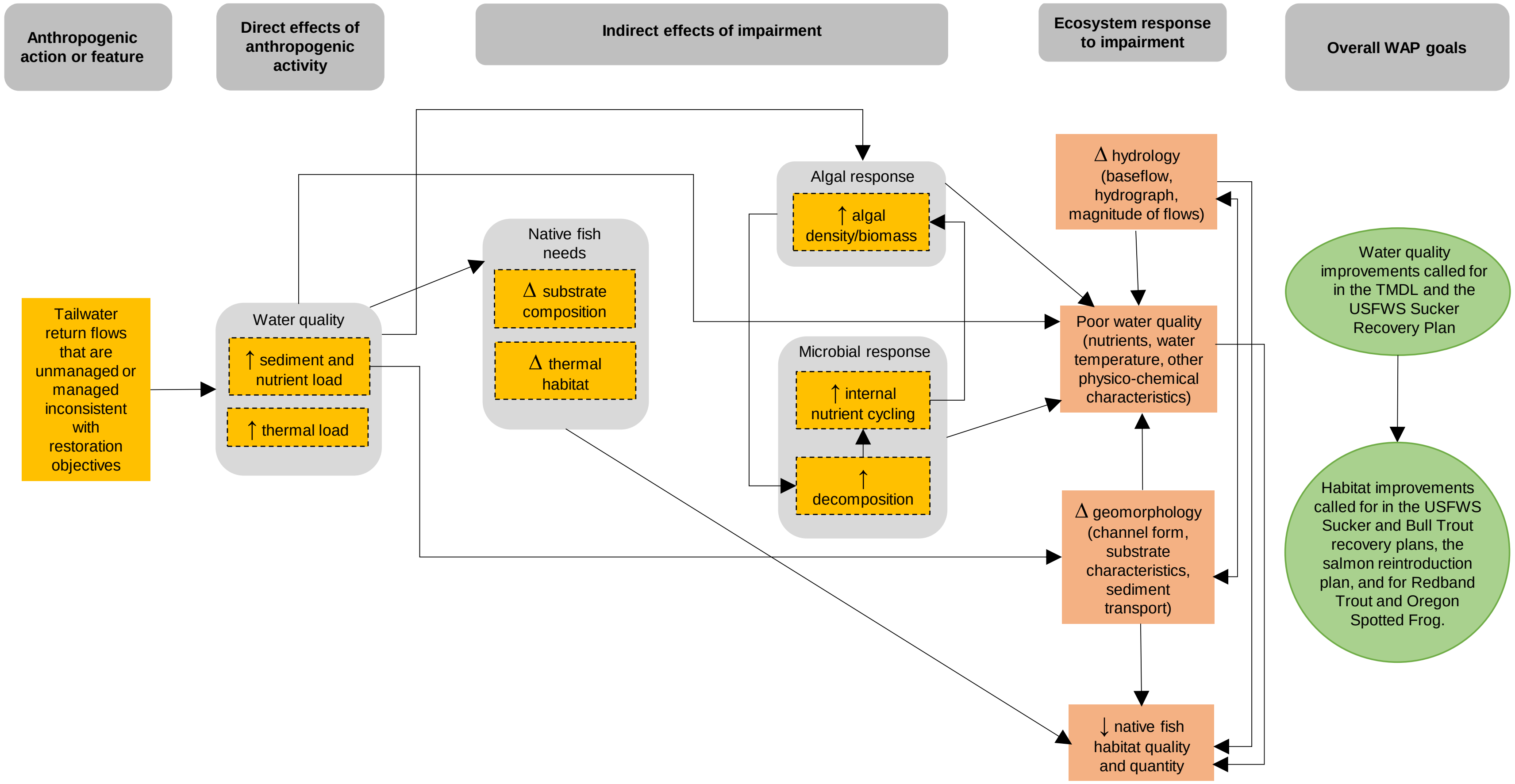

Figure 12a. Tailwater returns "impaired conditions" conceptual model. Δ indicates a change in conditions.

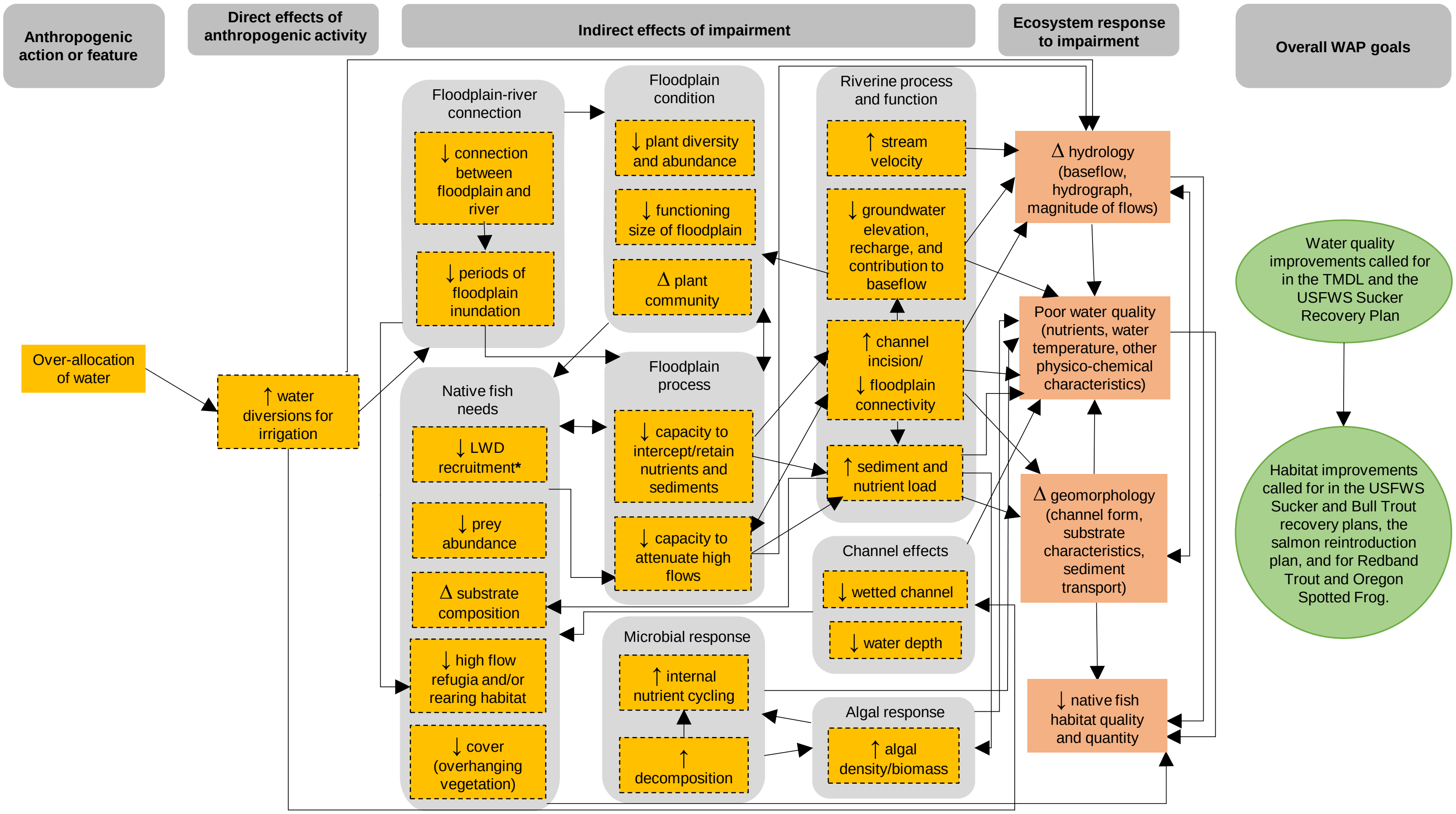

Figure 12b. Water allocation "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

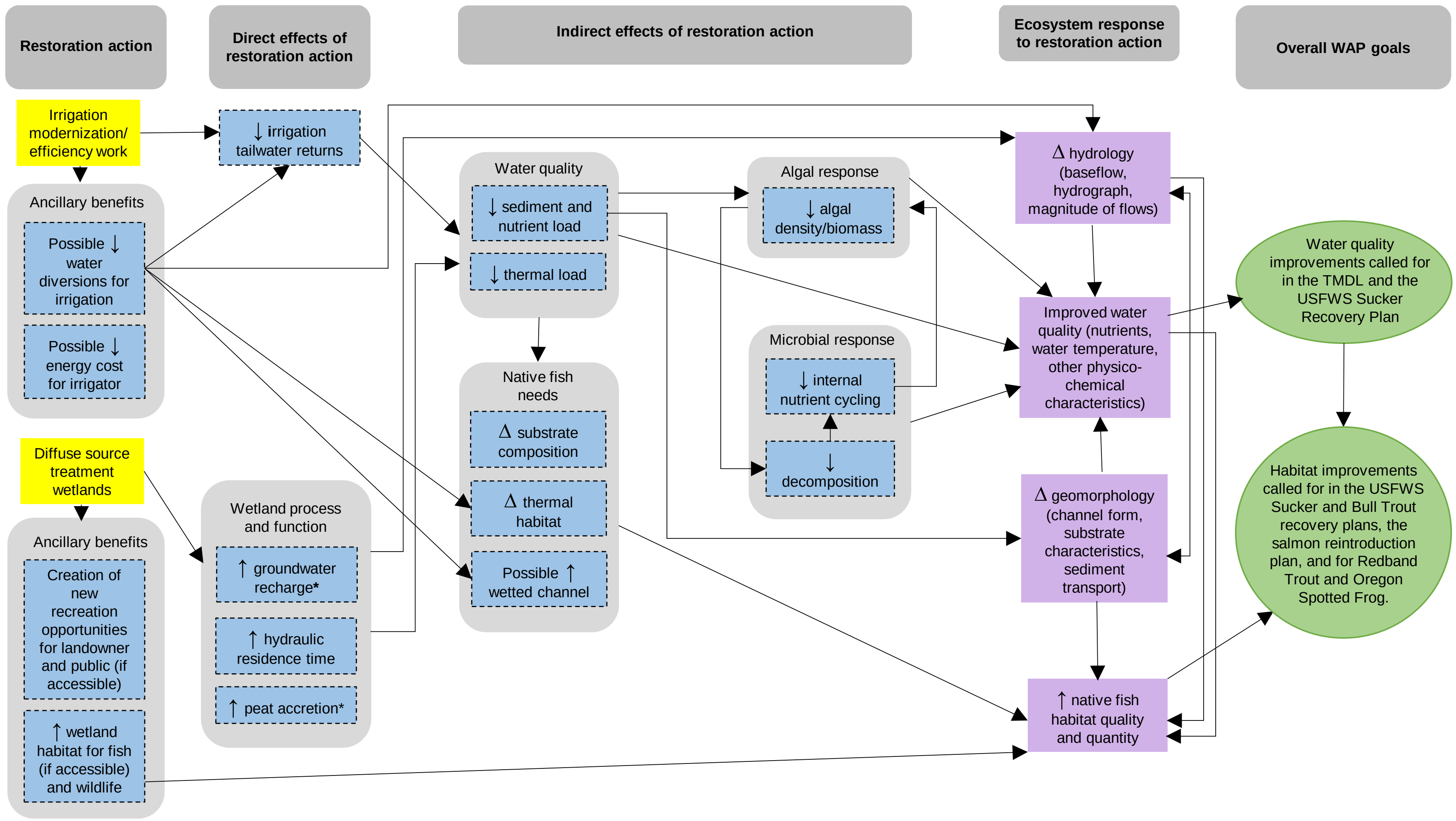

Figure 13a. Tailwater returns "restored conditions" conceptual model illustrating the responses to irrigation modernization and efficiency work and diffuse source treatment wetlands implemented to correct and repair impairments associated with inefficient irrigation practices (i.e., to reduce or treat irrigation tailwater returns). Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

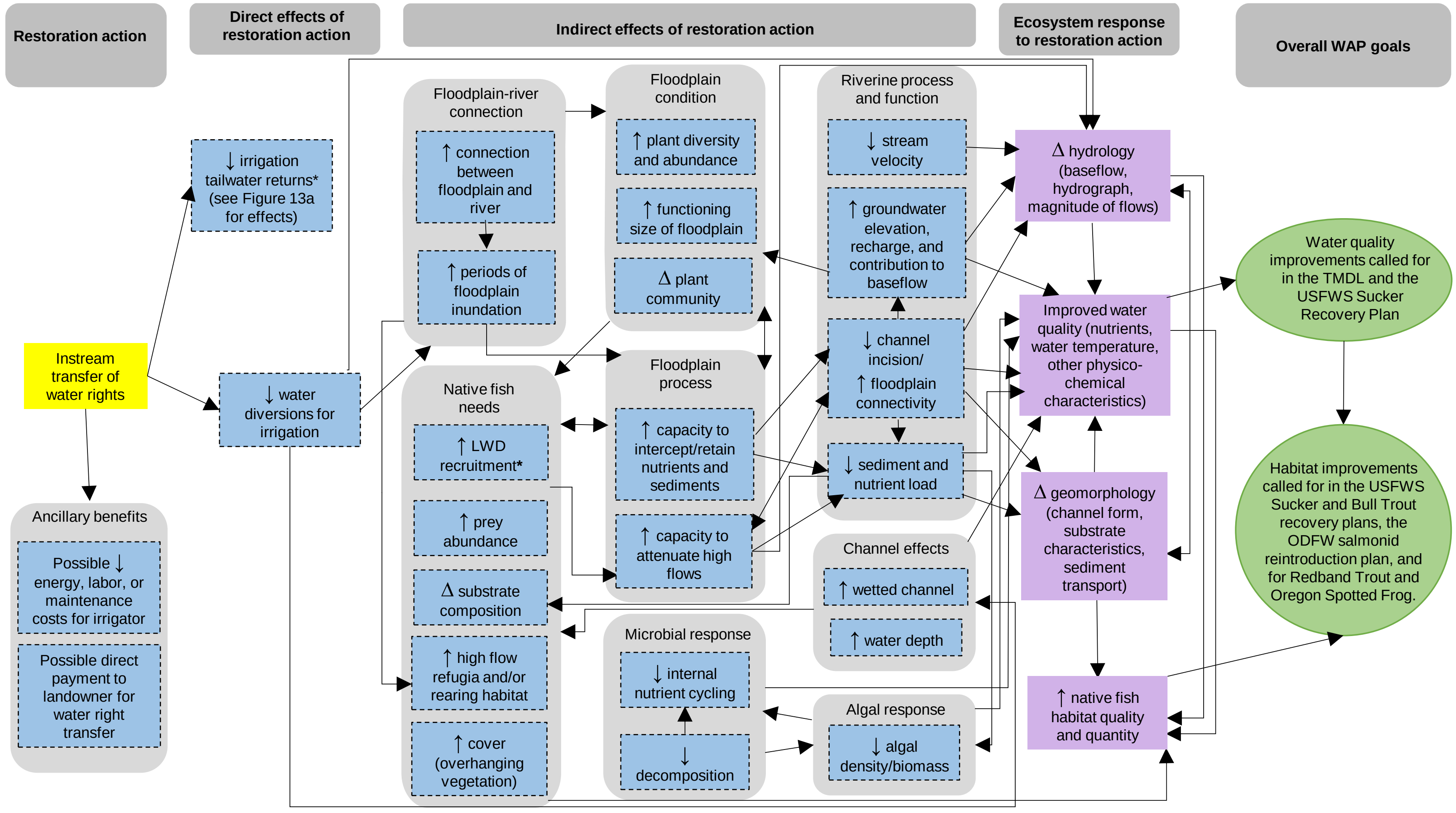

Figure 13b. Water allocation "restored conditions" conceptual model illustrating the responses to transferring water rights for instream uses. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

SPRINGS

Many UKB surface water systems are affected by surface-groundwater interactions with springs and other groundwater sources that contribute substantial baseflow, moderate stream temperature, and provide discrete thermal refugia. Although much groundwater interaction occurs directly to and through stream and lakebeds in the UKB, many discrete springs are located in off-channel/on-shore areas. A number of these springs have been disconnected from mainstem rivers, tributaries, and lakes through damming, diversions, rerouting, and other practices related to agriculture and infrastructure construction and maintenance. Restoring cold, groundwater-driven flows provides substantial benefits to native fish, and the subsequent water quality improvements can even reduce instream flow requirements for certain aquatic species (Null et al. 2010).

Impaired Conditions

The "impaired conditions" springs conceptual model represents an impairment associated with multiple anthropogenic activities within the UKB that lead to spring disconnection, rather than a single specific activity.

The direct effect of disconnection of springs from surface water bodies is a change in riverine (or lacustrine) process and function and changes in factors affecting native fish; specifically a decrease in groundwater contribution to baseflow, a decrease in the diversity of available fish habitat and cold water refugia, and changes in thermal habitat (Figure 14).

A reduction in groundwater contribution to baseflow results in increased water temperature, decreased baseflow, and changes in fish habitat (Gu et al. 1998, Power et al. 1999, Pollock et al. 2014, Weber et al. 2017). Increases in water temperature result in changes in stream thermal conditions, relative to fish needs. A reduction in baseflow also affects stream thermal conditions, including an increase in stream temperature and loss of optimal thermal habitat for fish. The mechanism supporting these linkages is the reduced dilution of warm surface water with colder groundwater[95], a reduction in total streamflow associated with a loss of spring contributions, and a reduced capacity to offset warm air temperatures due to less in-channel water volume (Gu et al. 1998, Power et al. 1999, Pollock et al. 2014, Weber et al. 2017).

Changes in the above described indirect effects subsequently result in changes in hydrology, water quality, geomorphology, and fish habitat at the basin scale when the effects of spring disconnection are appropriately multiplied over the watershed.

Under the "impaired conditions" model for springs, there are no linkages to the overall goals of the UKBWAP.

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[95] UKB groundwater (including from off-channel springs) is typically much colder than surface water during the late spring, summer, and early fall. However, during the late fall, winter, and early spring, groundwater is often warmer than surface water given temperature regimes associated with cold weather periods and with snowmelt run-off. In the Wood River in particular, spring-fed reaches are important fish feeding and rearing areas that are slightly warmer (and therefore more productive) than adjacent reaches without direct groundwater contributions.

Restored Conditions

The specific action to address impairments associated with disconnection of off-channel springs is reconnection and restoration of off-channel springs to mainstem rivers and tributaries (Figure 15).

The direct effect of spring reconnection is a restoration of riverine process and function, specifically an increase in groundwater contribution to baseflow, and an increase in the diversity of available fish habitat and cold water refugia (Figure 15).

An increase in groundwater contribution to baseflow results in decreased water temperature, increased baseflow, and restoration of fish habitat (Gu et al. 1998, Power et al. 1999, Pollock et al. 2014, Weber et al. 2017). Decreases in water temperature during baseflows result in improvements in stream thermal conditions, relative to fish physiological needs. An increase in baseflow also restores stream thermal conditions including a decrease in stream temperature and restoration of suitable thermal habitat for fish. The mechanism supporting these linkages is increased dilution of warm surface water with colder groundwater, an increase in total streamflow associated with spring contributions, and an increased capacity to offset the effect of warm air temperatures on water temperature due to additional in-channel water volume (Gu et al. 1998, Power et al. 1999, Pollock et al. 2014, Weber et al. 2017).

Restoration of site-appropriate stream temperature, baseflow, and specific fish habitat components subsequently results in restoration of hydrology, water quality, geomorphology, and fish habitat quality and quantity in the UKB and beyond, when the effects of spring reconnection are appropriately multiplied over the watershed. Spring reconnection, when implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the goals of the UKBWAP (Figure 15).

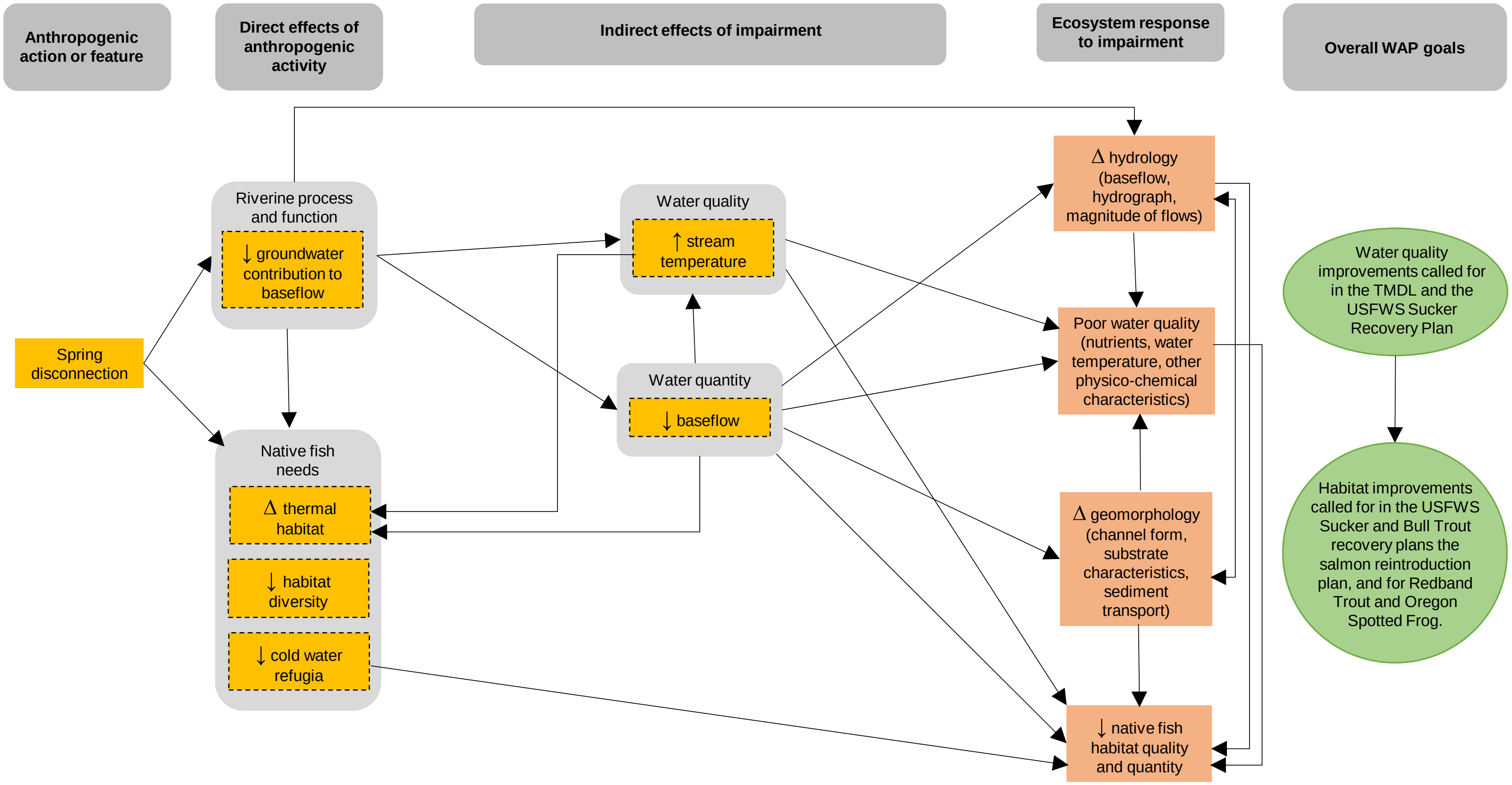

Figure 14. Springs “impaired conditions” conceptual model. Δ indicates a change in conditions.

