Klamath Basin Integrated Fisheries Restoration and Monitoring Plan (IFRMP) - Conceptual Models Summary Document

Prepared for the Pacific States Marine Fishery Commission

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List of Abbreviations

AE	Action Effectiveness
AM	Adaptive Management
AMA	Agricultural Management Assistance
BACI	Before-After-Control-Impact
BDA	Beaver Dam Analogs
BI	Biological Interactions
BMQ	Big Monitoring Questions
BOR	Bureau of Reclamation
CDFW	California Department of Fish and Wildlife
COPCO	California Oregon Power Company
CPI	Core Performance Indicator
CPUE	Catch Per Unit Effort
CPVI	Conservation Population Viability Index
CSP	Conservation Stewardship Program
CSS	Commercial Salmon Stamp
DEM	Digital Elevation Model
DIDSON	Dual Frequency Identification Sonar
DO	Dissolved Oxygen
DQO	Data Quality Objectives
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FA	Fisheries Actions
FERC	Federal Energy Regulatory Commission
FG	Fluvial Geomorphic Processes
FWS	Fish and Wildlife Service
H	Habitat
HGMP	Hatchery and Genetic Management Plan
HSC	Habitat Suitability Criteria
HVT	Hoopa Valley Tribe
IAP	Integrated Assessment Plan
IGD	Iron Gate Dam
IFRM	Integrated Fisheries Restoration and Monitoring
IFRMP	Integrated Fisheries Restoration and Monitoring Plan
IP	Intrinsic Potential
IRCT	Interior Redband Conservation Team
KBMP	Klamath Basin Monitoring Program
KHSA	Klamath Hydroelectric Settlement Agreement

KRE	Klamath River Estuary
KRRC	Klamath River Renewal Corporation
KTWQC	Klamath Tribal Water Quality Consortium
LKR	Lower Klamath River
LiDAR	Light Detection and Ranging
LWD	Large Woody Debris
MCDA	Multi-criteria Decision Analysis
MFMT	Maximum fishing mortality threshold
MRRIC	Missouri River Recovery Implementation Committee
MUK	Middle/Upper Klamath River
NCRWQCB	North Coast Regional Water Quality Control Board
NFMS	National Marine Fisheries Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAAF	National Oceanic and Atmospheric Administration Fisheries
NRC	National Research Council
NRCS	Natural Resource Conservation Service
OC	Ocean Conditions
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Water Resources Department
PCSRF	Pacific Coastal Salmon Recovery Fund
PIT	Passive Integrated Transponder
POM	Particulate Organic Matter
PSMFC	Pacific States Marine Fisheries Commission
PSU	Primary Sampling Unit
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SONCC	Southern Oregon/Northern California Coast
SRCD	Siskiyou Resource Conservation District
SRRC	Salmon River Restoration Council
SRWC	Scott River Watershed Council
SRWG	Sub-Regional Working Group
SSU	Secondary Sampling Units
ST	Status and Trends
SVRCD	Shasta Valley Resource Conservation District
SWAMP	Surface Water Ambient Monitoring Program

TAMWG	Trinity Adaptive Management Working Group
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
TRRP	Trinity River Restoration Program
TSS	Total Suspended Sediments
UKL	Upper Klamath Lake
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WG	Work Group
WI	Watershed Inputs
WPMP	Water Quality Management Plan
WQ	Water Quality
WQMP	Water Quality Management Plan
WTP	Water Transactions Program
WUA	Weighted Useable Area
WY	Water Year

1 Conceptual Models

This Document

Presents a range of **conceptual models** that:

- Illustrate Klamath IFRMP participants' common understanding of the problems that are the focus of the Plan.
- Express system understanding in a form that integrates across multiple dimensions (e.g., management actions, ecosystem components, sub-regions, and focal fish species).
- Provide a parsimonious representation of system components that is sufficient to stimulate collaborative discussions and decisions on three critical elements of the Plan:
    1. **Key stressors** which are most strongly constraining the productivity, abundance, distribution and diversity of each functional group of fish species in each sub-region;
    2. **Restoration actions** that could be implemented in each sub-region to reduce or eliminate the stressors defined in element 1.
    3. **Core performance indicators and associated informative indicators** required to assess progress towards habitat and species thresholds/triggers, and to assess the effectiveness of actions defined in element 2.

Note to reader: When these conceptual models were developed, it was not yet clear if the dams would be removed. Therefore, there may be mention of dams "potentially" being removed or "dams in / dams out" scenarios in the conceptual model diagrams.

Ecological systems are inherently complex. A large number of natural and human drivers can interact with a system's components to affect its form and function. A conceptual model is a simplified representation of a complex system which explicitly illustrates its parts and the cause-effect relationships among the parts. At the most basic level, conceptual models are communication tools that help an audience (e.g., scientists, managers, and the public) develop a common understanding about how a system works (Fischenich 2008). Conceptual models can also be used to help provide direction to management activities, including restoration activities, by defining the current understanding of the most important variables and interactive processes (Stanford et al. 2011). The models help to identify problems and establish the range of appropriate solutions, given recognition of uncertainties in the science (Ralls and Starfield 1995, Lichatowich et al. 2006, NRC 2008 as cited in Stanford et al. 2011). Well-designed conceptual models can thus provide a basis for informed decision making, if they accurately describe key relationships between ecosystem attributes and processes in relation to environmental stressors (Stanford and Poole 1996, NRC 2008 as cited in Stanford et al. 2011).

Conceptual models can be presented in a variety of forms that draw upon a variety of modeling approaches (see Nelitz et al. 2012, Jorgensen 1988, and Gucciardo et al. 2004 for summaries of different approaches for developing conceptual models). There is no *best* form for a conceptual model because the form and approach depend on its purpose. Schematics used for conceptual models vary widely, ranging from simple box and arrow diagrams to more sophisticated illustrations. Box and arrow diagrams are meant to aid in the development of explicit hypotheses about these relationships, which can be tested through monitoring or direct experimentation. Conceptual models are generally supported by narratives in tables or matrices, which provide a text description of the proposed hypotheses or pathways of effect represented and further characterize the nature of the model linkages (e.g., Jones et al. 1996).

1.1 Challenges in conceptual model development

Restoration of the Klamath Basin is a complex process with multiple dimensions. Attributes of the system which need to be represented in Basin conceptual models include:

- Five tiers of the ecosystem: 1) watershed inputs (e.g., water, coarse and fine sediments, nutrients, wood), 2) fluvial geomorphic processes, 3) habitat attributes, 4) biological interactions, and 5) fisheries actions;
- Stressors within each of these five tiers or domains that can directly or indirectly result in the decreased abundance, productivity, distribution and/or diversity of focal species; and
- Restoration and other management actions across Basin sub-regions which can reduce the identified stressors.

For the IFRMP we developed conceptual models for what we considered the primary drivers of habitat conditions for fish in the Basin (i.e. **fluvial geomorphic processes** and **water quality**) and for each of the **focal fish species** currently present within each Klamath Basin sub-region or potentially present if fish passage is restored in the future. Different participants in the Klamath IFRMP process will have different preferences for the best form of conceptual models, some preferring simpler representations of system components (the ‘lumpers’) while others will prefer more complex representations (the ‘splitters’). While detailed conceptual models may be helpful for certain purposes (e.g., description of a key process; development of a quantitative simulation model; detailed design of specific restoration action) simpler models will be more helpful in other cases to achieve the multi-purposes described above, particularly achieving a common understanding of the system. Many conceptual models of varying complexity have been developed previously in the Klamath for different sub-systems, or within particular areas of the Basin, or for particular species (e.g., USBR 2011, Kendall et al. 2014, Som et al. 2016). These provide useful background for informing the structure and content of the conceptual models developed here to support the Plan, but these past conceptual models are not easily merged.

We developed conceptual models of intermediate complexity, neither too simple nor too complex. They are intended to provide acceptable representations of Klamath Basin issues in a format that is relatively easy to understand, fulfill the stated purposes (described above), and stimulate collaborative engagement in technical workgroup and workshop settings. Attributes of the problem may vary across the four defined Basin sub-regions (Upper Klamath Lake, Middle/Upper Klamath River, Lower Klamath River, Klamath River Estuary) and across the 10 focal fish species (i.e., shortnose and Lost River suckers, redband trout, bull trout, coho, Chinook, steelhead, Pacific lamprey, green sturgeon, eulachon), and different phases/time periods of restoration. As this level of dimensionality has the potential to be overwhelming, some degree of simplification is essential.

1.2 IFRMP Conceptual Models

Our collaborative approach to development of conceptual models for the Klamath Basin attempted to establish clear connections between ecosystem elements and environmental stressors, to clarify the focus of restoration actions. We went through the following steps:

1. We assembled and reviewed all existing conceptual models for the Klamath basin (some of these were previously described within the Synthesis Report (ESSA 2017)).
2. Working collaboratively with regional scientists, we developed more detailed sub-models for fluvial geomorphic processes and water quality problems, to enable better specification of habitat restoration actions and monitoring indicators.
3. We developed a draft generic conceptual model structure that would be generally applicable to all focal fish species, sub-regions and major system components, to provide a common foundation. The generic conceptual model:
    a) has numbered/coded boxes for both actions and stressors within each of the five tiers described above (i.e., watershed inputs, fluvial geomorphic processes, habitat attributes, biological interactions, fisheries actions);
    b) includes both those stressors which are currently constraining the focal species' productivity, abundance, distribution and/or diversity; and those stressors which could become limiting in future restoration phases;
    c) visually clarifies how the effects of various restoration actions are expected to propagate through the system (by using colored dots and action codes within each stressor box to show which actions affect which stressors);
    d) provides an accompanying table which describes the hypothesized linkages between restoration actions, reductions in stressors, and expected biological responses;
    e) allows readers to easily distinguish between actions and stressors (e.g., by having them on different rows within each of the four tiers);
    f) allows readers to quickly ascertain the relative importance of different stressors (i.e. by different thicknesses of the borders around each stressor box – key proximate stressors with thicker borders); and
    g) avoids excessive complexity (i.e., "spaghetti" diagrams) and excludes arrows, instead noting in the supporting tables information about the key linkages affecting a given component, and the associated critical uncertainties.
4. We adapted the draft generic conceptual model into a set of *draft sub-regional conceptual models* for each of the focal species/functional species groupings found within that sub-region, either currently or potentially in the future (noting that not all species will be in all sub-regions, even if system connectivity is fully restored);

5. We used the draft generic and sub-regional conceptual models as a focus for the *conceptual modelling workshop,* catalyzing conversations by sub-regional work groups before, during and after the workshop, revising both the conceptual models and associated tables, and working towards agreement on:

   a) the *most important proximate stressors* for each functional species group within each sub-region; and

   b) the *types of restoration actions* required to reduce or eliminate the key stressors.

6. As model development proceeded, we organized the evolving conceptual models into a hierarchy, with the top of the hierarchy providing a common understanding of the whole system, and successive layers of the hierarchy enabling an increasingly detailed understanding of particular stressors or specific types of actions; and

7. We included all forms of models in the Plan (fluvial geomorphic, water quality, and focal species/sub-regional).

In the future, it will be important to revise the conceptual models as more is learned from research, restoration and monitoring activities.

We developed conceptual models for all focal fish species currently present within each sub-region or potentially present if fish passage is restored in the future. We combined some species with similar life-histories and presumed sensitivities into species functional groups to simplify the modeling exercise across species and sub-regions, converging to six distinct models: salmon (coho, Chinook, and steelhead combined), trout (redband and bull trout, combined for UKL sub-region), endangered suckers (Lost River and shortnose sucker combined), Pacific lamprey, green sturgeon, and eulachon. The conceptual model for the Klamath Estuary sub-region combines all focal species that utilize the estuary into a single model. We used symbols to identify particular stressors or actions that are specific to a particular species (for functional species group models) and/or life history stage.

Figure 1.1 shows the attributes of a conceptual model for an example Klamath focal species/functional species groups (i.e. endangered suckers). A species model is organized is organized by four primary tiers: watershed inputs (WI), fluvial geomorphic processes (FG), habitat (H) and biological interactions (BI). Additional tiers (i.e. fisheries actions (FA) and ocean conditions (OC)) are added to the species model where applicable (i.e. for currently harvested and/or anadromous species). Stressors are listed within each tier as are restorations that would be enacted within a particular tier (with the exception of ocean conditions). The sequence of cause-effect linkages flows from the top to the bottom of the figure for the first four tiers, so **actions in a given tier have potential benefits to both that tier and the other tiers listed below it**. Further considerations:

- **Watershed inputs** (top row)**:** While actions on the top row are essential to restoration of the tiers below it (i.e., increase supply of water, coarse sediment and wood to create and maintain habitat; decrease nutrients and fine sediment), it may be that some other actions need to occur first (e.g., floodplain re-contouring, removal of vulnerable buildings in floodplain) before those actions can occur. Decisions on the sequencing of actions will happen later in the process of developing the IFRMP.

- **Fluvial Geomorphic Processes** (second row): Actions that enable fluvial geomorphic processes which create and maintain habitat are listed here, addressing such stressors as channelization or lack of shallow, low velocity habitats.
- **Habitat** (third row): Actions to construct or manipulate fish habitat are included on this row, directly addressing such stressors as a shortage of spawning or rearing habitat, or water quality problems (e.g., high temperatures, low dissolved oxygen, and algal toxins).
- **Biological interactions** (fourth row): This tier applies to biological interactions which may be limiting fish populations (e.g., predation, competition with exotic species, hybridization), and the actions intended to decrease such stressors.
- **Target Fish** (fifth row): The yellow boxes represent various indicators of population response (e.g., the four criteria for Viable Salmonid Populations in McElhany et al. 2000, additional criteria for species with hatchery operations). These indicators will logically be near the top of the Objectives Hierarchy described in Section **Error! Reference source not found.**.
- **Fisheries Actions** (sixth row, if applicable to a species): This row lists actions to manage take of currently *harvested* focal fish species (e.g., fisheries management improvement, increased anti-poaching enforcement).
- **Ocean Conditions** (seventh row, if applicable to a species): For *anadromous* focal fish species (i.e., coho, Chinook, steelhead, Pacific lamprey, green sturgeon, eulachon) this row lists stresses that they may face during their period of ocean residency (e.g. predation, competition, food supply, environmental conditions). Defining potential restoration actions for these ocean stressors is outside the scope of the Plan.

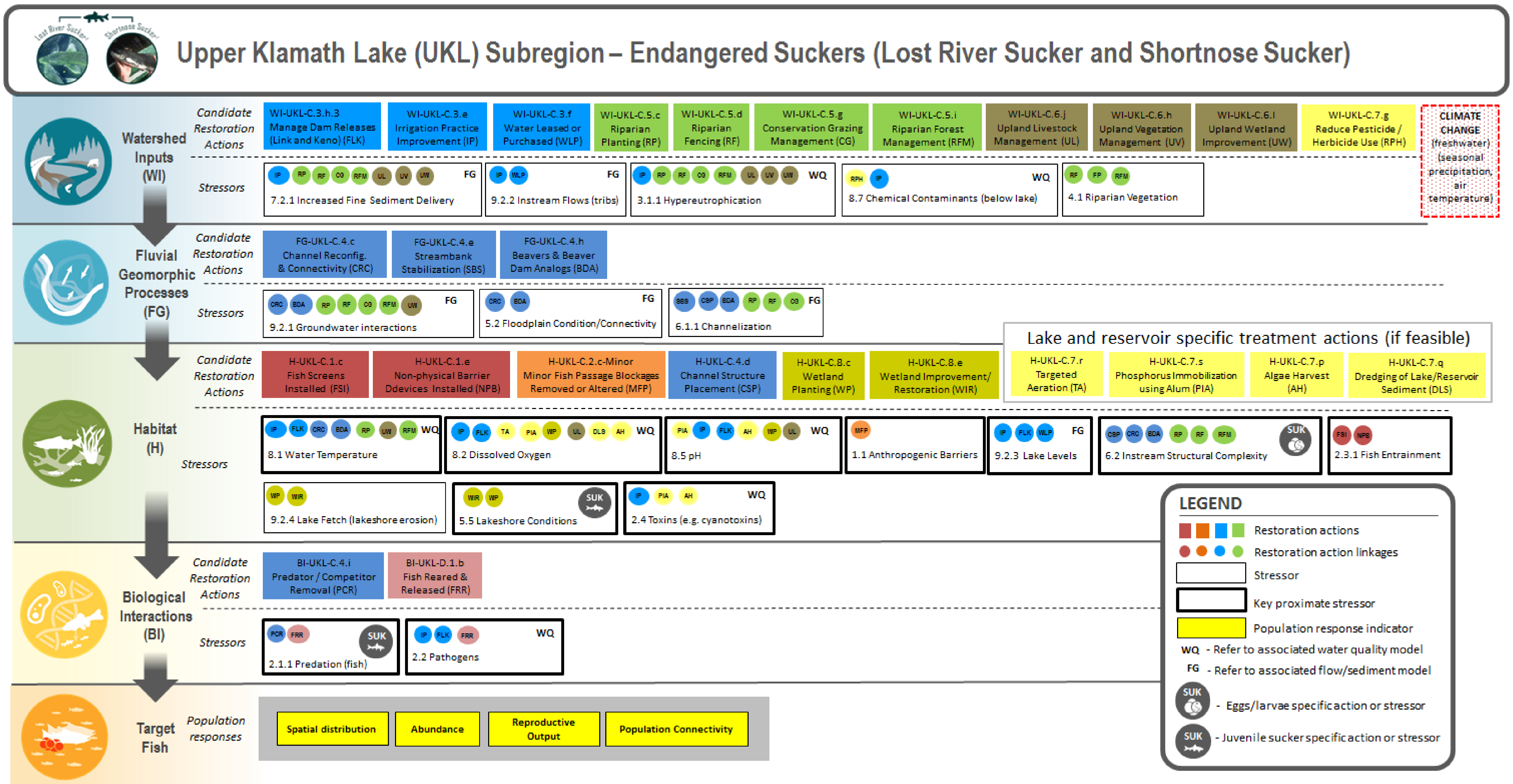


Figure 1.1. Example of the focal species conceptual modeln structure applied to endangered suckers (Lost River sucker and shortnose sucker species) in the Upper Klamath Lake (UKL) sub-region. Abbreviations: WI = Watershed Inputs; FG = Fluvial Geomorphic Processes; H=habitat; BI = Biological Interactions). Key "proximate" stressors for a species are identified by darker/thicker box lines.

