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).

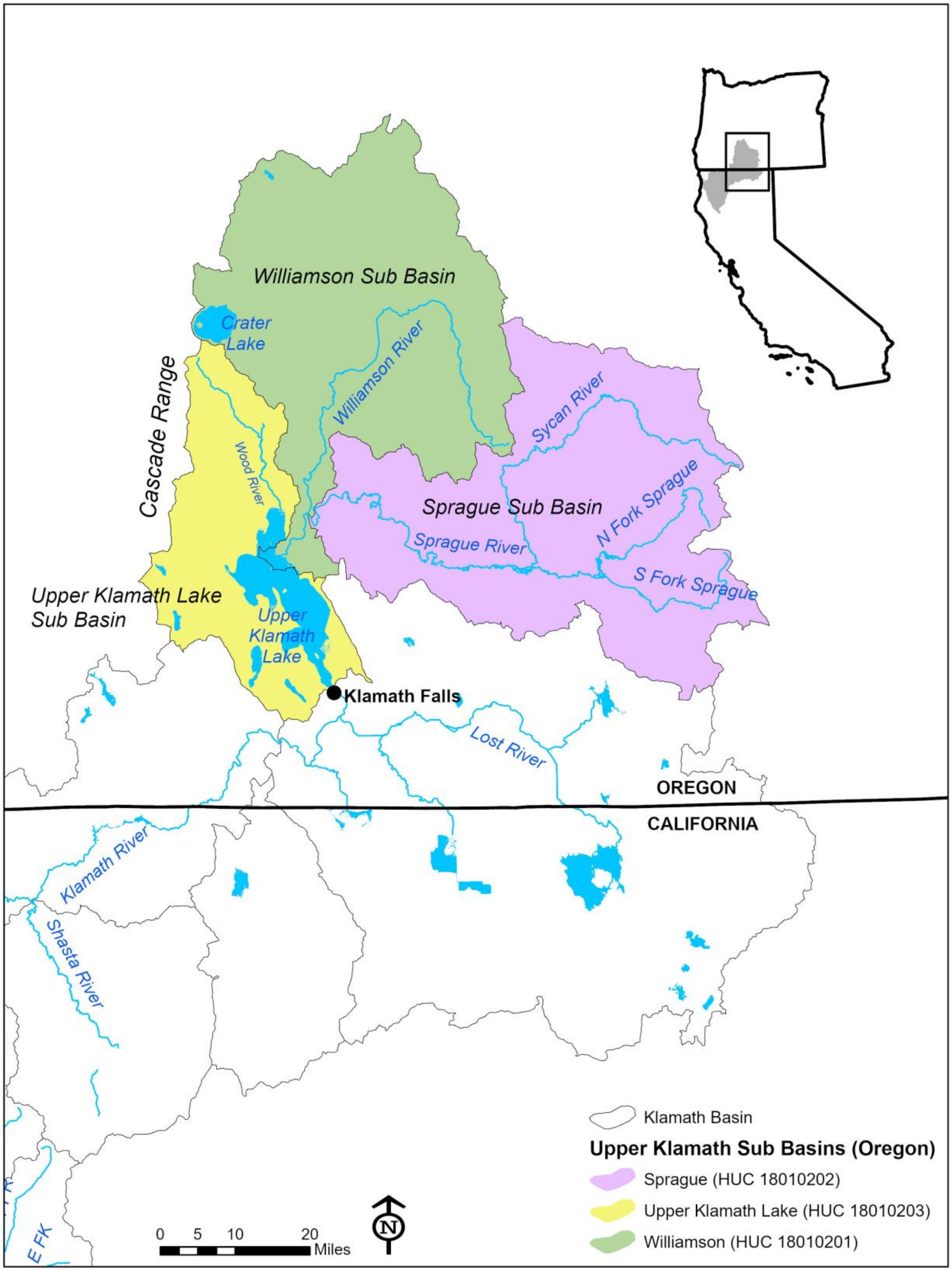

Figure 1. Geographic scope of Upper Klamath Basin, as defined in the Upper Klamath Basin Watershed Action Plan.

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).

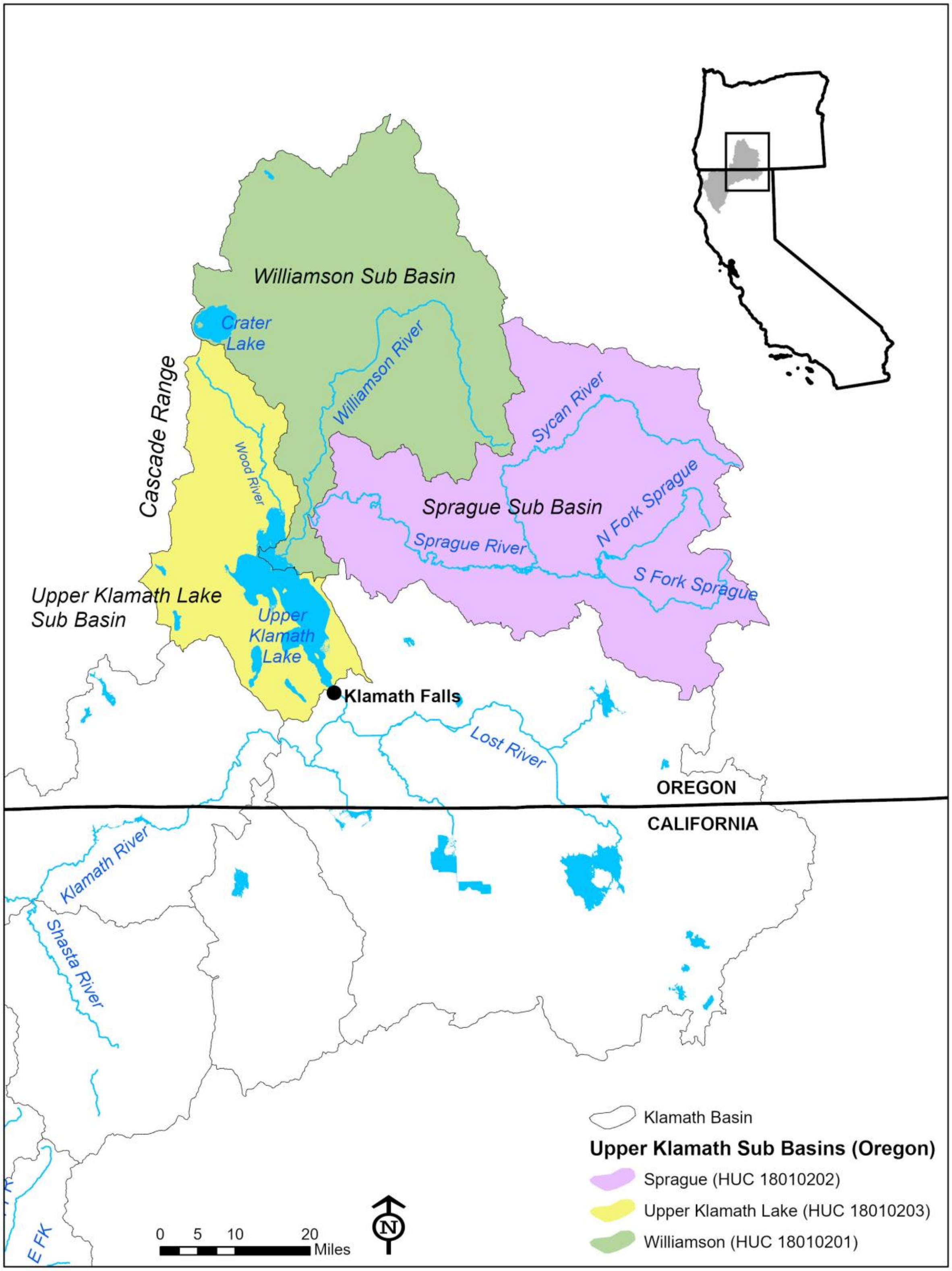

Figure 1. Geographic scope of Upper Klamath Basin, as defined in the Upper Klamath Basin Watershed Action Plan.

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).