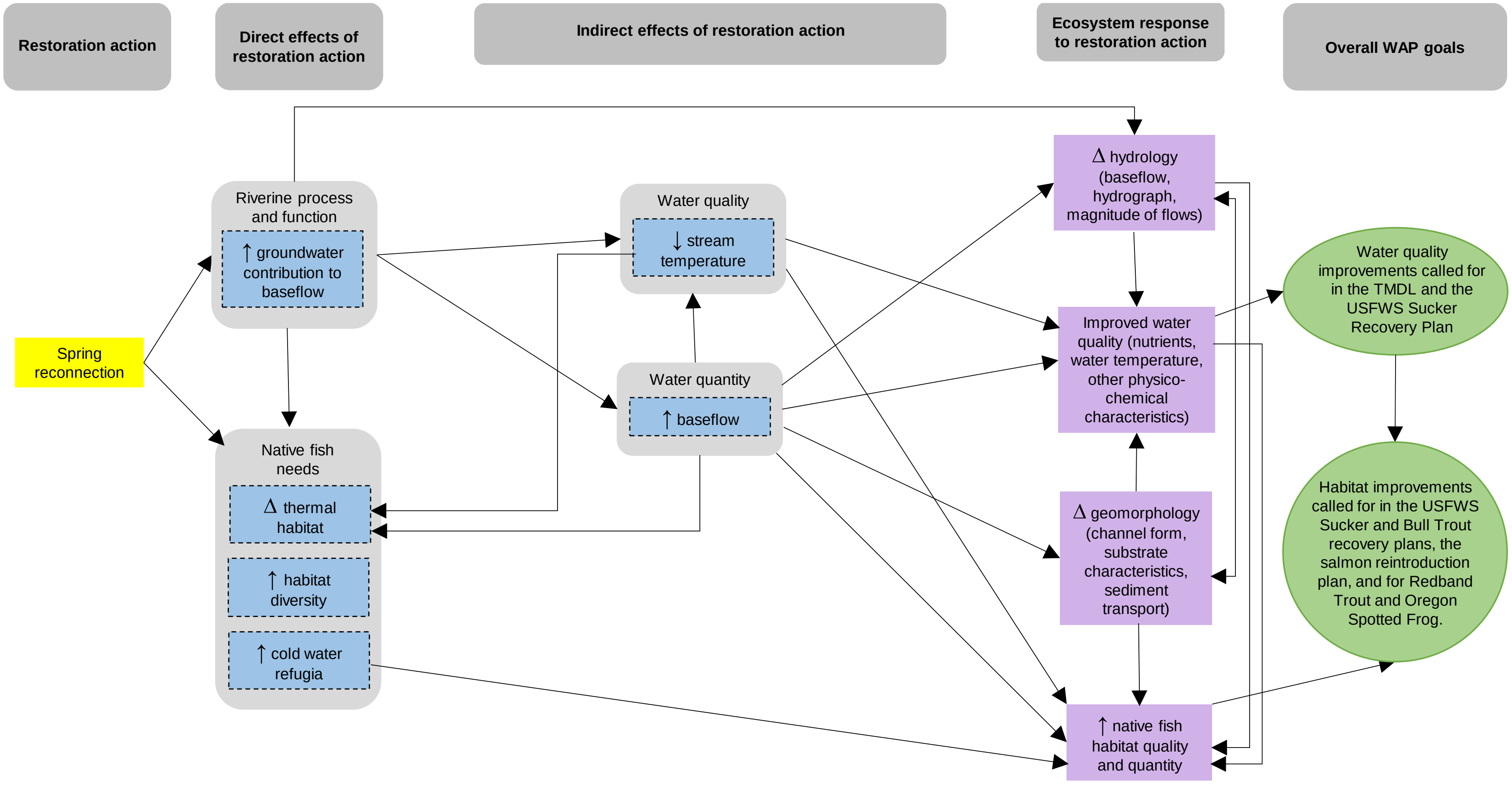

Figure 15. Springs “restored conditions” conceptual model illustrating the responses to off-channel spring reconnection implemented to correct and repair impairments associated with off-channel spring disconnection. Δ indicates a change in conditions to those considered appropriate for a given site.

FISH PASSAGE

Dams and other barriers limit the ability of fish and other aquatic organisms to migrate between stream and river reaches for rearing, feeding, and/or spawning. There is currently substantial commitment to restoring passage barriers in the Klamath Basin, as demonstrated by the removal of the Chiloquin Dam in 2008 and the planned removal of four dams on the mainstem Klamath River in the near future. However, concerns persist about numerous impassable culverts, small dams, and barriers in the UKB (KBEF and KBREC 2007).

Impaired Conditions

The fish passage "impaired conditions" conceptual model represents impairments resulting from a single specific anthropogenic activity (construction of fish passage barriers).

The direct result of fish passage barriers is changes in native fish habitat and channel morphology (Figure 16). Specifically, construction of fish passage barriers results in no or limited fish passage at the barrier site (O'Hanley and Tomberlin 2005), and changes in channel gradient and channel profile (e.g., width, depth; site-dependent) at the barrier site (Fencl et al. 2015).

Changes in channel morphology result in changes in hydrology, geomorphology, and riverine process and function (Fencl et al. 2015), including:

- Changes in sediment transport dynamics
- Changes in hydrology, especially within larger impoundments (which leads to changes in water quality[96])
- Changes in local hydraulics (e.g., velocity, water surface elevation, residence time)

Taken together, these impairments to riverine process and function result in changes to native fish habitat (namely, changes in substrate composition), and geomorphology and hydrology at the ecosystem level. The key mechanisms supporting these linkages include the changes in hydraulic residence time associated with impoundments of any size (Friedl and Wuest 2002). Longer hydraulic residence time in impoundments, relative to flowing systems, has a profound effect on sediment transport, nutrient dynamics, and water temperature because particulate matter can fall out of suspension, thermal stratification can form in larger impoundments (which can increase internal nutrient loading), and the water surface is exposed to more solar radiation for longer duration (Friedl and Wuest 2002). Additionally, large barrier structures may prevent transport of coarse sediment downstream, further affecting substrate composition in downstream reaches (Friedl and Wuest 2002, Fencl et al. 2015). Similarly, sequences of barrier structures

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[96] Changes in water quality described in this subsection apply to large impoundments created as a result of fish passage barrier construction (i.e., reservoirs that transform rivers and streams into lacustrine systems). When implemented appropriately and effectively, small impoundments (such as those behind beaver dams, check dams, etc.) may result in improvements to water quality, namely through sequestration of nutrient and sediment loads and increased groundwater-surface water interactions. Additionally, there may be some site-specific benefits to large impoundments, such as colder water temperatures downstream if releases are from deep within the reservoir.

may compound the sediment transport and water quality effects observed with a single structure (Fencl et al. 2015).

Changes in water quality as an indirect result of larger impoundments upstream of fish barriers includes changes in thermal regimes and nutrient dynamics (Friedl and Wuest 2002). Ultimately these changes can affect water quality at the ecosystem scale.

Under the "impaired conditions" model for fish barriers, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration actions to address impairments associated with fish passage barriers include removal or mitigation (e.g., by installing fish ladders or other bypass options) of culverts and other fish passage barriers (Figure 17).

The direct result of removal or mitigation of fish passage barriers is improvement in native fish habitat (i.e., restored access to habitat upstream of the barrier site) and restoration of site-appropriate channel morphology (Figure 17). Specifically, removal of fish passage barriers typically results in restoration of site-appropriate channel gradient and channel profile (e.g., width and depth), and a decreased potential for headcut development (Fencl et al. 2015, Yee and Roelofs 1980). Mitigation actions such as installation of fish ladders or other bypass options are unlikely to restore these geomorphic processes and features. Similarly, replacing culverts with bridges may not fully restore these geomorphic processes and features since a "pinch point" may still exist.

Improvements in channel morphology result in restoration of hydrology, geomorphology, and riverine process and function (Yee and Roelofs 1980, Fencl et al. 2015), including:

- Restoration of sediment transport dynamics and decreased sediment load (which affects water quality)
- Restoration of hydrology, especially within larger impoundments (which affects water quality)
- Restoration of local hydraulics (e.g., velocity, water surface elevation, residence time)

Taken together, restoration of riverine process and function results in improved native fish habitat (namely, site-appropriate substrate composition), and restoration of appropriate geomorphology and hydrology at the ecosystem level.

Improvement in water quality as an indirect result of larger impoundments behind fish barriers includes restoration of thermal regimes and nutrient dynamics. Ultimately these changes affect water quality at the ecosystem scale.

Removal or mitigation of fish passage barriers, implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 17).

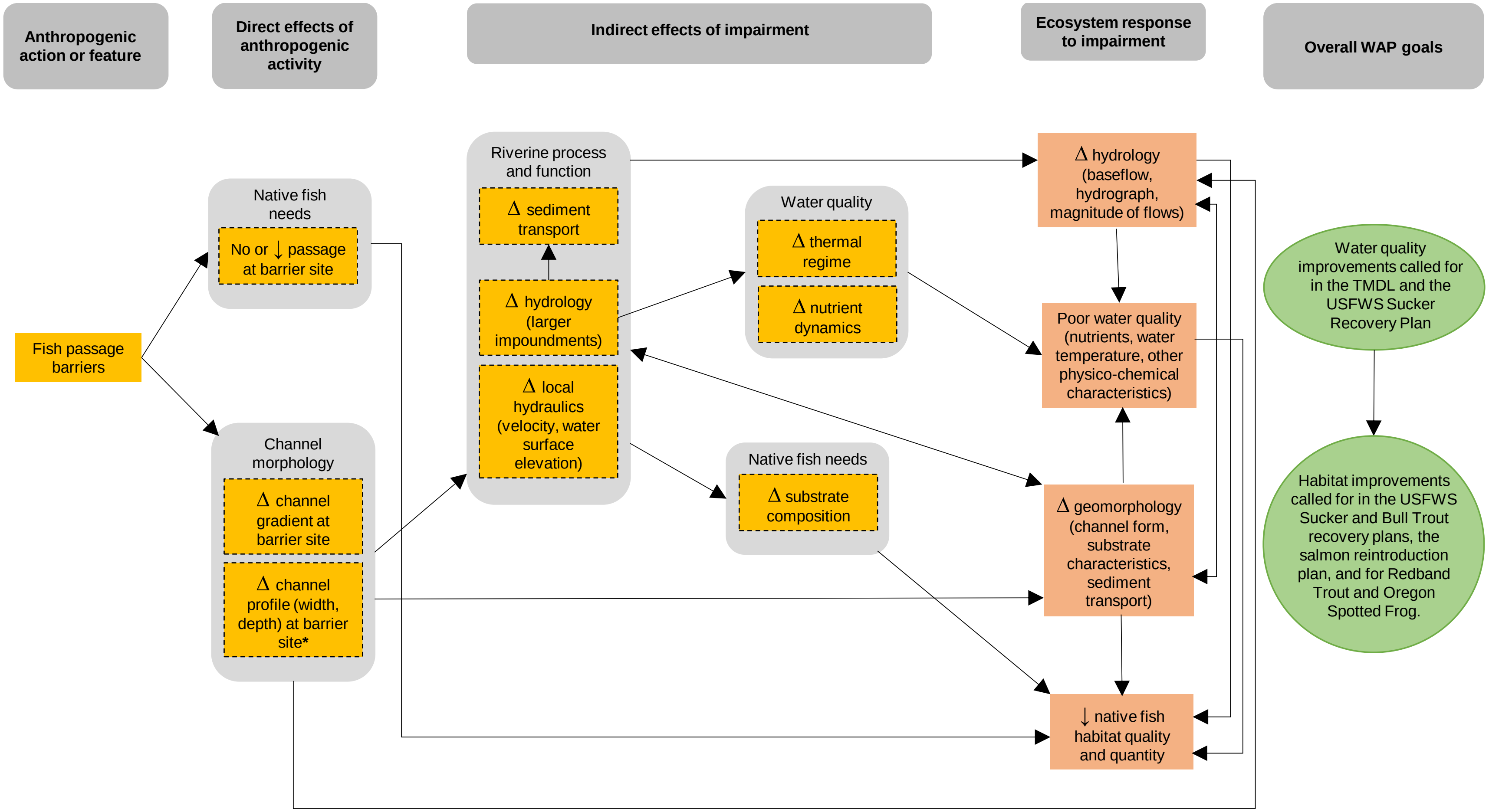

Figure 16. Fish passage “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

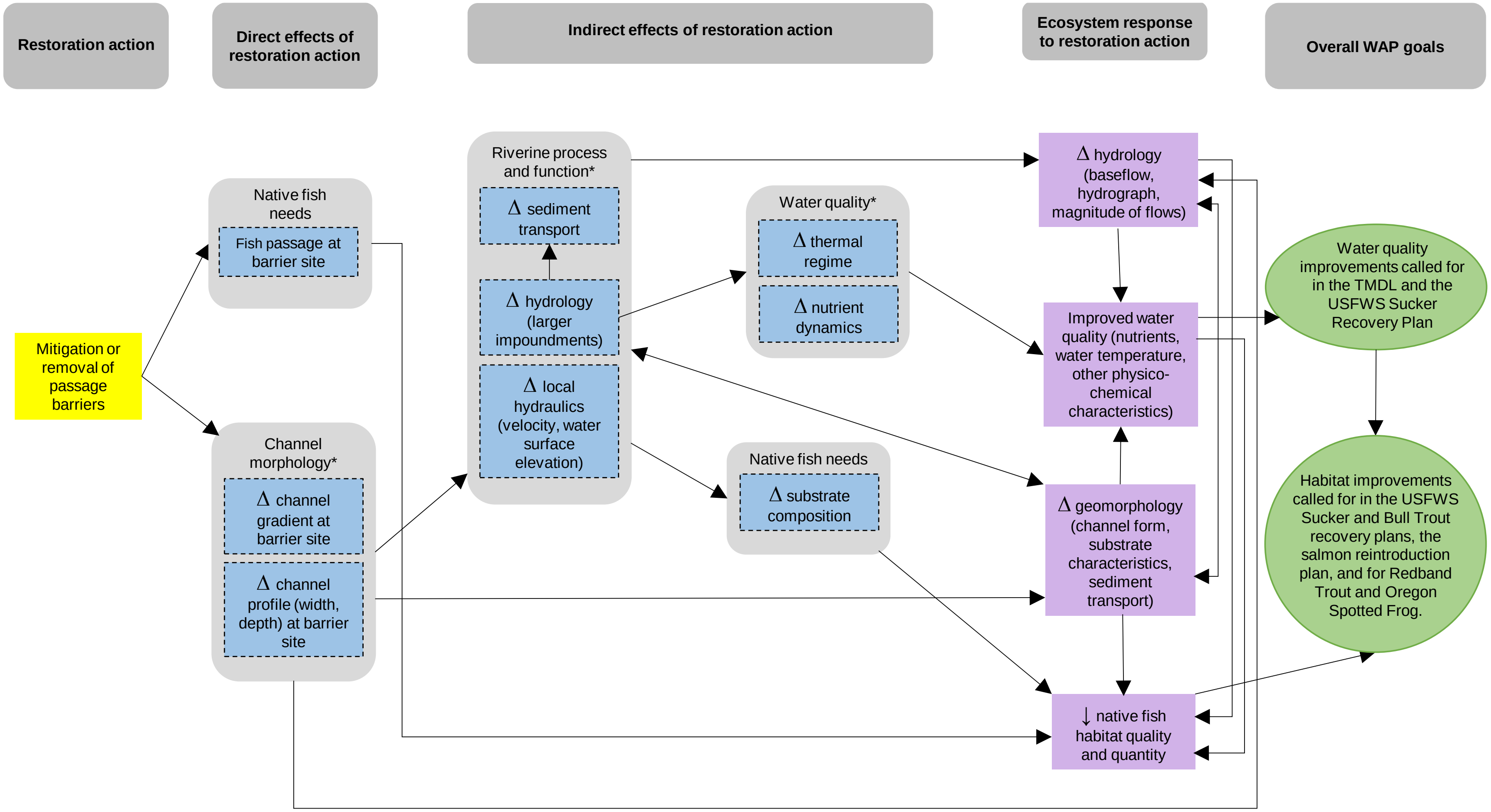

Figure 17. Fish passage "restored conditions" conceptual model illustrating the responses to removal or mitigation of non-culvert fish passage barriers implemented to correct and repair impairments associated with these barriers. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites, particularly if fish passage barriers were mitigated through installation of bypass structures).

ROADS

Numerous federal, state, county, city, and private roads exist in the UKB. Although state and federal highways, city and county roads, and private access roads occur throughout the lower elevation areas of the UKB, approximately 6,500 miles of paved and unpaved roads exist in the portion of the watershed within the Fremont-Winema National Forest (USFS 2014) to support recreation, timber harvest, and fire suppression efforts. Additionally, numerous private roads exist within private timberland to support timber harvest. Roads contribute to increased sediment load and changes in water quality (Yee and Roelofs 1980). There is a decades-long history of decommissioning, restructuring, and repairing National Forest and private roads to support aquatic habitat and water quality (Yee and Roelofs 1980) and as such, the UKBWAP primarily focuses on impairments and restoration actions targeting these types of roads.

Note that while culvert replacement relative to fish passage improvements is discussed above, these conceptual models also address the effects of culvert installation and subsequent removal/replacement because culverts are so commonly associated with National Forest and private timber roads.

Impaired Conditions

The “impaired conditions” roads conceptual model represents an impairment associated with a specific anthropogenic activity within the UKB (construction of roads including culvert installation).

The direct results of road construction and culvert installation are changes in upland condition, fish habitat, and channel morphology (Figure 18).

Changes in upland condition include an increase in impermeable surfaces (site and project-dependent), changes in drainage topography[97], soil disturbance and compaction, and introduction of non-native materials associated with the road bed (site and project-dependent) (Yee and Roelofs 1980, La Marche and Lettenmaier 2001, Switalski et al. 2004, McCaffery et al. 2007). Together, these changes in upland condition result in change to upland process, including:

- Decreased capacity to intercept and retain nutrients and sediment (which leads to increased sediment load) (Yee and Roelofs 1980, Switalski et al. 2004, McCaffery et al. 2007).
- Decreased capacity to attenuate and capture surface runoff[98] (La Marche and Lettenmaier 2001, Switalski et al. 2004).

Changes in upland process occur primarily through changes in surface roughness and the ability of roads and associated ditches to concentrate surface runoff, which limits runoff infiltration and capture of sediment and nutrient loads within the watershed (Yee and Roelofs 1980, La Marche

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[97] This can disrupt subsurface flow, thereby leading to decreased groundwater elevation and contribution to baseflow (La Marche and Lettenmaier 2001).

[98] This leads to decreased groundwater elevation, recharge, and contribution to baseflow; and changes in hydrology at the watershed scale.

and Lettenmaier 2001, Switalski et al. 2004). Note that this effect is independent of timber harvest (and therefore applicable to roads not associated with timber harvest operations), though timber harvest, particularly clear-cutting, exacerbates these changes (La Marche and Lettenmaier 2001). Impairments to upland process also result in change in riverine process and function, including:

- Decreased groundwater elevation, recharge, and contribution to baseflow (which affects hydrology and water quality) (La Marche and Lettenmaier 2001).
- Increased channel incision and decreased floodplain connectivity[99] (Kroes and Hupp 2010).
- Increased sediment and nutrient load (Bukaveckas 2007, McCaffery et al. 2007, Kroes and Hupp 2010)[100].

The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (Yee and Roelofs 1980, La Marche and Lettenmaier 2001), decreased infiltration of runoff and precipitation (Yee and Roelofs 1980, La Marche and Lettenmaier 2001, Switalski et al. 2004), and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include the effects of changes in channel morphology at the local scale on geomorphology at the watershed scale; the effect of increased sediment and nutrient load on UKL algal response[101], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies (which subsequently affect water quality parameters such as pH and DO); and changes in local fish habitat that ultimately result in changes to fish habitat at the ecosystem scale when the effects of roads are appropriately multiplied over the watershed.

Under the "impaired conditions" model for roads, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration actions to address impairments associated with road construction and culvert installation include road redesign, rerouting, and decommissioning (Switalski et al. 2004, McCaffery et al. 2007). These actions should include culvert removal (or replacement). Note that it is critically important to include actions to facilitate revegetation of the road surface or affected area in road decommissioning projects. Specifically, projects that included actions such as aerating soil (e.g., "road ripping"), preventing "surface sealing" in areas with clay and silt soils, amending soils, and reseeding or replanting demonstrated measurable improvements in infiltration, runoff, groundwater interaction, erosion, and fish and wildlife habitat components (Switalski et al. 2004). Similarly, McCaffery et al. (2007) suggested that watersheds with revegetated decommissioned roads contributed significantly less fine sediment load than watersheds with active roads and those with unvegetated decommissioned roads.

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[99] This affects hydrology, geomorphology, and water quality.

[100] This affects UKL algal response, native fish habitat, geomorphology, and water quality.

[101] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

The direct results of redesign, rerouting, and decommissioning (including culvert replacement or removal) are improvements in upland condition, fish habitat, and channel morphology (Yee and Roelofs 1980, Switalski et al. 2004, McCaffery et al. 2007) (Figure 19).

Improvements in upland condition include a decrease in impermeable surfaces (site and project-dependent), restoration of drainage topography, restoration of soil characteristics, and removal of non-native materials associated with the road bed (site and project-dependent) (Yee and Roelofs 1980, Switalski et al. 2004, McCaffery et al. 2007). Together, these improvements in upland condition result in restoration of upland process, including:

- Increased capacity to intercept and retain nutrients and sediment (which affects sediment load) (Switalski et al. 2004, McCaffery et al. 2007).
- Increased capacity to attenuate and capture surface runoff[102] (La Marche and Lettenmaier 2001).

Improvements in upland process occur primarily through restoration of surface roughness and the removal of road-associated ditches that previously concentrated surface runoff (La Marche and Lettenmaier 2001, Switalski et al. 2004); together these improvements increase runoff infiltration and capture of sediment and nutrient loads within the watershed. Improvement to upland process also result in restoration of riverine process and function, including:

- Increased groundwater elevation, recharge, and contribution to baseflow (which affects hydrology and water quality) (La Marche and Lettenmaier 2001).
- Decreased channel incision and increased floodplain connectivity[103] (Kroes and Hupp 2010).
- Restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, McCaffery et al. 2007, Kroes and Hupp 2010) (which leads to decreases in UKL algal response, improved native fish habitat, and changes in geomorphology and water quality)

The main mechanisms driving these effects include an increase in the capacity to retain sediment and particulate nutrients within the upland areas of the watershed (Yee and Roelofs 1980, La Marche and Lettenmaier 2001, Switalski et al. 2004, McCaffery et al. 2007), an increase in precipitation and runoff infiltration (Yee and Roelofs 1980, La Marche and Lettenmaier 2001), and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include restored channel morphology at the local scale leading to changes in geomorphology at the watershed scale, restoration of appropriate internal nutrient cycling and decomposition activity in UKL (which subsequently affects water quality parameters such as pH and DO), and improvements in local fish habitat that ultimately result in improvements to fish habitat at the ecosystem scale when the effects of road decommissioning and culvert removal are appropriately multiplied over the watershed.

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[102] This leads to increased groundwater elevation, discharge, recharge, and contribution to baseflow; and affects hydrology at the ecosystem scale.

[103] This affects hydrology, geomorphology, and water quality.