For each sub-region, we developed an accompanying table (example in Table 1.1), describing the stressors in the focal species models, and the linkages to candidate restoration actions intended to reduce the stressors in the sub-region. Codes are used to save space. We identified the key "proximate" stressors (i.e., those considered most immediately responsible for causing direct effects on the fish) based on our review of the literature and discussions with sub-regional working groups. Finally, we developed a Restoration Actions Dictionary which identifies the hypothesized mechanism(s) by which each candidate restoration action would reduce the stressors, and critical uncertainties in either implementation or effectiveness of the action.

Multiple actions can work together to alleviate each identified stressor. Similarly, a single action may alleviate multiple stressors, either within a tier or across multiple tiers. Once we completed conceptual models for all focal fish species within in a sub-region, we were able to distinguish stressors that were common across species, from those that were unique to particular species. We were also able to identify restoration actions that could help address stressors across multiple focal fish species, versus those actions focused only on particular species.

Table 1.1. Example of the tabular information accompanying conceptual models for a sub-region (listing of stressors affecting the focal fish species/functional groups in the sub-region and the candidate restoration actions that could help alleviate/mitigate each stressor); draft example shown for Upper Klamath Lake (UKL) sub-region. Detailed descriptions/definitions for the coded restoration actions, hypothesized mechanisms regarding how the actions can minimize or mitigate stressors, and the critical uncertainties around each restoration action are described in the Klamath IFRMP Master Restoration Actions Dictionary.

Upper Klamath Lake Focal Species Models Summary (Stressors and Candidate Restoration Actions)			
Tier	**Stressors**	**Candidate Restoration Actions to Alleviate Stressor**	**Restoration Action Code**
Watershed Inputs	7.2.1 Increased fine sediment input/delivery	Upland livestock management (UL)	FG-UKL-C.6.j
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Upland livestock management (UL)	WI-UKL-C.6.j
		Upland vegetation management (UV)	WI-UKL-C.6.h
	9.2.2 Instream flow (tribs)	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Water leased or purchased (WLP)	WI-UKL-C.3.f
	3.1.1 Hyper-eutrophication	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.j
		Riparian forest management (RFM)	WI-UKL-C.5.j
		Upland livestock management (UL)	WI-UKL-C.6.j
		Upland vegetation management (UV)	WI-UKL-C.6.h
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Wetland improvement/ restoration (WIR)	WI-UKL-C.8.e
		Reduce pesticide/herbicide use (RPH)	WI-UKL-C.7.g

Upper Klamath Lake Focal Species Models Summary (Stressors and Candidate Restoration Actions)			
Tier	**Stressors**	**Candidate Restoration Actions to Alleviate Stressor**	**Restoration Action Code**
	8.7 Chemical contaminants (below the lake)	Irrigation practice improvement (IP)	WI-UKL-C.3.e
	4.1 Riparian vegetation	Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
Fluvial Geomorphic Processes	9.2.1 Groundwater interactions	Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers and beaver dam analogues (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Upland wetland improvement (UW)	WI-UKL-C.6.l
	5.2 Floodplain condition/connectivity	Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
	9.2.3 Channelization	Streambank stabilization (SBS)	FG-UKL-C.4.e
		Channel structure placement (CSP)	H-UKL-C.4.d
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
Habitat	8.1 Water temperature	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Riparian forest management (RFM)	WI-UKL-C.5.i
	8.2 Dissolved oxygen	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Targeted aeration (TA)	H-UKL-C.7.r
		Phosphorus immobilization using alum (PIA)	HI-UKL-C.7.s
		Wetland planting (WP)	H-UKL-C.8.c
		Upland livestock management (UL)	WI-UKL-C.6.j
		Dredging of lake/reservoir sediment (DLS)	H-UKL-C.7.q
		Algae harvest (AH)	H-UKL-C.7.p
	8.5 pH	Phosphorus immobilization using alum (PIA)	H-UKL-C.7.s
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Algae harvest (AH)	H-UKL-C.7.p
		Wetland planting (WP)	H_UKL-C.8.c
		Upland livestock management (UL)	WI-UKL-C.6.j

Upper Klamath Lake Focal Species Models Summary (Stressors and Candidate Restoration Actions)			
Tier	**Stressors**	**Candidate Restoration Actions to Alleviate Stressor**	**Restoration Action Code**
	1.1 Anthropogenic barriers	Minor fish passage blockages removed or altered (MFP)	H-UKL-C.2.c-Minor
	9.2.3 Lake levels	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Water leased or purchased (WLP)	WI-UKL-C.3.f
	6.2 Instream structural complexity	Channel structure placement (CSP)	H-UKL-C.4.d
		Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
	2.3.1 Fish entrainment	Fish Screens Installed (FSI)	H-UKL-C.1.c
		Non-physical barrier devices installed (NPB)	H-UKL-C.1.e
	9.2.4 Lake fetch	Wetland planting (WP)	H_UKL-C.8.c
		Wetland improvement (WIR)	H-UKL-C.8.e
	5.5 Lakeshore conditions	Wetland planting (WP)	H_UKL-C.8.c
		Wetland improvement (WIR)	H-UKL-C.8.e
	2.4 Toxins (e.g., cyanotoxins)	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Phosphorus immobilization using alum (PIA)	H-UKL-C.7.s
		Algae harvest (AH)	H-UKL-C.7.p
Biological Interactions	2.1.1 Predation (fish)	Predator / Competitor Removal (PCR)	BI-UKL-C.4.i
	2.1.1 Competition	Fish Reared & Released (FRR)	BI-UKL-D.1.b
	2.2 Pathogens	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage Dam Releases (Link and Keno) (FLK)	WI-UKL-C.3.h.1
		Fish Reared & Released (FRR)	BI-UKL-D.1.b

1.2.1 Fluvial Geomorphic Processes Sub-Models

Fluvial geomorphic processes are a foundational consideration affecting the creation and maintenance of habitat for all fish species in the Klamath basin. We therefore created separate conceptual sub-models (see Appendix A) to help guide the selection of basin restoration actions and associated monitoring indicators. The fluvial geomorphology sub-models are at a more detailed level of organization than the sub-regional/focal species models (i.e., lower in the hierarchy of conceptual models), providing greater specificity in the description of stressors and restoration actions. Issues defined through development of the fluvial geomorphology models have helped to inform the content of the broader sub-regional/focal species models.

Fluvial geomorphic processes in the Klamath Basin and the current and/or potential future restoration actions that could improve impaired elements in this regard are represented through detailed conceptual diagrams (presented in Appendix A). These conceptual diagrams lay out the specific cause-effect pathways that lead from current and potential future Klamath Basin restoration actions through the effects on hydrological, physical and biological stressors and the broad possible responses of the Basin ecosystem to these actions. Appendix A also provides a text-based summary of the various factors that have altered fluvial geomorphic processes in the Basin, historically, currently, and potentially in the future as a foundation for the development of the fluvial geomorphology sub-models.

Statements of cause and effect linkages illustrated in the fluvial geomorphology conceptual diagrams (Appendix A) for the Klamath Basin are presented in Table A - 1 in Appendix A, with the hypothesized mechanisms of each possible restoration action. The key hypotheses identified propose that fluvial geomorphology-related restoration actions will have a beneficial effect on focal fish species by increasing the amount of water available for fish needs and by increasing the diversity, complexity and extent of fish habitats. It is further hypothesized that fluvial geomorphology-related restoration actions will reduce impairments to fish habitat caused by excessive fine sediments, water temperature, and other water quality stressors.

While broad, these hypotheses can be evaluated in the future via specific performance indicators to assess success of implemented restoration actions or other system needs within an adaptive management framework. Some candidate performance indicators for fluvial geomorphology actions can be qualitative but the majority of those identified should be largely quantitative, allowing for clearer tracking and comparisons over time.

Tracking the benefits of restoration actions can be used to evaluate the degree to which the four-target fluvial geomorphology-related systemic responses in the Basin (see Appendix A) are being achieved:

1) Do restoration actions promote self-maintaining physical processes to support channel complexity?
2) Have fish habitat objectives been achieved?
3) Were water temperature criteria met?
4) Was fish disease minimized?

1.2.2 Water Quality Processes Sub-Models

Water quality processes are considered a key cross-cutting issue affecting habitat conditions for all focal fish species in the Klamath Basin. We therefore also created separate water quality conceptual sub-models to illustrate causal links between potential restoration actions and hypothesized effects on processes that determine quality of water for fish in the Klamath Basin. Detailed conceptual diagrams for the UKL, tributaries to UKL, Keno Reservoir, MUK, and LKR sub-regions are presented in Appendix A, with associated supporting tables of hypothesized effects. The water quality sub-models (developed collaboratively with experts in basin water quality issues) are at a more detailed level of organization than the sub-regional/focal species models, providing greater specificity in the description of stressors and restoration actions. This is consistent with the concept of having a hierarchy of conceptual models. Issues defined through development of the water quality models are used to inform associated content within the broader sub-regional/focal species models. Appendix A also provides a text-based summary of the various factors that have altered water quality processes in the Basin, historically, currently and potentially in the future, as a foundation for the development of the water quality sub-models.

Many restoration strategies are currently being used or else are being considered for the future to improve water quality throughout the Klamath River Basin. Proposed changes in water use and reduced loading of nutrients to tributaries that flow to Upper Klamath lake, may be expected to do two things: One is to lower water temperature and increase stream flows through a connected floodplain; the second is to lower availability of nutrients that drive biological production in those streams and through the floodplain of Upper Klamath Lake. These actions will be the first step in curtailing the hypereutrophic state of Upper Klamath Lake. By limiting nutrient transport, the mobility of agricultural chemicals other than nutrients in manure and other sources would also be reduced, leading to reduced incidence of aquatic toxicity.

An overall response in Upper Klamath Lake will be reduced nutrient loading over time leading to a potential decline in production of phytoplankton and a decline in organic matter settlement to sediments that causes an exacerbation of hypereutrophication via oxygen demand and phosphorus release from sediments. While a decline in nutrient loading from external sources could happen in the short term (i.e., less than 10 years depending on scale of implementation of restoration actions), an actual change in trophic state of Upper Klamath Lake may not be apparent for much more than 10 years and potentially decades. This discrepancy will occur because Upper Klamath Lake presently contains nutrients in its sediments due to uptake and sedimentation processes occurring since the lake was formed and particularly since nutrient loading from land use started in the early 1920's. Given that waters of the Klamath Basin are naturally rich in phosphorus due to weathering of volcanic parent materials in the headwaters, external phosphorus loading will continue, and internal nutrient loading will contribute a large part of the pool of phosphorus that is used for biological production in the lake each year. The internal phosphorus loading will occur in places where anoxia is present or dissolved oxygen concentrations decline to low enough levels to favour phosphorus release from sediments. These sources and conditions will not go away. As a result, Upper Klamath Lake will change from a hypereutrophic lake at present to a eutrophic lake once restoration actions take effect. A further change to a mesotrophic state will not occur because of continued high external loading of naturally occurring phosphorus and long-lasting internal loading from sediments. The result will be a highly productive lake with continued oxygen demand but less extreme than at present. Diurnal pH fluxes will moderate but will still be present. Water temperature will remain high in summer and fall, potentially in a range too high to support salmonids because heating from solar irradiance will not change and potentially increase with climate forcing.

Keno Reservoir can be considered the water quality and fish passage bottleneck of the Klamath River. With continued nutrient loading from Upper Klamath Lake even with full implementation of restoration actions upstream of the lake and continued nutrient return from sediments, production of organic matter leading to anoxia over a shallow water column will continue to limit suitability of the reservoir to support fish. This hypothesis is particularly relevant to salmonids that favour cooler water than is found in Keno Reservoir in summer and early fall and need oxygen that is absent for much of the same period. This condition is not expected to change over decades of upstream restoration actions. Aggressive actions such as dredging, aeration, and alum treatments may alleviate some of the stresses on fish, but they are disruptive in themselves (e.g., dredging). They also only would treat the symptoms not the cause, which is external nutrient loading from upstream and internal nutrient loading from sediments. A hypothesis is that Keno Reservoir will continue to be a bottleneck for passage of fish even if major dam removal occurs, effecting salmonids during upstream migration to spawning areas and downstream migration of smolts. Some adults will successfully migrate if they attempt passage late in the run when dissolved oxygen is present, albeit at low concentrations. Some smolts will successfully migrate if they attempt passage early in the spring when dissolved oxygen is present, again at low concentrations. As a result, the Keno bottleneck will not completely block fish passage, but the neck of the bottle is slim and may only open within tight time windows. This conundrum will limit upstream passage of fish and potentially limit use of spawning and rearing habitat in upper reaches of the Klamath Basin.

Greatest response in the shortest time would come from removal of the four dams in the mid/upper Klamath River. The shear magnitude of change from hypereutrophic lentic dominated reaches to a completely connected river is expected to lower water temperature, reduce diel variation in pH and dissolved oxygen concentration, reduce toxins, and support a highly productive fish food web downstream of the dams. High concentrations of fine particulate organic matter and low inter-gravel dissolved oxygen concentrations that presently favour parasites of salmon (e.g., *C. shasta*) should not be present after dam removal, thus reducing incidence of mortality in migrating salmon caused by parasitism and disease. While long-term recovery of water quality in the mid/upper Klamath River is expected to occur, there will likely be short term issues with poor water quality. Dam removal is expected to produce turbid conditions in the river as fine sediment trapped behind the dams currently is released and transported downstream. Strategies must be developed to release water and sediment in ways to prevent acute lethality in fish and prevent undue embeddedness in river substrata that may inhibit production of fish food organisms. If undue effects on fish and fish habitat do occur, they are however expected to quickly dissipate and lead to rapid recolonization by fish and the fish food web as sediment load from the reservoirs is transported downstream.

Dam removal in the mid/upper Klamath River is also expected to be the main driver of improved water quality in the Lower Klamath River and Klamath River Estuary. Main changes from dam removal include lower water temperature because heating in reservoirs will be removed and lower incidences of disease and parasitism because organic matter that is conducive to parasite hosts will be removed with the increased fluvial transport of sediments.

1.2.3 Focal Fish Species Subregional Conceptual Models

The focal fish species found in the defined Klamath IFRMP sub-regions are:

- **Upper Klamath Lake (UKL) sub-region:** Trout (Bull Trout, Redband Trout), and endangered suckers (Lost River Sucker and Shortnose Sucker). Additional focal fish species that may be present in the UKL sub-region in the future (if passage can be successfully restored through dam removal or other actions) are Salmon (Chinook, Coho, Steelhead), and Pacific Lamprey.
- **Middle/Upper Klamath River (MUK) sub-region:** Salmon (Chinook, Coho, Steelhead), Pacific Lamprey, Redband Trout, endangered suckers (Lost River Sucker and Shortnose Sucker), and Green Sturgeon.
- **Lower Klamath River (LKR) sub-region:** Salmon (Chinook, Coho, Steelhead), Pacific Lamprey, Green Sturgeon, and Eulachon.
- **Klamath River Estuary (KRE) sub-region:** Eulachon, Green Sturgeon, Pacific Lamprey, and Salmon (Chinook, Coho, Steelhead)

Detailed conceptual diagrams identifying the specific stressors on focal species fish groupings found in the Upper Klamath Lake (UKL), Mid/Upper Klamath River (MUK), Lower Klamath River (LKR), and Klamath River Estuary (KRE) sub-regions and the potential restoration actions that could help to mitigate/minimize these stressors are presented in Appendix A. Text-based descriptions of cause and effect links between stressors and restoration actions that are illustrated within the focal species conceptual diagrams are also described in more detail in supporting sub-region-specific tables in Appendix A. For the UKL sub-region conceptual diagrams are provided both for focal species that are currently present in the sub-region and for focal fish species that may be present in that sub-region in the future (if passage for anadromous fish should be restored) (i.e., Chinook, Coho, Steelhead, and Pacific Lamprey). For the KRE sub-region only a single, combined conceptual diagram is presented of the stresses/associated potential restoration actions for the suite of focal fish species found in the estuary, as information available at this time does not allow clear separation of stressors by species.