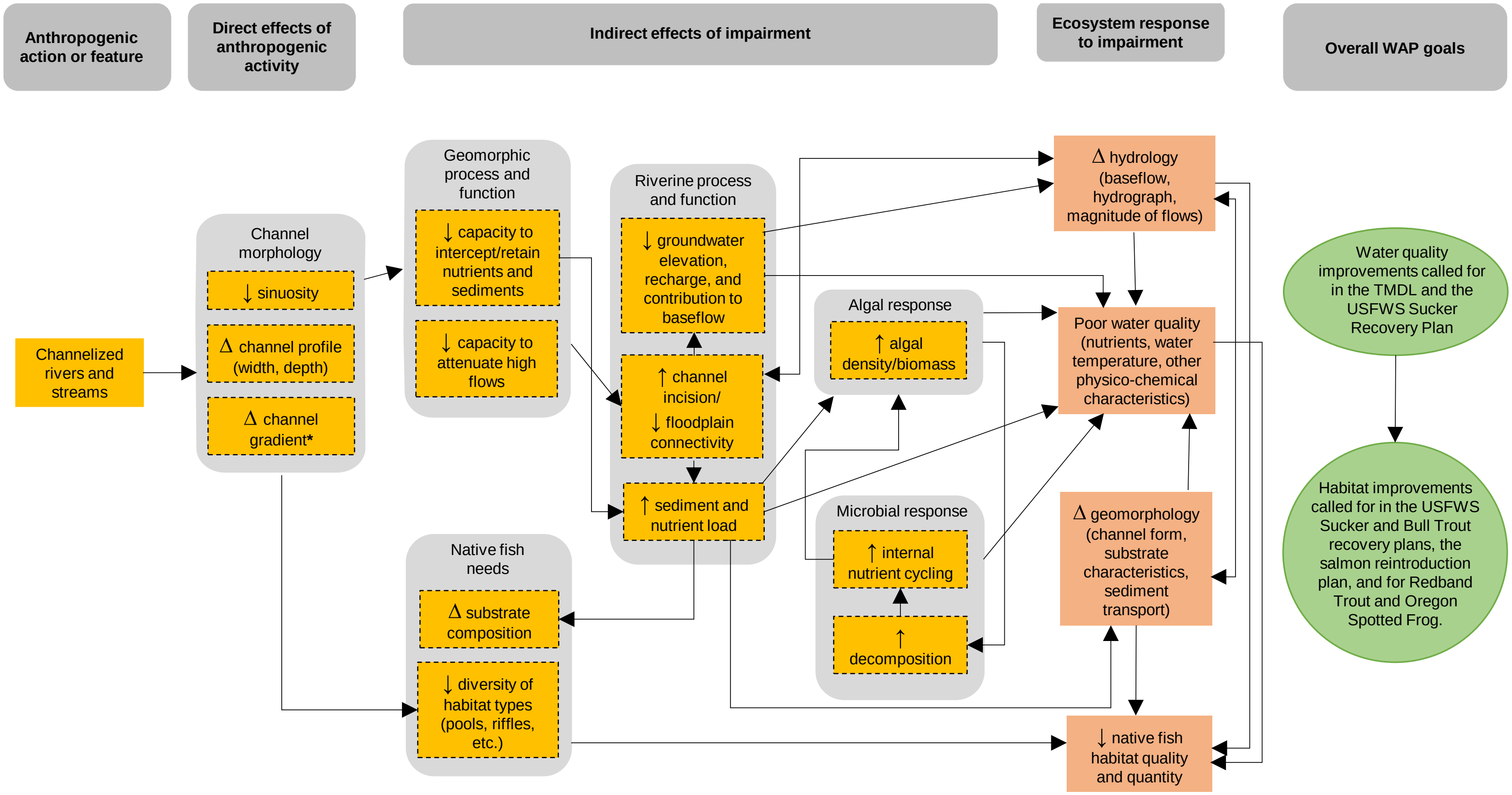

Figure 2. Channelization "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

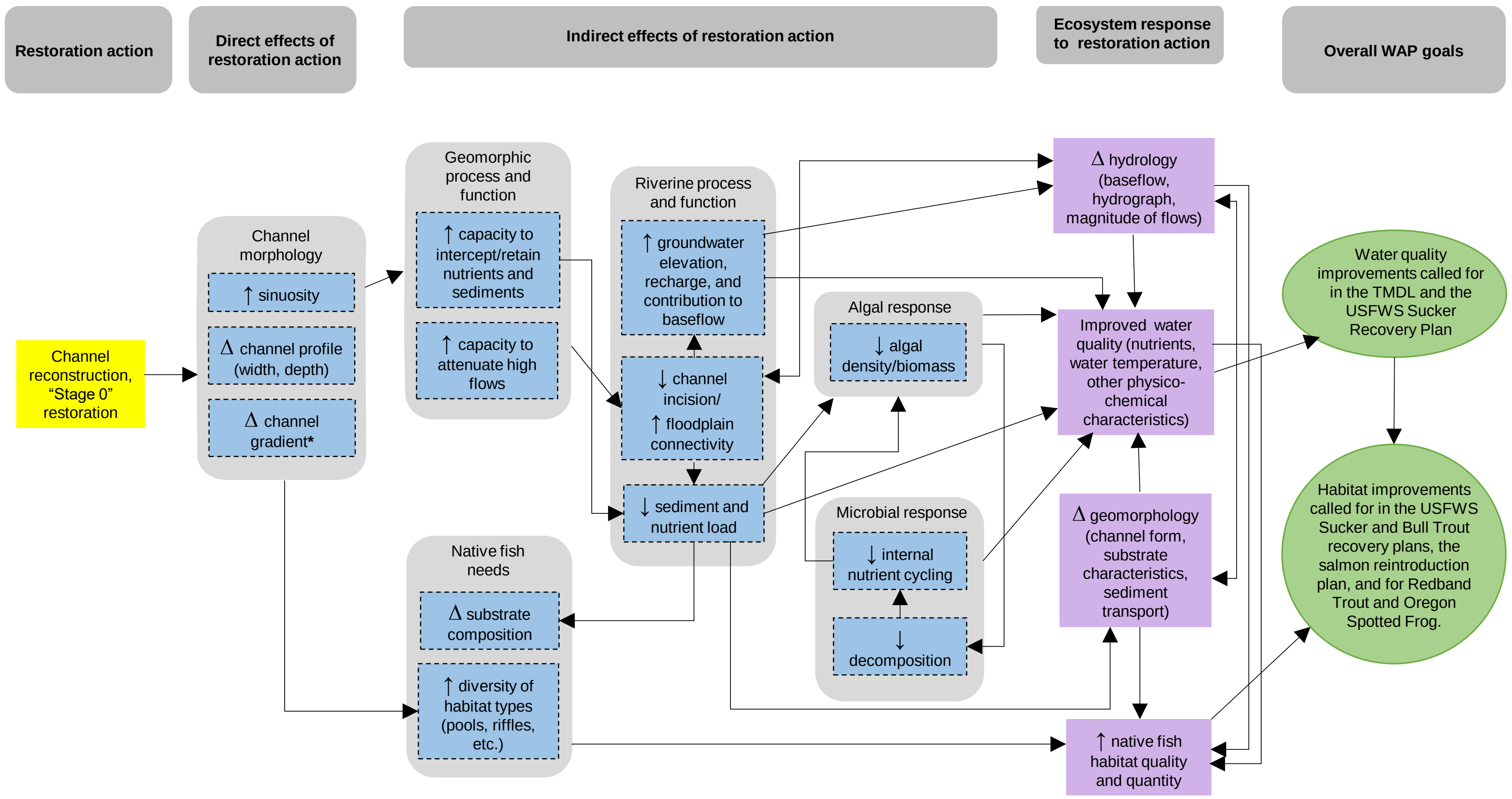

Figure 3. Channelization "restored conditions" conceptual model illustrating response to channel reconstruction or "Stage 0" methods implemented to correct and repair impairments associated with channelization. Δ indicates a change in conditions to those considered appropriate for a given site and * 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.

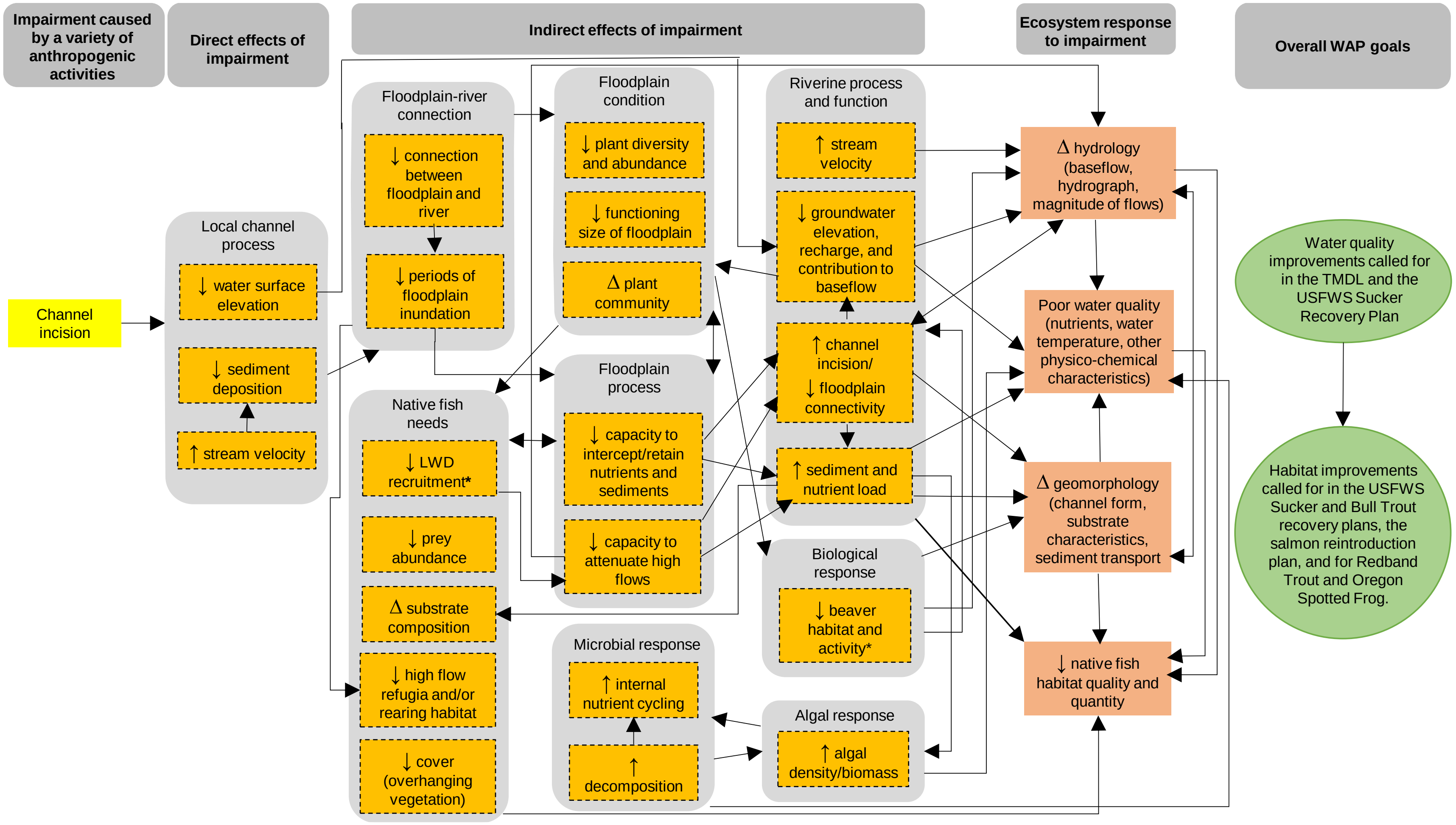

Figure 4. Channel incision "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

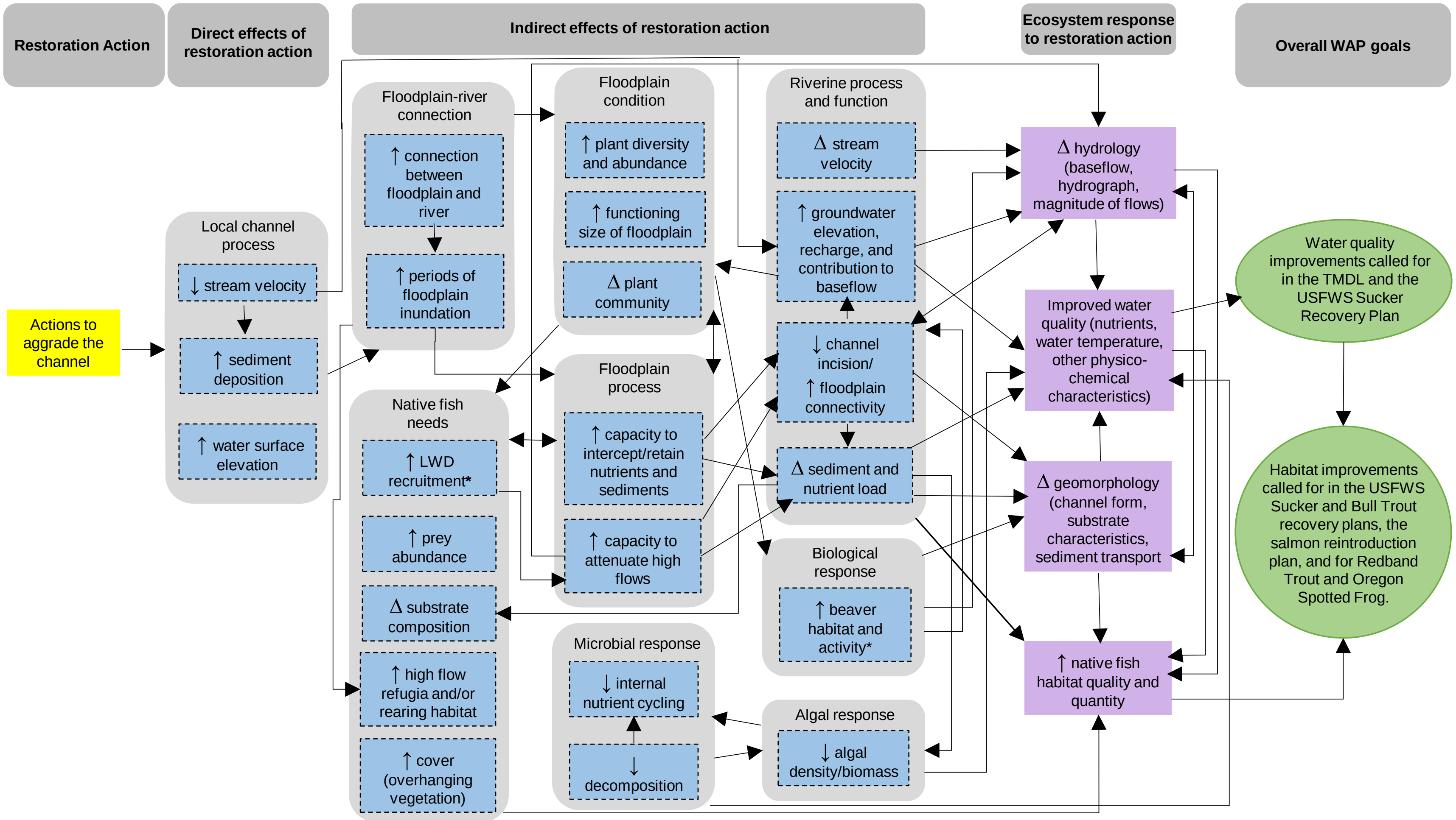

Figure 5. Channel incision "restored conditions" conceptual model illustrating response to projects that promote channel aggradation, implemented to correct and repair impairments associated with channel incision. Δ indicates a change in conditions to those considered appropriate for a given site and * 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.

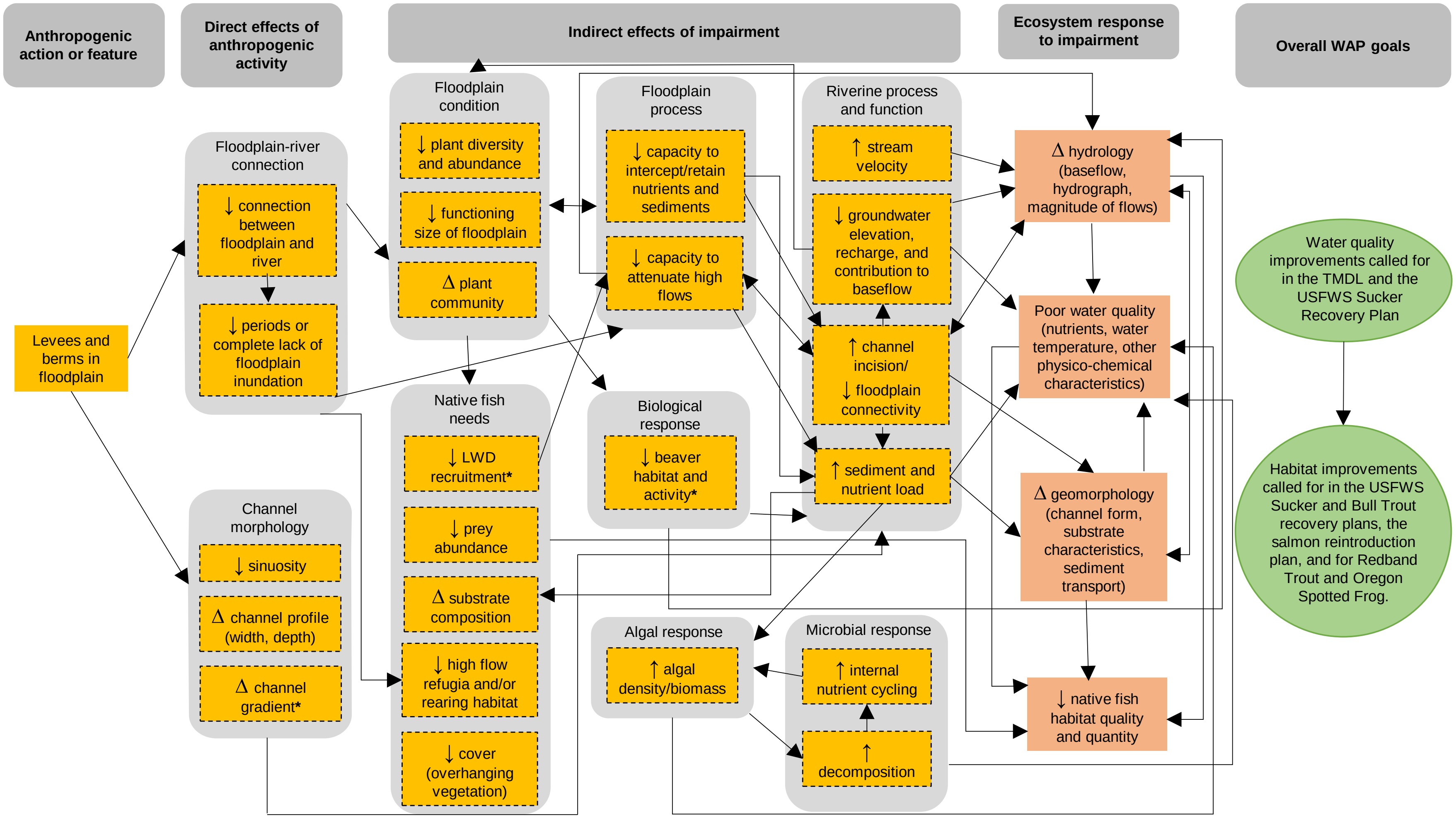

Figure 6. Levees and berms "impaired conditions" conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