Road decommissioning redesign, rerouting, and decommissioning (including culvert replacement or removal), when implemented effectively and at the appropriate scale throughout the watershed, indirectly results in achievement of the overall goals of the UKBWAP (Figure 19).

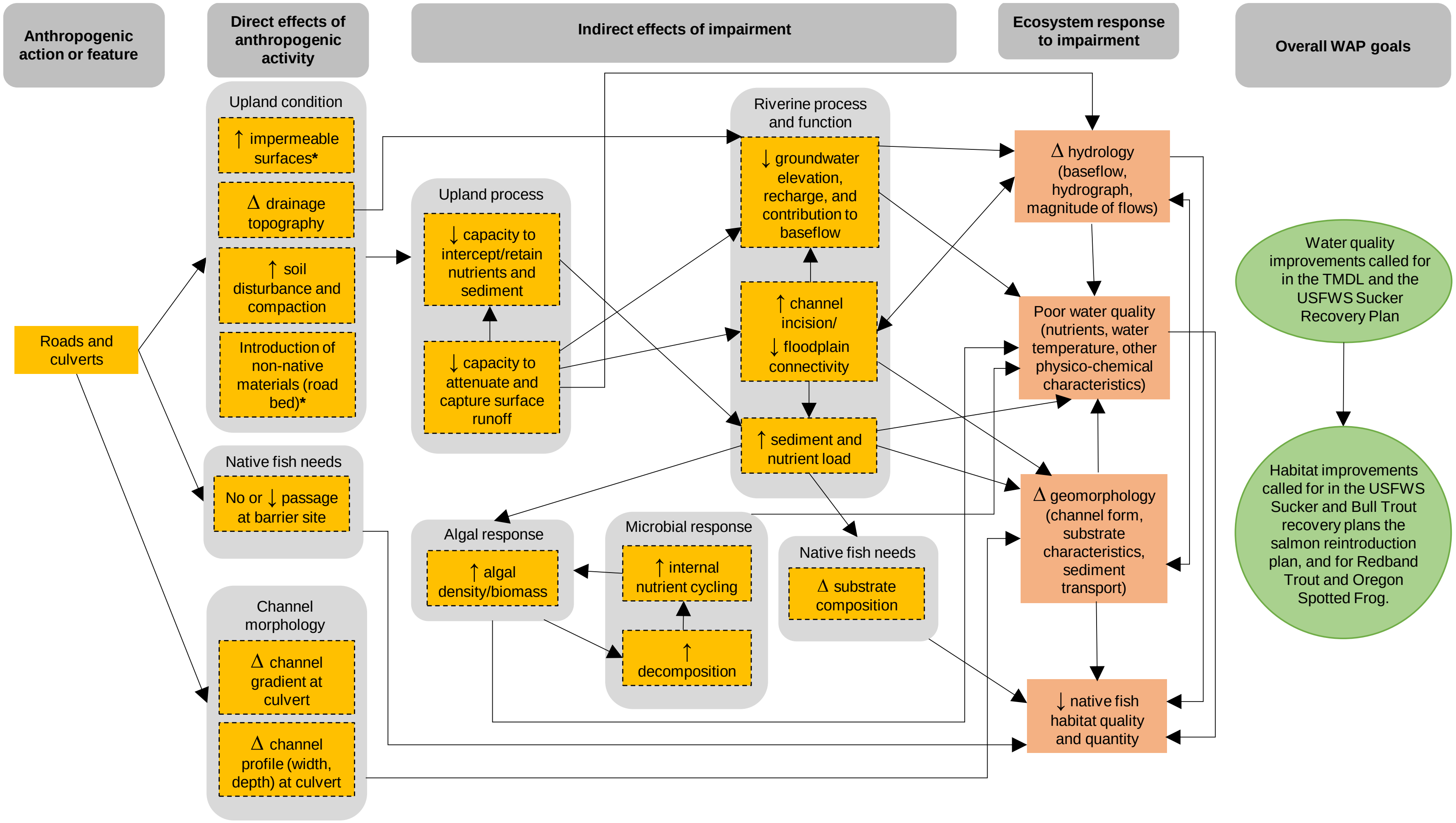

Figure 18. Roads “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

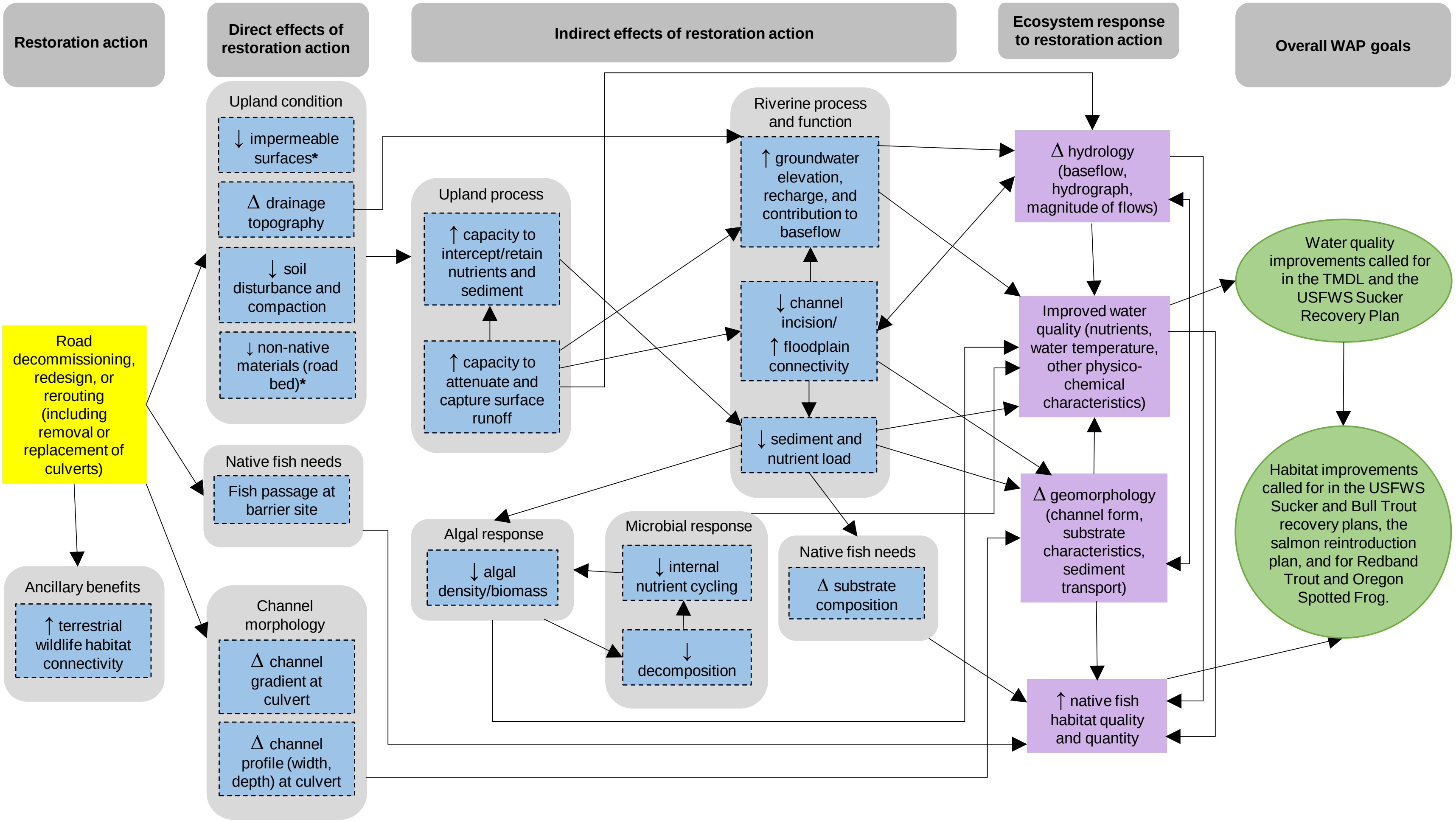

Figure 19. Roads “restored conditions” conceptual model illustrating the responses to road decommissioning, redesign, or rerouting (including culvert replacement or removal) implemented to correct and repair impairments associated with roads and culverts. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

FISH ENTRAINMENT

Fish entrainment, defined as transport of fish to waters not considered suitable habitat, usually occurs when water is diverted from a waterbody into irrigation ditches or pipes. This is a common issue throughout the west, particularly in areas dominated by agriculture or other industries that rely on withdrawals of surface water for operations. Entrainment often results in fish injury and/or mortality, and irrigation diversion screening is an effective method to prevent fish entrainment (Gale et al. 2008, Walters et al. 2012). Although there has been substantial UKB fish screening efforts (through ODFW's fish screening program) in the last decade, additional screens are still needed in the UKB (ODFW 2019).

Impaired Conditions

The "impaired conditions" fish entrainment conceptual model represents an impairment associated with a specific anthropogenic activity within the UKB (use of unscreened irrigation diversion points).

The direct effect of irrigation diversion through unscreened diversion points is increased entrainment risk to fish (Gale et al. 2008, Walters et al. 2012) (Figure 20). The indirect effect of increased entrainment risk is increased mortality associated with entrainment (Gale et al. 2008, Walters et al. 2012). This subsequently results in decreased fish populations in the UKB (and beyond in the case of anadromous fish) when the effects of unscreened diversions are appropriately multiplied over the watershed[104].

Under the "impaired conditions" model for fish entrainment, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration action to address impairments associated with unscreened irrigation diversion points is primarily installation of fish screens where they do not currently exist within documented fish habitat.

Screening irrigation diversions immediately decreases entrainment risk to fish (Gale et al. 2008, Walters et al. 2012) (Figure 21). The indirect effect of diversion screening is decreased mortality associated with entrainment (Gale et al. 2008, Walters et al. 2012). This subsequently results in

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[104] Throughout the UKB, diversion screening benefits species that exist in close proximity to the diversion, especially those individuals in vulnerable (i.e., larval and juvenile) life stages. Specifically, in the Wood River and Cascade tributaries (e.g., Sevenmile Creek), entrainment risk predominately applies to Redband Trout and potentially Bull Trout (pending population expansion). There is evidence that juvenile Lost River Suckers can and do rear in the Sprague River (Hayes and Rasmussen 2017) and therefore could be subject to entrainment at unscreened points of diversion within that sub-basin. Redband Trout spawn and rear in the Sprague River sub-basin and would be vulnerable to unscreened diversions there as well, while risks to Bull Trout in the Sprague River sub-basin would be confined to headwater tributaries (e.g. Deming Creek) where Bull Trout populations currently exist. Adult Lost River and Shortnose suckers typically occupy riverine habitat outside of the irrigation season (Perkins et al. 2000b), during which time entrainment risk is generally low.

increased fish populations[105] in the UKB (and beyond in the case of anadromous fish) when the effects of newly-screened diversions are appropriately multiplied over the watershed.

Diversion screening, when implemented effectively, at the appropriate locations, and at the appropriate scale throughout the watershed, indirectly results in achievement of the fish habitat-associated goals of the UKBWAP (Figure 21).

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[105] This assumes fish that would otherwise have been entrained survive other potential stressors and causes of mortality present in the UKB.

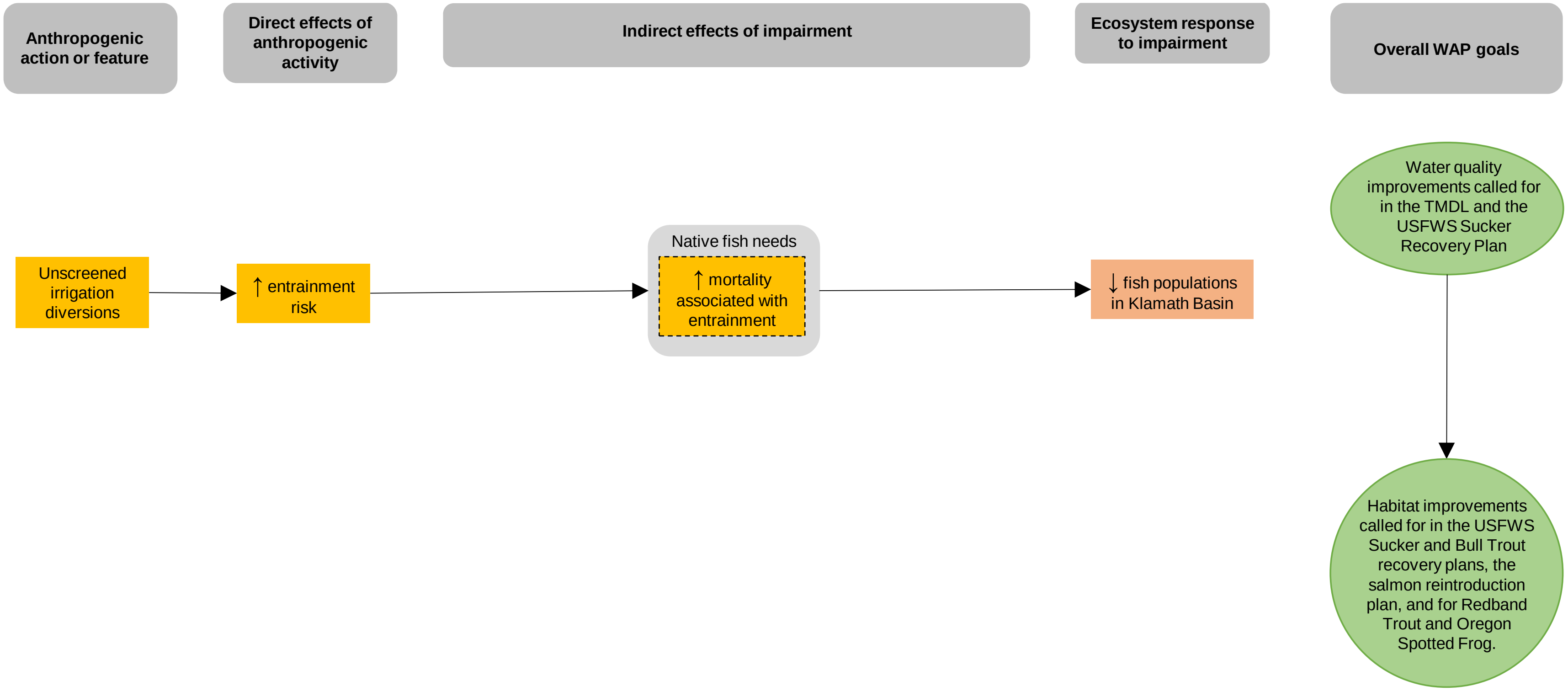

Figure 20. Fish entrainment "impaired conditions" conceptual model.

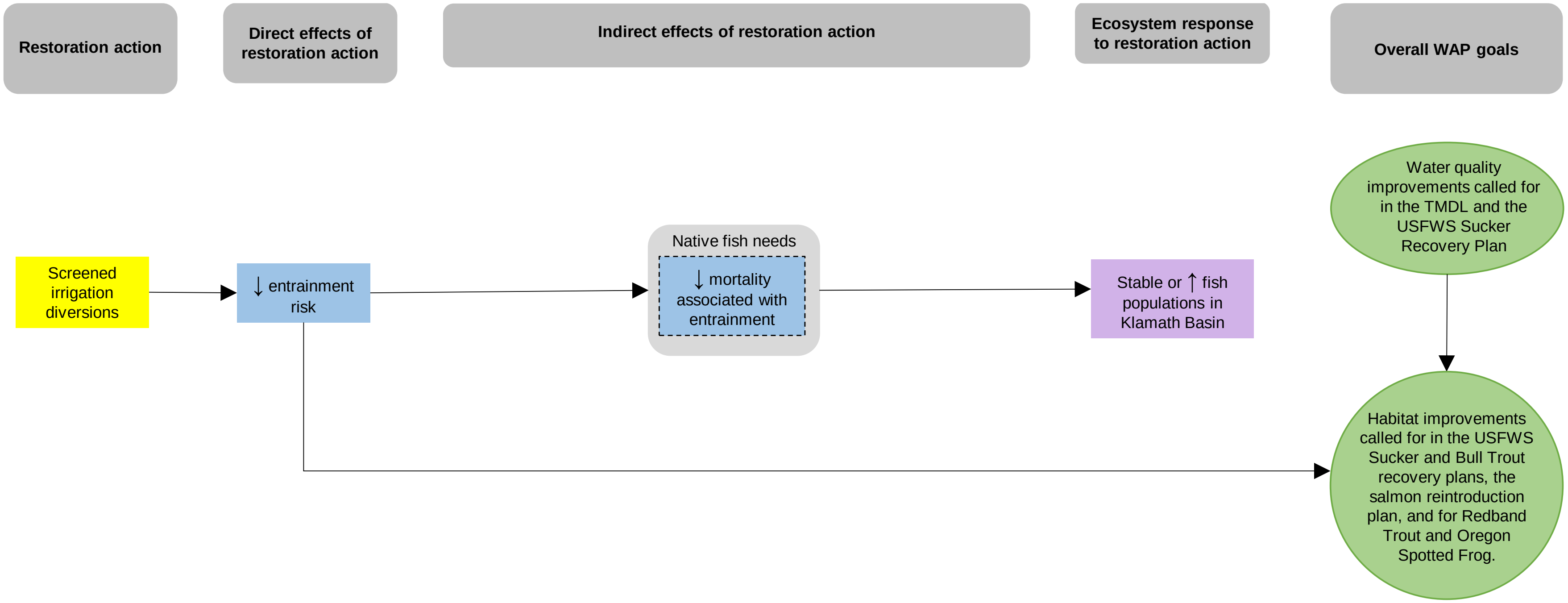

Figure 21. Fish entrainment "restored conditions" conceptual model illustrating the responses to diversion screening implemented to correct and repair impairments associated with unscreened irrigation diversions.

LARGE WOODY DEBRIS

Large woody debris is an important component of river ecosystems. Large woody debris increases channel complexity and can lead to changes in channel morphology, such as formation of bars, pools, and islands (Abbe and Montgomery 1996). Large woody debris was historically removed from many North American river systems for aesthetics, access, flood control, and/or safety purposes. Large woody debris recruitment is affected by changes in riparian vegetation and hydrology, and the degree of connection between rivers and floodplains (Abbe and Montgomery 1996).

Historically in the UKB, some riparian corridors and floodplains had a limited woody vegetation component, and thus LWD placement and attempted restoration of woody riparian vegetation should be carefully considered. Regardless, the addition of LWD can "kick start" recovery of some impaired riverine and geomorphic processes and functions, so restoration efforts involving LWD may be warranted even in areas where LWD was historically scarce. Similarly, although the UKBWAP emphasizes actions to restore processes and functions that could "naturally" lead to an increase in LWD recruitment, it may be necessary to implement LWD addition projects while ecosystem restoration is on-going, in order to achieve the objectives described in the "restored conditions" LWD conceptual model.

Impaired conditions

The "impaired conditions" LWD conceptual model represents an impairment associated with multiple anthropogenic activities within the UKB, rather than a single specific activity. Note that a lack of large woody debris may not be a sign of impairment in all locations; some areas historically had less potential for LWD given inherent site conditions. However, adding large woody debris in such areas may replace or restore process and function that is impaired for other reasons.

The direct results of a lack of LWD are changes in channel morphology[106] and native fish habitat due to a loss of channel complexity, a decrease in the diversity of instream habitat, decreased instream cover, and decreased high flow refugia (and holding and rearing habitat) (Abbe and Montgomery 1996, Roni and Quinn 2001) (Figure 22). Taken together, these changes in fish habitat result in a decrease in the abundance and diversity of fish prey due to a lack of prey habitat and food sources under the impaired condition (Genito et al. 2002, Miller et al. 2010, Arnaiz 2011); and a reduction in suitable spawning, incubation, and rearing habitat (Roni and Quinn 2001).

Decreased lateral and longitudinal complexity of river and stream channels results in impairments to geomorphic process and function, namely decreased capacity to intercept and retain nutrient and sediment loads and a decreased capacity to attenuate high flows (Abbe and Montgomery 1996). This indirect effect is largely due to a lack of channel complexity and roughness necessary to capture suspended sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010).

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[106] Specifically, decreased lateral and longitudinal complexity of the channel profile.

Changes in geomorphic process and function result in change in riverine process and function, including:

- Increased sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[107].
- Increased channel incision and decreased floodplain connectivity (Kroes and Hupp 2010)[108].
- Decreased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009) (which affects hydrology and water quality).

The main mechanisms driving these effects include a change in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the negative effect of a reduction in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include effects of UKL algal response[109], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies (which subsequently affect water quality parameters such as pH and DO).

Under the “impaired conditions” model for large woody debris, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

The specific restoration action to address impairments associated with a lack of LWD is primarily LWD additions (Figure 23), however other actions that result in riparian and floodplain restoration may also lead to an increase in LWD recruitment over time (see previous conceptual models).

The direct effect of LWD additions or an increase in LWD recruitment is improvements in channel morphology[110] and native fish habitat due to increases in channel complexity, diversity of instream habitat, instream cover, and high flow refugia (and holding and rearing habitat) (Abbe and Montgomery 1996, Roni and Quinn 2001) (Figure 23). Taken together, these improvements in fish habitat result in an increase in the abundance and diversity of fish prey due restoration of prey habitat and food sources under the restored condition (Genito et al. 2002, Miller et al. 2010, Arnaiz 2011); and a return to site-appropriate substrate composition, which affects fish spawning, incubation, and rearing habitat (Roni and Quinn 2001).

Increased lateral and longitudinal complexity of river and stream channels results in restoration of geomorphic process and function, namely increased capacity to intercept and retain nutrient and sediment loads and an increased capacity to attenuate high flows (Abbe and Montgomery 1996). This indirect effect is largely due to an increase in channel complexity and roughness

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[107] This affects substrate composition, water quality, and UKL algal responses.

[108] This leads to increased sediment and nutrient load; decreased groundwater elevation, recharge, and contribution to baseflow; and changes in hydrology.

[109] I.e., increased nutrient concentrations/loads lead to increased UKL algal productivity (ODEQ 2002).

[110] Specifically, improvements include increased lateral and longitudinal complexity of the channel profile.

necessary to capture suspended sediment and particulate nutrients within the watershed (Bukaveckas 2007, Kroes and Hupp 2010, Sholtes and Doyle 2010).

Improvement in geomorphic process and function result in restoration of riverine process and function, including:

- Restoration of site-appropriate sediment and nutrient load (Bukaveckas 2007, Kroes and Hupp 2010)[111].
- Decreased channel incision and increased floodplain connectivity (Kroes and Hupp 2010)[112].
- Increased groundwater elevation, recharge, and contribution to baseflow (Tague et al. 2008, Hardison et al. 2009) (which affects hydrology and water quality).

The main mechanisms driving these effects include an increase in the capacity to retain sediment and particulate nutrients within the watershed (as described above) and the positive effect of an increase in groundwater inputs on stream temperatures and baseflow (Kaandorp et al. 2019).

Additional linkages within this conceptual model include improvements in UKL algal response[113], which in turn affects decomposition activity and internal nutrient cycling (through redox-mediated interactions [Mortimer 1942, 1943]) in surface water bodies[114].

LWD additions and other restoration activities targeting LWD recruitment, when implemented effectively and at the appropriate scale throughout the watershed, indirectly result in achievement of the overall goals of the UKBWAP (Figure 23).

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[111] This affects substrate composition, water quality, and UKL algal responses.

[112] This leads to restoration of site-appropriate sediment and nutrient load; increased groundwater elevation, recharge, and contribution to baseflow; and changes in hydrology.