1.3 Synthesis of Key Stressors

Stressors on fish and fish habitats that were identified within each of the individual conceptual diagrams presented in Appendix A are summarized in Table 1.2 across the suite of focal species/functional groups found within each sub-region. Potential stressors for Chinook, coho, steelhead, and Pacific lamprey are also included in the summaries for the UKL sub-region, given their expected future movement into this sub-region once passage is re-established for these species. The key “proximate” stressors by focal fish species/functional group as identified within the conceptual diagrams are presented in Table 1.2 as yellow highlighted cells. The summary thus provides an overview of key stressors that are unique to a particular fish species/group or else are common across multiple species/functional groups. This initial summary of key sub-regional stressors (supplemented and further validated through continuing IFRMP discussions) is intended to help to focus design considerations for IFRMP restoration actions that can alleviate multiple stressors and potentially benefit multiple focal fish species.

Table 1.2: Synthesis of suggested key "proximate" stressors affecting focal fish species/functional groups across Klamath Basin sub-regions (as identified through IFRMP Synthesis Report and technical group conceptual modeling exercises).

(A) Upper Klamath Lake (UKL) sub-region

Stressor Tier	Stressor	Focal Fish Species[1,2]				
		SU	RT	BT	CH/CO/ST (future)	PL (future)
Watershed inputs (WI)	9.2.1 Klamath River flow regime		X		X	X
	9.2.2 Instream flow (tribs)	X	X	X	X	X
	9.2.4 Lake disturbance (e.g. fetch)	X	X		X	
	8.7 Chemical contaminants (below UKL)	X				
	3.1.1 Hypereutrophication	X	X		X	
	7.2.1 Increased fine sediment input/delivery	X			X	
	7.1.1 Decreased coarse sediment input/delivery				X	
	4.2 Large woody debris		X	X	X	X
Fluvial-geomorphic processes (FG)	9.2.1. Groundwater interactions	X	X	X	X	X
	6.1.1 Channelization		X	X	X	X
	6.2.3 Fine sediment retention		X	X		X
Habitat (H)	8.1 Water temperature	X	X	X	X	X
	8.2 Dissolved oxygen	X	X	X	X	X
	8.5 pH	X	X	X		X
	1.1 Anthropogenic barriers	X	X	X	X	X
	6.2 Instream structural complexity	X	X	X	X	X
	9.2.3 Lake levels	X				
	2.3.1 Fish entrainment	X	X	X	X	X
Biological Interactions (BI)	2.1.2 Predation (fish)	X	X	X	X	X
	2.1.2 Predation (mammals/birds)				X	X
	2.2 Pathogens	X	X		X	
	3.2 Competition				X	
	10.1 Hybridization			X		
	3.3.1 Salmon prey		X	X		
Fisheries Actions (FA)	11.1 Overharvest (& bycatch)		X		X	X

(B) Mid/Upper Klamath River (MUK) sub-region

Stressor Tier	Stressor	Focal Fish Species					
		PL	CH	CO	ST	RT	GS
Watershed inputs (WI)	9.3.1 Klamath River flow regime	X	X	X	X	X	X
	9.2.2 Instream flow (tribs)	X	X	X	X	X	
	7.2.1 Increased fine sediment input/delivery	X	X	X	X		X
	7.1.1 Decreased coarse sediment input/delivery	X	X	X	X		
	4.2 Large woody debris	X	X	X	X	X	
	3.1.2 Marine nutrients	X	X	X	X	X	
	3.1.1Hypereutrophication					X	
	8.7 Chemical contamination						X
Fluvial-geomorphic processes (FG)	9.2.1. Groundwater interactions	X	X	X	X	X	
	6.1.1 Channelization	X	X	X	X	X	
	6.2.3 Fine sediment retention	X	X	X	X	X	X
	8.4 Total suspended sediment						
Habitat (H)	8.1 Water temperature	X	X	X	X	X	X
	8.2 Dissolved oxygen	X	X	X	X	X	X
	8.5 pH	X	X	X	X	X	

[1] SU = endangered suckers (Lost River and Shortnose suckers), RT = Redband Trout, BT = Bull Trout, CH = Chinook, CO = Coho, ST = Steelhead, CH/CO/ST = Chinook, Coho & Steelhead combined, PL = Pacific Lamprey, GS = Green Sturgeon, EU = Eulachon

[2] Yellow highlighted cells in this table represent suggested key stressors for a focal species or species group within a particular sub-region

	1.1 Anthropogenic barriers	X	X	X	X	X	X
	6.2 Instream structural complexity	X	X	X	X	X	
	2.3.1 Fish entrainment		X	X	X	X	X
	6.2.2 Suitable (cobble) substrate						X
	6.2.1 Deep pools						X
	7.3. Contaminated sediment						X
Biological Interactions (BI)	2.1.1 Predation (fish)	X	X	X	X	X	X
	2.1.2 Predation (mammals/birds)	X	X	X	X		X
	2.2 Pathogens		X	X	X	X	
	3.2 Competition		X	X	X		
	3.3.2 Abundance of invertebrate prey						X
Fisheries Actions	11.1 Overharvest (& bycatch)	X	X	X	X	X	X

(C) Lower Klamath River (LKR) sub-region

Stressor Tier	Stressor	Focal Fish Species					
		GS	EU	CH	CO	ST	PL
Watershed inputs (WI)	9.3.1 Klamath River flow regime	X	X	X	X	X	X
	7.2.1 Increased fine sediment input/delivery	X	X	X	X	X	
	3.1.2 Marine nutrients			X	X	X	X
	8.7 Chemical contaminants	X	X				
	3.3.3 Nutrient influx		X				
	3.1.2 Marine nutrients			X	X	X	X
	4.2 Large woody debris			X	X	X	X
	9.2.2. Instream flows (tribs)			X	X	X	X
	7.1.1 Decreased coarse sediment input/delivery			X	X	X	X
Fluvial-geomorphic Processes (FG)	8.4 Total suspended sediments	X	X				
	6.1.1 Channelization			X	X	X	X
	9.2.1 Groundwater interactions			X	X	X	X
Habitat (H)	8.1 Water temperature	X	X	X	X	X	X
	8.2 Dissolved oxygen	X		X	X	X	X
	8.5 pH			X	X	X	X
	1.1. Anthropogenic barriers	X		X	X	X	X
	6.2.1 Deep pools	X					
	6.2.2 Suitable (cobble) substrate	X					
	6.2.3 Fine sediment retention			X	X	X	X
	2.3.1 Fish entrainment (larvae/juveniles)	X	X				
	7.3.1 Contaminated sediment	X	X				
	6.2 Instream structural complexity			X	X	X	X
	6.2.3. Fine sediment retention			X	X	X	X
Biological Interactions (BI)	2.1.2 Predation (fish)	X	X	X	X	X	X
	2.1.2 Predation (mammals/birds)	X		X	X	X	X
	3.3.2 Abundance of invertebrate prey	X					
	2.2 Pathogens			X	X		
	3.2 Competition			X	X	X	
Fisheries Actions	11.1 Overharvest (& bycatch)	X	X	X		X	X

(D) Klamath River Estuary (KRE) sub-region

Stressor Tier	Stressor	All focal species in sub-region combined
Watershed inputs (WI)	9.3.1 Klamath River flow regime	X
	7.2.1 Increased fine sediment input/delivery	X
	8.7 Chemical contaminants	X
	3.3.3a Nutrients	X
	3.3.3.b Particulate organic matter	X
	9.2.2 Instream flows (estuarine tributaries)	X

	4.1 Riparian vegetation	X
Fluvial-geomorphic Processes (FG)	6.2.3 Fine sediment retention	X
Habitat (H)	8.1 Water temperature	X
	8.6 Salinity	X
	8.5 pH	X
	8.4 Total suspended solids (TSS) (deposits/turbidity)	X
	8.2 Dissolved oxygen	X
	7.3.1 Contaminated sediment	X
	2.4 Toxins (e.g. cyanotoxins)	X
	4.2 LWD	X
	3.1 Altered primary productivity	X
	6.2 Instream structural complexity	X
	5.1 Wetland condition (estuarine wetlands)	X
	5.3.1 Estuary size	X
	5.3.2 Estuary lagoon depth	X
	5.3.3 Macro algae/macrophyte abundance & distribution	X
	5.5.3 Salt wedge (size & location)	X
	5.3.5 Estuary "perching" (frequency & duration)	X
	5.3.6 Estuary mouth closure (frequency & duration)	X
	5.3.7 Estuary plume (size)	X
	5.4 Nearshore conditions	X
Biological Interactions (BI)	2.1.1 Predation (fish)	X
	2.1.2 Predation (aquatic mammals)	X
	2.2 Pathogens	X
	3.2.2a Abundance of invertebrate prey	X
	3.3.2b Abundance of forage fish	X
	3.2 Competition	X
Fisheries Actions	11.1 Overharvest (& bycatch)	X

General issues of current concern within each of the defined Klamath IFRMP sub-regions include:

Upper Klamath Lake (UKL) sub-region:

The UKL sub-region is largely semi-arid with the hydrology of the tributaries upstream of Klamath Lake driven by spring snowmelt, although significant cold-water springs also contribute to flow throughout the area and provide refuge habitat for resident fish (Stanford et al. 2011). The aquatic habitats of the region are dominated by large shallow lakes, extensive marshlands, and relatively low gradient rivers (Adams et al. 2011). Extensive water diversions in the UKL sub-region for agriculture within USBR's Klamath Project and other smaller irrigation districts, however, have reduced flow inundation events, eliminated wetlands, and disconnected stream channels from their floodplains, while years of grazing have reduced riparian vegetation that provided shading for streams (Stanford et al. 2011).

Upper Klamath Lake is Oregon's largest lake but is hypereutrophic with massive blooms of blue-green algae occurring annually, owing to intrinsic fertility related to shallow water, warm climate, and accelerated inputs of nutrients from agricultural runoff. These blooms produce poor water quality including elevated pH and low dissolved oxygen (Kann and Smith 1999; Kann and Welch 2005). Much of the water column if hypoxic or anoxic during periods of thermal stratification (NRC 2004 as cited in Stanford et al. 2011). The section of the mainstem Klamath River from Keno Dam to Upper Klamath Lake also suffers from poor water quality and is often dominated by blue-green algae and characterized by seasonal low DO concentrations. High water temperatures and degraded water quality in the Keno Reservoir may represent barriers for fish migration during mid-summer even if passage over dams is created (Stanford et al. 2011). Greater detail on these water quality issues in the UKL sub-region is provided above in Section 2.2.2 in the Klamath IFRMP.

Middle/Upper Klamath River (MUK) sub-region:

The MUK sub-region is more bedrock in nature creating more incised river channels and along with a wetter, more marine climate has higher flows and cooler temperatures than the UKL sub-region. Processes in the upper section of the Klamath River in the MUK sub-region are strongly influenced by the presence of four reservoirs behind small hydropower dams that currently block the upstream passage of anadromous fish. While high nutrient concentrations from the upper basin are ameliorated somewhat by flows below Keno Dam, poor water quality can occur in the major reservoirs resulting in toxin-producing cyanobacteria blooms and anoxic hypolimina (Stanford et al. 2011).

Timing and magnitude of flows into the mainstem Klamath River below the reservoirs are regulated by Iron Gate Dam and this can have significant influence on geomorphic processes and conditions in the river, as well as affecting the survival of juvenile and adult salmon (Stanford et al. 2011). Greater detail on fluvial geomorphic issues in the Klamath River below the major dams is provided in Section 2.2.1 in the Klamath IFRMP. The absence of flushing flows, long durations of low flows and high water temperatures in the river are all considered factors contributing to the often high rates of disease in Klamath salmon resulting from pathogens like the myxosporean parasites *C. Shasta* and *P. minicornis*, as well as by bacterial and parasitic gill infections.

Anthropogenic impacts across the MUK sub-region include dams and hatcheries, land and water management, and mining and forestry practices (Adams et al. 2011). Impacts to tributary systems in the MUK sub-region include fish stranding from dewatering, grazing impacts on stream riparian areas, the diversion of water from numerous small dams/water withdrawals for agriculture, and the presence of extensive logging road networks. Historical impacts from suction dredging for gold are also present in the Scott and Salmon watersheds with associated issues with fine sediment deposition in spawning reaches (Stanford et al. 2011).

Lower Klamath River (LKR) sub-region:

The LKR sub-region includes the largest tributary of the Klamath, the Trinity River, and the South Fork Trinity, which is California's largest unregulated watershed. Inter-basin diversion of water into California's Central Valley can take, on average, approximately 51% of the Trinity's historic annual flow at Lewiston Dam, the diversion point (NRC 2008). Water diversions are based on five water-year types as described in USFWS/HVT (1999) and are currently managed by the Trinity River Management Council. The largest effect of this diversion is on spring flows (Vanderkooi et al. 2011). Reduced flows have caused channel degradation, impeded channel forming processes, and created floodplain disconnection.

Other issues include inaccessible upper river salmon habitat, lack of gravel recruitment, and erosion of fine sediments into streams from logging, grazing, and past placer mining (Stanford et al. 2011). The Trinity River hatchery was established to mitigate for the loss of historical salmon production in 160km upstream of the dam sites (Vanderkooi et al. 2011). Cool streams entering the lower reach of Klamath River below the confluence with the Trinity represent important refugia habitat for fish in the LKR sub-region (Vanderkooi et al. 2011) but can be prone to excessive fine sediment loading due to erosive soils and the heavy logging activity and associated high road densities in the area (Stanford et al. 2011).

Klamath River Estuary (KRE) sub-region:

The Klamath River estuary is relatively small and short, in terms of the size of its watershed in relation to other large river systems (although the overall size of the estuary varies and may have been larger, historically). Deltaic processes are not evident, and the estuary is small and similar to a pulsating or protected lagoon (Vanderkooi et al. 2011). Tidal influence only extends upriver to about river km 6.5 during typical high tides with saltwater intrusion ranging from only 4 to 6 km upstream of the mouth. Despite these limitations, the estuary is considered to serve an essential role to many Klamath River fishes as nursery and rearing habitat. It also functions as a critical staging area for anadromous species as they transition between freshwater and marine environments. Within the estuary, wetland, slough, and off-channel habitats provide important foraging areas for juvenile salmon and other brackish water fishes (Vanderkooi et al. 2011).

Beaver ponds in many of the small tributaries to the estuary are known to be important seasonal habitat for juvenile coho salmon and steelhead (Patterson 2009). Water quality within the estuary is likely a critical factor in the suitability of estuarine habitat fish, particularly juvenile salmonids. High water temperatures, as well as elevated nutrient and particulate organic matter (POM) loads from the river upstream may be impairments to the estuary (Stanford et al. 2011). Although the Klamath River estuary is located far downstream of Klamath River dams, water quality in the estuary can be affected by dam operations. Estuarine water temperature is linked to salinity, upstream hydrology, and periods of estuary mouth closure. Small changes in summer baseflows from the current operation of dams and water diversions on the Klamath and Trinity Rivers may affect mouth closure dynamics in the Klamath River estuary (Stillwater Sciences 2009). Mouth closure (caused by formation of a sand berm across the mouth of the estuary) can reduce the size of the estuary's salt water wedge, decrease overall salinity, and subsequently increase water temperatures in the estuary (Hiner 2006). Isolation of the estuary from the ocean for more than a few days can be detrimental to water quality and biota by allowing water temperatures to increase beyond optimal growth thresholds or critical thermal maxima for outmigrating salmonids and remain at untenable levels until the mouth is breached again (Stillwater Sciences 2009).

Potential impacts to estuarine habitats associated with increased sedimentation from timber practices and past mining upstream are not well understood (Adams et al. 2011). Nor is the role of the estuary in the transmission of diseases to migratory anadromous fishes. The largest concerning impact on the Klamath Basin estuary for the future may be projected climate change-induced sea level rise which could have profound effects on the estuary and lower river habitats (Adams et al. 2011).

1.4 Dependencies Across Sub-regions

The stressors affecting focal species summarized in Section 1.3 are categorized within Klamath Basin sub-regions. In reality there will be multiple biophysical interdependencies across the sub-regions relating to these stressors and their affects on focal fish species (see examples in Table 1.3). Habitats in lower river sub-regions will require sufficient inputs of water, nutrients, wood, and coarse sediment at the right times from upstream areas to maintain suitable conditions for resident fish. Migratory species will require suitable life history-stage specific habitats potentially across every sub-region and the ability to migrate successfully between the sub-regions.

It must also be recognized that while generally there will be an expectation that actions reducing stressors to the benefit of one species will also assist other fish species, there will be some cases where such actions may be detrimental to another species (e.g., restoring passage for migratory salmonids if major dams were removed may also clear a path for invasion by exotic species not previously present in areas above the dams). Such potential trade-offs between fish species across the sub-regions will need to be considered for fully evaluating the benefits and risks of potential restoration actions.