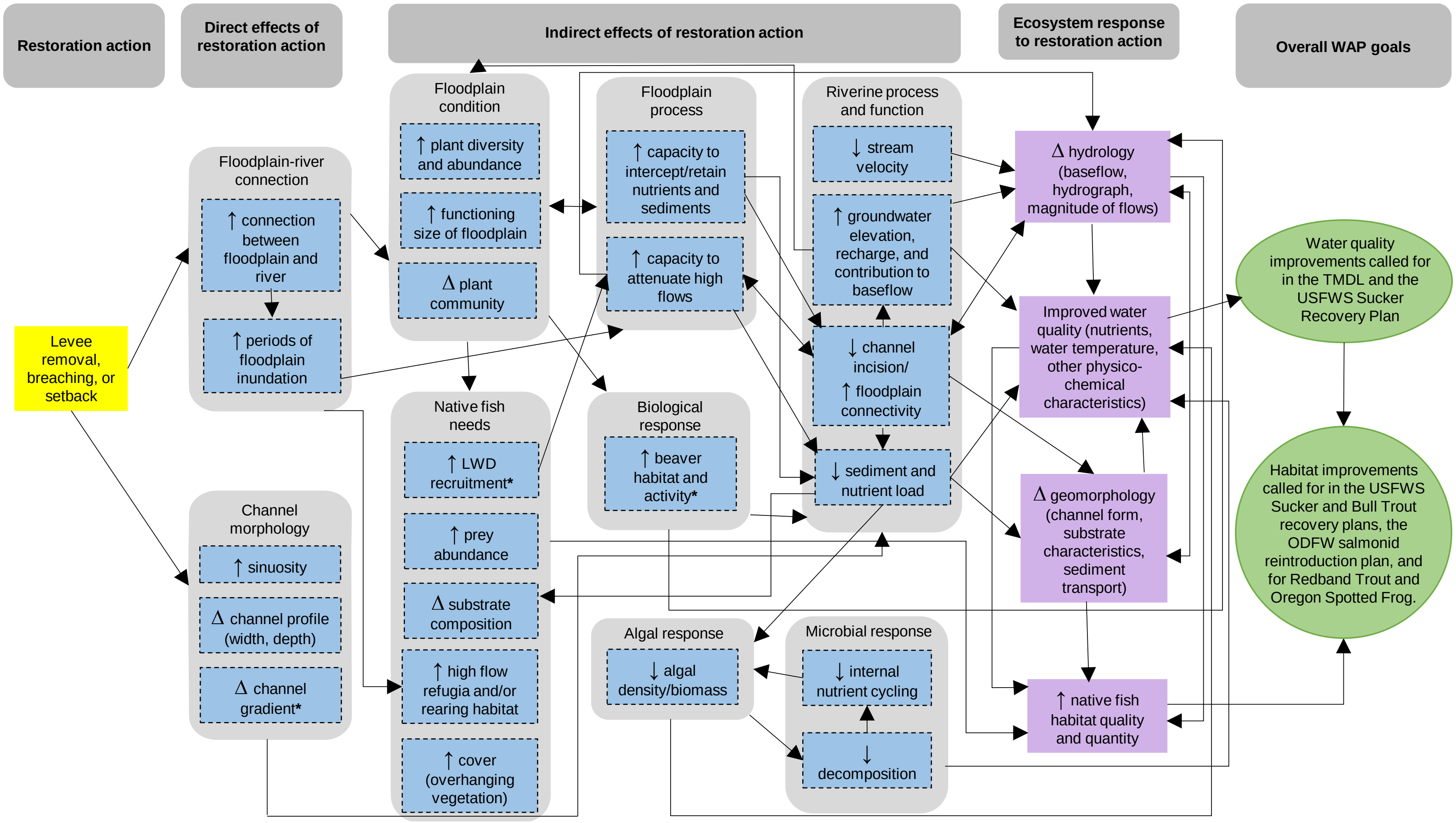

Figure 7. Levees and berms "restored conditions" conceptual model illustrating response to levee removal, set-back, or breaching, implemented to correct and repair impairments associated with levees and berms. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates 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.

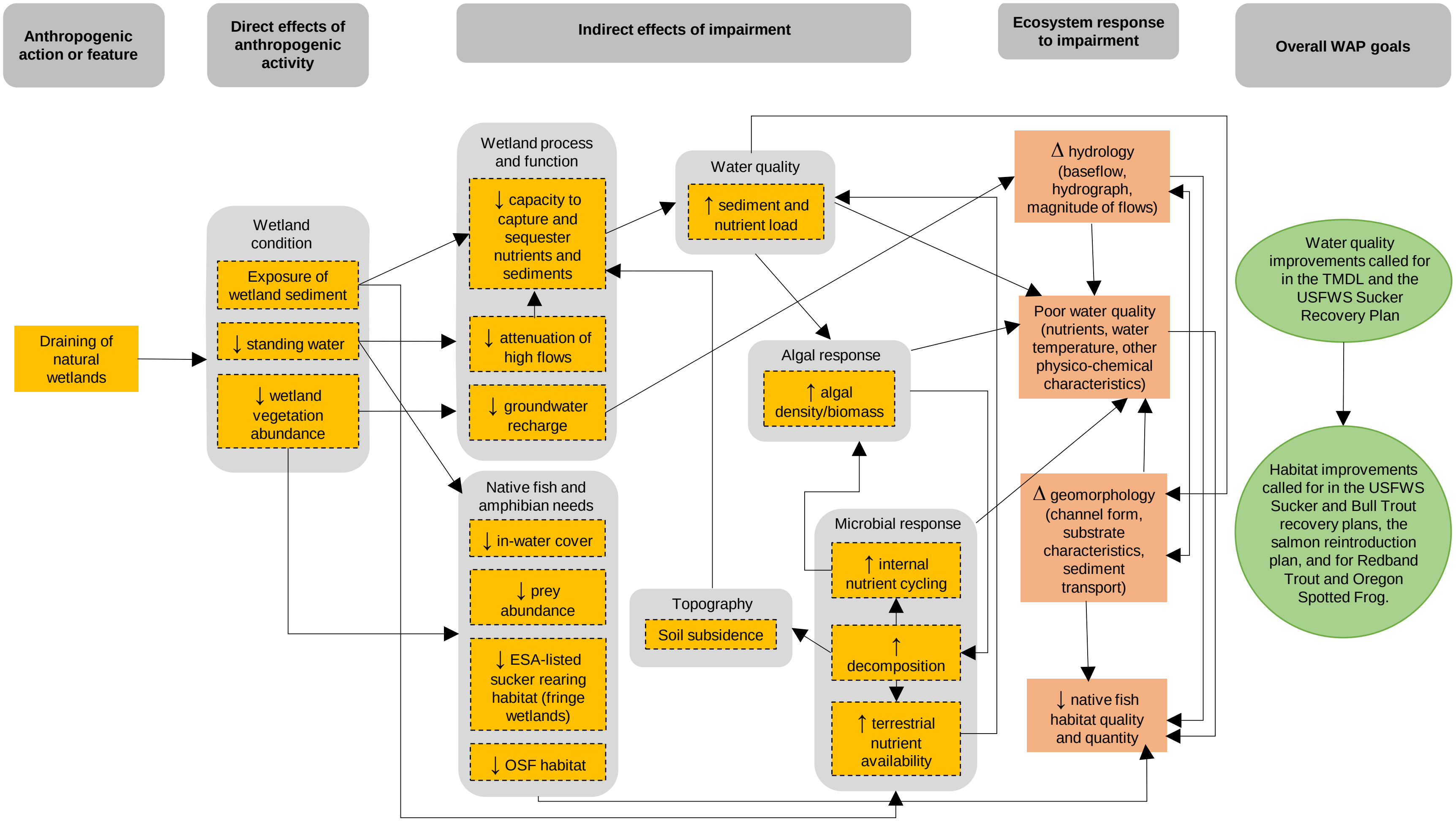

Figure 8. Wetlands "impaired conditions" conceptual model. Δ indicates a change in conditions. "OSF" is an acronym for Oregon Spotted Frog.

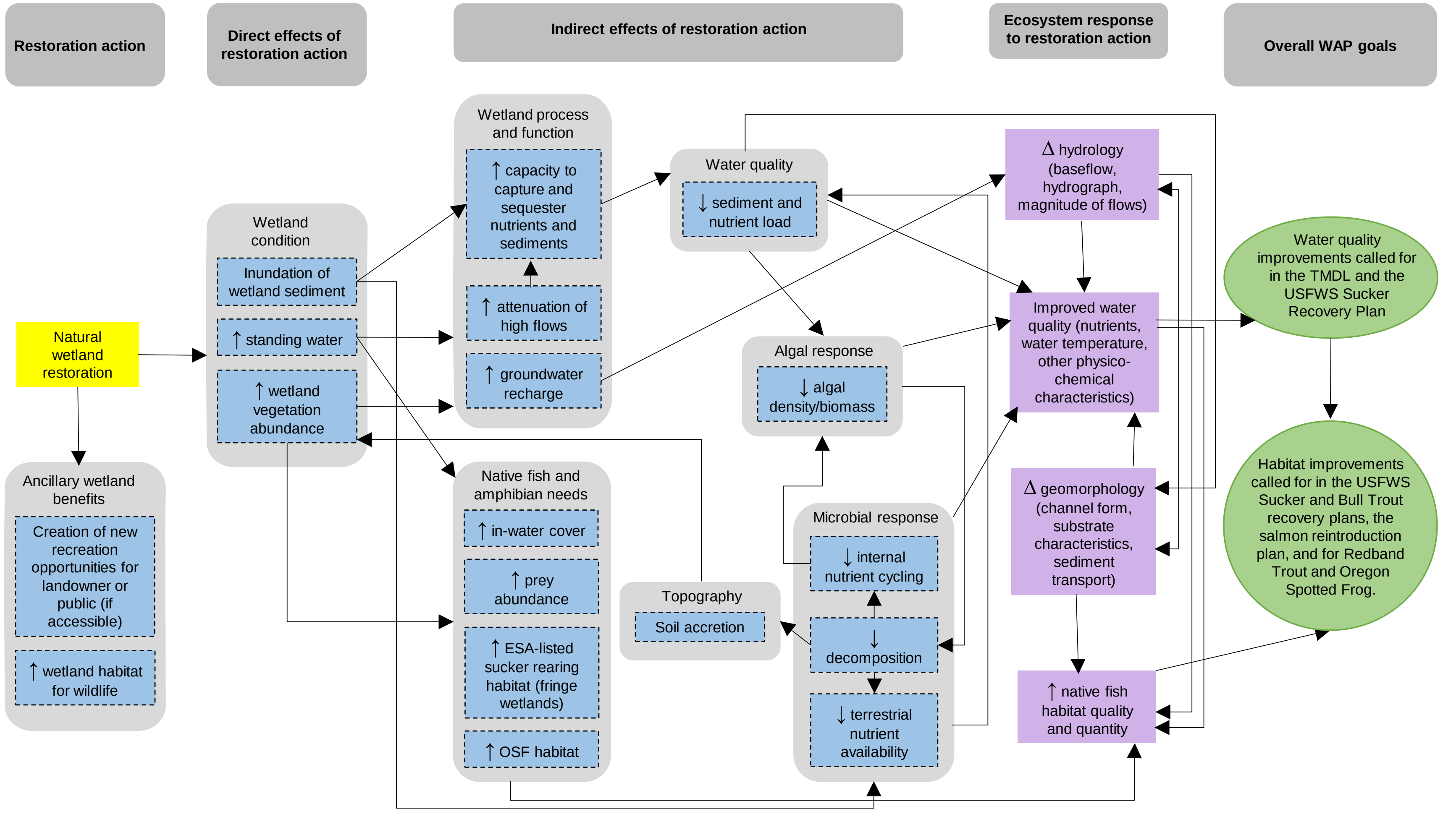

Figure 9. Wetlands "restored conditions" conceptual model illustrating response to wetland restoration implemented to correct and repair impairments associated with wetland drainage. Δ indicates a change in conditions to those considered appropriate for a given site.

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.