[113] I.e., decreased nutrient concentrations/loads lead to decreased UKL algal productivity (ODEQ 2002).

[114] This subsequently affects water quality parameters such as pH and DO.

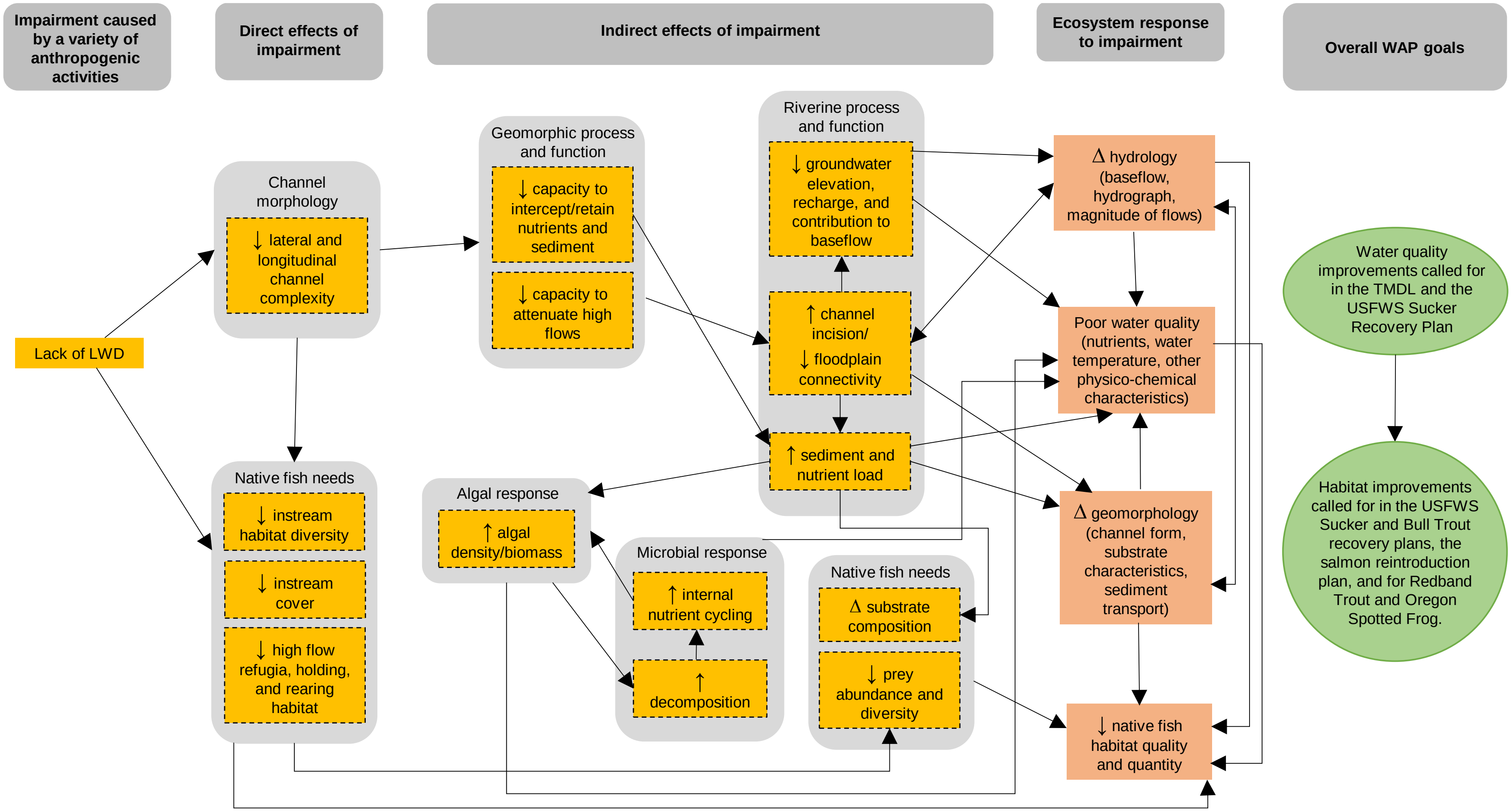

Figure 22. Large woody debris "impaired conditions" conceptual model. Δ indicates a change in conditions. Note that a lack of large woody debris may not be a sign of impairment in all locations; some areas historically had less potential for large woody debris given inherent site conditions. However, adding large woody debris in such areas may replace or restore process and function that is impaired for other reasons.

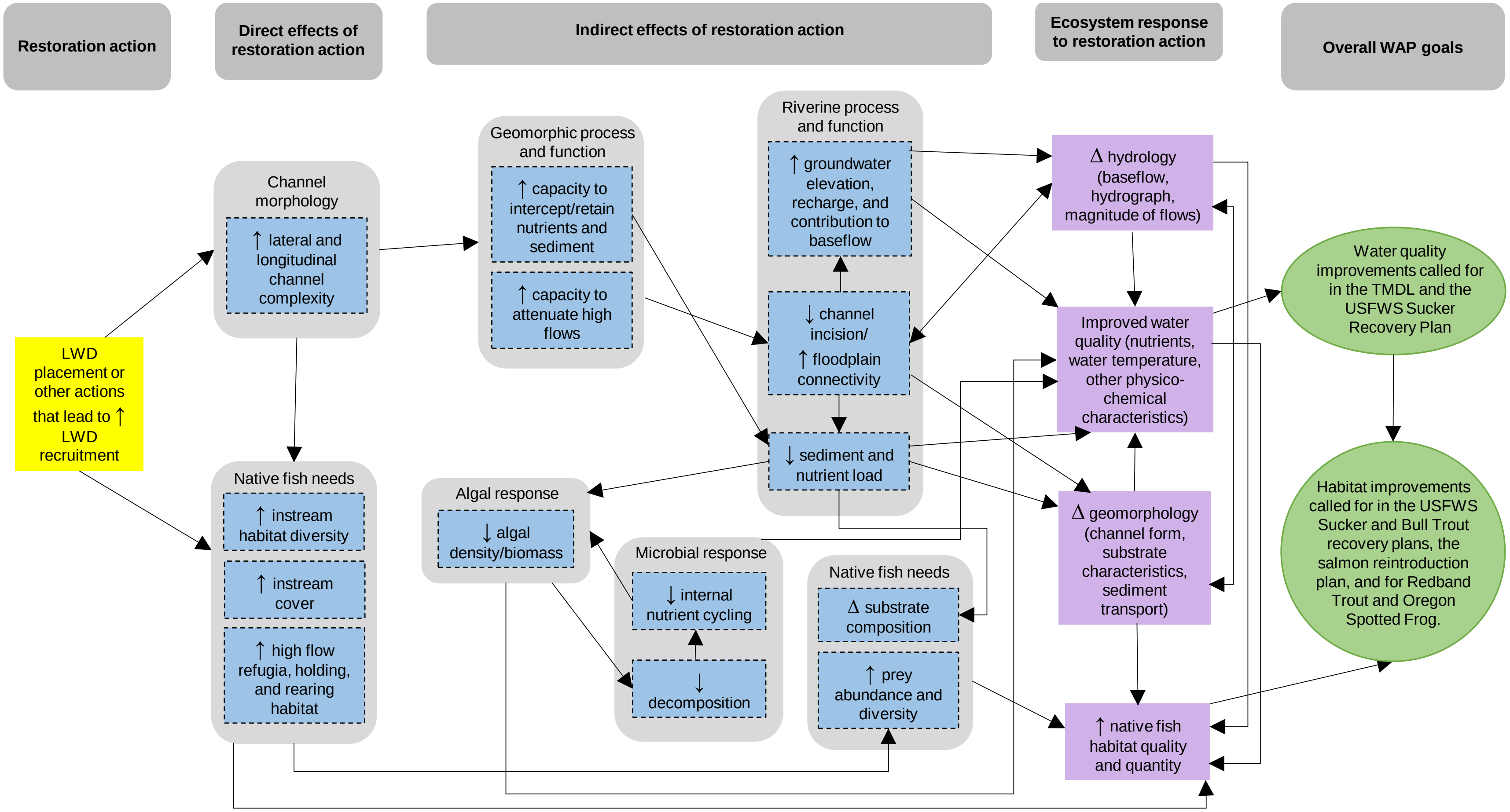

Figure 23. Large woody debris "restored conditions" conceptual model illustrating the responses to large woody debris placement, or restoration of processes that increase large woody debris recruitment, implemented to correct and repair impairments associated with a lack of large woody debris. Δ indicates a change in conditions to those considered appropriate for a given site.

SPAWNING SUBSTRATE

Bull trout, redband trout, Chinook, and steelhead require stable, well-oxygenated gravel of different sizes for successful spawning (KBEF and KBREC 2007). When fine sediments are deposited over and within spawning substrate, or when gravel is otherwise lost[115], spawning success and embryo survival is reduced. Spawning gravel additions can be effective in restoring spawning habitat in some areas (Barlaup et al. 2008), but this form of restoration offers only temporary benefits in many areas (McManamay et al. 2010). Gravel additions that occur in areas with limited sediment load (such as groundwater-dominated streams) are likely to be more successful in the long-term given limited sedimentation in such systems.

In the UKB, there are relatively limited areas with optimal gravel size for the species listed above due to inherent geology; however, the unique geology and geomorphology of the area is such that redband trout successfully spawn in areas with substrate size that is considered suboptimal. Notably, gravel additions in the UKB have been heavily used by fish almost immediately after placement and may serve as an effective means to increase spawning success of recolonizing anadromous fish in the future (pers. comm. Bill Tinniswood, ODFW).

Finally, the UKBWAP acknowledges that increasing the quality and quantity of spawning substrate is an objective of the actions to restore process and function. However, in the short term, supplementing spawning substrate is a key component of sustaining fish populations while restoration work is ongoing. The focus of the UKBWAP is actions to solve the underlying issues that lead to lack of spawning substrate throughout the UKB, but stopgap measures can and should be considered to ensure that fish communities persist to benefit from watershed restoration.

Impaired Conditions

The “impaired conditions” spawning substrate conceptual model represents an impairment associated with multiple factors within the UKB, including both anthropogenic and geologic/geomorphic in nature, rather than a single specific anthropogenic activity.

The direct effect of a lack of available spawning gravel is a lack of spawning habitat for native fish (Barlaup et al. 2008, McManamay et al. 2010) (Figure 24). Indirectly, a lack of spawning gravel also results in decreased spawning success, embryo survival, and recruitment (Bjornn and Reiser 1991). Ultimately, when considered watershed wide, this lack of spawning habitat can lead to decreased fish populations in the UKB.

Under the “impaired conditions” model for spawning substrate, there are no linkages to the overall goals of the UKBWAP.

Restored Conditions

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[115] Anthropogenic actions and other impairments that alter stream substrate composition (which naturally may or may not include gravel) include unmanaged riparian and floodplain grazing, channel incision, lack of LWD, channelization, presence of levees and berms, etc. as described throughout this chapter.

The specific restoration action to address impairments associated with a lack of spawning gravel is primarily gravel additions[116] (Figure 25); however, restoration actions that restore geomorphic process and function in areas with coarser sediment (e.g., the Sprague River) are long-term solutions to this issue.

The direct effect of spawning gravel additions is an increase in spawning habitat for native fish (Barlaup et al. 2008, McManamay et al. 2010). Indirectly, spawning gravel additions also result in increased spawning success, embryo survival, and recruitment (Bjornn and Reiser 1991). Ultimately, when considered watershed wide, this increase in spawning habitat can lead to increased fish populations in the UKB[117].

Spawning gravel additions and other actions that increase the availability and quality of spawning gravel, when implemented effectively and at the appropriate scale throughout the watershed, indirectly result in achievement of the fish habitat-associated goals of the UKBWAP (Figure 25).

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[116] The UKBWAP acknowledges that gravel additions are not likely a long-term solution to issues contributing to impaired spawning habitat in the UKB, however it is a relatively inexpensive and effective option for increasing spawning habitat in the near-term and thus spawning success in the UKB. Other actions to restore site-appropriate stream substrate (that may or may not include gravel) include riparian grazing management and/or fencing, actions to aggrade stream channels, LWD placement (or actions that naturally increase LWD recruitment), actions to address channelization, levee removal or setback, etc. as described throughout this chapter.

[117] This assumes fish that would otherwise have not survived as embryos survive other potential stressors and causes of mortality present in the UKB.

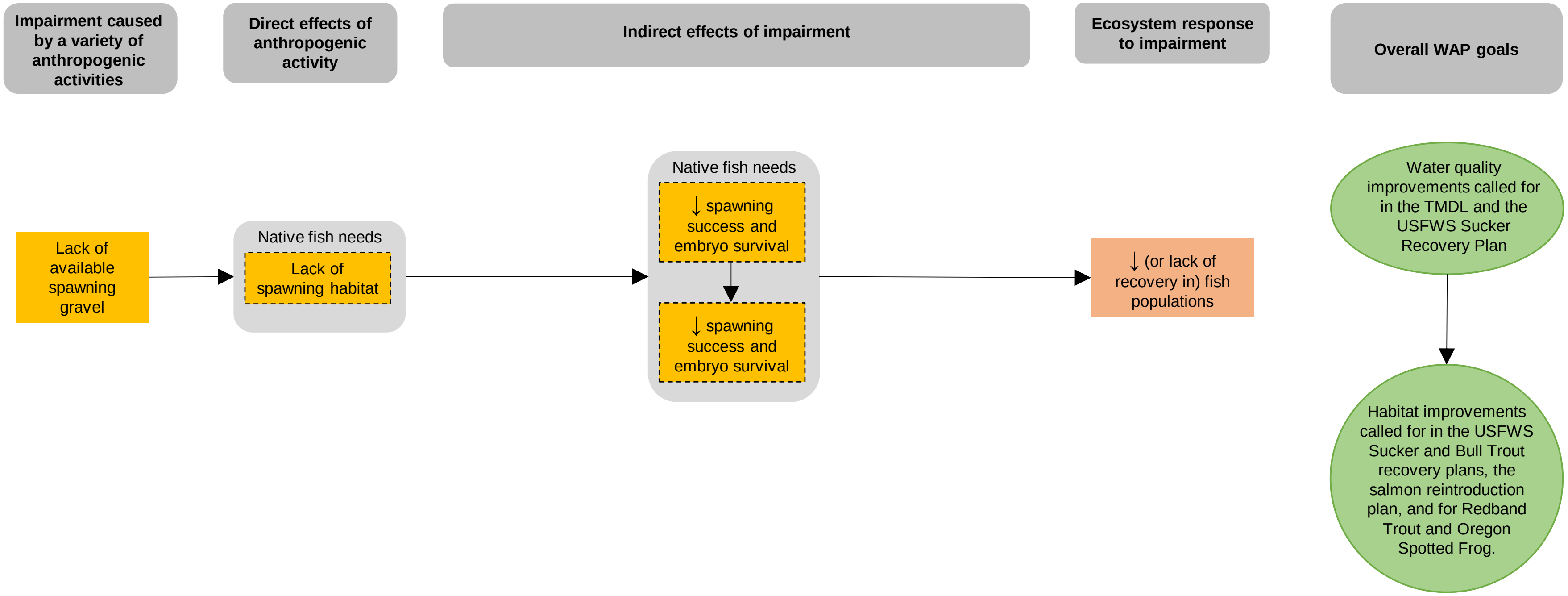

Figure 24. Spawning substrate "impaired conditions" conceptual model.

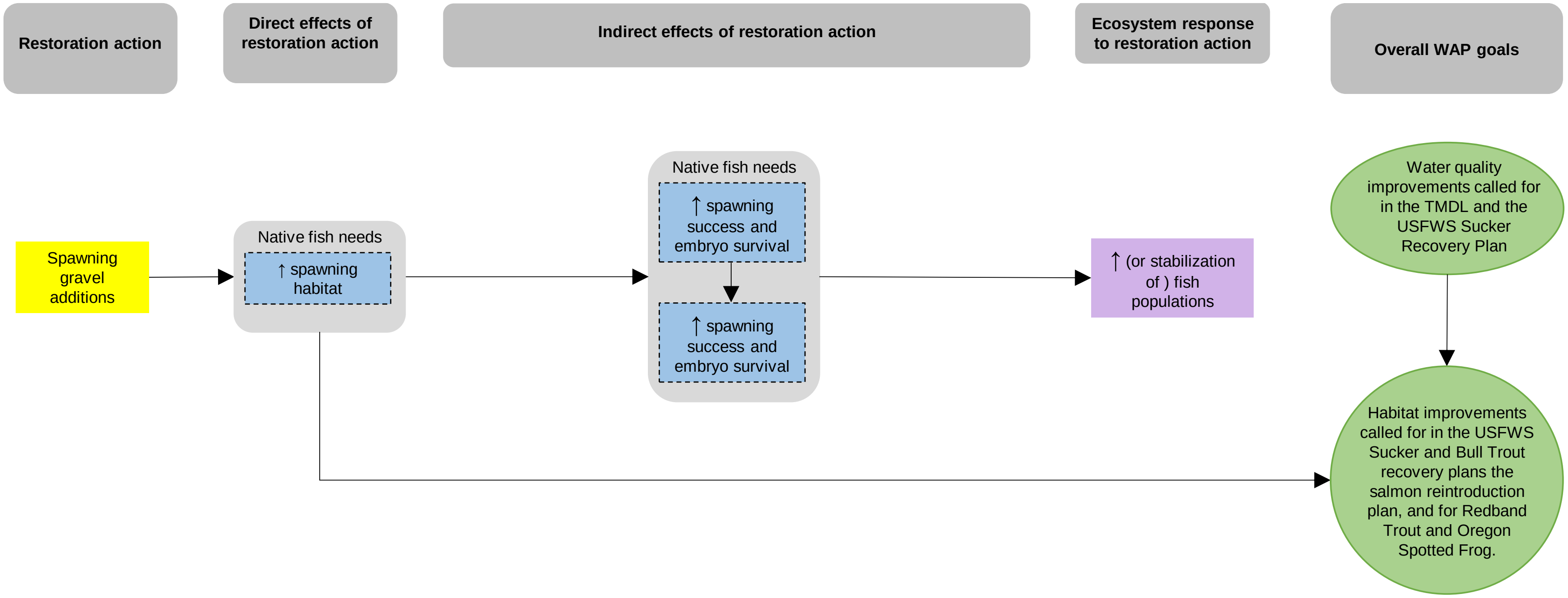

Figure 25. Spawning substrate "restored conditions" conceptual model illustrating the responses to spawning gravel additions, or restoration of processes that increase spawning gravel recruitment, implemented to correct and repair impairments associated with a lack of optimal spawning substrate.

CHAPTER 4: INTERACTIVE REACH PRIORITIZATION TOOL

OVERVIEW

The IRPT identifies the most impaired reaches within the UKB based on a score of 1 – 4 (with higher scores indicating greater impairment and therefore higher priority for restoration)[118] for both individual condition metrics, described below, and for an averaged metric score. The IRPT webpage includes metadata for each reach listing the reach number, averaged condition metric score, the score for each individual condition metric, and supplemental information that was not included in metric scoring (e.g., vertical incision height). The IRPT also includes additional layers that can be added to the IRPT (using the Add Data tool), including (but not limited to) designated critical habitat for Oregon Spotted Frog, Lost River Sucker, Shortnose sucker, and Bull Trout; beaver dam suitability index output; Klamath County publicly-available taxlot data; channelized reaches shapefile; levees and berms shapefile, irrigation returns and diversions point files; and the fish barriers point file, all described below. These additional layers are provided for reference only, and have not been incorporated into reach scoring.

The IRPT is designed to be used in concert with the conceptual models (Chapter 3) and Restoration Guide (Appendix A) to identify highest priority impairments, associated restoration options, and technical resources to assist in implementation of restoration and monitoring. Although the UKBWAP assumes that the highest priority reaches for restoration are those with poorest condition, restoration professionals can prioritize reaches in whatever way best meets their needs (e.g., if preservation is of interest, restoration professionals can use the IRPT to identify and prioritize for preservation reaches in “good” condition).

Although the IRPT offers a basin-scale assessment of reach-specific condition and reach prioritization for restoration, ground-truthing and professional/expert judgement are critical in determining if specific properties and/or potential project sites within prioritized reaches are indeed high priorities for restoration based on observations. The IRPT provides guidance but is not intended to replace professional opinion and judgement and/or ground-truthing, nor is it intended to be binding in any way. Site visits, thorough ground-truthing, and pre-project monitoring to better understand site conditions and impairments are critical elements in any restoration program and are strongly encouraged. No model or geospatial analysis will ever be fully accurate, so it is expected that as additional information becomes available (through site visits or otherwise), reach condition scores may change.

The UKBWAP does not include a narrative summary of averaged condition metric or individual metric score results for the UKB given that these metrics are likely to be reassessed regularly as new information becomes available. The relevant information for restoration planning and prioritization purposes can be accessed directly in the IRPT.

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[118] The reasoning here is that restoring areas with the greatest degree of impairment is more likely to achieve the overall goals of the UKBWAP, compared to preserving areas that are currently in good condition.

CONDITION METRICS METHODS

The condition metrics characterize the level of impairment (based on the best available information) at a reach scale for each impairment/anthropogenic activity described in the “impaired conditions” conceptual models in Chapter 3. This reach level assessment then informs the highest priority reaches for implementation of restoration actions described in the “restored conditions” conceptual models.

River reaches for this reach-level assessment were defined uniformly as 3 miles long, regardless of stream size and length, with the first reach beginning at the mouth of the river or stream of interest. In some cases, shorter reaches are present near headwater areas. Upper Klamath Lake shoreline segments were defined uniformly as 3 miles long, beginning at the mouth of the Williamson River and moving clockwise around the lake. The justification for a fixed-length approach is that it provides restoration professionals a relatively fine scale of assessment (such that condition scores are likely to be reflective of any given site within the reach/shoreline segment) while balancing the desire for landowner privacy (as each reach spans multiple ownership parcels). The justification for 3-mile long reaches was that this length allows for a finer-scale conditions assessment, but also protects the privacy of local landowners. In total, this reach designation method resulted in 268 stream reaches and 41 UKL shoreline segments.

To ensure consistency across metrics, the reach-level scores for each metric were determined based on the quantile values of the metric results, relative to all other reaches assessed. The distribution of those values then determined reach scores (Table 1).

Table 1. Reach-specific metric scores normalized by quantile. A score of 1 indicates low impairment or good condition, while a score of 4 indicates a high degree of impairment or poor condition.

Score	Quantile
1	0 - 25
2	>25 - 50
3	>50 - 75
4	>75 - 100

Condition metrics are applied using a scoring system that adds points for factors that increase impairment. In other words, higher metric scores indicate a more impaired condition, while lower metric scores indicate a less impaired condition.

Although each impairment is influenced by different factors and therefore not directly quantitatively comparable, each condition score has been scaled to the same 1 – 4 scoring scale to allow relative comparison. As is discussed further in the “Workflow” subsection below, condition metrics can be compared for initial restoration planning and prioritization purposes, but a site visit and professional/expert opinion are critical in determining the highest priority project type for a given project site.

Finally, note that some metrics associated with specific impairments are still under development or are likely to require future refinement using consistently updated data sources. As stated in Chapter 1, the UKBWAP is intended to be a living document that is revised and updated as additional information becomes available. As such, this chapter in particular is expected to change over time based on the best available information.

Methods used to develop the condition metrics are summarized by metric below, but described in more detail in Appendix D.