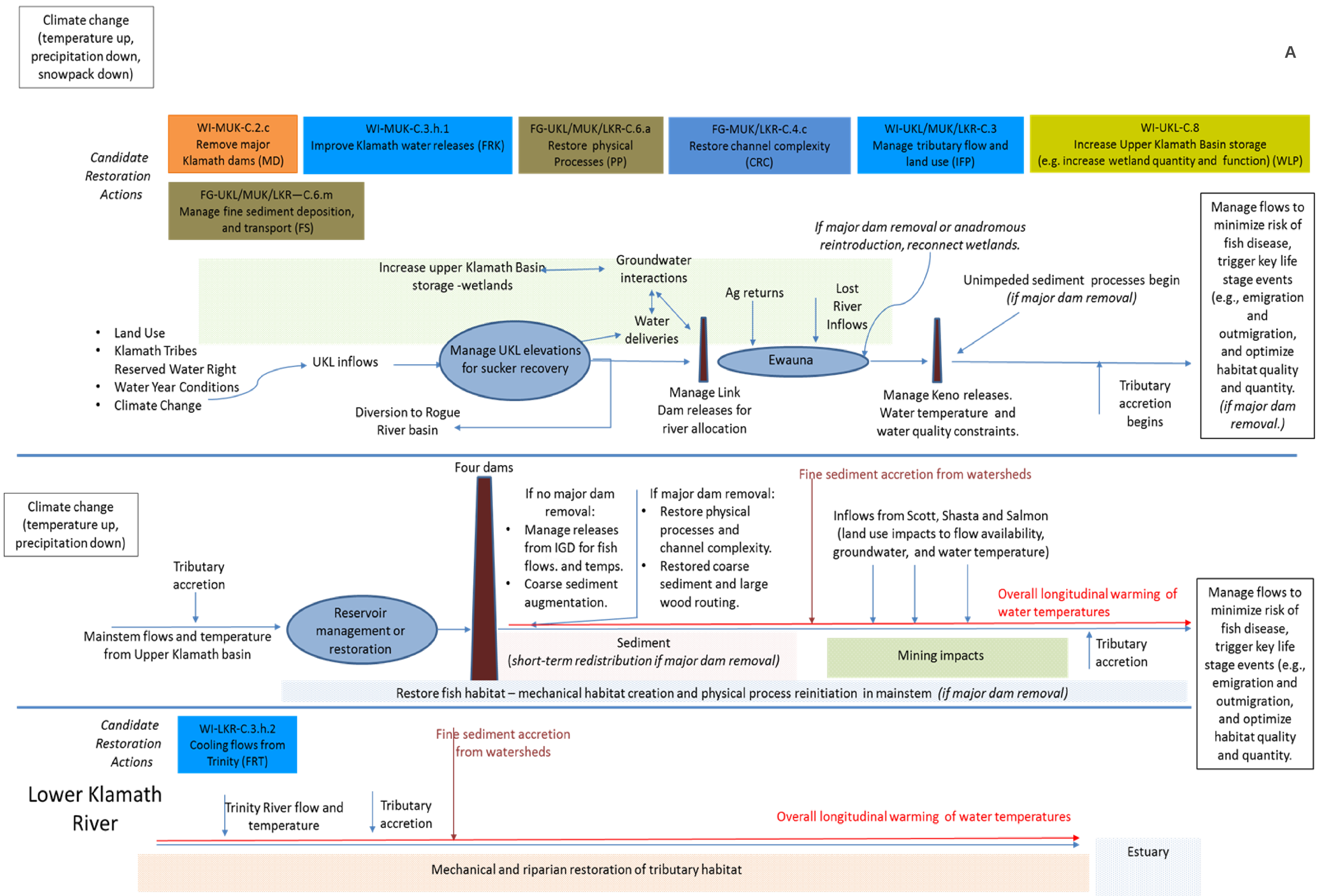
Within-species considerations may also exist and will also need to be identified (e.g., implications of temporal aspects of current and future dam/diversion operations that can/could benefit or impede upstream and downstream migration conditions for various populations of anadromous fish (e.g., spring vs. fall Chinook).

Table 1.3: Examples of possible biophysical interdependencies across sub-regions. Greyed cells represent interactions within a region. Off-diagonal cells represent movement of something from the sub-region listed on that row to the sub-region in that column. This table assumes that spawning and rearing of anadromous salmonids and Pacific Lamprey will become re-established in the Upper Klamath Lake (UKL) sub-region.

To→ / From↓	Klamath Estuary (KRE) / Ocean	Lower Klamath River (MUK)	Mid/Upper Klamath River (MUK)	Upper Klamath Lake (UKL)
Klamath Estuary / Ocean		• Marine survival rates • Import of marine nutrients • Disease organisms	• Marine survival rates • Import of marine nutrients • Disease organisms	• Marine survival rates • Import of marine nutrients • Disease organisms
Lower Klamath River (LKR)	• Outgoing migration of salmon smolts • Delivery / timing of freshwater • Fine and coarse sediment • Water quality		• Upstream migration of adult salmon • Disease organisms	• Upstream migration of adult salmon • Disease organisms
Mid/Upper Klamath River (MUK)	• Outgoing migration of salmon smolts	• Hydrological flow regime • Transport of LWD, fine sediment, coarse		• Upstream migration of adult salmon

		sediment, food organisms • Water quality (e.g., nutrients, temperature, pH, DO) • Outgoing parr and smolts		
Upper Klamath Lake (UKL)	• Outgoing migration of salmon smolts	• Hydrological flow regime • Transport of LWD, fine sediment, coarse sediment, food organisms • Water quality (e.g., nutrients, temperature, pH, DO, toxic algae) • Outgoing parr and smolts	• Hydrological flow regime • Transport of LWD, fine sediment, coarse sediment, food organisms • Water quality (e.g., nutrients, temperature, pH, DO, toxic algae) • Outgoing parr and smolts	

Appendix A: Conceptual Models



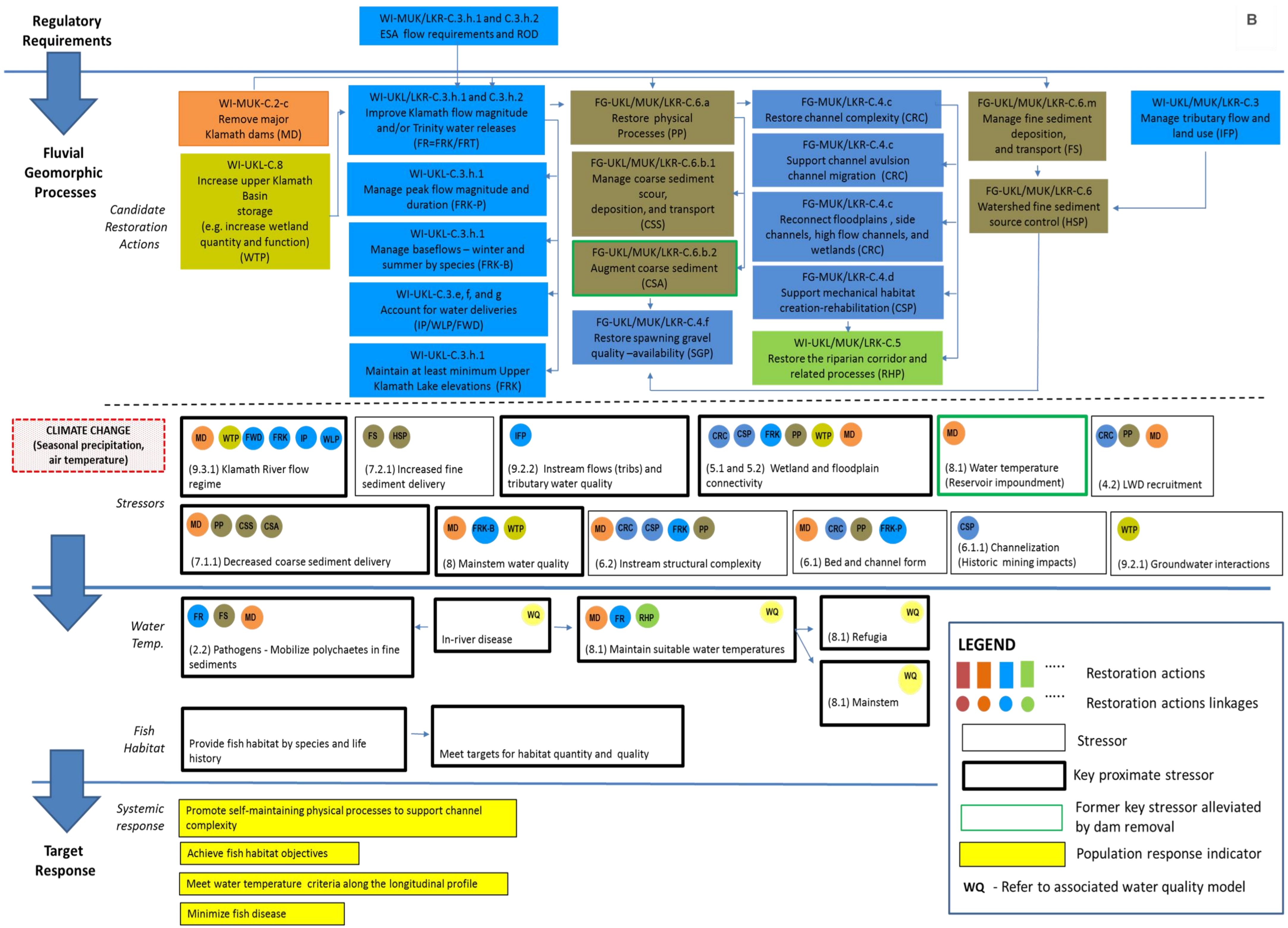


Figure A - 1. Conceptual diagrams of fluvial geomorphic processes in the Klamath Basin and effects of current and potential future candidate restoration actions on key related stressors. (A) provides a dynamic representation of geomorphic process interactions while (B) shows greater detail as to the linkages between specific geomorphic process-related stressors and the actions that could minimize or mitigate their impacts.

Table A - 1. Links between fluvial geomorphology-related stressors for fish across Klamath Basin sub-regions, candidate restoration actions and hypothesized effects of restoration actions on fish habitat, in support of the detailed linkages illustrated in Figure A - 1.

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
1	Watershed Inputs	Klamath River flow regime	UKL, MUK, LRK	Remove major dams	C.2.c-Major (MD)	Increases quantity of water available for fish needs
2	Watershed Inputs	See stressor in Row 1	UKL, MUK, LKR	Increase upper Klamath basin storage	C.8 (WTP)	See effect in Row 1
3	Watershed Inputs	See stressor in Row 1	UKL, MUK, LRK	ESA flow requirements and ROD	C.3.h.1 and C.3.h.2 (FRK/FRT)	See effect in Row 1
4	Watershed Inputs	See stressor in Row 1	UKL, MUK, LKR	Account for water deliveries	C.3.e, f, and g (IP/WLP/FWD)	See effect in Row 1
5	Watershed Inputs	Increased fine sediment delivery	UKL, MUK, LKR	Watershed fine sediment source control	C.6 (HSP)	Reduces excess fine sediment inputs that could impair fish habitats
6	Watershed Inputs	Instream flows (tribes) and tributary water quality	UKL, MUK, LKR	Manage tributary flow and land use	C.3 (IFP)	Increases quantity of water available for fish needs
7	Habitat	Wetland and floodplain connectivity	MUK, LKR	Restore channel complexity	C.4.c (CRC)	Increases extent and diversity of fish habitats
8	Habitat	See stressor in Row 7	MUK, LKR	Support channel avulsion and channel migration	C.4.c (CRC)	See effect in Row 7
9	Habitat	See stressor in Row 7	UKL, MUK, LKR	Reconnect floodplains, side channels, high flow channels, and wetlands	C.4.c (CRC)	See effect in Row 7
10	Habitat	See stressor in Row 7	UKL, MUK, LKR	Support mechanical habitat creation-rehabilitation	C.4.d (RHP)	See effect in Row 7
11	Habitat	See stressor in Row 7	UKL, MUK, LKR	ESA flow requirements and ROD	C.3.h.1 and C.3.h.2 (FRK/FRT)	See effect in Row 7
12	Habitat	See stressor in Row 7	UKL, MUK, LKR	Manage baseflows—winter and summer by species	C.3.h.1 (FRK)	See effect in Row 7
13	Habitat/Fluvial Geomorphic	See stressor in Row 7	UKL, MUK, LKR	Restore physical processes	C.6.a (PP)	See effect in Row 7
14	Habitat	See stressor in Row 7	UKL	Increase upper Klamath Basin storage	C.8 (WTP)	See effect in Row 7

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
15	Habitat	Water temperature (reservoir impoundment)	MUK	Remove major Klamath dams	C.2.c-Major (MD)	Reduces water temperatures in the mainstem
16	Habitat/Fluvial Geomorphic	Large wood debris (LWD) recruitment	UKL, MUK, LKR	Restore channel complexity	C.4.c (CRC)	Provides large woody debris and coarse sediment for habitat complexity and fish spawning needs downstream.
17	Habitat/Fluvial Geomorphic	See stressor in Row 16	UKL, MUK, LKR	Restore physical processes	C.6.a (PP)	See effect in Row 16
18	Habitat/Fluvial Geomorphic	See stressor in Row 16	UKL, MUK, LKR	Remove major dams	C.2c-Major (MD)	See effect in Row 16
19	Fluvial Geomorphic	Decreased coarse sediment delivery	MUK	Remove major dams	C.2c-Major (MD)	Provides additional quantities and distribution of coarse sediments for fish spawning habitats
20	Fluvial Geomorphic	See stressor in Row 19	UKL, MUK, LKR	Restore physical processes	C.6.a (PP)	See effect in Row 19
21	Fluvial Geomorphic	See stressor in Row 19	UKL, MUK, LKR	Manage coarse sediment scour, deposition, and transport	C.6.b.1 (CSS)	See effect in Row 19
22	Fluvial Geomorphic	See stressor in Row 19	MUK	Augment coarse sediment	C.6.b.2 (CSA)	See effect in Row 19
23	Watershed Inputs	Mainstem water quality	MUK	Remove major Klamath dams	C.2.c-Major (MD)	Improves water quality conditions for fish growth and survival
24	Watershed Inputs	See stressor in Row 23	UKL, MUK, LKR	ESA flow requirements and ROD	C.3.h.1 and C.3.h.2 (FRK/FRT)	See effect in Row 23
25	Watershed Inputs	See stressor in Row 23	MUK, LKR	Manage baseflows—winter and summer by species	C.3.h.1 (FRK)	See effect in Row 23
26	Watershed Inputs	See stressor in Row 23	UKL,	Increase upper Klamath Basin storage	C.8 (WTP)	See effect in Row 23
27	Habitat	Instream structural complexity	UKL, MUK, LKR	Remove major Klamath dams	C.2.c-Major (MD)	Increases extent and diversity of fish habitats
28	Habitat	See stressor in Row 27	UKL, MUK, LKR	Restore channel complexity	C.4.c (CRC)	See effect in Row 27
29	Habitat	See stressor in Row 27	MUK, LKR	Support channel avulsion and channel migration	C.4.c (CRC)	See effect in Row 27

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
30	Habitat	See stressor in Row 27	UKL, MUK, LKR	Reconnect floodplains, side channels, high flow channels, and wetlands	C.4.c (CRC)	See effect in Row 27
31	Habitat	See stressor in Row 27	UKL, MUK, LKR	Support mechanical habitat creation-rehabilitation	C.4.d (CSA)	See effect in Row 27
32	Habitat	See stressor in Row 27	MUK, LKR	Manage baseflows—winter and summer by species	C.3.h.1 (FRK)	See effect in Row 27
33	Habitat	See stressor in Row 27	MUK, LKR	Manage peak flow magnitude and duration	C.3.h.1 (FRK)	See effect in Row 27
34	Habitat	See stressor in Row 27	UKL, MUK, LKR	Restore physical processes	C.6.a (PP)	See effect in Row 27
35	Fluvial Geomorphic	Bed and channel form	UKL, MUK	Remove major Klamath dams	C.2.c-Major (MD)	Promotes processes that create increased extent and diversity of fish habitats
36	Fluvial Geomorphic	See stressor in Row 35	MUK	Support channel avulsion and channel migration	C.4.c (CRC)	See effect in Row 35
37	Fluvial Geomorphic	See stressor in Row 35	UKL, MUK, LKR	Reconnect floodplains, side channels, high flow channels, and wetlands	C.4.c (CRC)	See effect in Row 35
38	Fluvial Geomorphic	See stressor in Row 35	UKL, MUK, LKR	Restore channel complexity	C.4.c (CRC)	See effect in Row 35
39	Fluvial Geomorphic	See stressor in Row 35	MUK, LKR	Manage peak flow magnitude and duration	C.3.h.1 (FRK)	See effect in Row 35
40	Fluvial Geomorphic	See stressor in Row 35	UKL, MUK, LKR	Restore physical processes	C.6.a (PP)	See effect in Row 35
41	Fluvial Geomorphic	Channelization (historic mining impacts)	MUK	Mechanical habitat creation-rehabilitation	C.4.d (CSP)	Creates increased extent and diversity of fish habitats
42	Watershed Inputs	Groundwater interactions	UKL,	Increase upper Klamath Basin storage	C.8 (WTP)	Promotes processes that create increased extent and diversity of fish habitats

Fluvial Geomorphic Processes (Summary)

The dynamic fluvial geomorphic processes of a river ecosystem involve the interaction of flow, sediment, and riparian vegetation (Trush and McBain 2000). These processes impact erosion and mass wasting events, as well as sediment transport and sediment deposition, and are affected by precipitation, soil saturation, and the exchange of surface water and groundwater. Spatial and temporal variability in fluvial geomorphic processes govern patterns of disturbances that influence ecosystem structure and dynamics (VanderKooi et al. 2011). These processes are conspicuous in streams, rivers, and floodplains and dictate the formation and evolution of key landscape features like terraces and alluvial fans at the reach scale and riffles, pools, and cascades at the habitat scale. As such, the condition of habitats used by fish is either directly or indirectly linked to the suite of hydrologic and geomorphic processes operating in a basin.