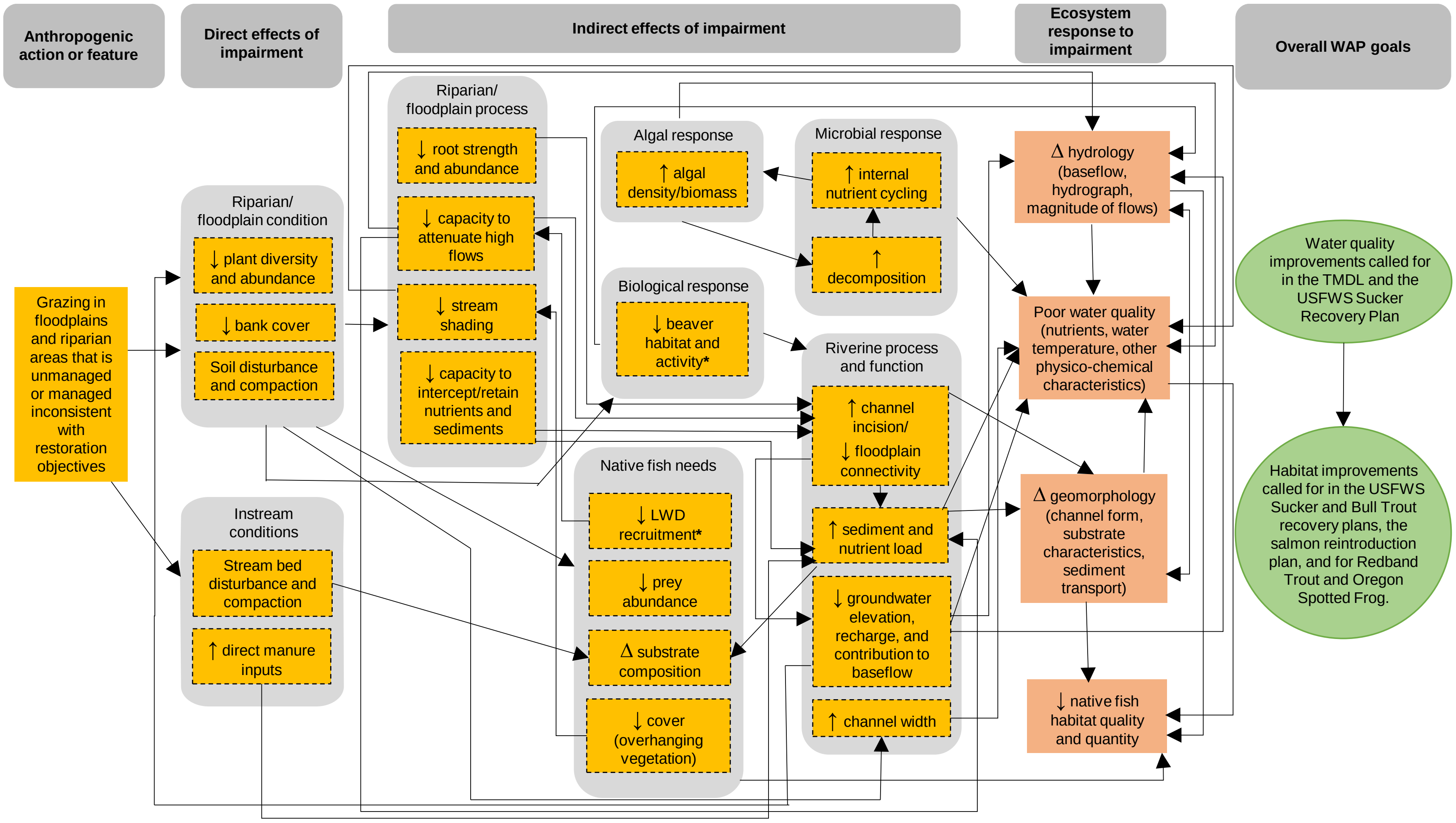

Figure 10. Riparian and floodplain vegetation “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

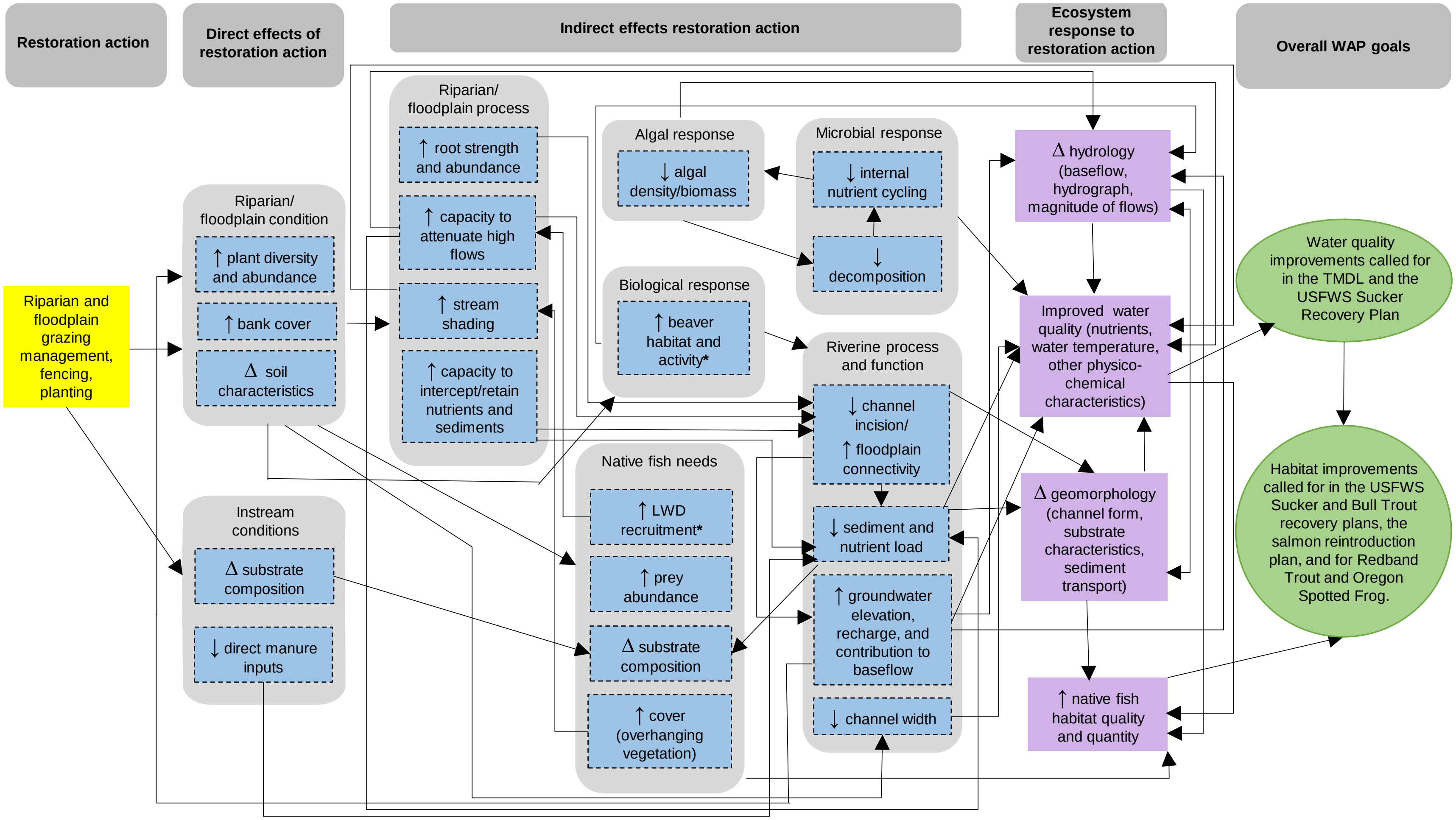

Figure 11. Riparian and floodplain vegetation "restored conditions" conceptual model illustrating response to wetland restoration implemented to correct and repair impairments associated with unmanaged riparian and floodplain grazing. Δ indicates a change in conditions to those considered appropriate 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.

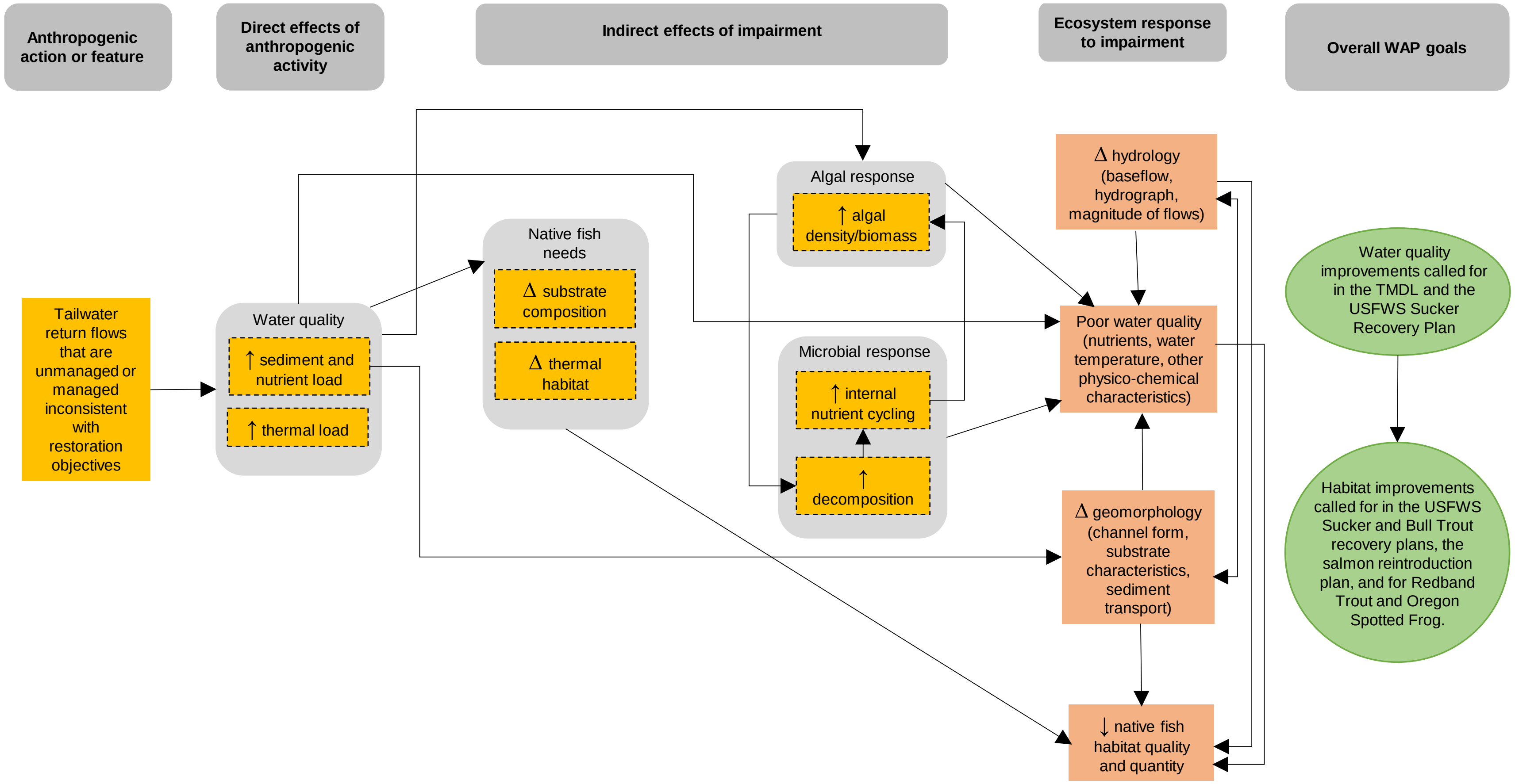

Figure 12a. Tailwater returns "impaired conditions" conceptual model. Δ indicates a change in conditions.

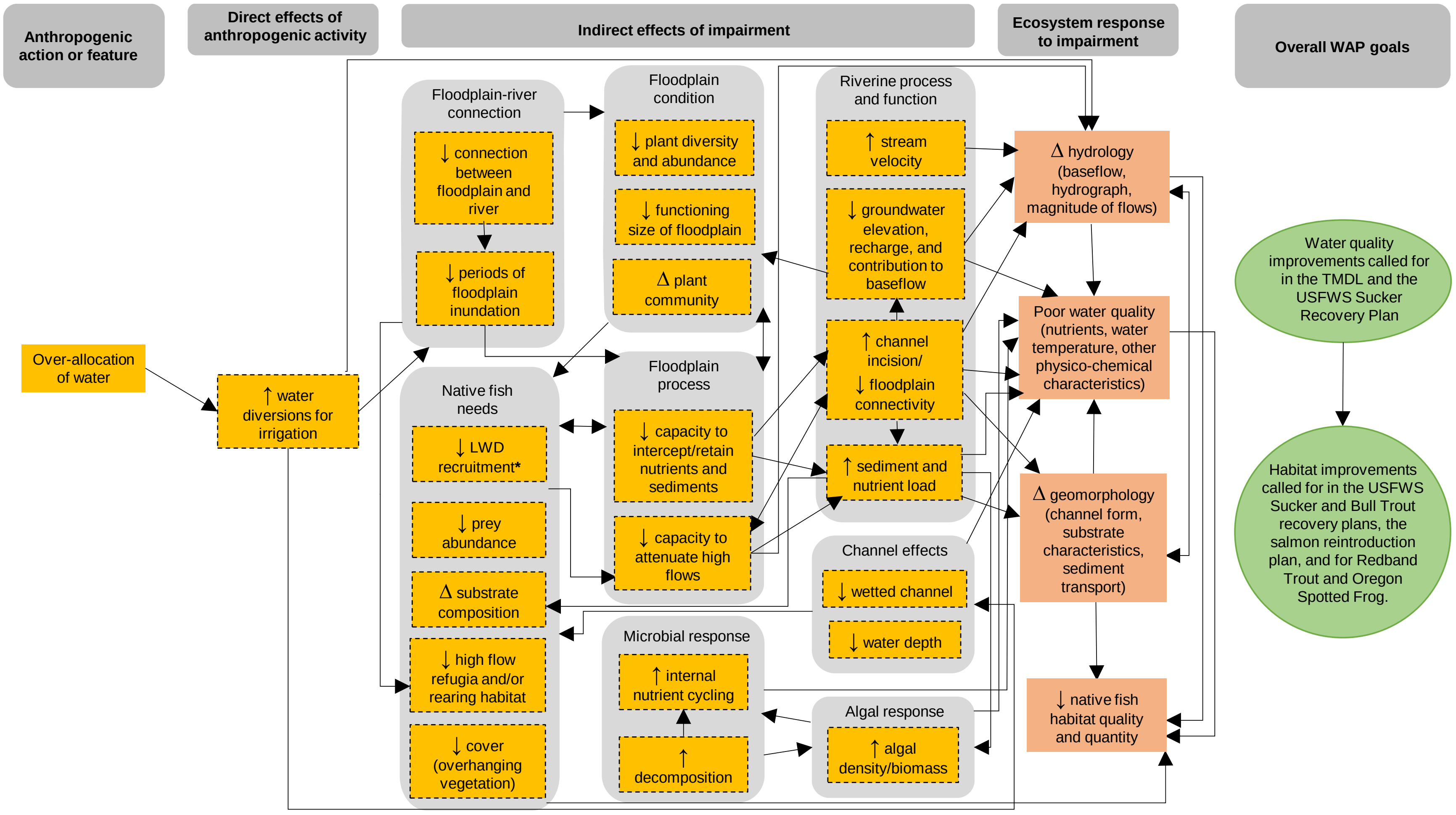

Figure 12b. Water allocation “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