Channelization

The channelization metric relies primarily on a shapefile identifying the linear extent of channel alignment changes, relative to historical conditions represented in aerial imagery from the 1950s and later (The Klamath Tribes 2015). This shapefile identifies the specific locations and lengths of stream characterized as "channelized" (see FlowWest 2017 for additional information regarding how the shapefile was developed). This metric was applied to stream reaches.

The channelization metric score was calculated by summing the length of the channelized segments, dividing the summed length of channelized segments by the total reach length, and then assigning scores based on the quantile values (Table 1).

Limitations for the channelization metric are related to the data available for historical comparisons. For instance, the "historical" aerial imagery used for this analysis was from the 1950s, when some anthropogenic activities and channel alignment changes were already well underway. This means that metric scores may not properly identify the degree of channelization in reaches channelized prior to the 1950s (e.g., these changes would not be identified as part of the analysis that compares channel alignment in the 1950s with present alignment). A specific example is for Sevenmile Creek/Canal that was constructed prior to the 1950s and therefore is not identified as having channel alignment changes. Furthermore, stream and river channels were not always visible for analysis, particularly where channels were narrow and/or shielded from view by dense canopy. Finally, channelized segments identified in the geospatial analysis were not ground-truthed.

Channel Incision

The channel incision metric was developed by applying U.S. Geological Survey's (USGS) Bank Slope Tool (Cartwright and Diehl 2017) to geospatial data from 2004 (Sprague and Wood river basins) and 2010 (Williamson River basin) LiDAR surveys in the UKB. The Bank Slope Tool identifies incised areas (i.e., steep, eroding stream banks) using slope and size thresholds. As applied to the UKB, incised areas have a minimum slope of greater than 35 percent and are greater than 400 square meters in size. We identified the total acreage of incised areas meeting these criteria within 25 meters of each stream reach centerline and then calculated the total acreage of incised areas at a reach scale. We divided the total area of incised stream banks by reach length and scaled scores to 1 – 4 using quantile distributions (Table 1) to determine final condition metric score. This metric was applied to stream reaches.

We used acreage (rather than incision depth) because it was a measure that could be compared across systems with different hydrologic characteristics. For instance, areas with greater stream power may have more potential for greater incision depth, but this does not necessarily represent a more impaired condition relative to systems dominated by groundwater that have a lower intrinsic potential for deep incision. Regardless, average vertical incision depth of incised areas is provided for reference in the IRPT. The IRPT results indicate incision in some reaches that have been characterized as having little vertical incision, or only localized incision, by O'Connor et al. (2015); because this metric scores degree of incision based on acreage (rather than vertical height), scores in these reaches are likely identifying slight changes that have occurred since the O'Connor et al. (2015) analysis.

The primary limitation associated with this metric is the geographical extent of the LiDAR coverage. Specifically, LiDAR data covered nearly all reaches, except 22 headwater tributaries of the Sprague. Ideally, future LiDAR acquisition efforts will cover the entire geographic area included in the UKBWAP and this metric can then be updated and expanded.

Levees and Berms

The levees and berms metric quantifies impairment based on a flow obstructions geodatabase (The Klamath Tribes 2016a) that relied on remote sensing and geospatial data (further described in Appendix D). This metric was applied to stream reaches.

The levees and berms metric is the sum of two separate measures described below:

1. *Proportion of reach that is obstructed by levees or berms*
   The levee and berms lengths were summed within each reach, and then divided by the reach length to calculate a preliminary levee and berm score. The quantile distribution was determined for preliminary levee and berm score, and each reach was then given a reach-specific score from 1 – 4 based on distribution quantiles (Table 1). Because this accounts for length on both banks, this sub-score may result in proportions between 0 and 2 (rather than between 0 and 1).

2. *Proportion of distance between channel and levee/berm to floodplain width*
   We calculated both the minimum distance from the wetted channel to the levee/berm, and floodplain width (Abood et al. 2012). We then divided the minimum distance from the wetted channel to the levee/berm by floodplain width. Finally, we scaled the score between 1 and 4 based on quantile distribution (Table 1). This portion of the score allows us to prioritize levees/berms that disconnect greater extents of the topographic floodplain. For instance, in an area with a 100 foot-wide floodplain, a levee/berm located 5 feet from the wetted channel would be a higher priority for removal than a levee/berm located 100 feet from the wetted channel.

To calculate the final reach-specific levees and berms metric score, we averaged the sub-scores of the two measures described above.

Limitations for the levees and berms metric are primarily related to a heavy reliance on remote sensing and geospatial data, limited ground-truthing, and a lack of hydrologic modelling to better understand the effects of individual levee breaching, removal, or setback projects. The UKBWAP Team has identified the lack of hydrologic modelling as a knowledge gap and hopes to pursue a modelling effort to further refine this metric in the future. Additionally, this metric does not account for possible implications for infrastructure and property associated with levee removal. For instance, many levees and berms provide flood protection and other beneficial functions and it therefore may be difficult or dangerous to change the placement or structural integrity of some levees. The infrastructure-related benefits of levees or berms should be reviewed on a case by case basis when evaluating potential restoration projects. Finally, the metric only characterizes impairments associated with channel confinement, not those for UKL shoreline areas.

Wetlands

The wetlands metric was developed using local expert opinion to prioritize areas around UKL for natural wetland restoration; this metric did not involve prioritization for construction of diffuse source treatment wetlands, which are considered as part of the irrigation practices metric described below. A final wetlands shoreline segment prioritization score was calculated by taking the average of all expert rankings for each reach.

Currently, the wetlands metric only applies to UKL shoreline segments. Future UKBWAP work includes developing a wetlands metric protocol for stream reaches. This will likely involve discussions with a group of local wetland experts.

Limitations associated with this metric are those common to assessments based on local expert opinion, as priorities and opinions can differ between experts. The UKBWAP Team may pursue geospatial methods to prioritize reaches for wetland restoration in the future.

Riparian and Floodplain Vegetation

The riparian and floodplain vegetation metric was developed using a land cover classification based on 1 meter spatial resolution National Agriculture Imagery Program (NAIP) aerial photographs acquired in late June 2016. We used the imagery to calculate the Normalized Difference Vegetation Index (NDVI)[119] and associated four simple land cover types with NDVI value ranges. NDVI is a dimensionless measure of vegetation biomass and vigor ranging from 1 (more biomass) to -1 (less biomass) and is widely used to characterize riparian condition (Griffith et al. 2002, Fu and Burgher 2014, Norman et al. 2014, Silverman 2019). Land cover types defined for this metric include mesic vegetation (most commonly associated with healthy riparian areas), xeric vegetation (more common in upland areas), bare ground, and open water. Mesic vegetation was defined based on NDVI values greater than 0.3 (Donnelly et al. 2016); additional methods for land cover classification are provided in Appendix D.

To determine metric scores, we calculated the percent mesic vegetation within the terrestrial (i.e., non-water) portions of a buffer of the stream reach centerline. We used a 25 meter buffer width for most reaches except high order portions of the Williamson, Sprague, and Wood rivers, where we used 50 or 75 meter buffers to ensure that the buffer included riparian areas and area of other

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[119] NDVI is calculated using the reflections in the near-infrared (NIR) spectrum and red range (RED) of the spectrum. Specifically, NDVI = (NIR – RED) / (NIR + RED). See Appendix D for specific JavaScript code used in Google Earth Engine to calculate NDVI.

terrestrial land cover (i.e., xeric vegetation and bare ground) along these wider stream reaches. Finally, we assessed the percent mesic vegetation within the buffer in each reach and scaled scores to 1 – 4 based on quantiles (Table 1). Reaches with higher scores had a smaller proportion of mesic vegetation (vegetation associated with riparian areas).

This metric was applied only to stream reaches. Potential future work includes a protocol for riparian conditions along UKL.

Uncertainties and limitations associated with this metric are primarily related to the collection timing of the available NAIP imagery. Specifically, the data currently available for analysis is from 2016, prior to recent changes in water rights regulation in the UKB (primarily affecting the Sprague River sub-basin). As such, riparian areas affected by irrigation in 2016 may have NDVI values that are not representative of current conditions. The UKBWAP Team plans to update this metric when more recent NAIP layers become available. Additionally, NDVI does not distinguish between plant species or even vegetation type (such as grasses vs. woody vegetation) within vegetation classes. Rather, it simply characterizes riparian condition based on "greenness" of the NDVI data, which is a proxy for biomass and vigor.

Finally, the UKBWAP Team did consider using the Riparian Condition Assessment Tool (RCAT; MacFarlane et al. 2007) to characterize riparian condition. RCAT defines valley width (to represent the riparian and floodplain area) and then characterizes historical and current vegetation classes. Reaches with the greatest divergence between historical and current vegetation are classified as the most impaired (MacFarlane et al. 2007). The UKBWAP Team determined that RCAT scores were misrepresenting riparian impairment, largely due to a mischaracterization of current riparian vegetation. Given these results, the UKBWAP Team determined it was necessary to explore other options.

Irrigation Practices

This metric was developed separately for stream reaches and UKL shoreline segments, as described below. Note that this metric does not specifically identify priority areas for flow restoration through instream transfer of water rights. The UKBWAP Team recommends additional data collection and analysis to identify reaches in need of flow restoration.

As for other metrics described above, site visits and pre-implementation monitoring are strongly recommended in reaches characterized as impaired by irrigation tailwater returns prior to restoration project implementation, particularly when DSTWs are being considered for implementation. Specifically for DSTWs, an assessment of the magnitude of flows passing through the wetlands and seasonal water quality sampling (namely for different phosphorus fractions) prior to implementation is critical in informing wetland design and placement.

Stream Reaches

In the Sprague and Williamson sub-basins, the irrigation tailwater metric is based on the irrigation return point features from the irrigation and return database (The Klamath Tribes 2016b, FlowWest 2017). The data layer associated with the database is a point file with attribute information that identifies the point as an irrigation diversion point or a return flow location. For the Wood River valley, irrigation return points were identified manually using aerial imagery.

To calculate a reach-specific irrigation tailwater metric score, the number of irrigation returns were summed by reach and normalized by reach length. The quantile distribution of the normalized irrigation return points per reach was calculated and each reach was scored based on distribution quantiles (Table 1).

Limitations for this metric are primarily related to reliance on remote sensing and geospatial data, limited ground-truthing, and a lack of hydrologic modelling to better understand the magnitude of discharge from each return point. The UKBWAP Team has identified the lack of hydrologic modelling as a knowledge gap and hopes to pursue a modelling effort to further refine this metric in the future.

UKL Shoreline Segments

The irrigation tailwater metric for UKL shoreline segments was developed using local expert opinion to prioritize areas around UKL. A final irrigation tailwater shoreline segment prioritization score was calculated by taking the average of all expert rankings for each shoreline segment.

Limitations associated with this metric are those common to assessments based on local expert opinion, as priorities and opinions can differ between experts. The UKBWAP Team may pursue geospatial methods to prioritize shoreline segments for actions to decrease or treat tailwater returns in the future.

Springs

The springs metric for stream reaches was developed using local expert opinion to prioritize reaches for stream reconnection and/or restoration; this metric currently does not include prioritization scores for UKL shoreline segments. A final springs reach prioritization score was calculated by taking the average of all expert rankings for each reach.

Limitations associated with this metric are those common to assessments based on local expert opinion, as priorities and opinions can differ among experts. The UKBWAP Team may pursue geospatial methods to prioritize reaches for springs restoration/reconnection in the future.

Fish Passage

The fish passage metric uses a fish passage barriers database (Trout Unlimited 2018) developed by combining numerous basin-specific data sources, including the 2014 ODFW fish passage database, suspected barriers identified via aerial imagery, and road and stream intersection points. The database only includes points within one kilometer of ODFW’s redband trout distribution layer, and all duplicate points were cleaned. Specifically, the metric was developed by selecting barriers that were recorded as full or partial fish passage barriers or having an unknown status. This metric was applied to stream reaches.

To calculate the score for this metric, we first weighted each barrier based on stream level (e.g., a barrier on the lower portion of the mainstem Williamson would be weighted higher than a barrier in a headwater area). We then calculated the number of passage barriers (and associated weight) in each reach and divided by the total reach length. The final fish passage metric score was assigned based on the quantile distribution (Table 1) of the preliminary score resulting from the parameters described above.

The dataset used to develop the fish passage metric identifies 31 full fish passage barriers, 59 partial barriers, and 254 barriers with an unknown fish passage status within the UKBWAP geographical area. Per OAR 635-412-0035, evaluation criteria for fish passage requirements at a site should include "(A) Native migratory fish currently or historically present at the site which require fish passage; (B) Life history stages which require fish passage; and (C) Dates of the year and/or conditions when passage shall be provided for the life history stages and native migratory fish." Since this data is largely absent for most of the barriers in the passage barriers dataset used in the UKBWAP, further evaluation is recommended as part of the ongoing and future passage restoration planning process.

A major caveat of the fish passage metric is that it does not include information regarding the specific seasons or life stages when passage is limited at each structure. For instance, some passage barriers identified in the passage barrier database may only be impassable during low flows or may only affect one particular life stage. Suspected barriers identified through remote sensing should be ground-truthed, and barrier status should be reviewed and updated regularly. An updated passage barrier dataset from ODFW was published in 2019 and additional ground-truthing in the upper Sprague River basin was conducted in 2020; these datasets will be incorporated into this metric as soon as possible.

Roads

The roads metric was developed using the Oregon state roads geodatabase (ODOT 2019), exclusive of state and U.S. highways that are unlikely to be relocated or decommissioned. Metric scores were calculated by determining road density within 100 meters of stream centerlines, and scoring 1 — 4 based on quantile distribution (Table 1).

This metric was applied to stream reaches.

One potential limitation associated with the road metric is the accuracy of the roads dataset, which focuses on publicly maintained roads and may exclude smaller private roads. This metric may be applied to areas adjacent to UKL in the future.

Fish Entrainment

The fish entrainment metric relies on a geospatial dataset of irrigation diversions and returns points (Klamath Tribes 2016b). This dataset was developed by mapping features from aerial imagery and the National Hydrography Dataset; and integrating data from ODFW, the Oregon Watershed Restoration Inventory, and a 2007 aerial thermal infrared remote sensing study (FlowWest 2017). The data layer is a point file with attribute information that identifies the point as an irrigation diversion point or a return flow and includes a screen status field. This data covers the Sprague and Williamson rivers. For the Wood River Valley, a dataset of points of diversion (Trout Unlimited 2016) was used; this dataset was developed based on water rights spatial data from the Oregon Water Resources Department (OWRD) website, OWRD's Water Right Information System data, and Klamath Basin Fish Screen Inventory for the Wood River sub-basin. This data also includes a screen status field. This metric was applied to stream reaches.

To calculate the metric score for each reach, the number of diversions in a given reach was divided by reach length and then weighted by screened status (e.g., “unscreened” was weighted higher than diversions with unknown screen status).The quantile distribution of the preliminary fish entrainment metric score for each reach was determined and each reach was assigned a final score based on the quantile distribution (Table 1).

Limitations associated with this metric are primarily related to the quality and quantity of data within the diversion screening dataset. Specifically, the only information on screening comes from the FlowWest (2017) and Trout Unlimited (2016) databases, and additional surveying efforts and field verification are needed. Due to the limited information on screening, screening status on 79 percent of diversions in the Sprague and Williamson Rivers and 50 percent of diversions in the Wood River valley are classified as unknown or unidentifiable. Ground-truthing of diversion screen status is also needed to confirm status. Additionally, this metric does not provide information about where fish are entering and exiting irrigation systems, and there is a possibility in some locations that fish may be entrained at irrigation returns as well as diversions. Finally, no data exist on abundance of fish becoming entrained in specific diversions, which would assist in refining the metric.

Large Woody Debris

The LWD metric was developed for both stream reaches and UKL shoreline segments using local expert opinion to prioritize areas for LWD addition or other restoration actions to promote recruitment of LWD. A final LWD reach prioritization score was calculated by taking the average of all expert rankings for each reach.

Limitations associated with this metric are those common to assessments based on local expert opinion, as priorities and opinions can differ between experts. The UKBWAP Team may pursue geospatial methods to prioritize reaches for LWD additions and actions that increase LWD recruitment in the future.

Spawning Substrate

The spawning substrate metric was developed for both stream reaches and UKL shoreline segments using local expert opinion to prioritize areas for gravel addition or other restoration actions to improve spawning conditions. A final spawning substrate reach prioritization score was calculated by taking the average of all expert rankings for each reach.

Limitations associated with this metric are those common to assessments based on local expert opinion, as priorities and opinions can differ between experts. The UKBWAP Team may pursue geospatial methods to prioritize reaches for restoration of spawning habitat in the future. Furthermore, no data exist on spawning substrate limitations for specific native fish species. This would help in refining the metric.

AVERAGED CONDITION METRIC

The reach/shoreline segment-specific averaged condition metric score is the average of the individual condition metric scores for a given reach/shoreline segment[120]. As with the individual condition metric scores, the averaged score is from 1 – 4, with a score of 4 indicating the highest degree of impairment or poorest condition.

We chose to use an unweighted average for the averaged condition metric score in order to avoid subjectively prioritizing and weighting some impairments over others. There is likely a great number of different weighted combinations restoration professionals may be interested in. The approach here was meant to provide a simple and straightforward guide including information that allows individual restoration professionals to further refine reach prioritization based on their expertise and priorities, rather than the UKBWAP Team's own set of priorities.

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[120] Each individual metric score was equally weighted in this calculation.

IRPT WORKFLOW

The IRPT webpage is designed to guide restoration professionals and members of the public. Although the IRPT allows restoration professionals and others to better understand degree of impairment at a reach scale, the IRPT relies on geospatial data that may not always accurately represent current conditions at a reach or project site-scale. As such, the IRPT is meant to guide efforts at a landscape scale, but site visits and professional opinion are critical in determining what is most appropriate and the highest priority at a given project site.

The IRPT can be used in a number of ways, including (but not limited to):

- To identify a priority reach for a specific restoration project

This approach allows restoration professionals to pursue funding for a single type of restoration activity and then identify the highest priority reaches for landowner outreach and subsequent implementation. Specifically, this approach identifies the highest priority reaches for a specific restoration activity based on the individual condition score associated with that restoration activity. For example, if restoration professionals have funding to implement riparian restoration (including fencing, grazing management, and/or planting), then the riparian and floodplain vegetation metric would help identify the highest priority reaches for that project type. Once highest priority reaches are identified in the IRPT, it is likely necessary to engage in landowner outreach and recruitment in the reach of interest (see Appendix C, *in prep.*; the Stakeholder Outreach and Engagement Plan, for information regarding outreach and engagement strategies). If and when an interested landowner within the reach of interest is identified, restoration professionals would then schedule a site visit and use their expertise to determine if the restoration activity of interest is appropriate for the site and/or if other impairments are higher priorities at the project site.

- To identify highest priority reaches for restoration of any kind

This approach allows restoration professionals to understand answers to the questions of “where and what”. Specifically, with this approach, restoration professionals identify the highest priority reaches based on the averaged condition metrics score and then compare the individual condition metric scores within a priority reach of interest to better understand which impairments are highest priority. As with the approach described above, once highest priority reaches are identified in the IRPT, it is likely necessary to engage in landowner outreach and recruitment in the reach of interest (see Appendix C, *in prep.*; the Stakeholder Outreach and Engagement Plan, for information regarding outreach and engagement strategies). If and when an interested landowner within the reach of interest is identified, restoration professionals would then schedule a site visit and use their expertise to determine if the impairments and priority restoration activities identified by the IRPT and the Restoration Guide (Appendix A) are appropriate for the site and/or if other impairments are higher priorities at the project site.

- To understand impairments and priority restoration actions in a pre-selected reach

This approach is appropriate if a specific reach has been selected for restoration (e.g., a restoration professional is approached by a landowner for restoration in a specific reach). Once the specific reach is identified, restoration professionals can access the IRPT to better understand impairments and restoration priorities within the reach of interest.

CHAPTER 5: RESTORATION GUIDE

OVERVIEW

The Restoration Guide (Appendix A) is composed of a table providing suggested restoration actions to reverse or mitigate the impairments illustrated in the conceptual models; technical resources regarding implementation of these actions; and other considerations such as permitting, legal criteria, and associated governing agencies. This table is not intended to be an exhaustive list, but rather a resource providing current and/or locally-relevant technical information that can guide restoration planning. Practitioners should always consider the requirements and processes of restoration funders and permitting agencies, such as compliance with the National Environmental Protection Act and certification that the practice meets standards/criteria.

Appendix A also includes literature reviews and reports offering more specific information about implementation, monitoring, and potential outcomes of restoration actions such as riparian restoration (fencing, grazing management, planting) and beaver restoration (BDAs and other actions that facilitate beaver re-establishment).

WORKFLOW

The Restoration Guide (Appendix A) is meant to be used by restoration professionals to guide restoration implementation after priority reaches and restoration activities have been identified (using the IRPT), and this information has been confirmed with a site visit.

CHAPTER 6: MONITORING FRAMEWORK

OVERVIEW

The conceptual models described in Chapter 3 form the basis for the Monitoring Framework (Appendix B). The Monitoring Framework is organized by impairment, restoration project type necessary to correct each impairment, the quantifiable indirect and direct effects at both the local (near the project site) and watershed scales associated with each impairment/restoration action model pair, and the appropriate monitoring methods to measure each quantifiable effect.

The Monitoring Framework is intended to inform both project and watershed-scale monitoring regimes (as described below) based on objectives associated with specific restoration project types. Targeted and effective monitoring is a critical component of adaptive management (as discussed in Chapter 1), specifically aimed at strengthening technical understanding of ecosystem processes and functions and improving and adjusting restoration implementation methods to achieve desired objectives. The UKBWAP will utilize new information from voluntary monitoring to validate and refine the conceptual models (Chapter 3) and the restoration actions recommended in the Restoration Guide (Appendix A). To answer both watershed and project-scale questions, simultaneous multi-scale monitoring is often necessary, and the UKBWAP therefore considers monitoring at multiple scales (the importance of each scale is further described below).

Finally, while the Monitoring Framework serves as a guideline for developing monitoring regimes associated with specific restoration project types, there is an expectation that restoration professionals will assess site-specific conditions and make adjustments as appropriate and based on expert judgement.

For context regarding the monitoring methods and objectives highlighted in the Monitoring Framework, the following subsections describe the different scales of monitoring that may be used to quantify the effects of restoration.

WATERSHED-SCALE MONITORING

Status and trend monitoring is critical in understanding how restoration actions applied across a watershed or sub-basin affect water quality, hydrology, geomorphology, and biological parameters at a landscape scale (MacDonald et al. 1991). Status and trend monitoring is defined as an approach in which measurements are made at regular time intervals to determine the long-term trend of a parameter of interest (MacDonald et al. 1991). This type of monitoring is typically not suitable for evaluating effectiveness of single restoration projects, unless projects are very large in scale and scope (Schiff et al. 2011). However, status and trend monitoring is a key aspect of adaptive management, informing whether large scale implementation of specific actions is affecting parameters of interest (MacDonald et al. 1991).

In the UKB, The Klamath Tribes and USGS have been instrumental in implementing long-term status and trend monitoring, specifically examining discharge, riverine sediment and nutrient load, and water quality dynamics (including algal dynamics) in UKL. The Klamath Tribes' Aquatics Program has been collecting discrete samples in UKL (10 sites; 10 parameters) from 1990 to 2019 and UKL tributaries (12 sites; 10 parameters) since 2001. USGS is currently sampling UKL using the same methods at The Klamath Tribes used from 1990 to 2019. Additionally, USGS has been collecting continuous sonde data in UKL since 2007, continuous discharge at various tributary sites since 1987, and continuous turbidity data (used as a proxy for suspended sediment concentrations and phosphorus concentrations) in the Sprague River near Chiloquin and Williamson River below Sprague River since 2008. Overall temporal and spatial trends in discharge and water quality parameters have been summarized in Walker et al. (2012) and Kann et al. (2015).