The Klamath Basin is very large (>31,000 km^2) with a fluvial geomorphic setting that varies across different sub-regions, based on the physical environment, regional geography, reach-specific channel geometry, climate, precipitation, and local flow availability and timing. The Klamath River's headwaters begin in gently sloped desert, marshlands and open valleys. Downstream of Upper Klamath Lake, these waters coalesce into the river's mainstem and proceed toward the Pacific Ocean at a much steeper gradient (Stanford et al. 2011). Flow regimes in the lower basin are more variable than in the upper basin. In the upper basin, peak flows occur during snowmelt in late spring/early summer (NMFS 2015). In the lower basin, peaks occur from November to March when rainfall is highest (NMFS 2015). Creeks in the lower basin commonly dry up during summer low-flow conditions (Voight and Gale 1998), and flash flood events frequently occur in winter (NMFS 2015).

Water diversion and the mainstem Klamath dams have had geomorphic effects on the river. The dams have trapped coarse sediments, resulting in bed coarsening downstream as smaller gravels are transported out of the area without being replaced by gravels supplied from upstream (PacifiCorp 2004, as cited in NRC 2008). The river bed downstream of Iron Gate Dam has become dominated by larger gravels and cobbles unsuitable for use by spawning fish (Hetrick et al. 2009). Similarly, the operation of the Reclamation's Klamath project, as well as PacifiCorp's hydroelectric facilities, have altered the natural flow regime of the Klamath river, attenuating peak flow magnitude, duration and frequency at various locations throughout the basins. These hydrologic changes hamper the amount of geomorphic work high flow events are able to achieve, constraining the ability of channel forming processes to create and maintain the complex habitats fundamental to the success of focal fish species.

Management/restoration actions in the Klamath River basin directly affecting fluvial geomorphic processes

The management actions directly affecting fluvial geomorphic processes can broadly be categorized as flow management, which includes operation of Reclamation's Klamath Project for water deliveries and groundwater pumping, as well as coarse and fine sediment management.

Current management/restoration actions

Water allocation within the basin is not affected by the six dams (USBR 2011). However, management of water released through the dams does affect flow timing and magnitudes of peak releases. Reclamation's Klamath Project operations are directed by provisions in the 2013 Biological Opinion to prevent jeopardy of ESA listed species in Upper Klamath Lake and the Klamath River.

The volume of water available to fish species throughout the basin is affected primarily by Reclamation's Klamath Project water deliveries to upper basin water users. Even with potential future dam removal, water deliveries will continue. During water year (WY) 2015, a recent dry year, water deliveries constituted 36% of allocated water managed by the Klamath Project, even with drought conservation measures in effect (USBR 2015). During WY 2017, under extremely wet hydrologic conditions, water deliveries comprised 25% of allocated water (USBR 2017) (Table A - 2).

Table A - 2. Compared balance of water allocated to core uses in the Klamath Basin under Reclamation's Klamath Project for WY 2015 and WY 2017, under dry and extremely wet hydrologic conditions, respectively (sources: USBR 2015 and 2017).

	WY 2015 Dry Hydrologic Conditions		WY 2017 Extremely Wet Hydrologic Conditions	
	(acre-feet)	*Percent of total*	*(acre-feet)*	*Percent of total*
Upper Klamath Lake Reserve	120,845	18%	142,208	11%
Environmental Water Allocated for Klamath River releases	320,000	47%	801,617	64%
Water deliveries	245,500	36%	309,000	25%

Groundwater pumping is extensive in the upper Klamath Basin and heavily relied on to support water deliveries managed by the Klamath Project and other out-of-basin uses. Groundwater is an important component of inflow to Upper Klamath Lake (NMFS and USFWS 2013). Groundwater pumping also occurs in other primary tributaries, such as the Scott River (S.S. Papadoplos & Associates 2012).

Wetlands in the Upper Klamath Basin are heavily associated with groundwater. Water diversions in the Klamath Basin have drained 75 percent of the original wetlands (NRC 2004, as cited in Stanford et al. 2011). The loss of upper basin wetland-habitat interactions associated with groundwater pumping, and water deliveries in general, is a significant factor in the decline of focal fish species across the basin, as well as fundamental ecological functions.

Instream flow management, as regulated by the 2013 Biological Opinion to protect endangered fish species, establishes minimum lake elevations in Upper Klamath Lake and flows in the Klamath River, largely for fish habitat availability and water temperature management purposes. These minimum flows released to the river do not guarantee that high flow releases of significant magnitude and duration that result in geomorphic work will also occur. Under the 2013 Biological Opinion, even flood releases are counted against the annual water allocation dedicated to the mainstem Klamath River for Coho salmon protection. Daily average flows during spring months, when peak flows would naturally be higher under an unaltered snowmelt hydrograph, are suppressed for water allocation purposes and are modeled on a daily average target of 37.5 cms (m^3/s) or less, far below that needed for a geofluvial flow event.

High flow releases downstream of Iron Gate Dam are entirely dependent on flood-related releases for upstream flood control purposes or tributary accretion in the reaches downstream of Link River Dam at the outlet of Upper Klamath Lake. During dry years, such as WY 2015, peak flows downstream of Iron Gate Dam increased as high as 90.3 cms for a single day, but generally remained at or near the minimum flow thresholds established in the 2013 Biological Opinion. Comparatively, during WY 2017—an extremely wet water year – peak flows during winter and spring months remained well above the minimum flow thresholds and reached as high as 286.0 cms (Figure A - 2). It is during these wetter water years when flood-related releases and tributary accretion are greatest that high flows are available to the river downstream of the four dams to support geofluvial processes and reduce the risk of habitat simplification.

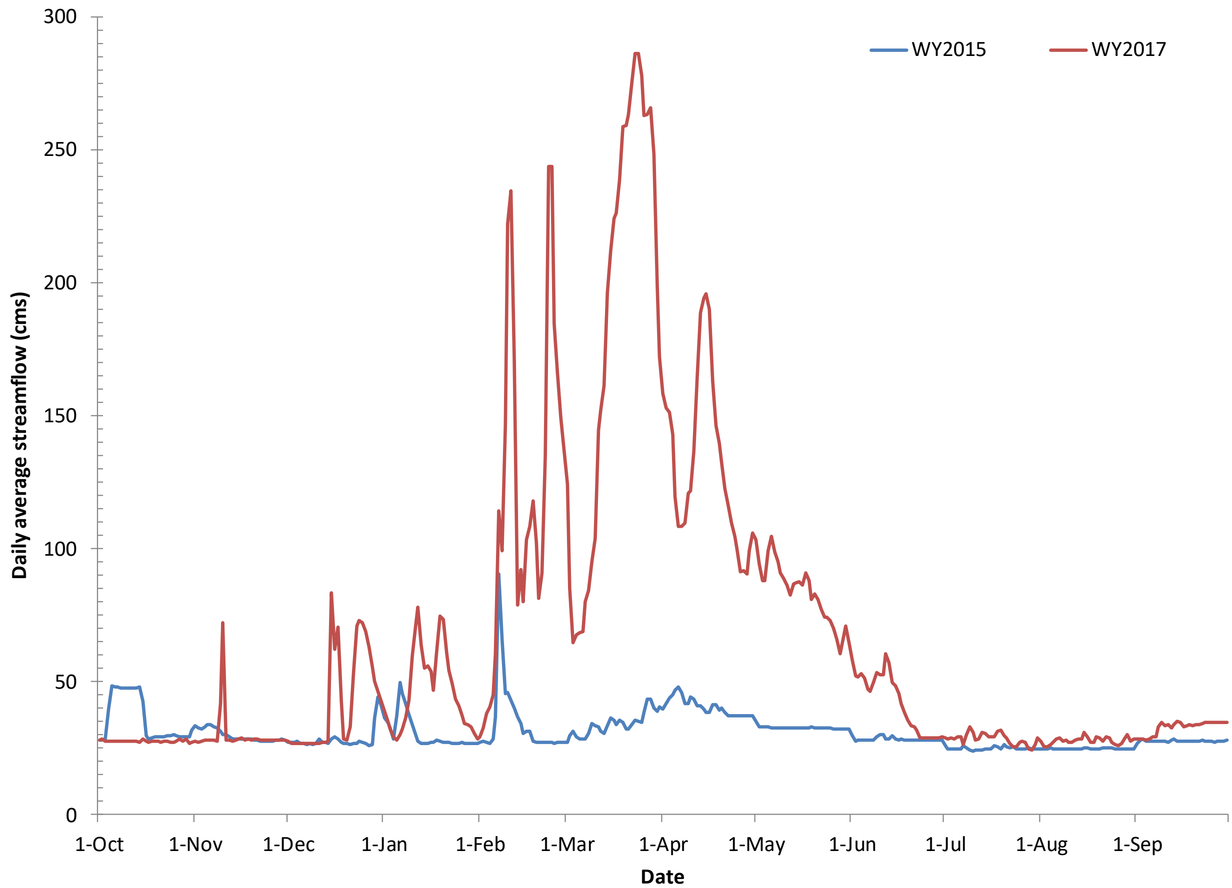


Figure A - 2. Daily average flow releases downstream of Iron Gate Dam during WY 2015 and WY 2017, constituting relatively dry (blue line) and extremely wet (brown line) hydrologic years, respectively.

Fish disease suppression is managed through flow releases from Iron Gate Dam, as well as Trinity River releases from Lewiston Dam. Peak flows of sufficient magnitude and duration, sometimes timed to coincide with natural hydrologic events, have been implemented in the Klamath River to help deter the establishment of aquatic vegetation and disrupt the life cycle of fish pathogens and their polychaete host (Hetrick et al. 2009). Research is ongoing to determine which flow timing events and peak discharge thresholds may be most effective in polychaete suppression.

Fine sediment inputs from upslope and tributary sources and related fine sediment reduction efforts are part of the Klamath Basin fluvial geomorphic setting. Fine suspended sediment concentrations are a concern in the mainstem Klamath River and basin tributaries, especially where fires (NRC 2008) or wide-scale timber harvest has occurred (NMFS and USFWS 2013). High concentrations of fine sediment can fill pools and simplify instream habitats used by fish (NRC 2008). High concentrations of suspended sediment can also disrupt normal feeding behavior by fish, reduce growth rates, and affect survival of juvenile salmonids by interfering with normal development and emergence (Berg and Northcote 1985; Chapman 1988). Currently, concentrations and duration of exposure to fine suspended sediment in the Klamath has been implicated in creating major physiological stress and associated reduced growth of coho salmon in most years for certain life stages (NMFS and USFWS 2013). Sedimentation arising from harvest-related landslides and extensive road networks continues to impact habitat even from modern-day harvesting operations, although at much reduced levels compared to early logging in the Klamath Basin (NMFS and USFWS 2013).

Coarse sediment is a fundamental building block of river systems, providing material for construction of riffles, bars, banks, and floodplains. Coarse sediment within a river is supplied from upstream sources (e.g., hillslopes, tributaries) and then transported and deposited downstream. The mobility of available coarse sediments through high flows is essential for establishing and maintaining floodplain connectivity and floodplain forming process, especially in the reaches downstream of Iron Gate dam. Because high flows and coarse sediment availability have been altered by the six existing dams on the Klamath River mainstem, the availability and quality of fish habitats created and maintained in the lower river have also been impaired.

In addition to the six dams, natural inputs of coarse sediment have also been depleted, and the movement and deposition of coarse sediment has been affected historically by multiple past geomorphic alterations in the Klamath Basin (NRC 2008). These have included historical mining, floating of logs, building of splash dams to push logs downstream, and blasting rock outcrops in the river bed to improve log passage (NRC 2008). Placer gold mine workings in the basin often included displacing the channel and excavating down to bedrock. These past activities had the effect of simplifying the river channel through the elimination of bedrock and other channel irregularities that interfered with the efficient flow of water and through the physical effect of the logs themselves battering the banks (NRC 2008), resulting in changes to sediment routing. Dredging of gravels on the floodplains also simplified the river channel through direct modification, while mine dredging and processing of placer deposits released fine sediments into the water column, with associated damage to fish habitats (NRC 2008). The negative effects of mining on fish abundance were observed as early as 1930 (NMFS and USFWS 2013). Since the 1970s, however, large-scale commercial mining operations have been eliminated in the basin due to stricter environmental regulations, and in 2009 California suspended all instream mining using suction dredges (NMFS and USFWS 2013).

Potential future management/restoration actions

Removal of the major Klamath River dams will restore natural sediment processes in the downstream reaches. Floodplain forming processes downstream of Iron Gate Dam are expected to improve after dam removal. Modeled post-dam hydraulics estimate a slight increase in peak flood flows for the 18 miles of river immediately downstream of Iron Gate Dam due to the elimination of storage in the upstream reservoirs which currently attenuates floods (USBR 2011). Increased flood peaks will result in increased sediment mobility downstream to Cottonwood Creek and, over time, will also see a return to the natural gravel supply (USBR 2011). After dam removal, USBR (2011) predicted the frequency of gravel mobilization will increase from once every four years to every other year.

Estimates vary as to the amount of sediment stored behind the four dams that would be removed. Analysis previously developed for PacifiCorp estimated that 20.4 million cubic yards of sediment is trapped in three of four reservoirs considered for removal and noted that sediments stored behind Copco 2 are negligible (GEC 2006, as cited by Hetrick et al. 2009). USBR (2011) conversely estimated that 15 million cubic yards of sediment will be stored in the reservoirs by 2020, over 80% of which are fine sediments. Dam removal is predicted to release 1/3 to 2/3 of that volume, depending on the water year type immediately following dam removal (USBR 2011). Sediment concentrations are expected to return to background levels by the end of the summer following dam removal (USBR 2011). The bed material within the reservoir footprints is expected to have a high sand content (30% to 50%) and will require a flushing flow of at least 6,000 cfs sustained for several days to weeks before the substrate will return to a cobble and gravel bed (USBR 2011).

Changes in flow management, independent of future major dam removal, are also a key factor in the restoration of geofluvial processes in the basin. Managing peak flow magnitude, frequency, and duration are fundamental to flushing of fine sediments from the system, fish disease management, gravel mobilization for habitat forming processes, and the creation and maintenance of suitable spawning habitat in all reaches accessible to salmonids. Changes in flow management will need to account for water deliveries obligated by the Klamath Project and required water elevations in Upper Klamath to protect and recover focal fish species in the upper Klamath Basin. Initial negotiations between the Department of Interior and Basin stakeholders on a new long-term water-use agreement in this regard are currently underway (Dillemuth 2018).

The **restoration of geomorphic processes** can be achieved through the combined management of flow and sediment related activities to mobilize coarse sediments to target thresholds necessary to activate fossilized bars, form new alluvial habitat features, maintain a complex riparian corridor, and provide spawning habitat for salmonids. Restoration of geomorphic processes can be prioritized at varying scales (site-specific, reach, or river wide) based on a spatial needs assessment (e.g., where existing geomorphic processes are most constrained or where is spawning habitat most limited?). In the event of major dam removal, geomorphic processes downstream of JC Boyle reservoir and Iron Gate Dam will likely experience a period of initial rapid adjustment as retained sediments are released and begin to route downstream. In general, however, and depending on the magnitude and frequency of high flow events and correlated coarse sediment availability and grain size, the restoration of geomorphic processes in the river may occur on a much longer-term time scale. In the event a major dam removal does not occur, **augmentation of coarse sediment** may be necessary to supplement geomorphic processes in specific reaches.

The restoration of geomorphic processes, combined with site-specific mechanical habitat restoration as needed, would contribute to the **restoration of channel complexity** and channel forming processes, such as channel avulsion and channel migration. High flows and coarse sediment can be managed to reconnect floodplains, as well as build and maintain side channels and other off-channel habitats, including wetlands. In some reaches, the channel remains impacted by the legacy effects of mining impacts, such as channelization. A combination of natural riverine processes and mechanical habitat restoration may be necessary to recover full geofluvial function and habitat attributes in these areas.