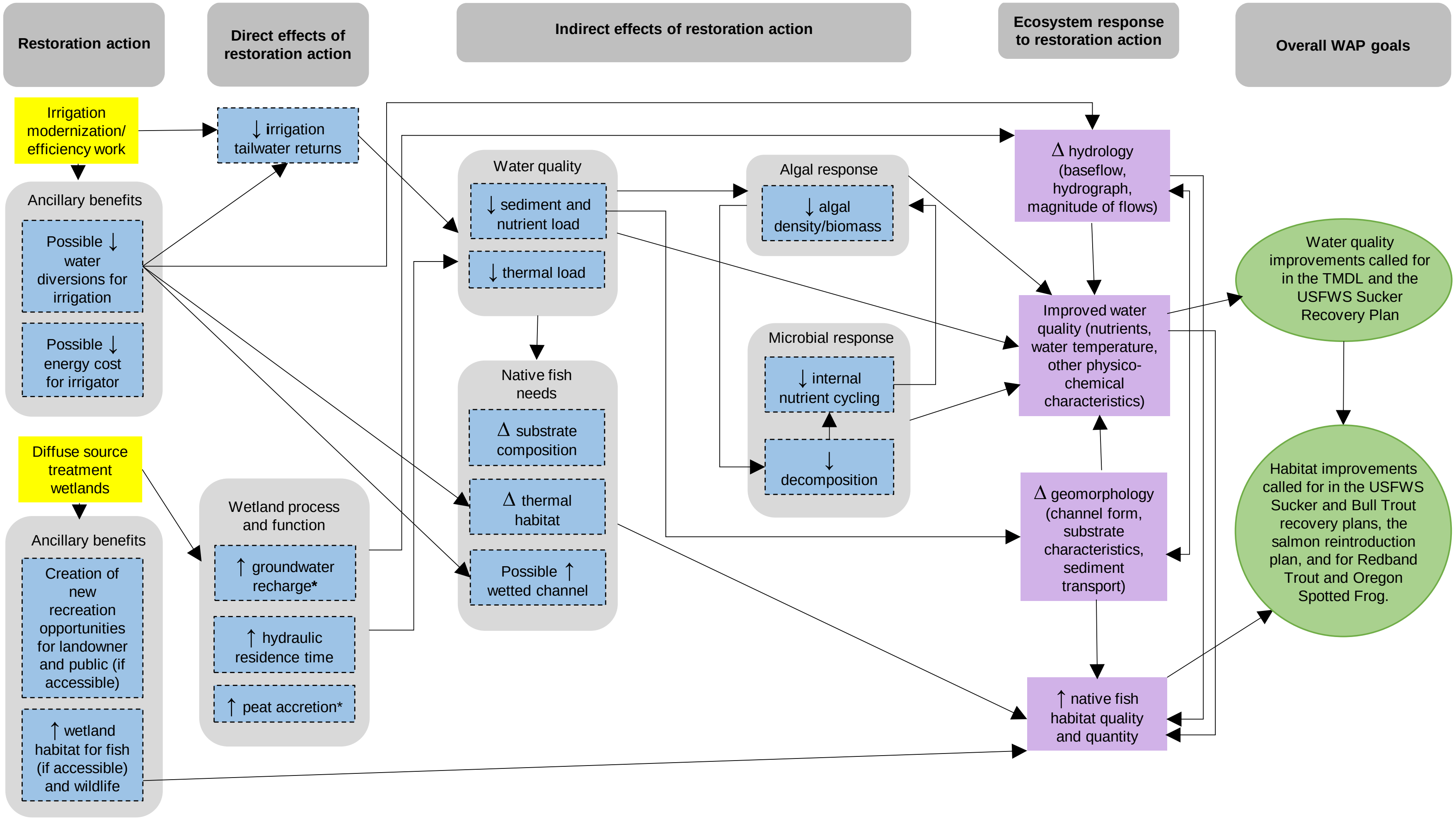

Figure 13a. Tailwater returns "restored conditions" conceptual model illustrating the responses to irrigation modernization and efficiency work and diffuse source treatment wetlands implemented to correct and repair impairments associated with inefficient irrigation practices (i.e., to reduce or treat 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).

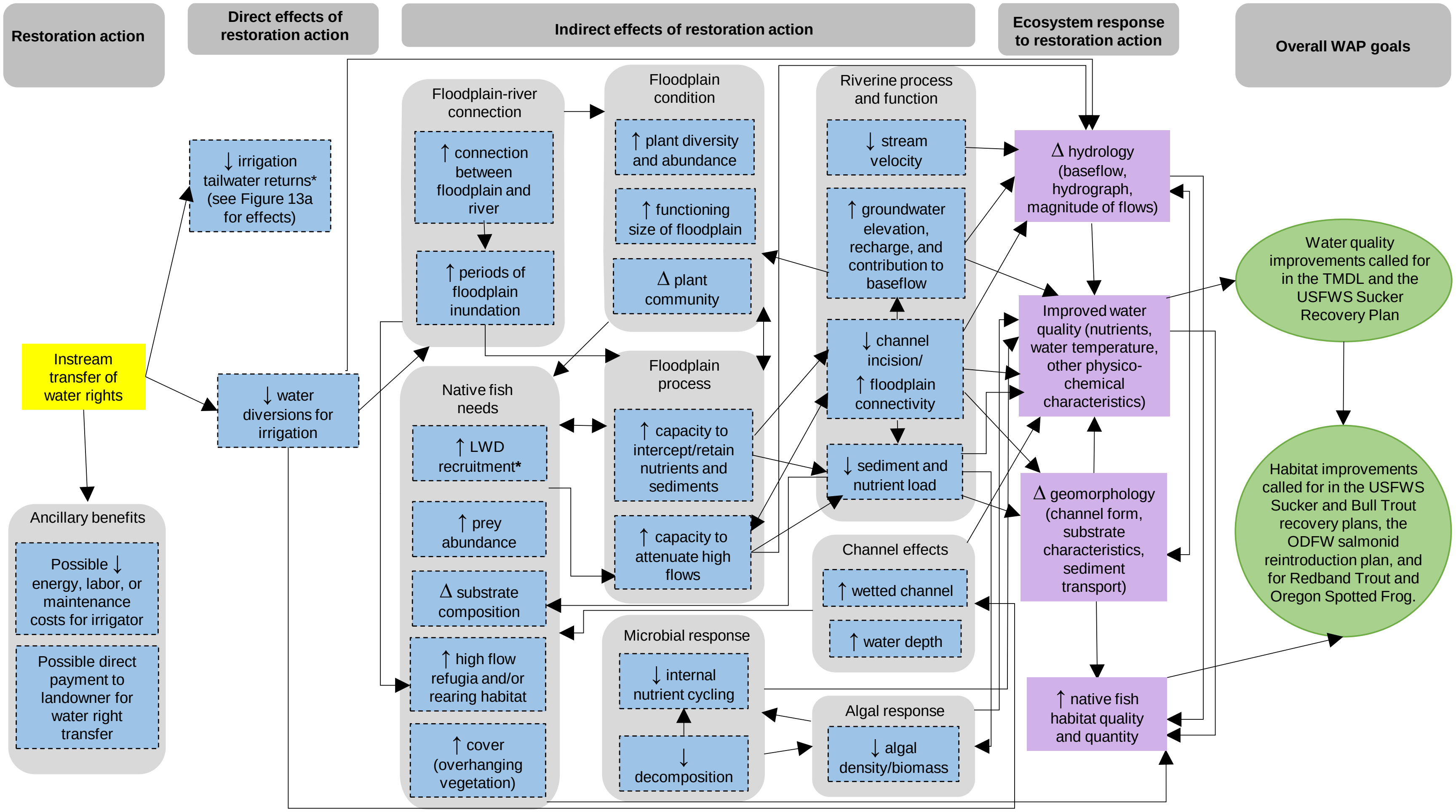

Figure 13b. Water allocation "restored conditions" conceptual model illustrating the responses to transferring water rights for instream uses. Δ indicates a change in conditions to those considered appropriate for a given site and * indicates processes for which effects are site-dependent (i.e., changes 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).

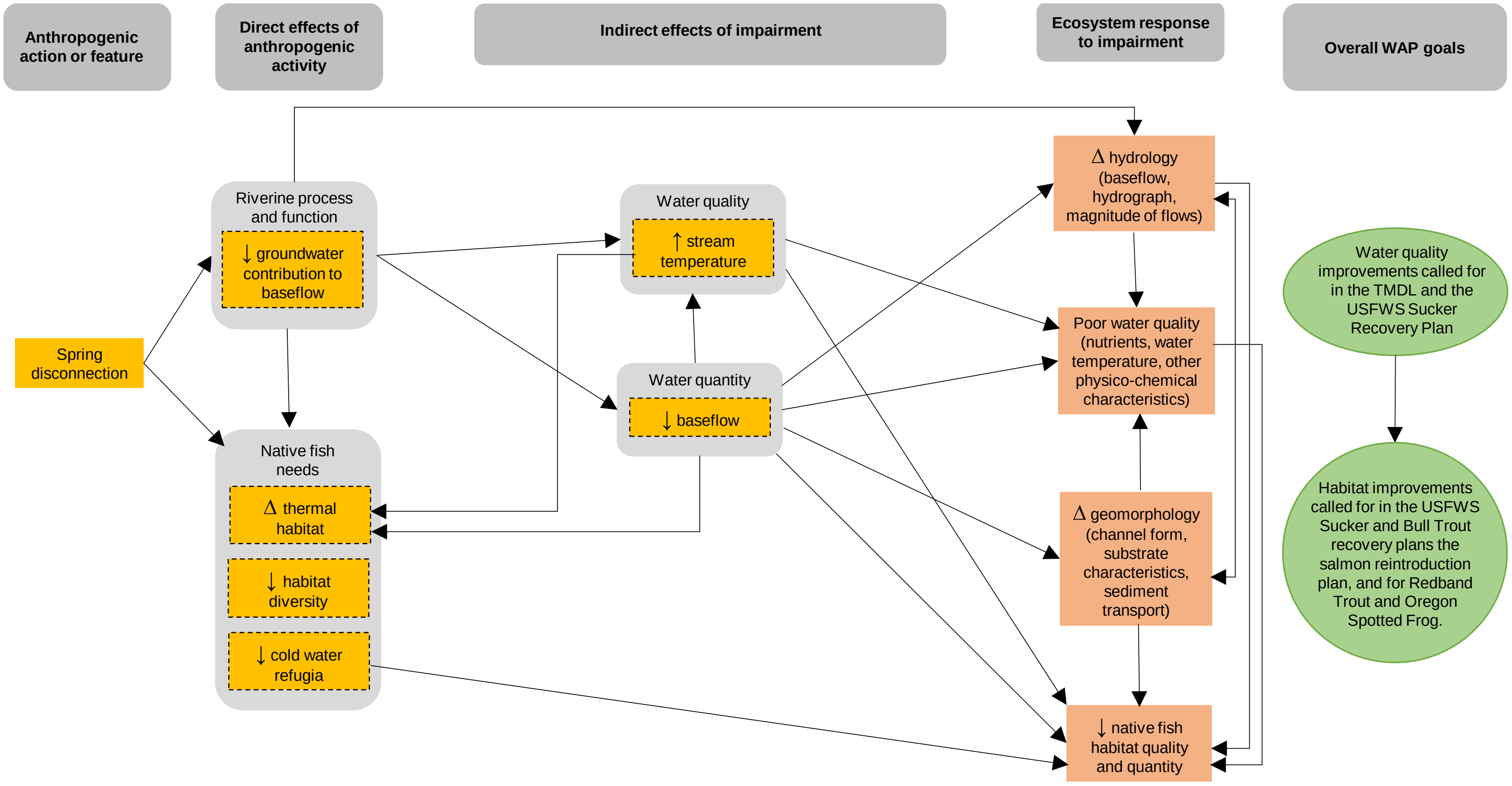

Figure 14. Springs “impaired conditions” conceptual model. Δ indicates a change in conditions.