Additionally, USGS began long-term monitoring of UKL adult and juvenile Lost River and Shortnose sucker populations in 1995 and 2015, respectively, to assess sucker production, survival, growth, and recruitment.

PROJECT-SCALE MONITORING

The UKBWAP highlights three types of project-scale monitoring:

1. Pre-implementation baseline monitoring
2. Implementation monitoring
3. Post-implementation effectiveness monitoring

Pre-implementation baseline monitoring is necessary to quantify and understand baseline conditions at the project site prior to project implementation. Pre-implementation baseline monitoring should include parameters related to project objectives with an emphasis on project effects that are expected to be direct and localized and can be quantitatively measured. This type of monitoring is an essential component of project-scale monitoring because it facilitates evaluation of project effectiveness after implementation through comparison of "before and after" conditions. Pre-implementation baseline monitoring should also include a control site that will also be monitored as part of the post-implementation effectiveness assessment. Including "before and after" data and data from a control site allows restoration professionals to assess the effectiveness of restoration projects even when inter-annual variations in weather and other conditions that may affect restoration work exist. This type of study design is termed "before-after-control-impact" or "BACI."

Implementation monitoring determines if a project was implemented as designed and expected. This type of monitoring is strongly recommended given that local and watershed-scale responses to restoration efforts are relative to whether or not the project was implemented as expected. In other words, this type of monitoring is necessary to ensure that any project effects anticipated to be observed based on the original project design can actually be realized. If implementation monitoring indicates a project was not implemented as desired, this type of monitoring also provides an opportunity to correct or adjust the project.

Post-implementation effectiveness monitoring is necessary to determine if there are changes in conditions after project implementation and is therefore critical for determining if the project, as implemented, is achieving the expected objectives and resulting in the expected effects. Post-implementation effectiveness monitoring should measure the same parameters (using the same methods) as for pre-implementation monitoring to ensure that comparisons between the “pre” and “post” conditions are valid. Similarly, a post-implementation effectiveness monitoring program should include a control site, as mentioned above.

Finally, while the Monitoring Framework is primarily intended for use in future restoration efforts to allow for monitoring planning to begin before project implementation, the monitoring portion of the Monitoring Framework can also inform monitoring regimes for projects already implemented. For instance, if the objective of a past project was to restore channel-floodplain connection, but cross-sections measured after implementation do not indicate this connection has been achieved, then there is an opportunity, even without pre-implementation baseline data, to adjust project design or implement additional projects to address the impairment.

RESTORATION PROJECT TRACKING

In addition to watershed and project-scale monitoring, tracking restoration project implementation is also critical in applying adaptive management to watershed-scale restoration programs. Specifically, it is important to understand the type and location of restoration projects implemented in the past to avoid duplicative efforts and to understand where certain actions have or have not been effective in the past.

There are two efforts in the UKB to track restoration projects. First, the Oregon Watershed Enhancement Board (OWEB) maintains the Oregon Watershed Restoration Inventory (OWRI) through OWRI Online (OWRIO). The OWRI includes both mandatory and voluntary project reporting. Reporting is mandatory for restoration grants administered by OWEB (Open Solicitation and Small Grants), ODEQ 319 grants, and some ODFW Restoration and Enhancement program grants. OWRI also encourages voluntary reporting of projects. More information for OWRIO can be found at the following link: https://apps.wrd.state.or.us/apps/oweb/owrio/default.aspx. The UKBWAP Team encourages all restoration practitioners in the UKB to include their projects in the OWRI.

In addition to the OWRI, the Klamath Tracking and Accounting Program (KTAP) framework was developed to track restoration work in the Upper Klamath Basin. KTAP was archived because of lack of stakeholder interest, but the initial goal was to quantify the collective benefit of restoration and land management projects for water quality and habitat for native fish in the Klamath Basin. KTAP developed the Stewardship Project Reporting Protocol as a voluntary system to track restoration and conservation projects and help practitioners make informed decisions for future restoration and conservation projects. Because the framework and protocols have been collaboratively developed by stakeholders, KTAP could be a useful tool in the future.

Further information can be found at the following link: http://www.kbmp.net/stewardship/about-ktap-and-faqs.

WORKFLOW

The UKBWAP envisions the following workflow for the Monitoring Framework:

1. The restoration professional can identify an appropriate restoration action based either on those identified in the conceptual models (Chapter 3) and the Restoration Guide (Appendix A), or through previous efforts (such as identifying a single restoration project type and pursuing funding to implement this type of project throughout the watershed; see Workflow subsection in Chapter 4 for specific discussion).

2. The restoration professional can then review the list of quantifiable effects associated with the restoration project type of interest, focusing first on the direct and local effects. These quantifiable effects correspond to quantifiable project objectives, thereby allowing the user to select specific project objectives that can be evaluated through monitoring.

3. Once the restoration professional has identified specific project objectives, they can determine the appropriate monitoring method and review associated documents for further information about monitoring implementation.

4. After monitoring methods are selected, the restoration professional would ideally begin pre-implementation monitoring to quantify the baseline condition (preferably at both project and control sites) prior to project implementation. Additional sampling is necessary (preferably at both project and control sites; using the same methods to measure the same parameters as for pre-implementation monitoring) after project implementation to quantify the effects of the project.

As discussed above, the Monitoring Framework is not intended to replace expert judgement and local expert opinion. The Monitoring Framework is a guideline for restoration and monitoring and there is an expectation that restoration professionals will assess conditions at potential project sites to validate (and revise, when appropriate) UKBWAP recommendations.

MONITORING FUNDING

Although the need for monitoring to assess the effectiveness of restoration actions and better understand if collective restoration action has achieved watershed restoration goals is clear, it is often difficult to secure sufficient funding for such monitoring activities. Developing monitoring regimes that quantify restoration project objectives not only advances the restoration community's knowledge and expertise, such that project types or design are adapted to better achieve the objectives of current and future objectives, but also serves to protect the investments restoration funders make. Indeed, in the Columbia River Basin alone, the federal government spends approximately $400 million annually, but there is little information available with which to assess whether or not these investments have yielded positive ecological outcomes (as summarized in Katz et al. 2007). Additionally, empirical data is also necessary to assess the effectiveness of new or novel restoration techniques to determine if they can be applied broadly, safely, and effectively to achieve restoration objectives.

To assist in obtaining funding for restoration project monitoring (at any scale), the UKBWAP Team suggests including the following information in project implementation funding requests:

- How the proposed monitoring can protect the funders investment in the project
- How the monitoring can and will be used to adapt project design or implementation both for the current project and future projects that rely on the same or similar techniques
- How the monitoring can determine whether or not project objectives have been met
- Why obtaining both pre and post-implementation data, and including a control site, is critical in assessing whether or not project objectives have been met

CHAPTER 7: DATA GAPS AND NEXT STEPS

DATA GAPS

The development of the IRPT identified several key data and knowledge gaps essential for making well-informed prioritization of restoration activities at the UKB-scale.

Condition metrics

The UKBWAP Team plans to investigate methods to prioritize stream reaches for wetland restoration and UKL shoreline segments for springs restoration and work to mitigate fish entrainment.

The UKBWAP Team identified more general future data and/or study needs to enhance and expand the IRPT:

- Channel bathymetry
- Flood control infrastructure (to evaluate constraints of any proposed channel realignment)
- Detailed, field-verified irrigation infrastructure data
- Hydrodynamic model output (e.g., to better gage the amount of floodplain made accessible by levee removal)
- Status of fish passage barriers currently characterized as “unknown status”
- Impact of passage barriers on specific fish life stages
- Impact of passage barriers during specific seasonal flow conditions
- Fish screen status in areas labelled currently “unknown status”
- Stream velocity and depth information
- Fish habitat mapping
- More spatially resolved grazing and farming data and management practices
- Vegetation maps with species, wetland indicator status, soil stabilizer properties, diversity, and age
- Updated LiDAR covering the geographic scope of the UKBWAP
- A comprehensive restoration project tracking system/database
- Identifying sources of sediment in suspended sediment loads, and phosphorus fractions in sediment loads

As higher resolution imagery becomes available, some of the data needs outlined above may be met through remote sensing coupled with machine learning techniques.

Riparian and Aquatic Habitat

Additional information about habitat location and quality was a key data need identified during this project. Data on existing habitat and habitat quality, miles of protected stream, and miles of managed riparian areas were all discussed as important information for future efforts to improve the IRPT.

Hydrodynamic Model

A hydrodynamic model of the UKB is needed to examine different scenarios of changes to existing channel geometry and/or flood control infrastructure, evaluate the potential impacts of restoration actions, and plan and prioritize implementation. In particular, this data would facilitate refinement of the levees and berms, channelization, and irrigation practices metrics. Even with improved information about levee and berm features, without potential inundation extents, depths, and velocities that could be provided from such a model, it will be difficult to prioritize levee changes with the goal of restoring floodplain-channel connection. Similarly, evaluating and planning channel reconstruction restoration will be greatly advanced by access to hydrodynamic modeling outputs. Finally, the methods used to identify irrigation return point locations do not include information about the magnitude of discharge from such points. This information would be very helpful in refining prioritization of reaches for actions that address irrigation tailwater returns.

Cost

Although not critical for ecological prioritization of restoration activities, information regarding project cost is critical for restoration planning. Future cost estimates for project types should be confirmed by pilot projects that are currently on-going and should also include reflections on the efficacy of pilot projects and projected maintenance estimates. Relative to past projects, it would be valuable to future restoration activities to attribute data from USFWS, USDA Resource Advisory Committees, the Natural Resources Conservation Service, Bureau of Reclamation, OWEB, and the Bureau of Land Management with cost information, when possible.

NEXT STEPS

The UKBWAP is envisioned as a multi-phase project that, in this first phase, produced a draft IRPT. The UKBWAP uses an adaptive management framework such that as additional data become available, the IRPT can be enhanced with additional data and updated.

Specific next steps include:

- Updating the fish passage metric to include information in the 2019 ODFW fish passage barrier update and the 2020 ground-truthing project, and adding known barriers not currently included.
- Developing a wetlands metric for stream and river reaches.
- Developing springs and fish entrainment metrics for UKL shoreline segments;
- Investigating metrics for upland areas.
- Exploring options to prioritize reaches or systems for instream water rights transfers.
- Developing the Stakeholder Outreach and Engagement Plan (Appendix C) and completing the associated activities identified therein (and summarized in Chapter 1).
- Continuing to assess new information and data, and revising the UKBWAP accordingly.
- Exploring the feasibility of and support for adding the Lost River sub-basin to the UKBWAP.

- Continuing to engage with the restoration community, local landowners, technical experts, and other interested parties to ensure that the UKBWAP meets the needs of the community and remains a technically-sound document.
- Continuing to investigate methods to incentivize voluntary restoration, particularly that on private lands.

In the interim period, interested parties are encouraged to contact any of the UKBWAP Team members to provide input and recommendations for future iterations of the UKBWAP. Additionally, the UKBWAP Team welcomes the participation by other interested parties for development of future phases of the UKBWAP.

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FEEDBACK AND QUESTIONS

As outlined above, the UKBWAP Team plans to update the UKBWAP at least annually and any time new information becomes available. To provide feedback or obtain additional information about the UKBWAP, please contact Megan Skinner at megan_skinner@fws.gov.

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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

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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.

Riparian Grazing or Exclusion?

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

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

Riparian Pastures

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

Grazing Timing and Intensity

A period of grazing rest (i.e., livestock exclusion) prior to implementation of managed riparian grazing may be necessary in areas with a history of heavy unmanaged grazing, or grazing management that was inconsistent with riparian restoration objectives (Clary and Webster 1990, Myers and Swanson 1995, Kidd and Yeakley 2015, Swanson et al. 2015). Clary and Webster (1990) recommend a period of rest for areas with early seral vegetation and suggest that the rest period should continue until mid to late seral vegetation is observed[‡]. 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.

Additional Considerations for Grazing Management

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

Finally, applying the principle of adaptive management is necessary for any riparian grazing management program. Specifically, monitoring of vegetation utilization, plant community characteristics, bank condition, amount of bare ground present, and possibly more complex assessments such as Proper Functioning Condition should be included as part of grazing plans to ensure that restoration objectives are being met. For specific information regarding monitoring methods, see Appendix B in The Watershed Action Plan Team (*in prep.*).

Riparian Planting

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

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

Additional Considerations for Riparian Restoration

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

Conclusion

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

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

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

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

A period of passive restoration (e.g., grazing management) is generally recommended prior to engaging in more active forms, such as a planting program. This approach is advantageous for numerous reasons, including that it allows the project site to indicate to the restoration professional what types of vegetation may be best suited for conditions at the site, where certain types of vegetation are more likely to establish and survive, where sufficient natural revegetation is occurring, and any indication of additional issues that should be addressed prior to planting. If riparian planting is necessary, determining physical site characteristics, and adjusting planting plans accordingly, will increase the likelihood of plant survival and establishment. Including some form of protection from rodent and wild or domestic ungulate damage in the planting plan is also advised.

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

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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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Introduction

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

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

Beaver dam analog overview

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

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

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

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

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

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

Effects of BDAs on abiotic and biotic riverine and riparian components

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

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

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

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

In the UKB, groundwater-dominated streams (e.g., Wood River, Williamson River above the confluence with the Sprague River) tend to have lower sediment loads (Walker et al. 2012) and less channel incision, suggesting that BDAs in these systems have less potential for sediment deposition, and thus channel aggradation (or facilitation of lateral migration) may be less of priority for these types of projects in those areas. Conversely, the Sprague River and tributaries (especially the Sycan River) and snowmelt run-off dominated streams on the west side of the UKB can convey substantial sediment loads (e.g., approximately 812,000 cubic meters [2.9 million cubic feet] per year for the Sycan River [calculated using total suspended solids data reported in Walker et al. 2015]), which could facilitate channel aggradation if BDAs were implemented in incised reaches in these systems. Furthermore, stream reaches in the UKB often lack complexity, and implementing BDAs can assist in restoring more dynamic geomorphic processes. Finally, due to the relatively high phosphorus content of UKB soils (ODEQ 2002, Walker et al. 2015), actions to increase deposition of sediment within the watershed (rather than continued conveyance of sediment loads into higher order rivers and Upper Klamath Lake) have the potential to reduce total phosphorus load to impaired waterbodies in the UKB. A 40 percent reduction in total phosphorus load is an explicit goal of the Upper Klamath Lake Drainage Total Maximum Daily Load document (ODEQ 2002), and BDAs and natural beaver dams could assist in achieving these goals through a reduction in particulate phosphorus associated with sediment loads.

Groundwater-surface water interactions and water temperature

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

Although BDAs can increase wetted channel widths substantially (Bouwes et al. 2016, Weber et al. 2017), which reduces the shading effect from riparian vegetation and thereby potentially increases the exposure of streams to solar radiation, numerous studies (Bouwes et al. 2016, Weber et al. 2017, Charnley 2018, Orr et al. 2019) reported reductions in stream temperature after installation of BDAs, or a combination of declines in temperature and no change in stream temperature, depending on study site. Specifically, Bouwes et al. (2016) determined that in Bridge Creek, maximum stream temperatures were on average 1.47°C cooler in reaches with BDAs and natural beaver dams, relative to those without. Additionally, sites with BDAs and natural beaver dams had substantially more cool-water refugia and stream temperatures were generally cooler during both the day and night, relative to reaches without BDAs and natural beaver dams (Bouwes et al. 2016). Similarly, Weber et al. (2017) found that Bridge Creek beaver dam density (whether BDAs or natural beaver dams) was negatively correlated with summer maximum stream temperature. These studies attributed the above described changes in water temperature to increased groundwater-surface water interactions associated with BDAs and natural beaver dams. Interestingly, it also appeared that the presence of BDAs and natural beaver dams was associated with average reductions in summertime diel temperature fluctuations of 2.6°C (meaning that maximum temperature decreased and minimum temperature increased), which the authors attributed to the buffering effect of increased water volume associated with ponds behind BDAs and beaver dams (Weber et al. 2017). Finally, Pollock et al. (2007) observed pockets of cool water averaging 4.1°C below ambient stream temperatures downstream of BDAs and beaver dams in Bridge Creek in late summer. These effects on temperature combined with the increase in groundwater upwelling within beaver dam complexes led Bouwes et al. (2016) and Weber et al. (2017) to conclude that BDAs and natural beaver dams resulted in increased coldwater fish habitat in Bridge Creek. This was further supported by increases in salmonid density and production in Bridge Creek (Bouwes et al. 2016) as described in detail below.

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

Dissolved nutrients

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

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

Dissolved phosphorus is removed from the water column of wetlands, shallow lakes, and ponds via sorption to metal hydroxides-oxides; uptake by aquatic plants, algae, and macrophytes; and accretion in the sediments as a result of incomplete decomposition and subsequent burial of plant biomass (Kadlec 1997). Sorption is often a temporary mechanism (e.g., hours to weeks) for phosphorus sequestration, with fluctuations between sorption and desorption occurring frequently when oxic sediment conditions are not consistently maintained (Mortimer 1941). Biomass uptake can effectively sequester phosphorus during the growing season, but phosphorus is often released during senescence in the fall (Walbridge and Struthers 1993, Mayer et al. 1999). And finally, accretion typically results in long-term sequestration of phosphorus assuming that the conditions under which plant tissues are only partially decomposed (e.g., anoxic sediment conditions and relatively low pH, as observed in peat wetlands) are maintained (Kadlec 1997, Graham et al. 2005, Juston et al. 2013). See Skinner (2016) for a detailed technical discussion regarding the specific mechanisms associated with these processes.

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

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

Riparian vegetation

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

Although there is both empirical and theoretical evidence that BDAs and natural beaver dams improve riparian condition, it is worth considering riparian planting in addition to BDA implementation and other beaver-related restoration actions. Specifically, when beaver recolonization is a specific project objective and riparian vegetation is sparse or in poor condition, it may take several years for recovery to the point that sufficient riparian vegetation is available as a food source to encourage wild beaver recolonization (Orr et al. 2019); as such it may be necessary to implement riparian planting. Conversely, BDAs and natural beaver dams have the potential to dramatically change channel morphology and floodplain topography (as described above and below; could result in riparian planting losses), and it may therefore be advisable to delay any planned planting activities until channel and floodplain changes begin to materialize. The cost-benefit ratio of actively planting versus allowing volitional colonization should be assessed for each project site.

Fish

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

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

In addition to physical habitat, another important consideration associated with BDAs and natural beaver dams is fish passage. There are numerous studies (Lokteff et al. 2013, Bouwes et al. 2016, Pollock et al. 2019) supporting the idea that BDAs and natural beaver dams do not block fish passage, particularly for salmonids and trout. Lokteff et al. (2013) concluded that natural beaver dams were not passage barriers to native and invasive trout and that trout used the diversity of flow paths (over, through, under, and around) associated with natural beaver dams to pass both up and downstream of the structures. Similarly, Pollock et al. (2019) found that both Coho and steelhead juveniles had little difficulty passing BDAs in a tributary of the Scott River; passage was possible by jumping over a 40 centimeter (15.7 inch) waterfall or swimming up a short side channel (which in some cases were specifically constructed to facilitate fish passage, but that certainly occur naturally, as discussed throughout this review) with an 8 to 11 percent gradient. Charnley (2018) also noted that juvenile salmonids traveling upstream in tributaries of the Scott River were more likely to pass around, rather than jumping over, BDAs and Pollock et al. (2018) further supported this observation by suggesting that in most studies, it appears fish rarely pass BDAs and beaver dams by jumping over the face of the dam. Bouwes et al. (2016) observed that BDAs and natural beaver dams did not hinder juvenile or adult salmonid passage even noting that several sexually mature adult steelhead passed over two hundred BDAs and natural beaver dams en route to spawning grounds. Finally, Kemp et al. (2012) noted that 78 percent of studies reviewed that cite BDAs and natural beaver dams as negatively impacting fish passage did not support this claim with data, but relied on speculation instead (Kemp et al. 2012). Of the remaining 22 percent of studies reviewed indicating negative effects of BDAs and natural beaver dams on fish passage, several determined that passage issues were often associated with low flows (e.g., Mitchell and Cunjak 2007) or below-average flows (e.g., Taylor et al. 2010). Kemp et al. (2012) concluded that fish passage limitations were very difficult to predict in both time and space, indicating further research and monitoring is necessary to determine when, where, and if BDAs and natural beaver dams limit fish passage. Regardless, experts surveyed by Kemp et al. (2012) indicated that BDAs and natural beaver dams were overwhelmingly beneficial to fish populations through increases in production and community diversity (as highlighted by case studies cited above), even if and when passage was temporarily limited.

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

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

Oregon spotted frog

Oregon spotted frog (*Rana pretiosa*) is an amphibian that requires perennial wetland habitat, including areas of open water, for numerous life history stages (USFWS 2020). The Oregon spotted frog was listed as threatened under the Endangered Species Act in 2014 (USFWS 2014). Due to habitat loss, in many cases associated with beaver removal (USFWS 2014), it is estimated that this species has been extirpated from at least 78 percent of its historical range (USFWS 2020). Beaver removal from the historical range of the Oregon spotted frog was identified as one of six threats to the features critical for the conservation of this species, and beaver-related restoration and management is considered essential in ensuring that suitable wetland habitat exists for species survival and recovery, particularly within designated critical habitat in the UKB (USFWS 2013, 2016). Specifically, Pollock et al. (2018) notes that beaver pond characteristics such as cover associated with emergent vegetation and slightly warmer surface water in the spring months compared to upstream and downstream areas may provide preferred habitat for egg survival and embryo development. Pearl et al. (2018) also reported that areas with beaver activity were important wintering habitats for the species. Furthermore, Columbia spotted frog (*Rana 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.

Beavers

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

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

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

Other fauna

There is abundant evidence that BDAs and natural beaver dams create conditions beneficial to a variety of other animals including benthic macroinvertebrates (as discussed briefly in the "Fish" section above), reptiles, and birds. For a comprehensive review of studies reporting these benefits, see Pollock et al. (2018).

BDAs, natural beaver dams, and climate change

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

Considerations for design and implementation

Site selection

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

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

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

BDA complexes

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

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

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

BDA components

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

In terms of planform design, posts can be placed:

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

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

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

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

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

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

BDA lifespan

Natural beaver dams are typically temporary structures that are often abandoned as beavers relocate up- or downstream or build dams in different areas of the same reach (Pollock et al. 2018). As such, BDAs are meant to be ephemeral, rather than permanent, structures. Specifically, a two-year BDA lifespan from the point that beavers begin occupying the project site is thought to be sufficient to establish viable beaver colonies given beaver reproduction cycles and other life history timelines (Pollock et al. 2018). If beaver recolonization is not a specific project objective, shorter or longer lifespans can be considered based on site conditions and project objectives.