Management of fine sediment deposition and transport is also fundamental to restored fluvial geomorphic processes, consideration of both the significant volume of small grained material that would be released after dam removal and ongoing upslope inputs of sediments from the mainstem and tributary watersheds. Fine sediments accumulate in spawning gravels and other habitats, impacting salmonids and providing desirable conditions for fish disease pathogens. Watershed fine sediment source control activities, such as forest road removals, erosion control efforts, and restoration of burn areas, will help reduce future fine sediment inputs into the Klamath River.

The **management of land uses that affect tributary flows**, relative to both water quantity and quality, is fundamental to the recovery of the Klamath River. Improving the quantity of flow and associated water quality of tributary inputs will have a beneficial effect on the tributaries themselves as well as Klamath River mainstem habitats and geomorphic processes in the river.

Critical fluvial geomorphic uncertainties

Of the critical uncertainties facing fluvial geomorphic processes in the Klamath River, major dam removal is clearly the most obvious. The future restoration of the fluvial geomorphic environment will be significantly more challenging under a dams-in scenario. While efforts to mitigate the geomorphic impacts downstream of large dams are not uncommon, the challenge is an entirely distinct experiment. As has been observed elsewhere in the Basin, substantial efforts to restore geomorphic processes and improve fish habitats on the Trinity River downstream of Lewiston Dam (by combining high flow releases and large quantities of coarse sediment augmentation with extensive mechanical habitat restoration over the course of more than a decade) has yet to produce satisfactory results (e.g., Buffington et al. 2014; Boyce et al. 2018).

Furthermore, should major dam removal occur, the accuracy of the modeled sediment release estimates is uncertain. The rate of geomorphic response to dam removal will depend on the magnitude and duration of high flows the following water year as well as the sequences of high geomorphic-effective flows across multiple future years. USBR (2011) predicts that the majority of the fine sediment stored behind the reservoirs will flush out of the river within a year following dam removal; however, the actual fine and coarse sediment signature of the removal of four major dams remains to be seen. Copco 1, the first of the four dams, was built in 1918, with Copco 2, and J.C. Boyle following; Iron Gate was built in 1962. Is it plausible that a hundred years of sediment accumulation can be flushed through 190 miles of mainstem channel to the Pacific Ocean in a single year without somehow altering the geomorphic setting of the Klamath River, for at least some period of time?

Managers have yet to have opportunity to test the ability of high flows to mobilize fossilized bars currently limiting habitat downstream of Iron Gate Dam (Hetrick et al. 2009). The extent to which removal of the dams will support channel forming and channel maintaining processes, given the future hydrologic setting is unlikely to significantly change, is questionable. It is possible the grain size of the contemporary channel surface and fossilized bars is not suitably scaled to the corresponding high flows, under a future water allocation agreement. Thus, desired scour and mobility might not be fully achievable within the desired time period.

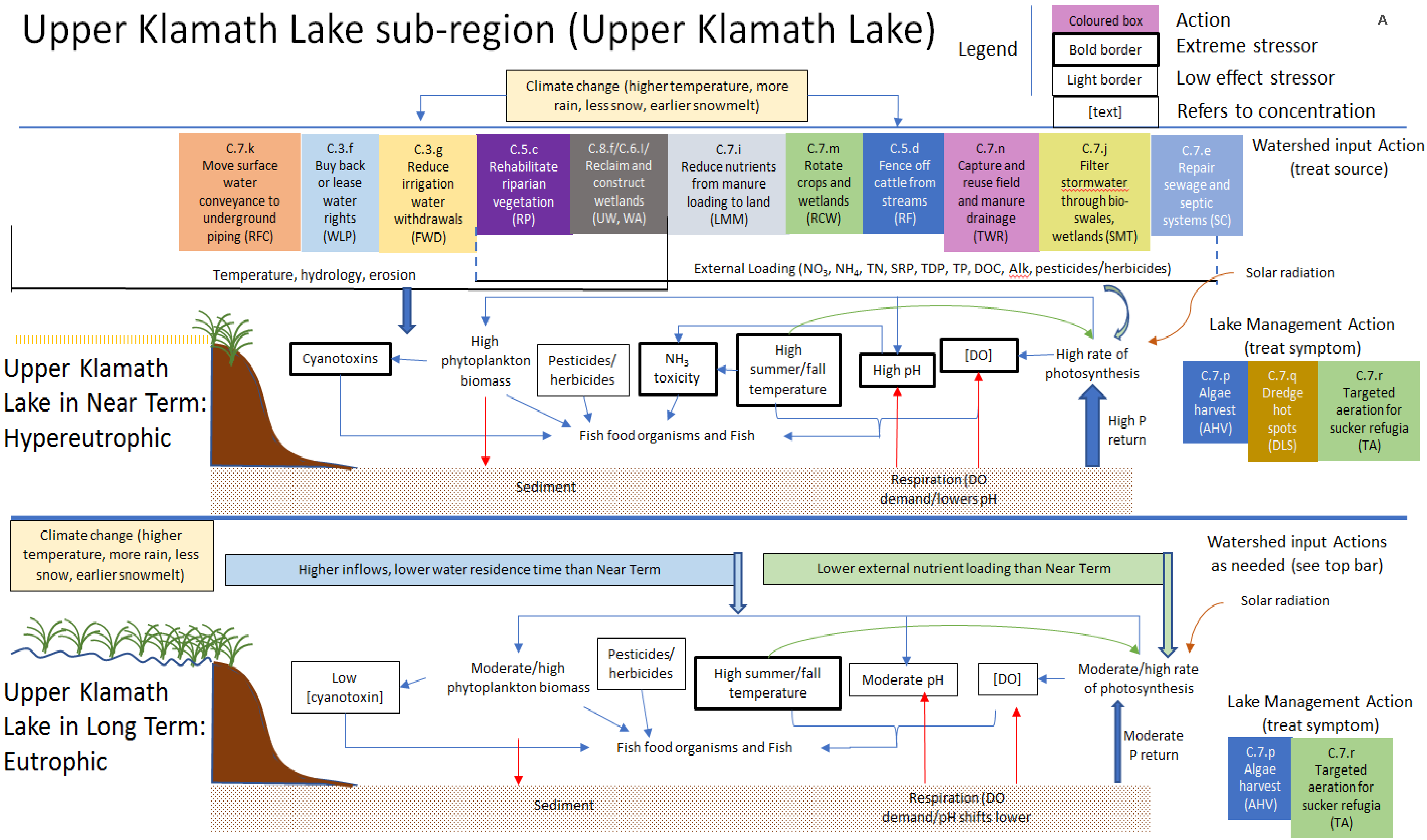
Additionally, fish habitat objectives remain largely undeveloped. To date, the scientific analyses used to support dam removal has primarily focused on fish passage, hypothesizing that the amount of new mainstem and tributary habitats, in their present condition, being made available will help recover focal fish species. An evaluation of habitat condition, the potential quantity of habitat, and overall habitat availability relative to a likely flow regime remains largely outstanding, especially in the reaches upstream of Iron Gate Dam. Thus, when managers express the need for “more habitat,” the bookends remain undetermined and the physical potential of the channel, even in a restored fluvial geomorphic setting, to offer up the requisite amount of useable habitat required to assist recovery, remains unassessed.

With the removal of the four dams, upper basin habitats should again be accessible to previously excluded anadromous salmonids and lamprey. However, it is unclear if the existing fluvial geomorphic environment of the mainstem river upstream of Iron Gate Dam will again be welcoming for salmonids. The Keno reach is largely recognized as a significant constraint for fish—the dam is unpassable, and the resulting water quality is hostile at best. Efforts to arrive at a Keno solution are underway, but their outcome is far from determined. In addition to the concerns surrounding the Keno reach, the riverine environment between Link River Dam and Iron Gate Dam has never been managed for anadromous fisheries purposes under the modern framework of environmental regulation and science and additional future challenges related to habitat condition and function may remain unidentified.

Similarly, while efforts to restore and reconnect upper basin wetlands are already underway, remaining wetland habitats in the upper basin represent only a small fraction of their former extent and are heavily constrained by land use, groundwater pumping, and private ownership. The degree to which former wetlands associated with Upper Klamath Lake and Lake Ewauna can be reconnected to the Klamath River to support the biological needs of all focal fish species in the Klamath Basin, as well as provide gains in water storage capacity, remains undetermined.

The potential future removal of the four major dams does not guarantee a future flow regime that is beneficial for Upper Klamath Lake suckers or target riverine species. Future assessment and negotiation between federal agencies, tribes, and water users will be required to arrive at an updated flow regime. Given the pervasive over-allocation of water throughout the basin, it is unlikely a future flow regime would be any more beneficial for fish. In fact, a flow allocation that further reduces instream flows, mitigated with additional habitat availability and compounded by less water availability due to climate change, is also plausible.

Like the mainstem Klamath River, tributary flows are also over allocated. Throughout the basin, many key tributaries such as the Scott and Shasta River are parsed out across numerous landowners. Land uses in many of these watersheds are heavily dependent on instream flows and groundwater pumping associated with agriculture, grazing, and marijuana cultivation, among other water dependent uses. Some watersheds remain heavily impacted from legacy logging and mining impacts, as well as more contemporary fire-related effects. Combined, fine sediment contributions can be significant, instream flows are impaired during low flow periods, and water temperatures can exceed lethal thresholds for fish survival. Managers and communities are working together currently to address these outstanding impairments, but the outcome remains uncertain.


Upper Klamath Lake sub-region (Upper Klamath Lake)
Legend
Coloured box
Action
Bold border
Extreme stressor
Light border
Low effect stressor
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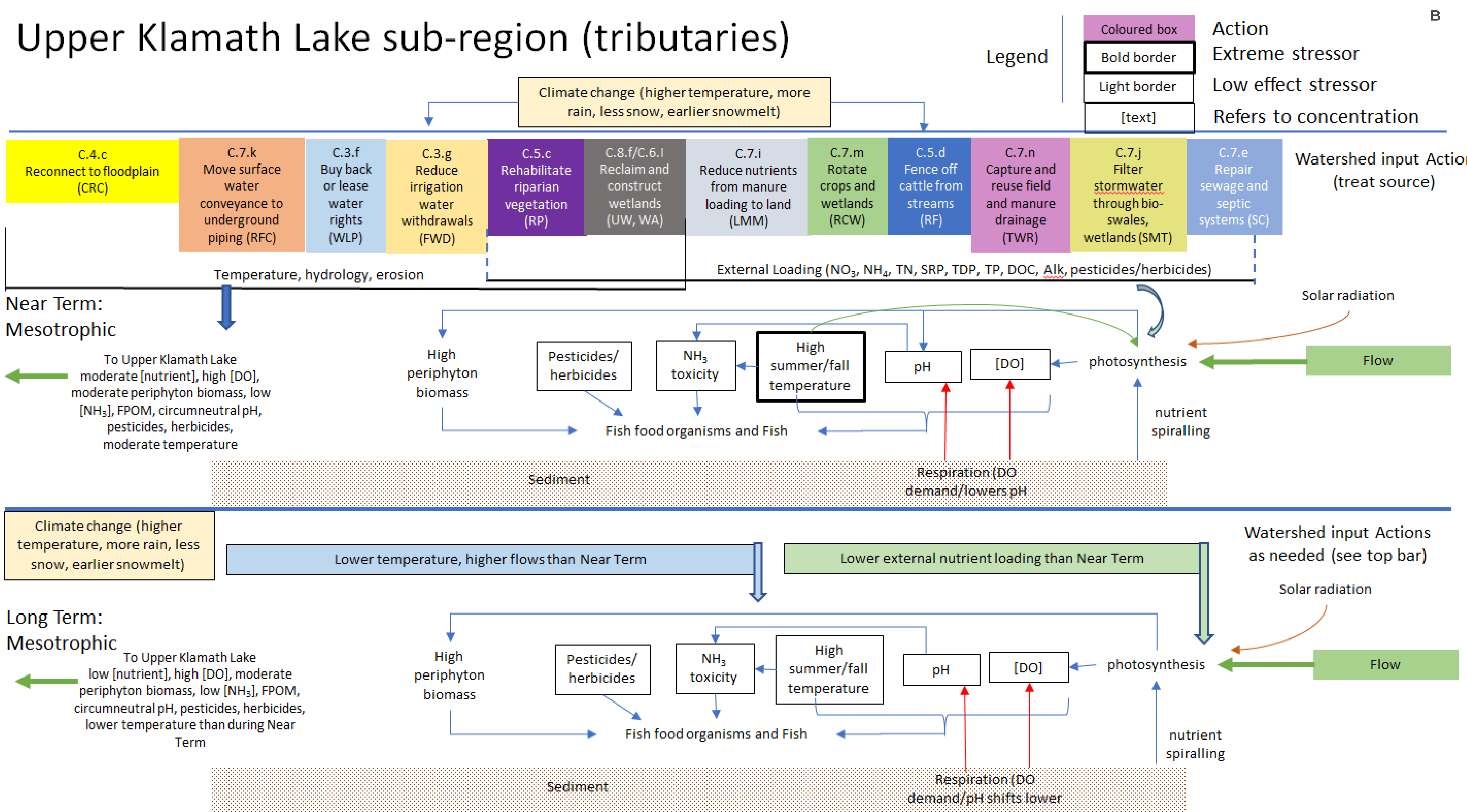
Refers to concentration
A
Climate change (higher temperature, more rain, less snow, earlier snowmelt)
C.7.k Move surface water conveyance to underground piping (RFC)
C.3.f Buy back or lease water rights (WLP)
C.3.g Reduce irrigation water withdrawals (FWD)
C.5.c Rehabilitate riparian vegetation (RP)
C.8.f/C.6.l/ Reclaim and construct wetlands (UW, WA)
C.7.i Reduce nutrients from manure loading to land (LMM)
C.7.m Rotate crops and wetlands (RCW)
C.5.d Fence off cattle from streams (RF)
C.7.n Capture and reuse field and manure drainage (TWR)
C.7.j Filter stormwater through bio-swales, wetlands (SMT)
C.7.e Repair sewage and septic systems (SC)
Watershed input Action (treat source)
Temperature, hydrology, erosion
External Loading (NO_3, NH_4, TN, SRP, TDP, TP, DOC, Alk, pesticides/herbicides)
Solar radiation
Upper Klamath Lake in Near Term: Hypereutrophic
Cyanotoxins
High phytoplankton biomass
Pesticides/ herbicides
NH_3 toxicity
High summer/fall temperature
High pH
[DO]
High rate of photosynthesis
High P return
Fish food organisms and Fish
Sediment
Respiration (DO demand/lowers pH
Lake Management Action (treat symptom)
C.7.p Algae harvest (AHV)
C.7.q Dredge hot spots (DLS)
C.7.r Targeted aeration for sucker refugia (TA)
Climate change (higher temperature, more rain, less snow, earlier snowmelt)
Higher inflows, lower water residence time than Near Term
Lower external nutrient loading than Near Term
Watershed input Actions as needed (see top bar)
Solar radiation
Upper Klamath Lake in Long Term: Eutrophic
Low [cyanotoxin]
Moderate/high phytoplankton biomass
Pesticides/ herbicides
High summer/fall temperature
Moderate pH
[DO]
Moderate/high rate of photosynthesis
Moderate P return
Fish food organisms and Fish
Sediment
Respiration (DO demand/pH shifts lower
Lake Management Action (treat symptom)
C.7.p Algae harvest (AHV)
C.7.r Targeted aeration for sucker refugia (TA)


Upper Klamath Lake sub-region (tributaries)
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Legend
Coloured box
Action
Bold border
Extreme stressor
Light border
Low effect stressor
[text]
Refers to concentration
Climate change (higher temperature, more rain, less snow, earlier snowmelt)
C.4.c Reconnect to floodplain (CRC)
C.7.k Move surface water conveyance to underground piping (RFC)
C.3.f Buy back or lease water rights (WLP)
C.3.g Reduce irrigation water withdrawals (FWD)
C.5.c Rehabilitate riparian vegetation (RP)
C.8.f/C.6.l Reclaim and construct wetlands (UW, WA)
C.7.i Reduce nutrients from manure loading to land (LMM)
C.7.m Rotate crops and wetlands (RCW)
C.5.d Fence off cattle from streams (RF)
C.7.n Capture and reuse field and manure drainage (TWR)
C.7.j Filter stormwater through bio-swales, wetlands (SMT)
C.7.e Repair sewage and septic systems (SC)
Watershed input Action (treat source)
Temperature, hydrology, erosion
External Loading (NO3, NH4, TN, SRP, TDP, TP, DOC, Alk, pesticides/herbicides)
Near Term: Mesotrophic
To Upper Klamath Lake moderate [nutrient], high [DO], moderate periphyton biomass, low [NH3], FPOM, circumneutral pH, pesticides, herbicides, moderate temperature
High periphyton biomass
Pesticides/ herbicides
NH3 toxicity
High summer/fall temperature
pH
[DO]
photosynthesis
Solar radiation
Flow
nutrient spiralling
Fish food organisms and Fish
Sediment
Respiration (DO demand/lowers pH
Climate change (higher temperature, more rain, less snow, earlier snowmelt)
Lower temperature, higher flows than Near Term
Lower external nutrient loading than Near Term
Watershed input Actions as needed (see top bar)
Long Term: Mesotrophic
To Upper Klamath Lake low [nutrient], high [DO], moderate periphyton biomass, low [NH3], FPOM, circumneutral pH, pesticides, herbicides, lower temperature than during Near Term
High periphyton biomass
Pesticides/ herbicides
NH3 toxicity
High summer/fall temperature
pH
[DO]
photosynthesis
Solar radiation
Flow
nutrient spiralling
Fish food organisms and Fish
Sediment
Respiration (DO demand/pH shifts lower