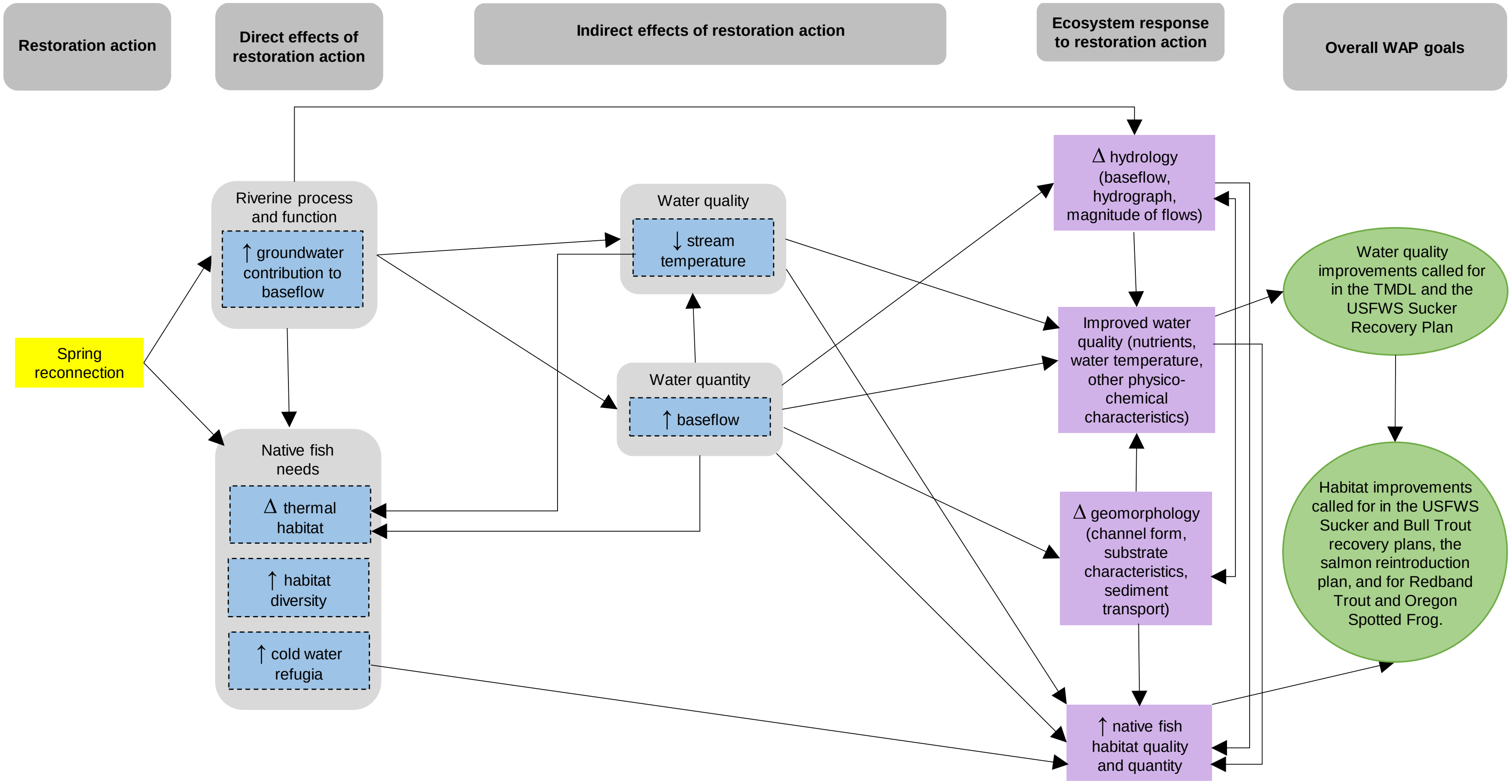

Figure 15. Springs "restored conditions" conceptual model illustrating the responses to off-channel spring reconnection implemented to correct and repair impairments associated with off-channel spring disconnection. Δ indicates a change in conditions to those considered appropriate for a given site.

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).

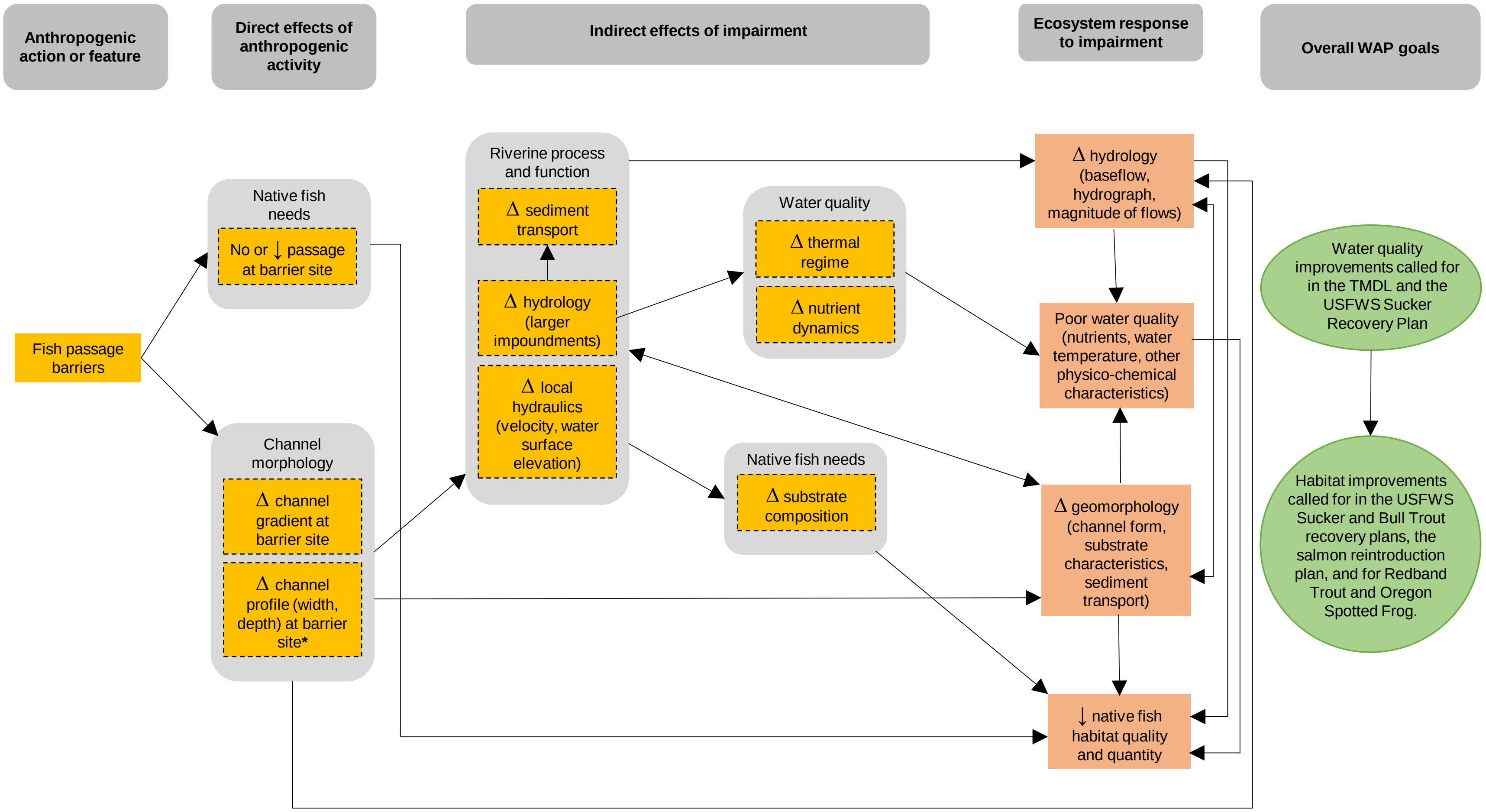

Figure 16. Fish passage “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

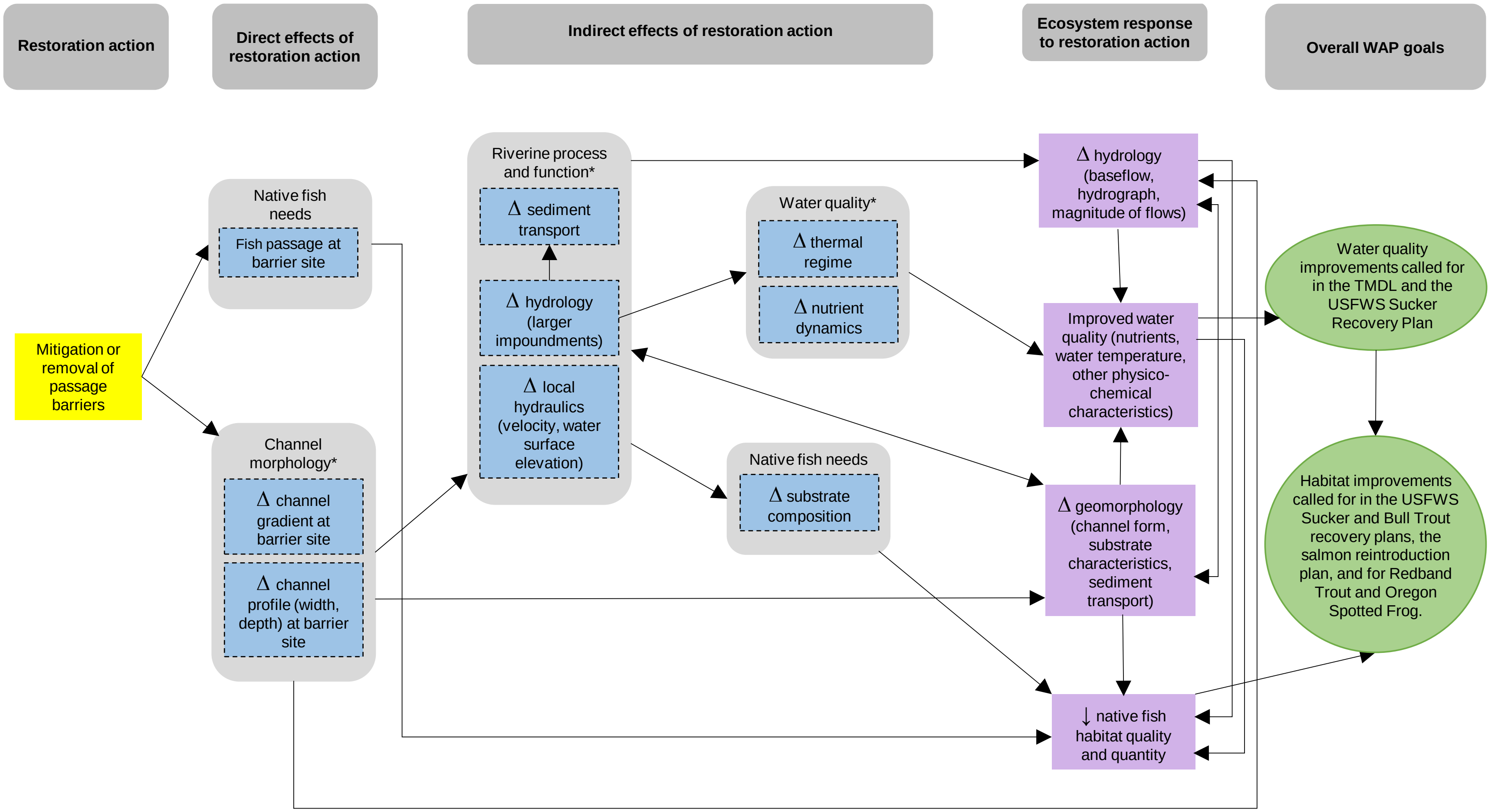

Figure 17. Fish passage "restored conditions" conceptual model illustrating the responses to removal or mitigation of non-culvert fish passage barriers implemented to correct and repair impairments associated with these barriers. Δ indicates a change in conditions to those considered appropriate for 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).

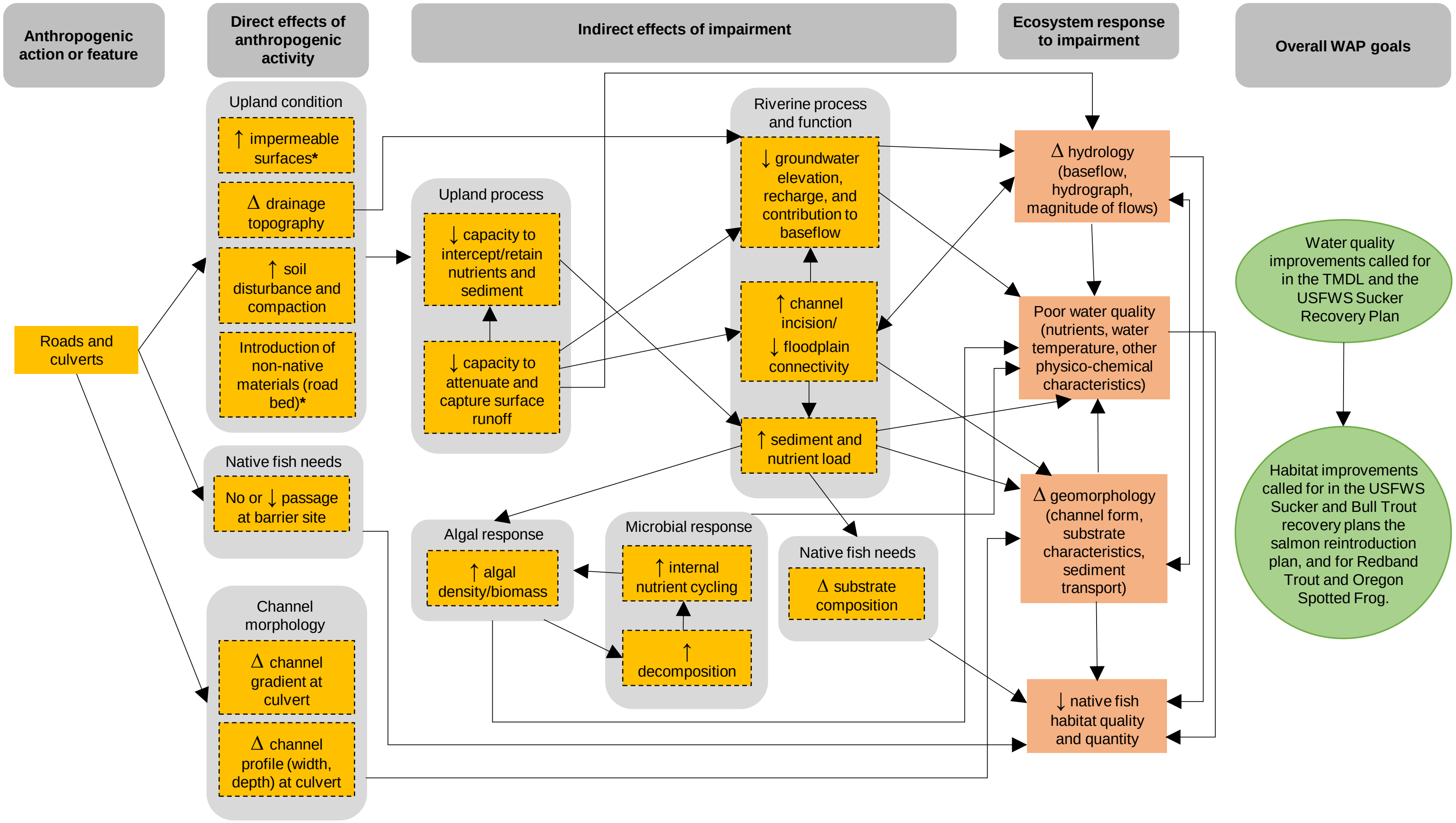

Figure 18. Roads “impaired conditions” conceptual model. Δ indicates a change in conditions and * indicates processes for which effects are site-dependent (i.e., changes or an increase or decrease may not occur at all sites).