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

Cost

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

Construction sequence for individual BDAs

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

1. Pound posts, spaced 30 centimeters to 1 meter apart (11.8 inches to 3.3 feet), 50 centimeters to 1 meter (1.6 to 3.3 feet) deep within the channel substrate using a hydraulic post-pounder, and adjust height of posts to 30 centimeters (11.8 inches) above bankfull height or less, depending on site conditions and project objectives;
2. Weave willow whips or other branches in between posts to approximately bankfull height or less (depending on site conditions and project objectives) to create a porous dam;
3. Line the upstream base of the dam with cobble and other large material;
4. Add finer-grained material and vegetation to the upstream face of the dam until desired 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, continutous 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.

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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, 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
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, continutous 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

Under development

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. 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).
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. 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_flowlines"
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.

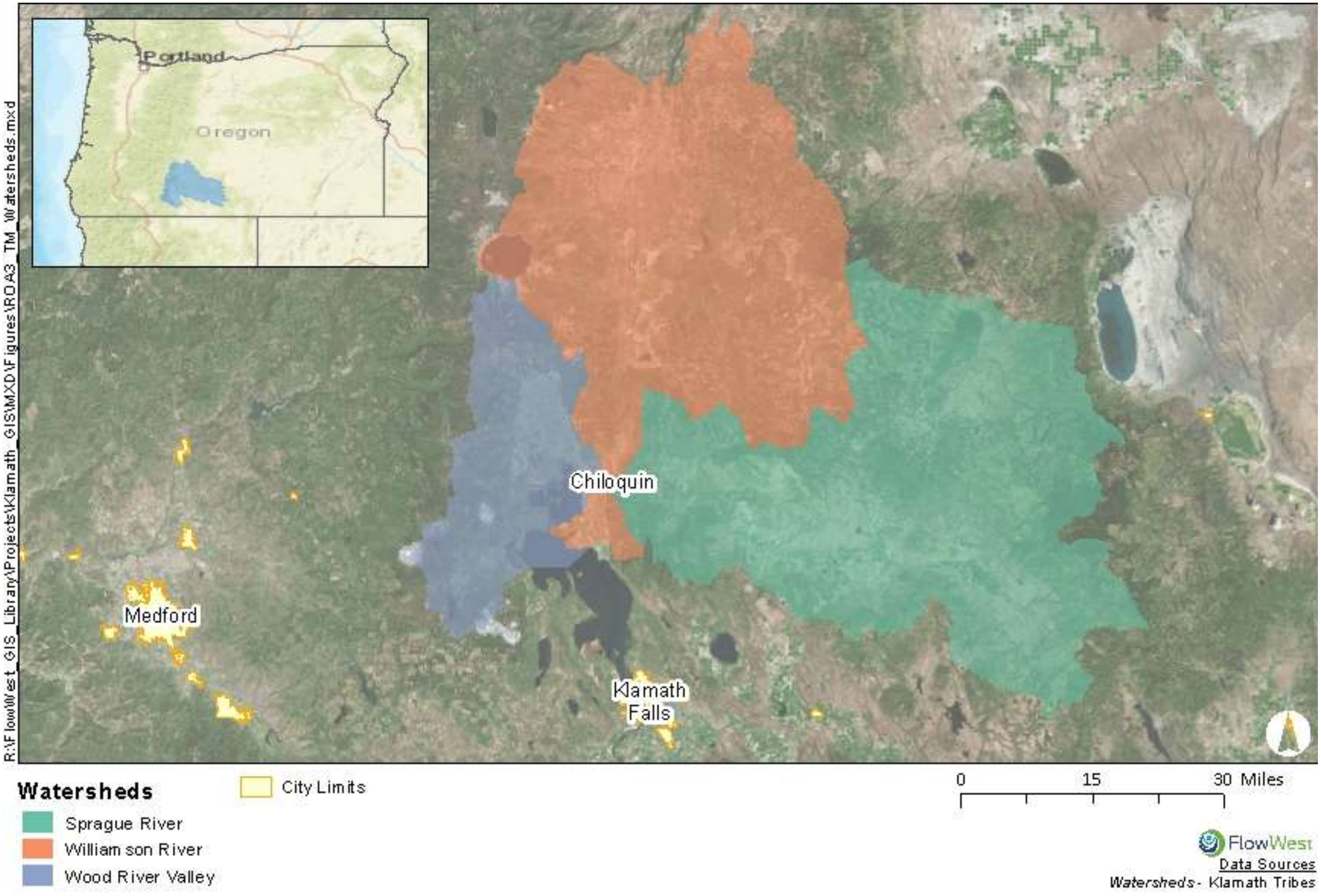

FIGURE 1: STUDY AREA WATERSHEDS.

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).

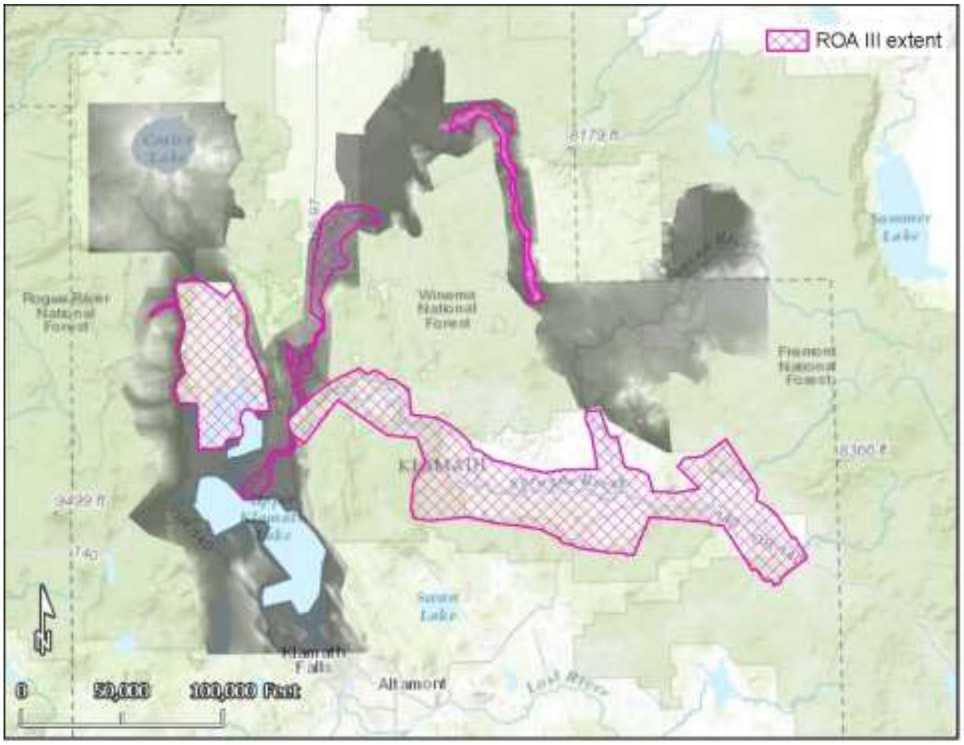

FIGURE 2: USGS 2010 DEM EXTENT.

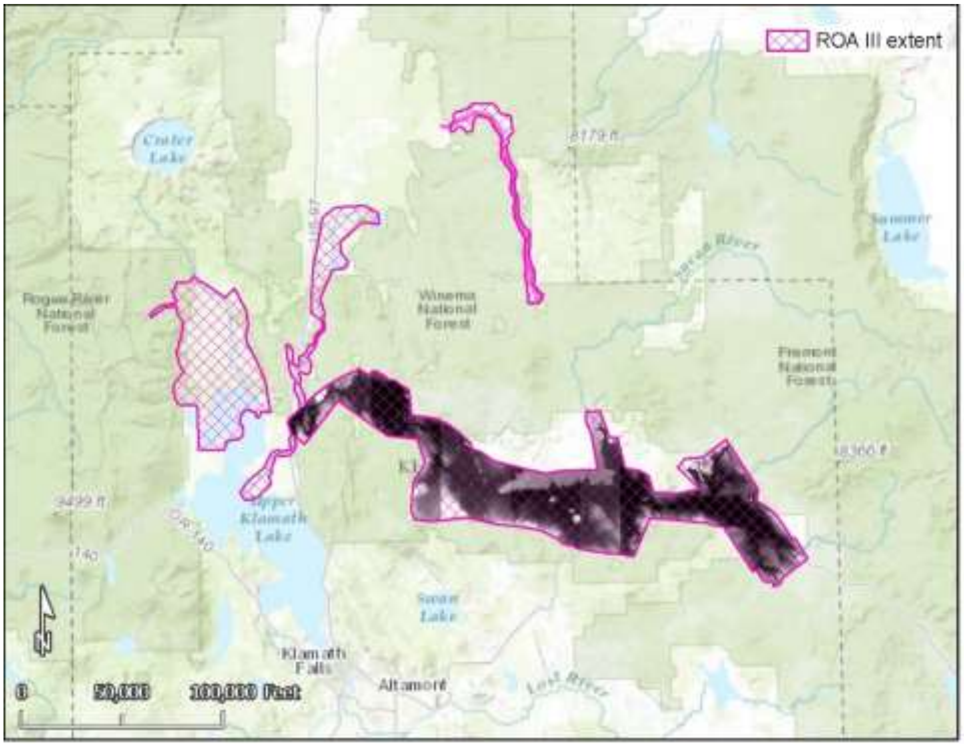

FIGURE 3: KLAMATH TRIBES 2004 SPRAGUE DEM EXTENT.

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

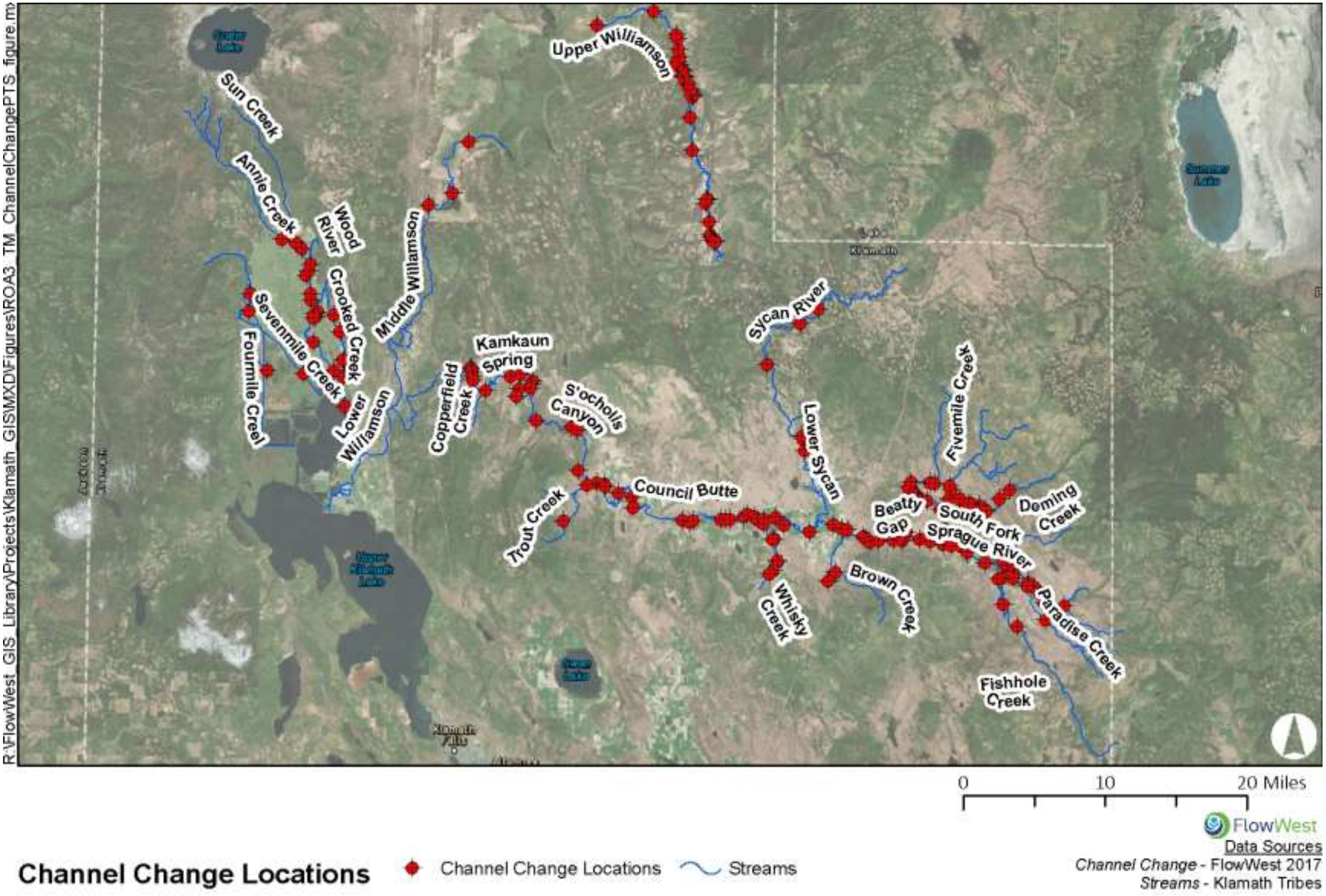

FIGURE 5: LOCATION OF CHANNEL CHANGE FEATURES.

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.

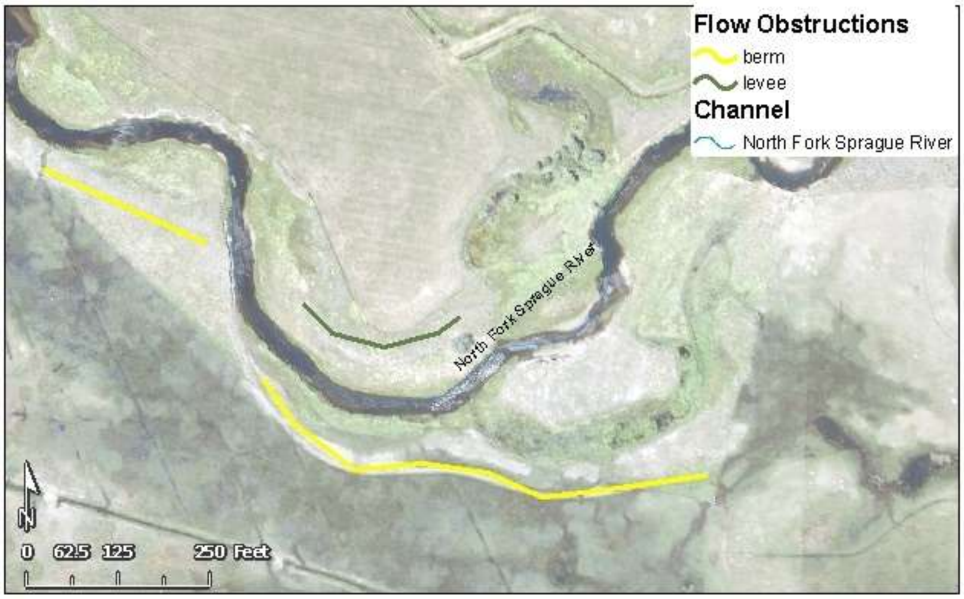

FIGURE 6: EXAMPLE OF BERM AND LEVEE FEATURES DELINEATED ALONG THE NORTH FORK SPRAGUE RIVER.

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.

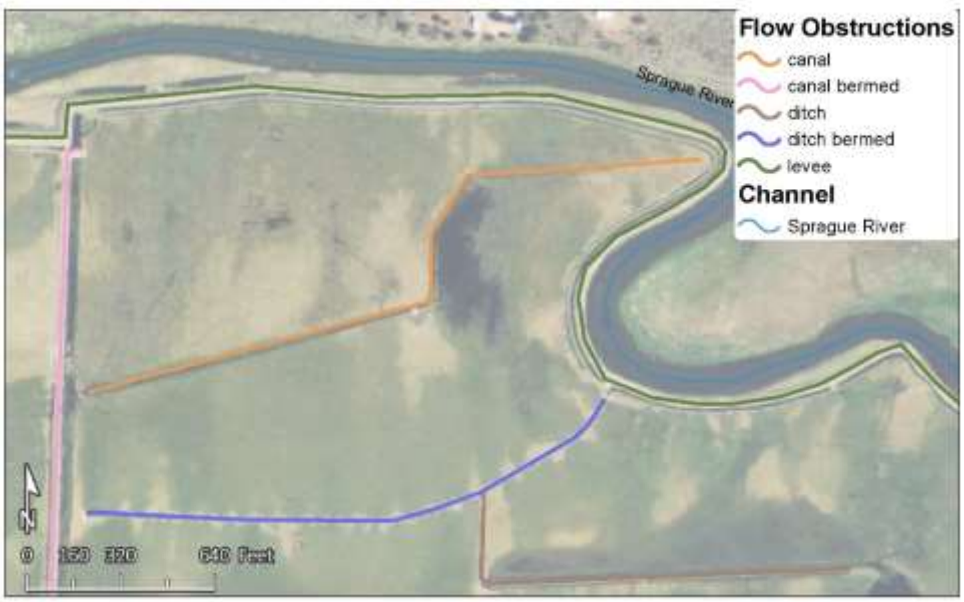

FIGURE 8: EXAMPLE OF CANAL, CANAL BERMED, DITCH, DITCH BERMED, AND LEVEE FEATURES DELINEATED ALONG THE SPRAGUE RIVER.

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.

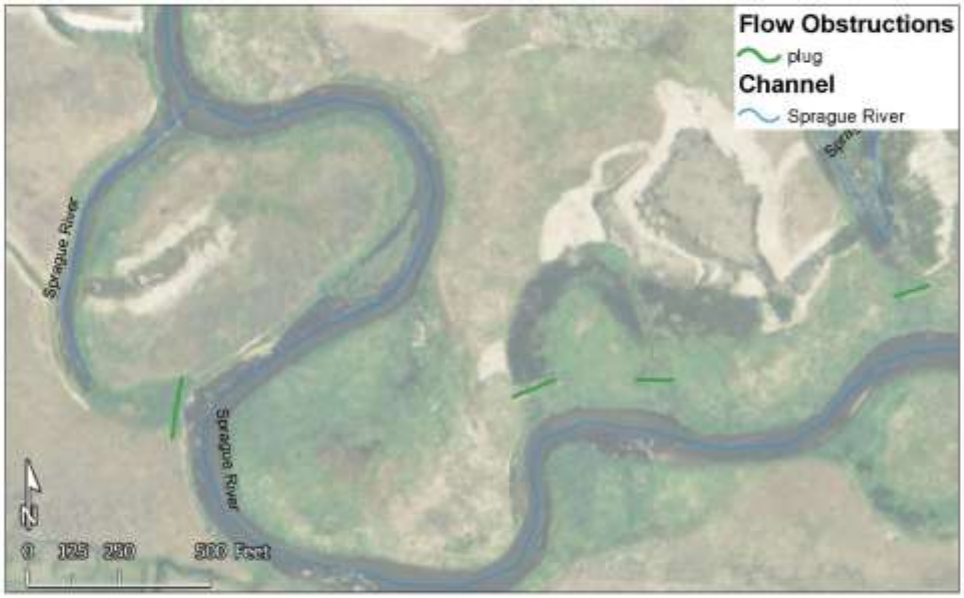

FIGURE 10: EXAMPLE OF PLUG FEATURES DELINEATED AT A RESTORATION SITE ALONG THE SPRAGUE RIVER.

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.

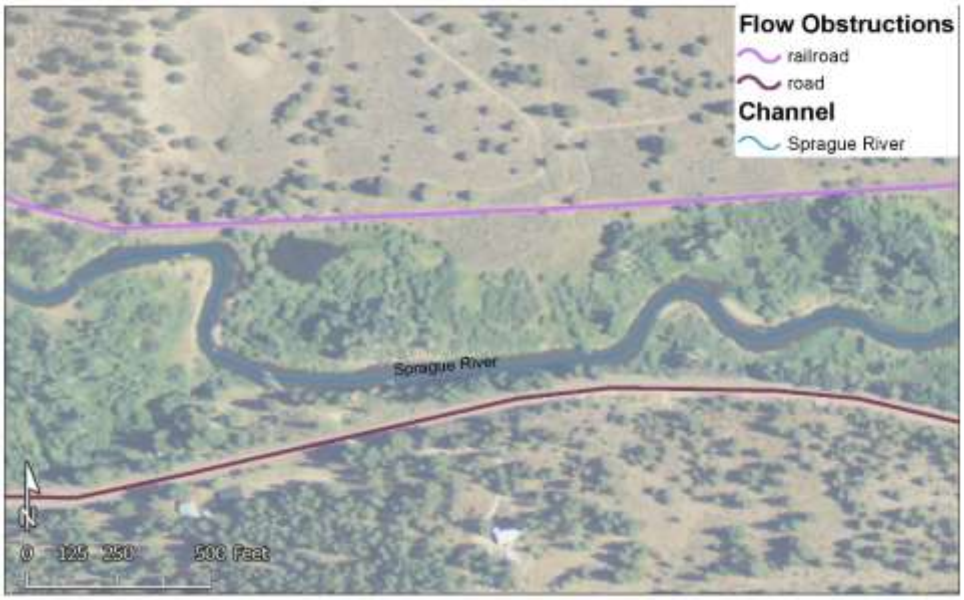

FIGURE 11: EXAMPLE OF RAILROAD AND ROAD FEATURES DELINEATED ALONG SPRAGUE RIVER.

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.

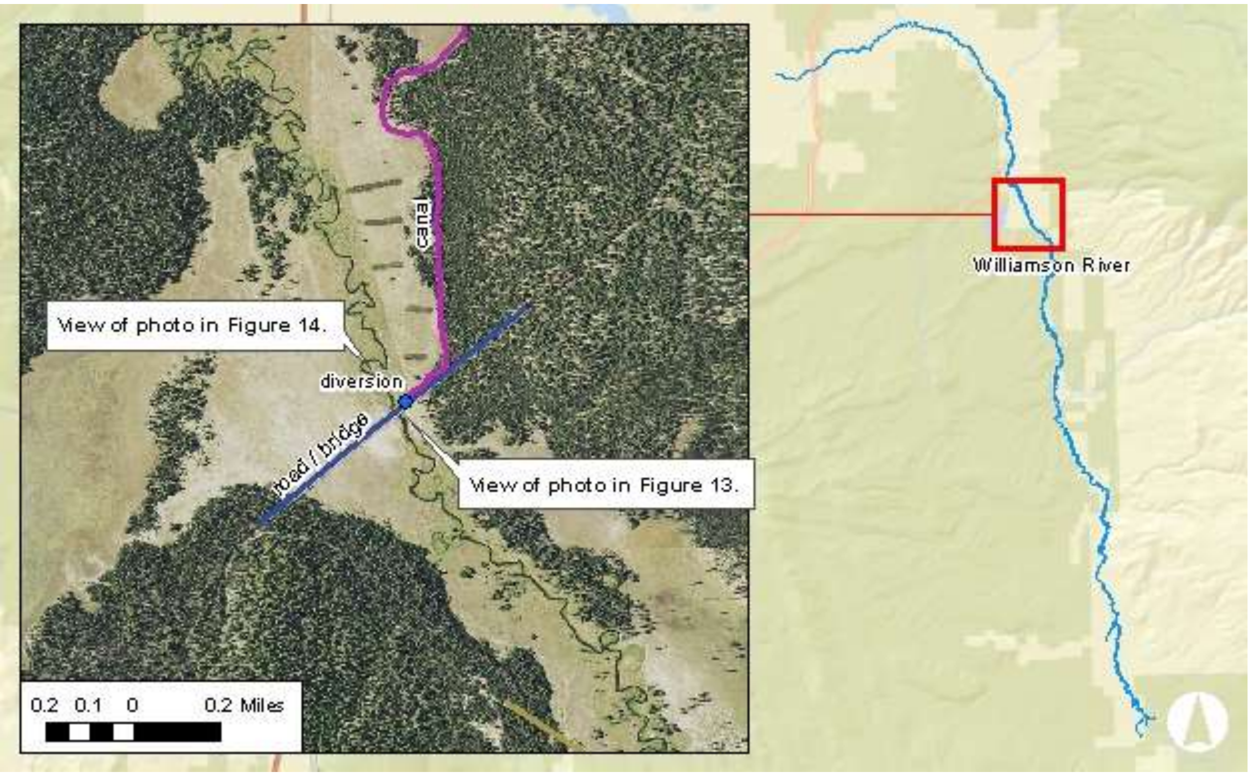

FIGURE 12: REFERENCE MAP FOR FIGURES 13 AND 14

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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.