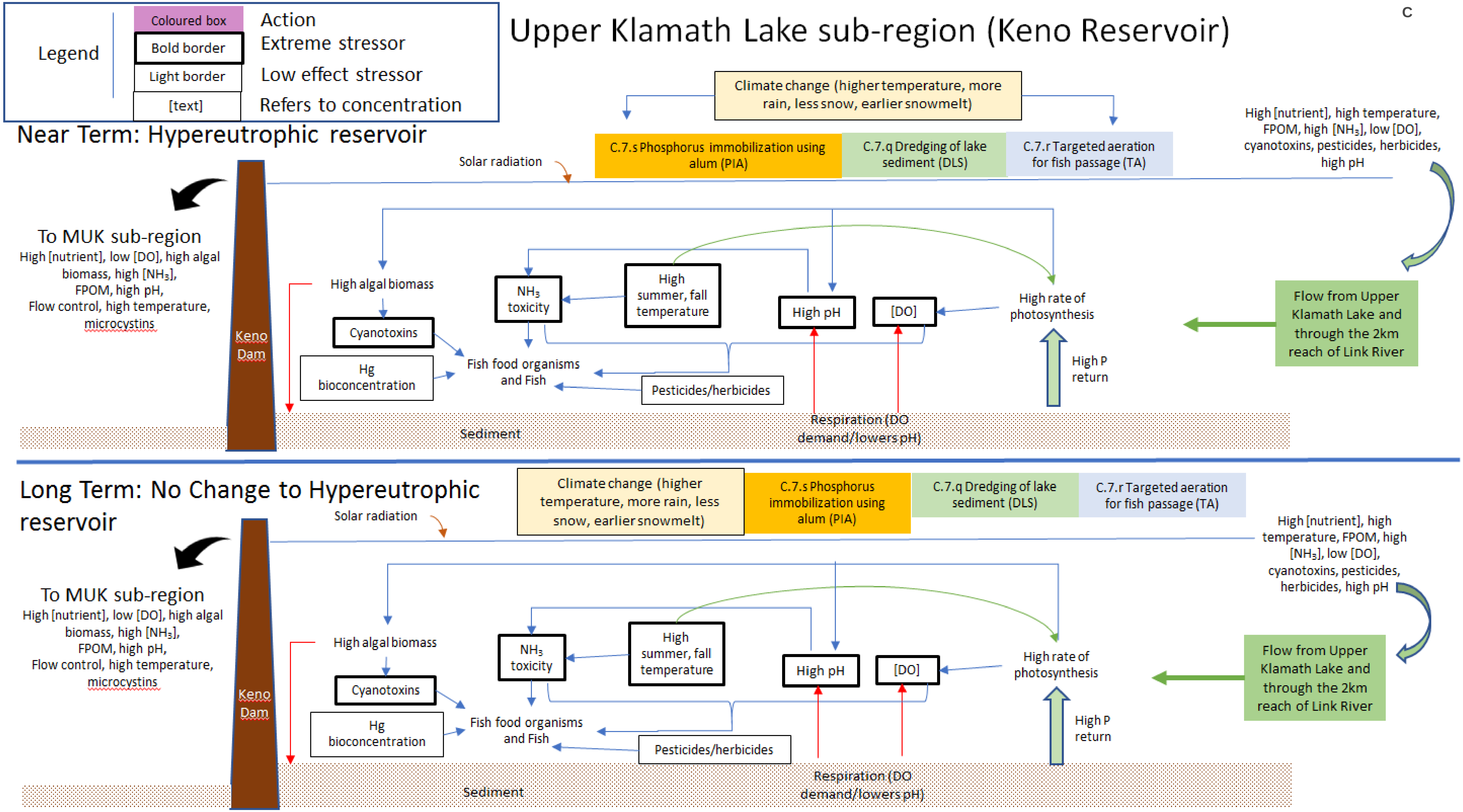


Figure A - 3. Conceptual model of water quality issues in the Upper Klamath Lake (UKL) sub-region (A) within Upper Klamath Lake, (B) within upper basin tributaries, and (C) within Keno reservoirs, both currently (near term in figure) and following restoration actions (long term in figure). Boxes with bold borders are considered extreme stressors, and those with light borders are considered low effect stressors.

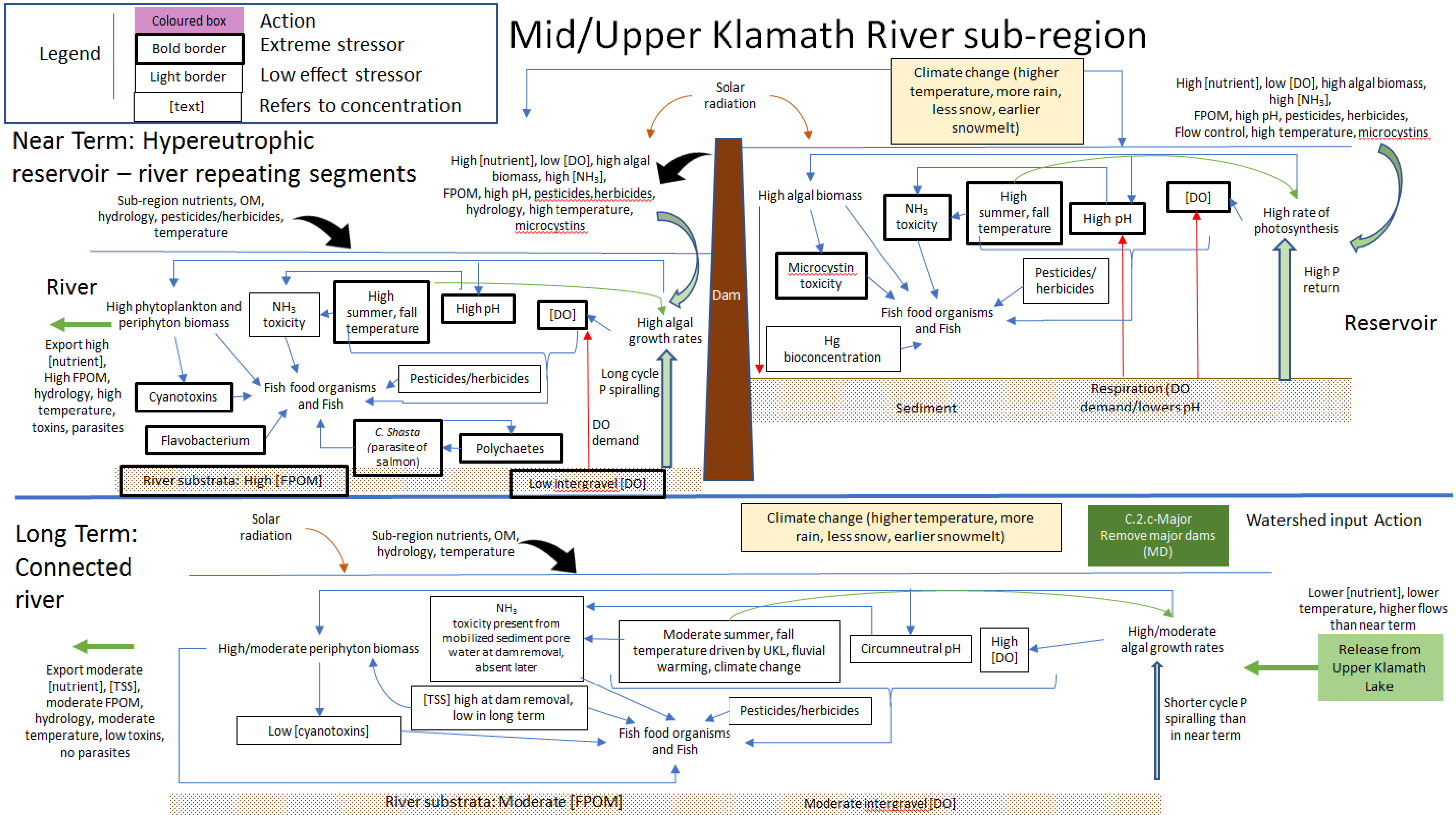


Figure A - 4. Conceptual model of water quality issues in the Mid/Upper Klamath River sub-region (MUK) both currently (near term in figure) and following restoration actions (long term in figure). Boxes with bold borders are considered extreme stressors, and those with light borders are considered low effect stressors.

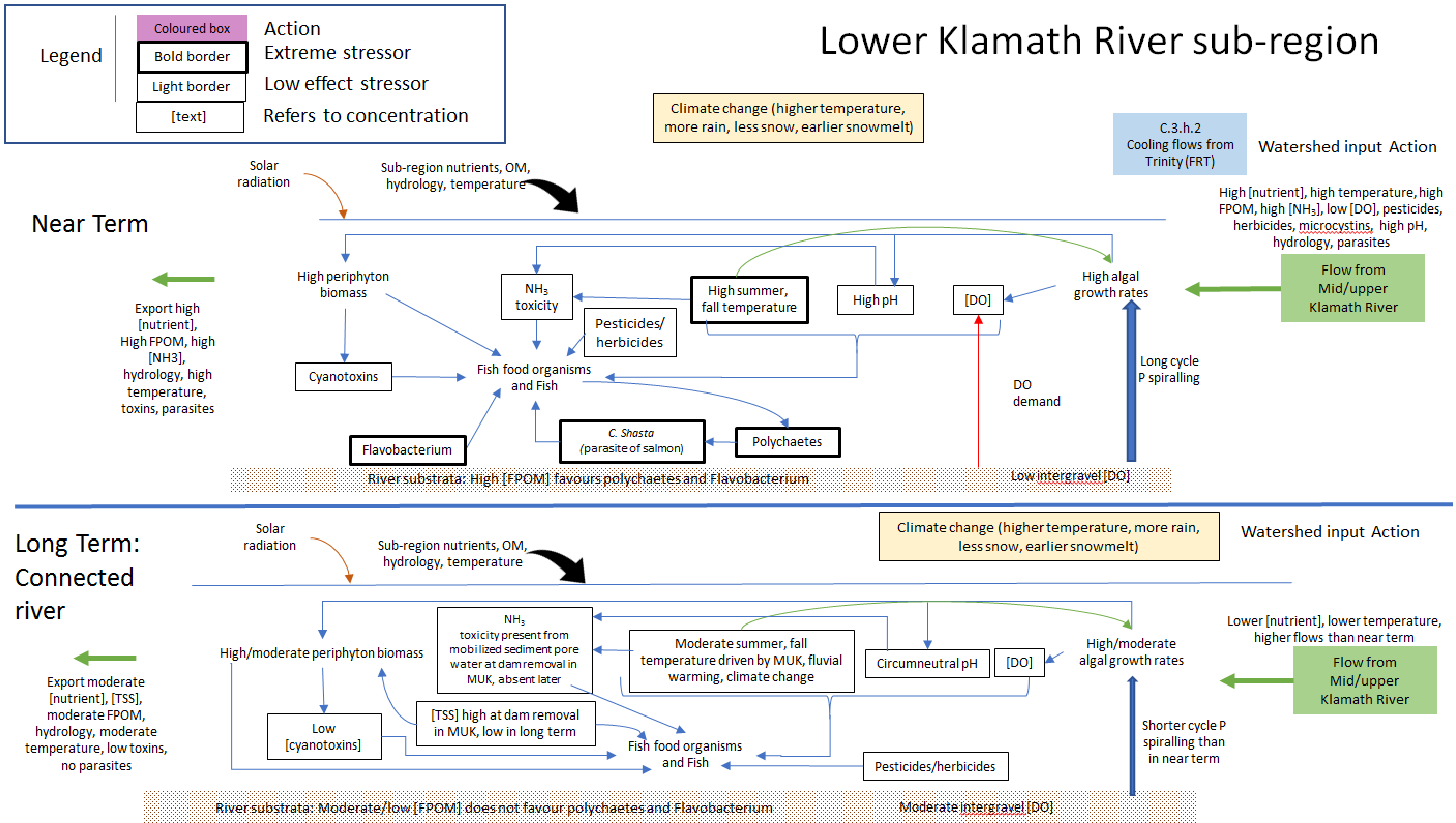


Figure A - 5. Conceptual model of water quality issues in the Lower Klamath River sub-region (LKR) both currently (near term in figure) and following restoration actions (long term in figure). Boxes with bold borders are considered extreme stressors, and those with light borders are considered low effect stressors.

Table A - 3. Links between water quality-related stressors for fish across Klamath Basin sub-regions, candidate restoration actions, and hypothesized effects of restoration actions on habitat and fish populations in support of the Klamath Basin Water Quality subregional models.

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
1	Watershed Inputs	**High water temperature in summer and early fall that is lethal to fish** • Climate change increases water temperature • Agriculture (alfalfa, hay, grains, potatoes, onions, and livestock (among others)) has replaced wetland, reduced water storage in wetlands, reduced cooling of surface waters by wetlands. • Water withdrawal for agriculture lowers flows and raises water temperature. • Reservoirs in MUK cause cumulative warming of water	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Keno Reservoir • Reservoirs and river in MUK	Move surface water conveyance to underground piping	C.7.k (RFC)	Temperature attenuation
2	Watershed Inputs	See stressor in Row 1	UKL	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake	Buy back or lease water rights from land owners for conversion to wetlands	C.3.f (WLP)	See effect in Row 1
3	Watershed Inputs	See stressor in Row 1	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Reduce irrigation water withdrawals	C.3.g (FWD)	See effect in Row 1
4	Watershed Inputs	See stressor in Row 1	UKL, MUK, LKR	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK • River in LKR	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 1

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
5	Watershed Inputs	See stressor in Row 1	UKL	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake	Reclaim and construct wetlands on non-private lands	C.8.f (WA)	See effect in Row 1
6	Habitat	See stressor in Row 1	MUK	• Reservoirs and river in MUK • River in LKR	Remove major Klamath dams (eliminates warming in surface layer of reservoirs)	C.2.c-Major (MD)	See effect in Row 1
7	Watershed Inputs	See stressor in Row 1	LKR	• River in LKR	Use flows from Trinity River to cool Lower Klamath River	C.3.h.2 (FRT)	See effect in Row 1
8	Watershed Inputs	**Episodic high pH that is toxic to fish** • High rates of photosynthesis in Upper Klamath Lake and reservoirs produces episodic high pH that exceeds tolerance range for fish	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Buy back or lease water rights from land owners for conversion to wetlands	C.3.f (WLP)	Lowers the rate of photosynthesis by reducing nutrient loading • Photosynthesis is driven by light (not managed), temperature (managed in rows 1-7), nutrient load and concentrations (managed in rows 8-17)
9	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 8
10	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Reclaim and construct wetlands on non-private lands	C.6.l (UW)	See effect in Row 8
11	Watershed Inputs	See stressor in Row 8	MUK	• Reservoirs and river in MUK	Reduce fertilizer use on agricultural lands	C.7.l (RFT)	See effect in Row 8

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
12	Watershed Inputs	See stressor in Row 8	UKL, MUK		Rotate crops and wetlands	C.7.m (RCW)	See effect in Row 8
13	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Fence off cattle from streams	C.5.d (RF)	See effect in Row 8
14	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Capture and reuse field and manure drainage	C.7.n (TWR)	See effect in Row 8
15	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Filter storm-water through bio-swales and wetlands	C.7.j (SMT)	See effect in Row 8
16	Watershed Inputs	See stressor in Row 8	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Repair sewage and septic systems	C.7.e (SC) (SC)	See effect in Row 8
17	Habitat	See stressor in Row 8	MUK	Reservoirs and river in MUK	Remove Klamath dams (eliminates a source of high pH)	C.2.c-Major (MD)	See effect in Row 8
18	Habitat	See stressor in Row 8	UKL	Upper Klamath Lake	Harvest algae	C.7.p (AHV)	See effect in Row 8
19	Habitat	See stressor in Row 8	MUK	Keno Reservoir	Alum treatment	C.7.s (PIA)	See effect in Row 8
20	Habitat	See stressor in Row 8	UKL	Streams upstream of Upper Klamath Lake	Reconnect floodplain	C.4.c (CRC)	See effect in Row 8
21	Watershed Inputs	**Episodic low [DO] that is lethal to fish** • Occurs inversely to rates of photosynthesis in Upper Klamath Lake. When photosynthetic rate drops, respiratory demand for DO in sediments increases and causes a drop in water column [DO] that is below the tolerance range for fish	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Buy back or lease water rights from land owners for conversion to wetlands	C.3.f (WLP)	Lowers the rate of respiration in sediments by reducing nutrient loading • Nutrient loading drives the production of organic matter in Upper Klamath Lake, streams, and Klamath River