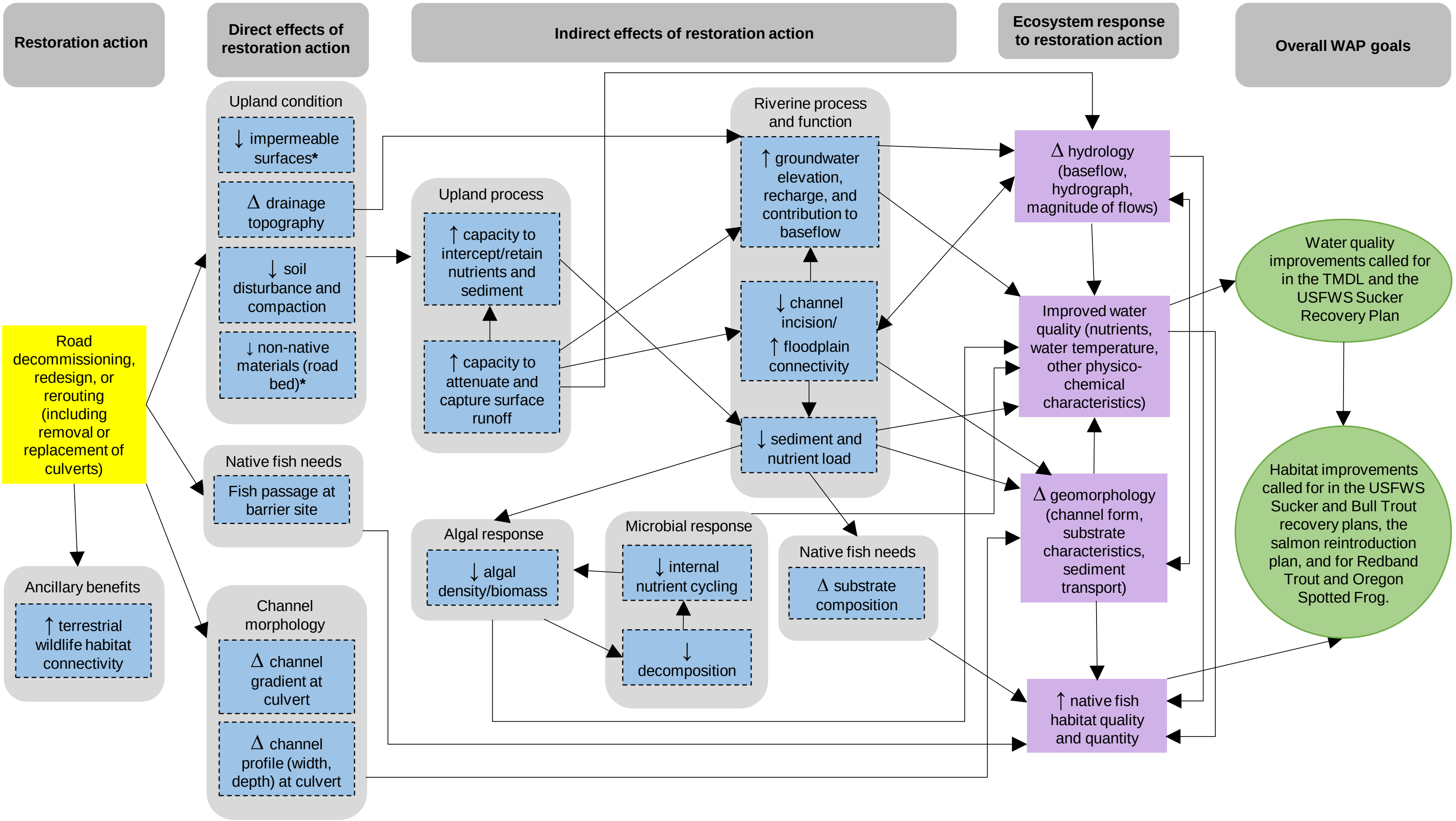

Figure 19. Roads "restored conditions" conceptual model illustrating the responses to road decommissioning, redesign, or rerouting (including culvert replacement or removal) implemented to correct and repair impairments associated with roads and culverts. Δ indicates a change in conditions to those considered 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.

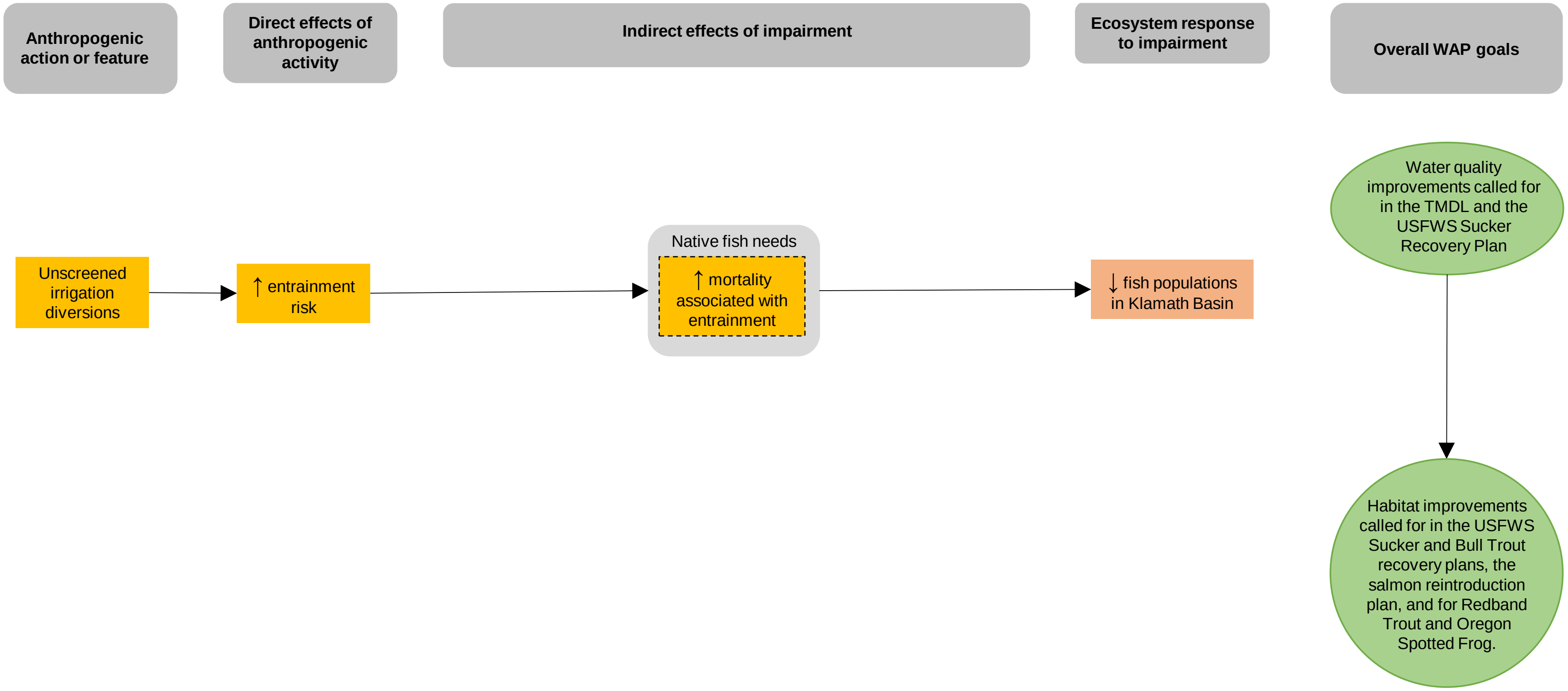

Figure 20. Fish entrainment "impaired conditions" conceptual model.

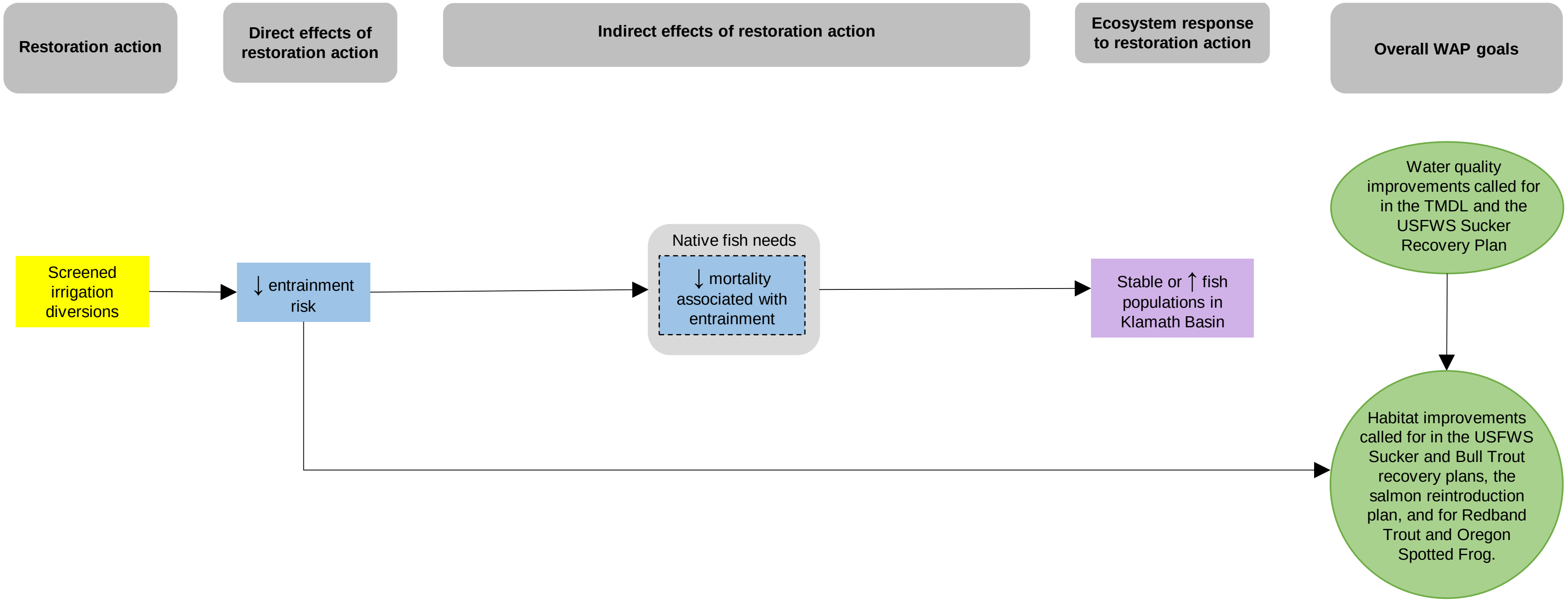

Figure 21. Fish entrainment "restored conditions" conceptual model illustrating the responses to diversion screening implemented to correct and repair impairments associated with unscreened irrigation diversions.

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.