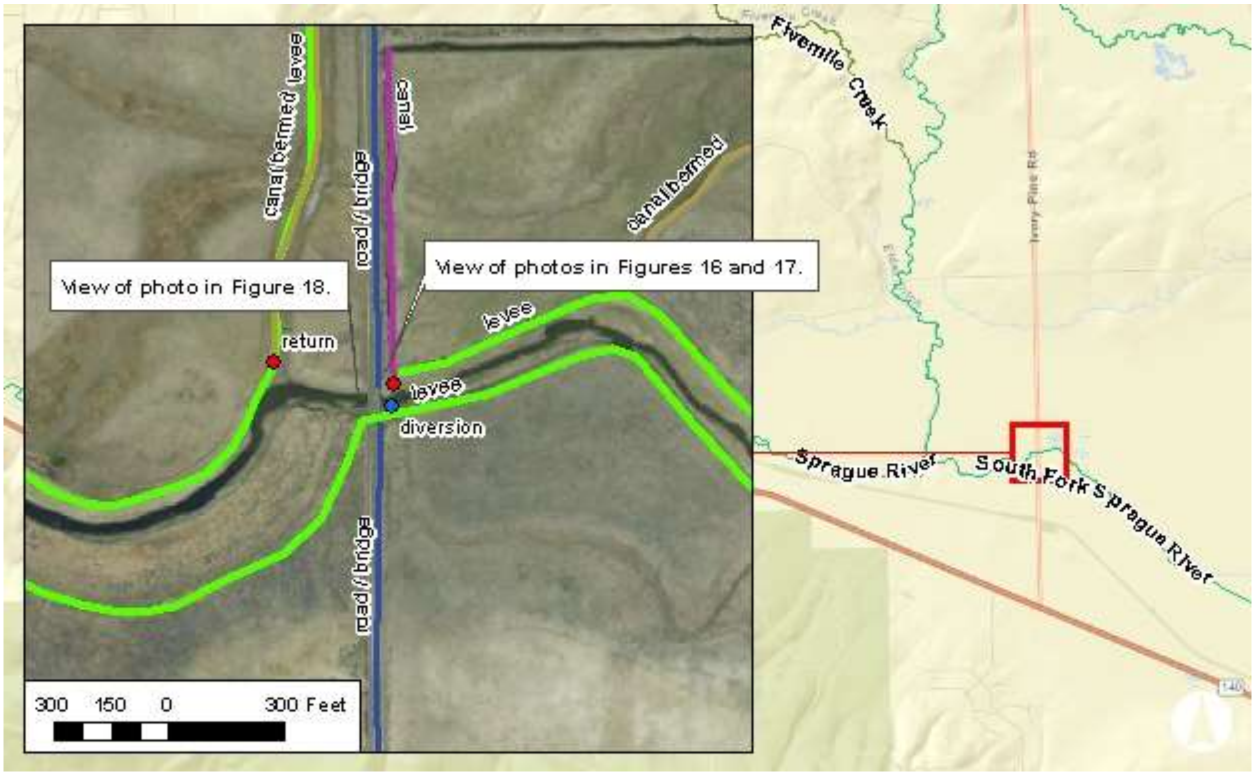

FIGURE 15: REFERENCE MAP FOR FIGURES 16, 17, AND 18.

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.

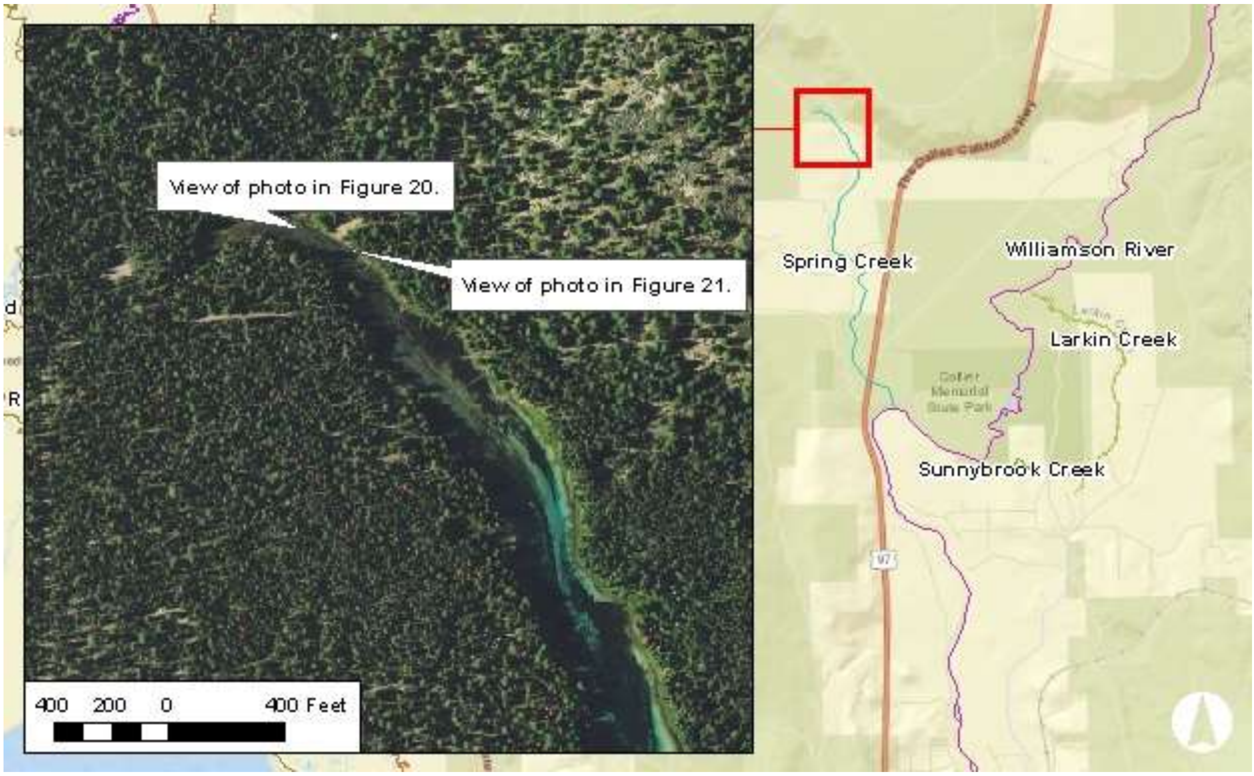

FIGURE 19: REFERENCE MAP FOR FIGURES 20 AND 21.

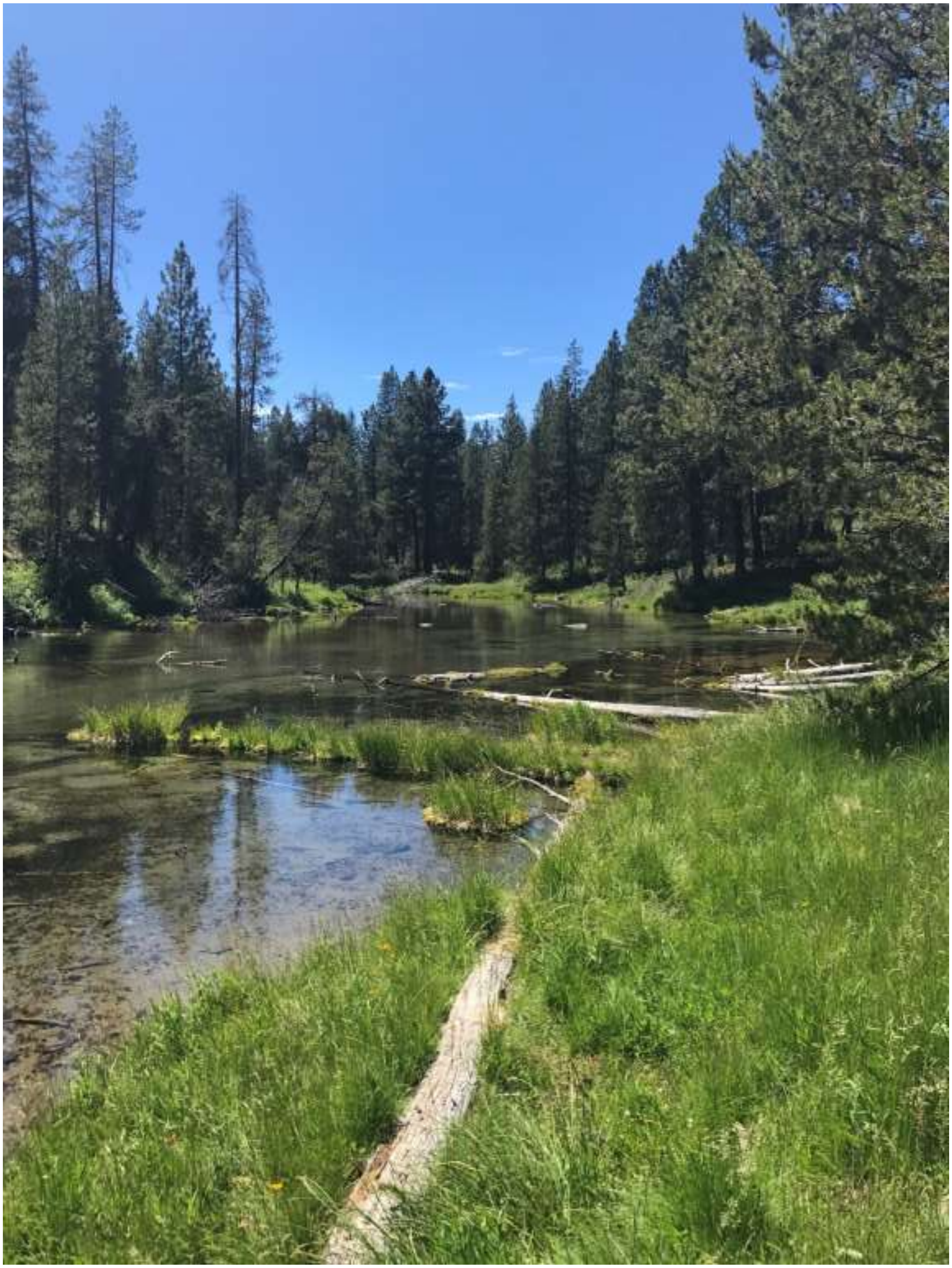

FIGURE 20: SPRING CREEK (LOOKING UPSTREAM) AT LOCATION WHERE A SMALL DIRT ROAD WAS MISIDENTIFIED AS A CANAL FROM ELEVATION DATA.

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

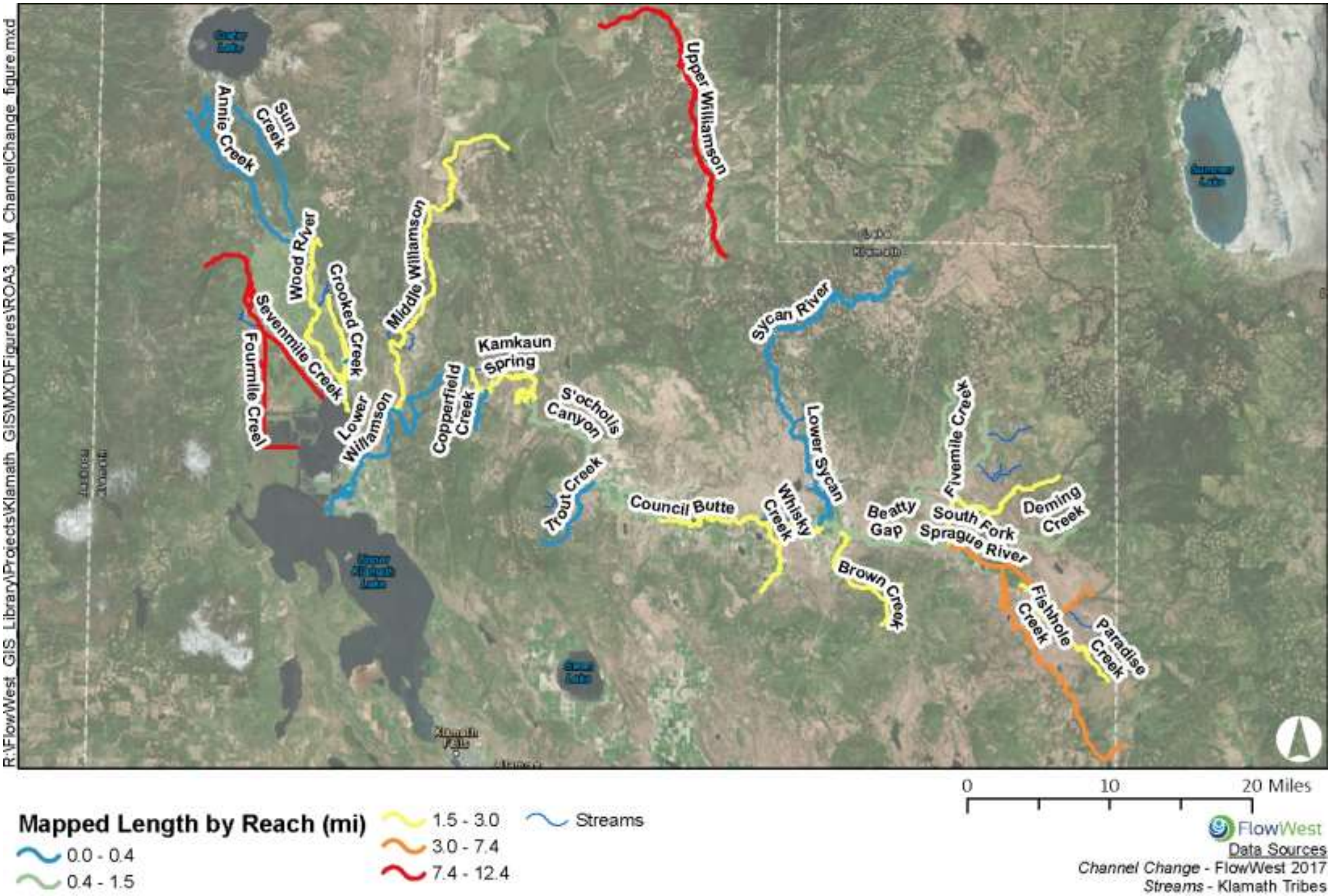

FIGURE 22: CUMMULATIVE LENGTH OF MAPPED CHANNEL CHANGE FEATURES PER REACH IN THE SPRAGUE, WILLIAMSON, AND WOOD RIVER VALLEY WATERSHEDS. THE "STREAMS" LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE CHANNEL CHANGE OR WERE NOT INCLUDED IN THE STUDY SCOPE.

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

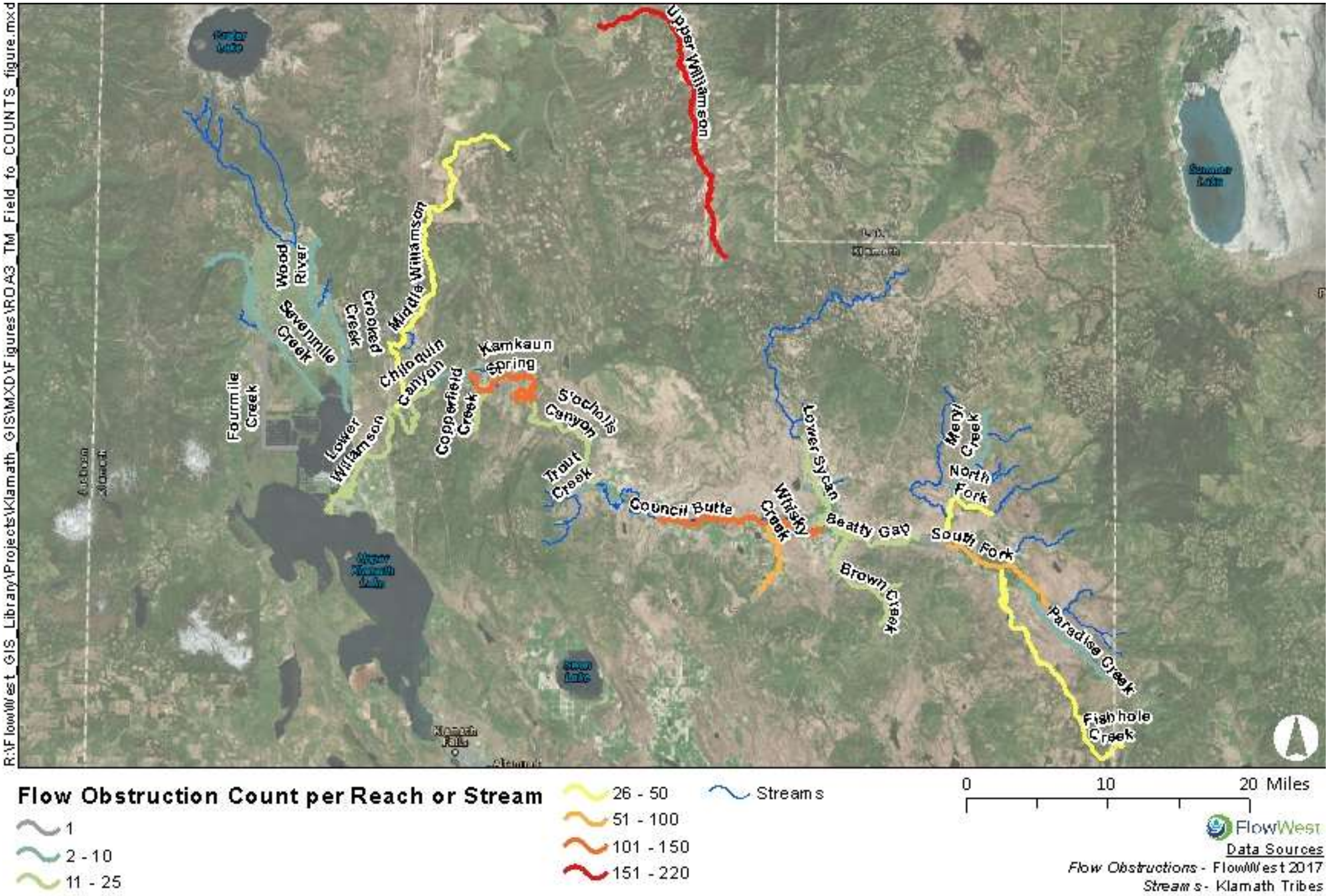

FIGURE 23: FLOW OBSTRUCTIONS PER REACH OR STREAM IN THE SPRAGUE AND WILLIAMSON RIVER WATERSHEDS. THE “STREAMS” LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE FLOW OBSTRUCTIONS OR WERE NOT INCLUDED IN THE STUDY SCOPE.

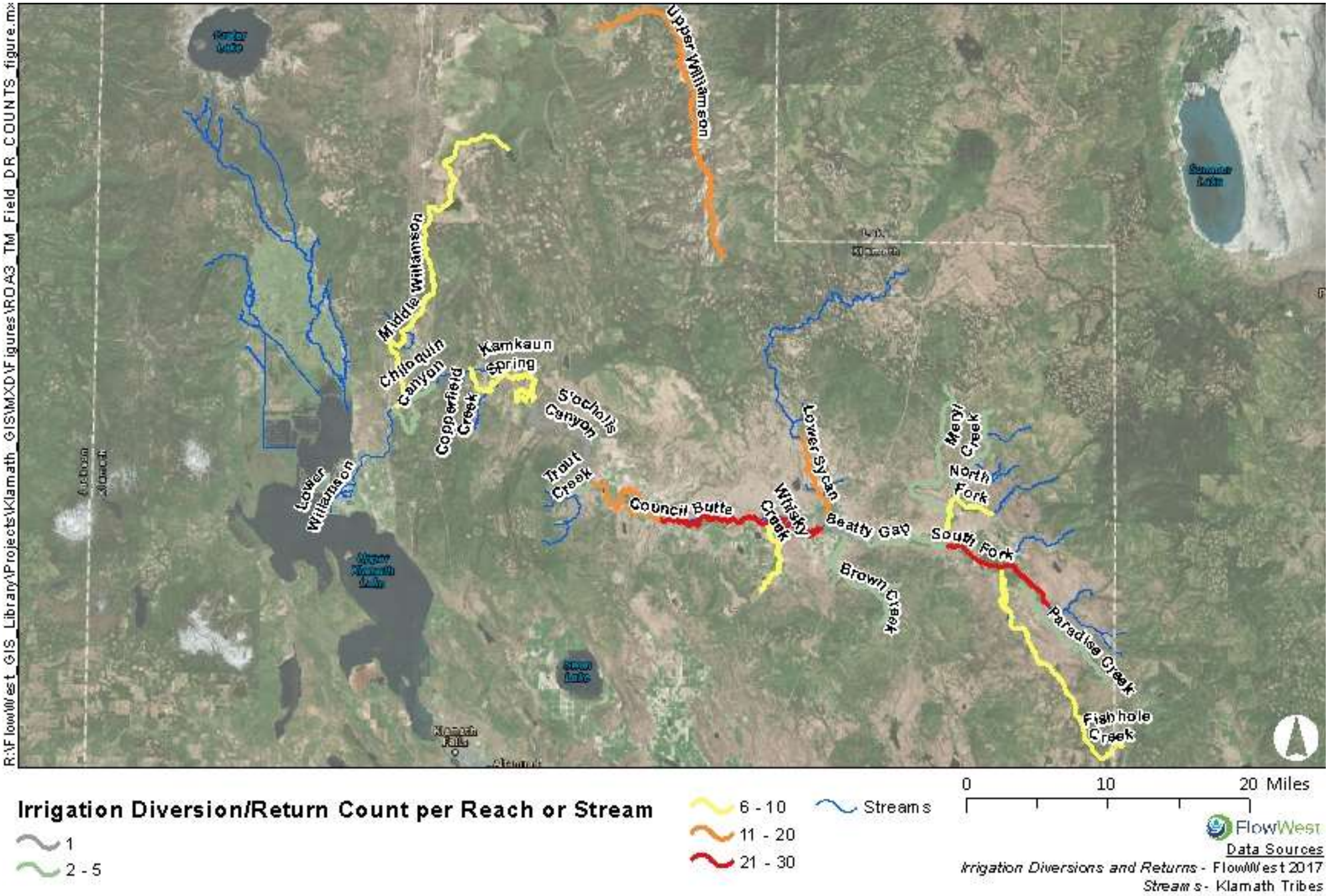

FIGURE 24: IRRIGATION DIVERSION AND RETURN POINTS PER REACH OR STREAM IN THE SPRAGUE AND WILLIAMSON RIVER WATERSHEDS. THE "STREAMS" LAYER DEPICTS WATER BODIES THAT EITHER HAD NO IDENTIFIABLE IRRIGATION DIVERSIONS OR RETURNS, OR WERE NOT INCLUDED IN THE STUDY SCOPE.

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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