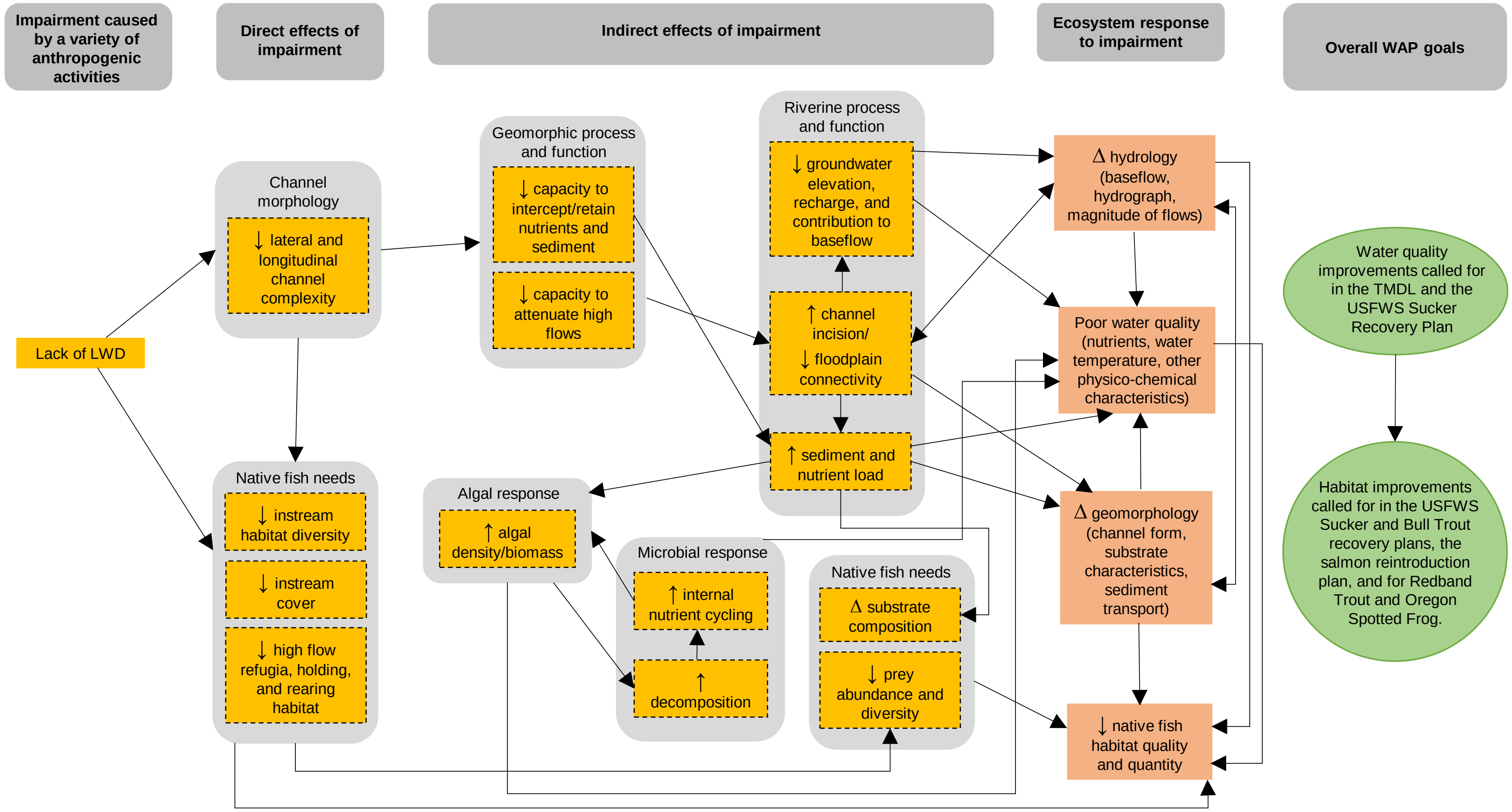

Figure 22. Large woody debris “impaired conditions” conceptual model. Δ indicates a change in conditions. Note that a lack of large woody debris may not be a sign of impairment in all locations; some areas historically had less potential for large woody debris given inherent site conditions. However,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

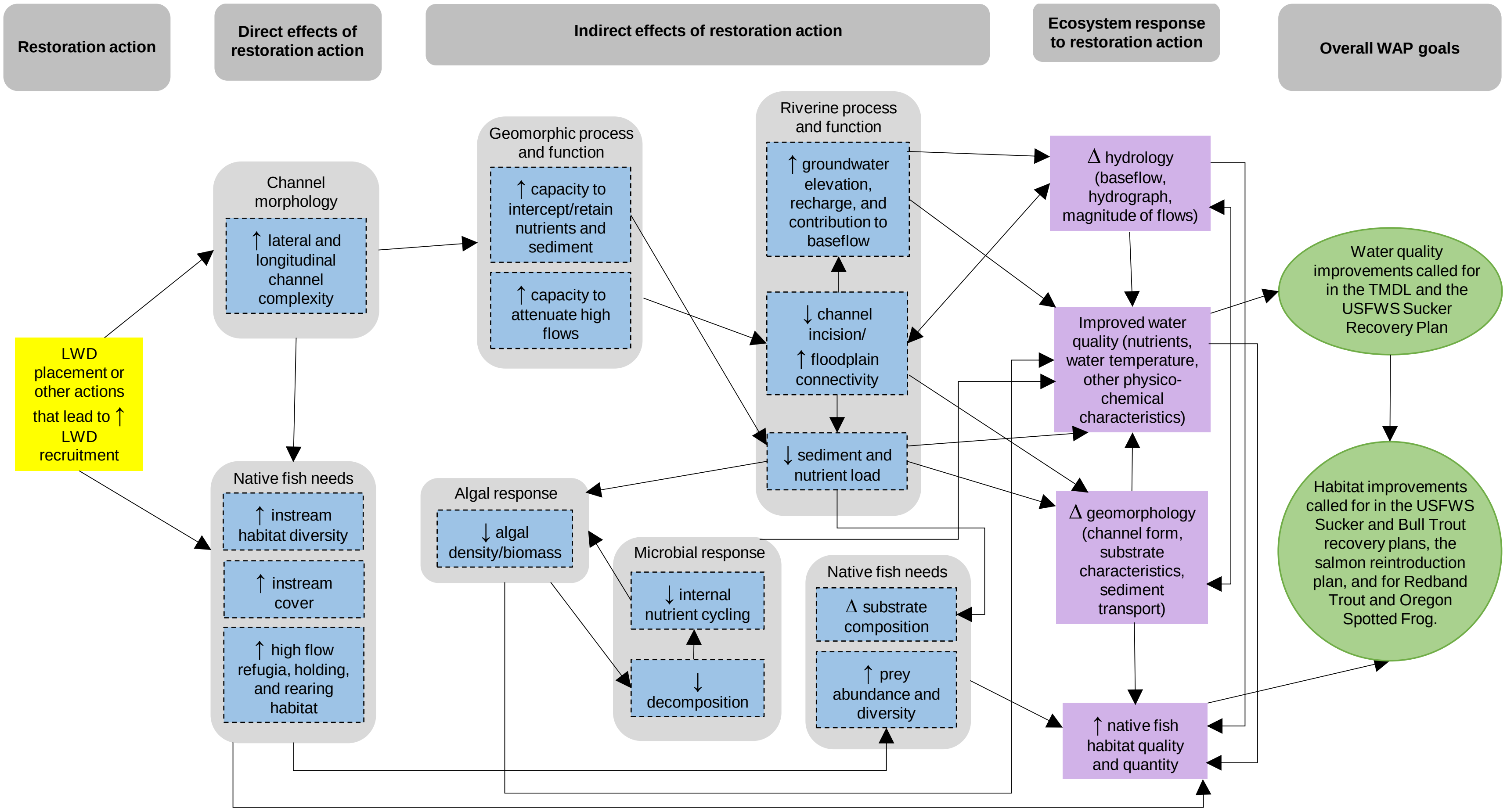

Figure 23. Large woody debris "restored conditions" conceptual model illustrating the responses to large woody debris placement, or restoration of processes that increase large woody debris recruitment, implemented to correct and repair impairments associated with a lack of large woody debris. Δ indicates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

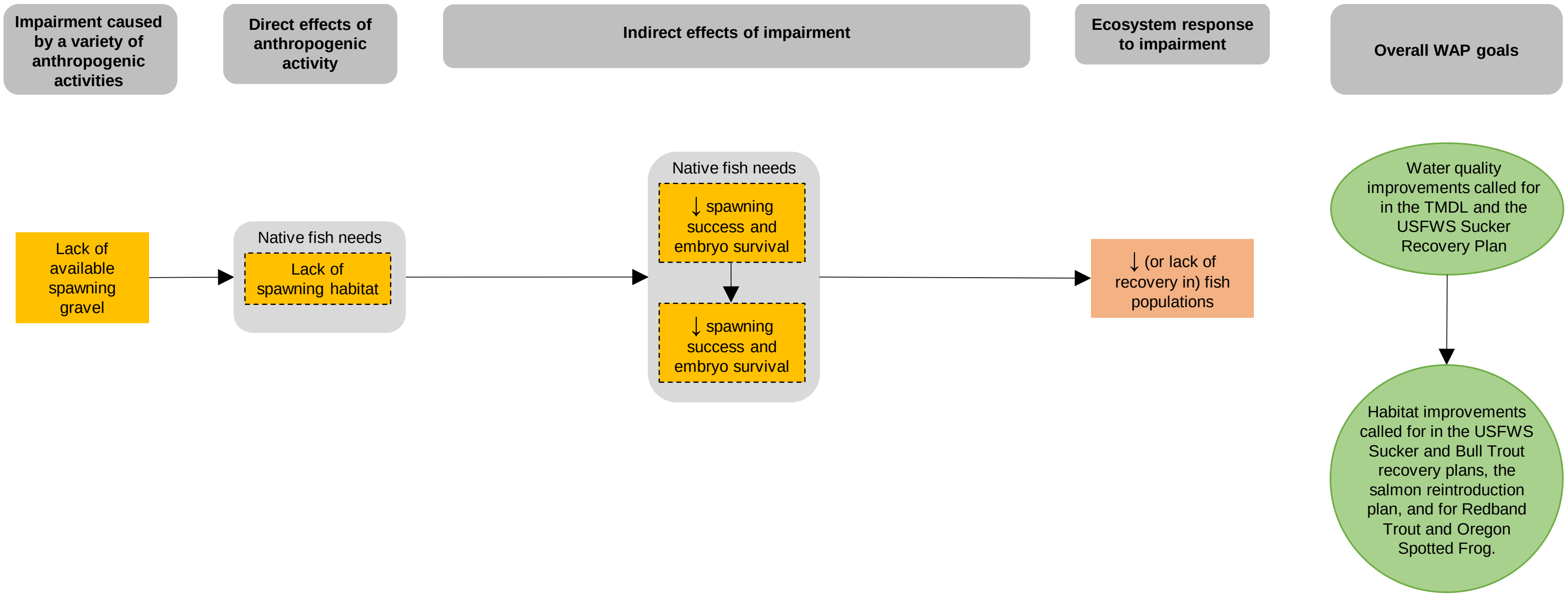

Figure 24. Spawning substrate "impaired conditions" conceptual model.

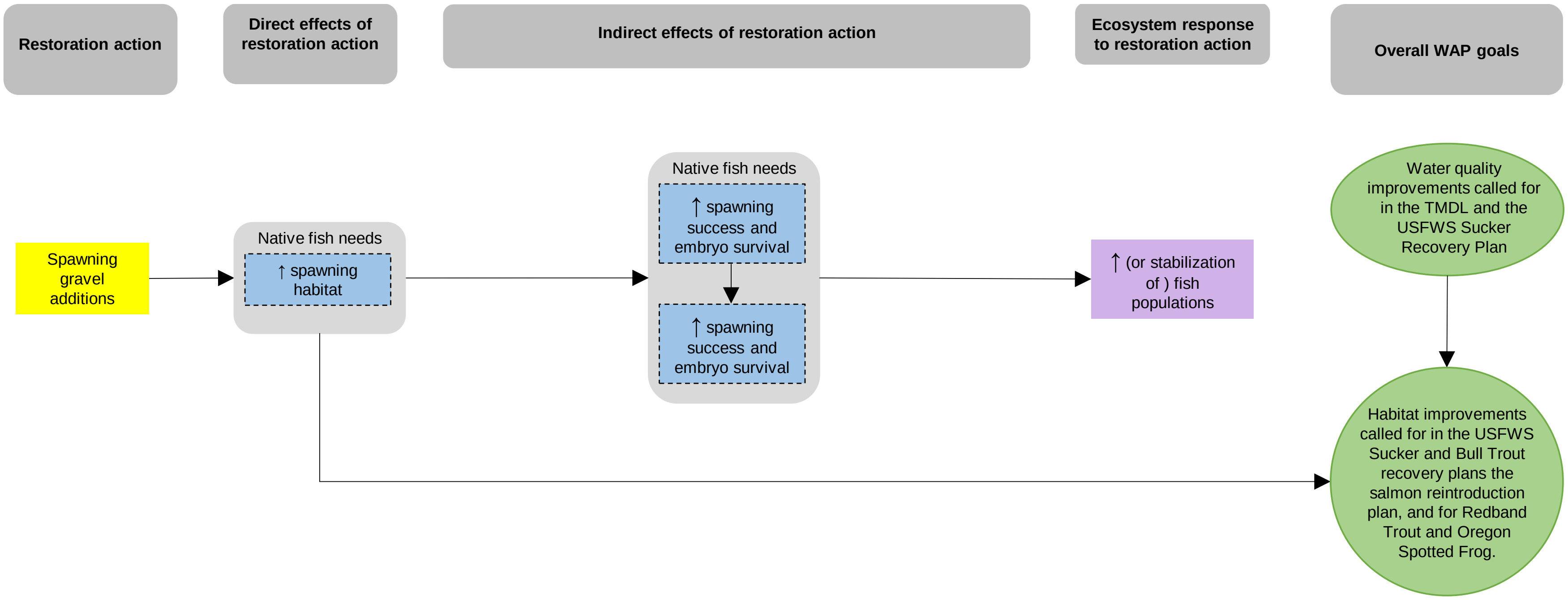

Figure 25. Spawning substrate “restored conditions” conceptual model illustrating the responses to spawning gravel additions, or restoration of processes that increase spawning gravel recruitment, implemented to correct and repair impairments associated with a lack of optimal spawning substrate.

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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