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
22	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 21
23	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Reclaim and construct wetlands on non-private lands	C.6.l (UW)	See effect in Row 21
24	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Reservoirs and river in MUK	Reduce fertilizer use on agricultural lands	C.7.l (RFT)	See effect in Row 21
25	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Rotate crops and wetlands	C.7.m (RCW)	See effect in Row 21
26	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Fence off cattle from streams	C.5.d (RF)	See effect in Row 21
27	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Capture and reuse field and manure drainage	C.7.n (TWR)	See effect in Row 21
28	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Filter storm-water through bio-swales and wetlands	C.7.n (TWR)	See effect in Row 21
29	Watershed Inputs	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Repair sewage and septic systems	C.7.e (SC)	See effect in Row 21
30	Habitat	See stressor in Row 21	MUK	• Reservoirs and river in MUK	Remove Klamath dams (eliminates a source of low [DO])	C.2.c-Major (MD)	See effect in Row 21
31	Habitat	See stressor in Row 21	UKL	• Upper Klamath Lake	Harvest algae	C.7.p (AHV)	See effect in Row 21
32	Habitat	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake, Keno Reservoir	Dredge “hot spots”	C.7.q (DLS)	See effect in Row 21
33	Habitat	See stressor in Row 21	UKL, MUK	• Upper Klamath Lake, Keno Reservoir	Targeted aeration for sucker refugia	C.7.r (TA)	See effect in Row 21
34	Habitat	See stressor in Row 21	MUK	• Keno Reservoir	Alum treatment	C.7.s (PIA)	See effect in Row 21
35	Habitat	See stressor in Row 21	UKL	• Streams upstream of Upper Klamath Lake	Reconnect floodplain	C.4.c (CRC)	See effect in Row 21

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
36	Watershed Inputs	**NH3 toxicity** (loss of equilibrium, hyperexcitability, increased respiratory activity and oxygen uptake, and increased heart rate. At extreme ammonia levels, fish may experience convulsions, coma, and death) • NH3 is the un-ionized form of ammonia. The ionized form is NH_4. • NH3 is favoured at high pH (rows 8-17) according to the equilibria **$NH_3 + H_2O \Leftrightarrow NH_4+ + OH^-$** If pH rises the equilibria shifts to the left and produces more NH3. • NH3 formation is also favoured at high temperature (rows 1-7)	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Buy back or lease water rights from land owners for conversion to wetlands •	C.3.f (WLP)	Lowers the rate of nitrogen loading from watersheds • This N loading directly contributes to total ammonia in water bodies. High pH and high temperature in those water bodies drive formation of un-ionized ammonia (NH3) • Lower the rates of photosynthesis that shifts pH up (rows 8-17) by reducing nutrient loading
37	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 36
38	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Reclaim and construct wetlands on non-private lands	C.6.l (UW)	See effect in Row 36
39	Watershed Inputs	See stressor in Row 36	MUK	• Reservoirs and river in MUK	Reduce fertilizer use on agricultural lands	C.7.k (RFC)	See effect in Row 36
40	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake	Rotate crops and wetlands	C.7.m (RCW)	See effect in Row 36

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
				• Reservoirs and river in MUK			
41	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Fence off cattle from streams	C.5.d (RF)	See effect in Row 36
42	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Capture and reuse field and manure drainage	C.7.n (TWR)	See effect in Row 36
43	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Filter storm-water through bio-swales and wetlands	C.7.j (SMT)	See effect in Row 36
44	Watershed Inputs	See stressor in Row 36	UKL, MUK	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Reservoirs and river in MUK	Repair sewage and septic systems	C.7.e (SC)	See effect in Row 36
45	Habitat	See stressor in Row 36	MUK	• Reservoirs and river in MUK	Remove Klamath dams (eliminates a source of total ammonia from reducing conditions at the sediment-water interface in reservoirs)	C.2.c-Major (MD)	See effect in Row 36
46	Habitat	See stressor in Row 36	UKL	• Streams upstream of Upper Klamath Lake	Reconnect floodplain	C.4.c (CRC)	See effect in Row 36
47	Watershed Inputs	**Microcystin toxicity from cyanobacteria that are favoured at high [bio-available P]**	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Buy back or lease water rights from land	C.3.f (WLP)	Lower production of cyanobacteria that produce microcystins

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
					owners for conversion to wetlands		
48	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 47
49	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Reclaim and construct wetlands on non-private lands	C.6.l (UW)	See effect in Row 47
50	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Reservoirs and river in MUK	Reduce fertilizer use on agricultural lands	C.7.l (RFT)	See effect in Row 47
51	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Rotate crops and wetlands	C.7.m (RCW)	See effect in Row 47
52	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Fence off cattle from streams	C.5.d (RF)	See effect in Row 47
53	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Capture and reuse field and manure drainage	C.7.n (TWR)	See effect in Row 47
54	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Filter storm-water through bio-swales and wetlands	C.7.j (SMT)	See effect in Row 47
55	Watershed Inputs	See stressor in Row 47	UKL, MUK	• Upper Klamath Lake • Reservoirs and river in MUK	Repair sewage and septic systems	C.7.e (SC)	See effect in Row 47
56	Habitat	See stressor in Row 47	MUK	• Reservoirs and river in MUK	Remove Klamath dams	C.2.c-Major (MD)	See effect in Row 47
57	Habitat	See stressor in Row 47	UKL	• Upper Klamath Lake	Harvest algae	C.7.p (AHV)	See effect in Row 47
58	Habitat	See stressor in Row 47	MUK	• Keno Reservoir	Alum treatment	C.7.s (PIA)	See effect in Row 47
59	Habitat	See stressor in Row 47	UKL	• Streams upstream of Upper Klamath Lake	Reconnect floodplain	C.4.c (CRC)	See effect in Row 47
60	Biological interactions	**Pathogens**	MUK, LKR	• Reservoirs and river in MUK	Buy back or lease water rights from land	C.3.f (WLP)	Lower parasitism and disease in salmonids by

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
		• *C.Shasta* parasite causes hemorrhaging and necrosis of the intestine of salmon and trout resulting in mortality, especially at high water temperatures. Mature myxospores released from fish infect a freshwater polychaete worm and develop into actinospores for the parasite to be able to infect another fish and continue its lifecycle. *C. shasta* is not transmissible to humans • Also, *flavobacterium* infections of fish that cause septicemic diseases in salmonids		• River in LKR	owners for conversion to wetlands		removing conditions that are favoured by C. Shasta and flavobacteria (POM is driven by nutrient supply and primary production)
61	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Rehabilitate riparian vegetation	C.5.c (RP)	See effect in Row 61
62	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Reclaim and construct wetlands on non-private lands	C.6.l (UW)	See effect in Row 61
63	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Reduce fertilizer use on agricultural lands	C.7.l (RFT)	See effect in Row 61
64	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Rotate crops and wetlands	C.7.m (RCW)	See effect in Row 61
65	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Fence off cattle from streams	C.5.d (RF)	See effect in Row 61
66	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Capture and reuse field and manure drainage	C.7.n (TWR)	See effect in Row 61

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
67	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Filter storm-water through bio-swales and wetlands	C.7.j (SMT)	See effect in Row 61
68	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Repair sewage and septic systems	C.7.e (SC)	See effect in Row 61
69	Biological interactions	See stressor in Row 60	MUK, LKR	• Reservoirs and river in MUK • River in LKR	Remove Klamath dams	C.2.c-Major (MD)	See effect in Row 61
70	Watershed Inputs	**Pesticides and herbicides used in agricultural practices that can be harmful to fish**	UKL, MUK, LKR	• Below Upper Klamath Lake • Keno Reservoir • Reservoirs and river in MUK • River in LKR	Implementation of best agricultural management practices such as low or no till agriculture, conservation land management; or, upland irrigation water management for water conservation.	C.6.i (UA)	Lower the impacts of toxic pesticides and herbicides used in agricultural practices
71	Watershed inputs	See stressor in Row 70	UKL, MUK, LKR	• Streams upstream of Upper Klamath Lake • Upper Klamath Lake • Keno Reservoir • Reservoirs and river in MUK • River in LKR	Reduce usage of herbicides, pesticides, or other chemical products.	C.7.g (RHP)	See effect in Row 71
72	Habitat	**Hg bioconcentration in fish**	MUK	• All reservoirs	Remove Klamath dams. This action will eliminate a source of Hg and reducing conditions that favour the formation of methyl Hg at the	C.2.c-Major (MD)	Eliminate conditions favouring methylation of Hg (low [DO])

Row	Framework tier	Stressor for fish	Sub-region(s) affected	Water bodies affected	Candidate restoration action	Restoration action identifier	Hypothesized effect of restoration action
					sediment-water interface in reservoirs		

Water Quality Processes (Summary)

A legacy of large-scale development of mining, forestry, agriculture and ranching operations in the Klamath Basin has degraded water quality with impacts on fisheries and other resources (NMFS and USFWS 2013). Excessive loading of phosphorus linked to watershed development has been a key factor driving the massive blooms of the nitrogen-fixing cyanobacteria *Aphanizomenon flos-aquae* that dominate Upper Klamath Lake (Walker et al. 2012). Phosphorus enters surface waters in the upper basin both naturally (e.g., from groundwater discharge) and through land-disturbing activities such as farming, grazing, timber harvest, and road building (KTWQC 2016). A number of restoration actions have either been implemented or are proposed with an objective to reduce nutrient loading to water courses, ultimately lowering rates of biological production and associated decomposition of organic matter that imparts poor conditions for migration, rearing, and spawning of the many fish populations throughout the Klamath Basin. These actions are required to meet total maximum daily loads (TMDL's) of various chemicals to water courses as defined in the Clean Water Act (e.g., Kirk et al. 2010, Rounds et al. 2009).

Management/restoration actions in the Klamath River basin directly affecting water quality processes

Upper Klamath Lake sub-region (UKL)

The many stressors affecting water quality in the Upper Klamath Lake sub-region were described in the Synthesis Report (ESSA 2017). Restoration actions in this sub-region are focused on limiting nutrient release from land and changing water use patterns. Cumulatively, these groups of actions may change water temperature, water flow, trophic state of Upper Klamath Lake, organic matter processing in streams and lake waters, production of toxins, dissolved oxygen concentration, and extreme shifts in pH, all of which affect the quality of habitat supporting fish (Stillwater et al. 2013, ESSA 2017).

There are three distinct but connected hydrologic parts in the Upper Klamath River (UKL) sub-region. Tributaries draining from basin headwaters to the inflow floodplain of Upper Klamath Lake form one part. These tributaries directly receive nutrient loads and changed flows from water use patterns and thus are the conduit that changes downstream water quality. The next part is Upper Klamath Lake itself that responds to the upstream nutrient loading and water use, modified by internal lake biogeochemistry. The third part is Keno Reservoir wherein flow control exacerbates hypereutrophic conditions induced by nutrient loading from upstream.

In the UKL sub-region water has been withdrawn from the upper basin to meet agricultural demand, potentially lowering annual inflow to Upper Klamath Lake. This can increase water temperature in surface streams and increase water residence time in Upper Klamath Lake, thus exacerbating the hypereutrophic state at present rates of nutrient loading to the lake. In response, a first group of potential restoration actions focused on changes to water use such as a buy back of water leases that presently supply water to agriculture. This action can lead to a reduction in intensive agriculture and a return to wetlands in many areas where they were historically present. Decreased water use for crops and grazing lands could lead to a more natural hydrograph in rivers and streams and a potential decline in water residence time in Upper Klamath Lake. Streams could then be reconnected with the lake floodplain rather than be channelized. This reconnection can restore biological connectivity and enhance nutrient uptake in complex and longer stream lengths woven through wetlands. Reconnection to cool groundwater within the floodplain can help to expand thermal refugia for fish.

Where agriculture remains active, water that presently drains from managed soils to channelized ditches may be pumped back to fields, not only providing water for agricultural needs but also reducing a nutrient load that is contained in the drainage, particularly from cattle grazing lands. High water temperature from solar heating may be lowered by changing from existing open ditches that are exposed to solar heating to underground piping that is not exposed to heating. This reuse of water in combination with strategies to lower overall water use by agriculture may reduce agricultural demand for water and increase flows in natural stream channels. These actions as a package could increase natural stream flows and lower overall stream temperature, making habitat in headwaters through to floodplain streams more suitable to support fish populations.

A second focus of restoration actions deals with nutrient loading, the main cause of hypereutrophy and poor water quality (Stillwater et al. 2013, ESSA 2017). A buy back of water rights from agricultural operations could lead to less use of land for cattle grazing and less loading of land with manure, the main source of nutrient loading. This change in ownership of water rights could lead to wetland construction and reclamation and rehabilitation of riparian vegetation corridors along presently exposed ditches and streams (settlements in water rights agreements may involve continued use of some lands for cattle grazing but not in all years, thereby rotating a fixed head of cattle among different fields between years). This action is essentially a type of crop rotation to reduce present rates of nutrient loading from manure over all agricultural lands in the UKL sub-region. Crop rotation can also involve using some areas for agriculture in some years but leaving as wetlands in other years as a strategy to retain nutrient load and limit downstream nutrient transport over time. Where cattle grazing remains active, fencing around water courses can be used to prevent direct nutrient loading. Within urban areas (e.g., Klamath Falls), storm-water management can include filtering of water through bio-swales and small wetlands before discharge to natural water courses. This strategy may reduce nutrient and other chemical loading downstream. For suburban areas where wastewater is treated in septic tank and field systems, mandatory repair and maintenance along with regulatory checks of treatment performance can be used to lower nutrient. This action is necessary because many septic systems may not be maintained and thus become ineffective in controlling nutrient discharge over time.

There is a third group of actions that are directly associated with Upper Klamath Lake: algae harvest, dredging of hot spots, and targeted aeration for sucker refugia. These actions are part of lake management that do not target the source of poor water quality. They only target symptoms and thus represent potential stop gap measures to protect fish populations until effects of the larger causal actions associated with nutrient loading and water use are realized. For a variety of reasons these suggested Upper Klamath Lake-focused restoration actions may also not be feasible (see critical uncertainties for these actions).

Similarly to Upper Klamath Lake, a group of actions may be considered to treat symptoms in Keno Reservoir directly, as opposed to upstream causes. Production of algal biomass within the reservoir produces large variation in dissolved oxygen concentration (higher concentration during the day during photosynthesis, lower at night when respiration consumes oxygen), resulting in diurnal periods of oxygen stress on fish. This symptom of hyper-eutrophication may be treated with alum (e.g., Huser et al. 2011) to immobilize phosphorus thereby reducing availability of phosphorus for biological production in the reservoir, dredging the reservoir sediment to remove a source of phosphorus that has accumulated from the legacy of nutrient loading from upstream, and/or targeted aeration to facilitate fish passage and avoid fish kills during times of fish migration (e.g., anadromous salmonids). While many participants in the UKL regional workgroup have suggested that these actions are likely impractical, they have been retained in the conceptual models as currently we are not aware of documented evidence to refute any consideration of these actions. This is also the case for potential actions to treat symptoms within Upper Klamath Lake. Until further documented evidence is available in the form of an assessment of treatment viability (not opinion), potential actions to treat in-lake and in-reservoir symptoms are retained in the conceptual models.

Superimposed on all potential restoration actions across Klamath basin sub-regions is climate change. Models in the literature for the Klamath River basin hypothesize that mean annual temperature will increase, more precipitation will be as rain rather than snow, resulting in a smaller snowpack and an earlier snowmelt progressing over time (Walsh et al. 2014, Thorne et al. 2015). The Klamath IFRMP water quality conceptual models developed for the UKL sub-region as well as the MUK and LKR show climate change patterns potentially modifying the effectiveness of all water quality-related restoration actions. Uncertainty around climate change means that monitoring of action effectiveness requires a design that separates effects of climate change from other treatment actions to learn over time what restorations will be most effective in the face of changing patterns of temperature, amounts and kind of precipitation, and trends in snowpack.

Mid/Upper Klamath River sub-region (MUK)

There is one large proposed restoration action in the Mid/Upper Klamath River sub-region (MUK): removal of Iron Gate, Copco I, Copco II and J.C. Boyle dams. Removal of impoundments associated with these dams is expected to: 1) lower heating of water that is released downstream in summer and fall, 2) reduce or eliminate oxygen demand at the sediment-water interface that affects oxygen concentrations in the overlying water column, 3) eliminate phosphorus return from trapped sediments (presently occurring during anoxia or other form of oxygen depletion) that contributes to excess production of organic matter that induces oxygen demand, and 4) improve flows for resident and migrating fishes. Any bioconcentration of mercury would also be eliminated in a change from storage reservoirs to a free-flowing river. The Klamath River will continue to be affected by nutrient loading from upstream if the dams are removed and thus will likely continue to produce large algal mats. Removal of impoundments will be a benefit even with this continued nutrient loading and transport however by eliminating key water quality limits to fish passage: conditions fostering disease, episodic low dissolved oxygen concentrations, conditions supporting hyper-eutrophication and related toxin production.

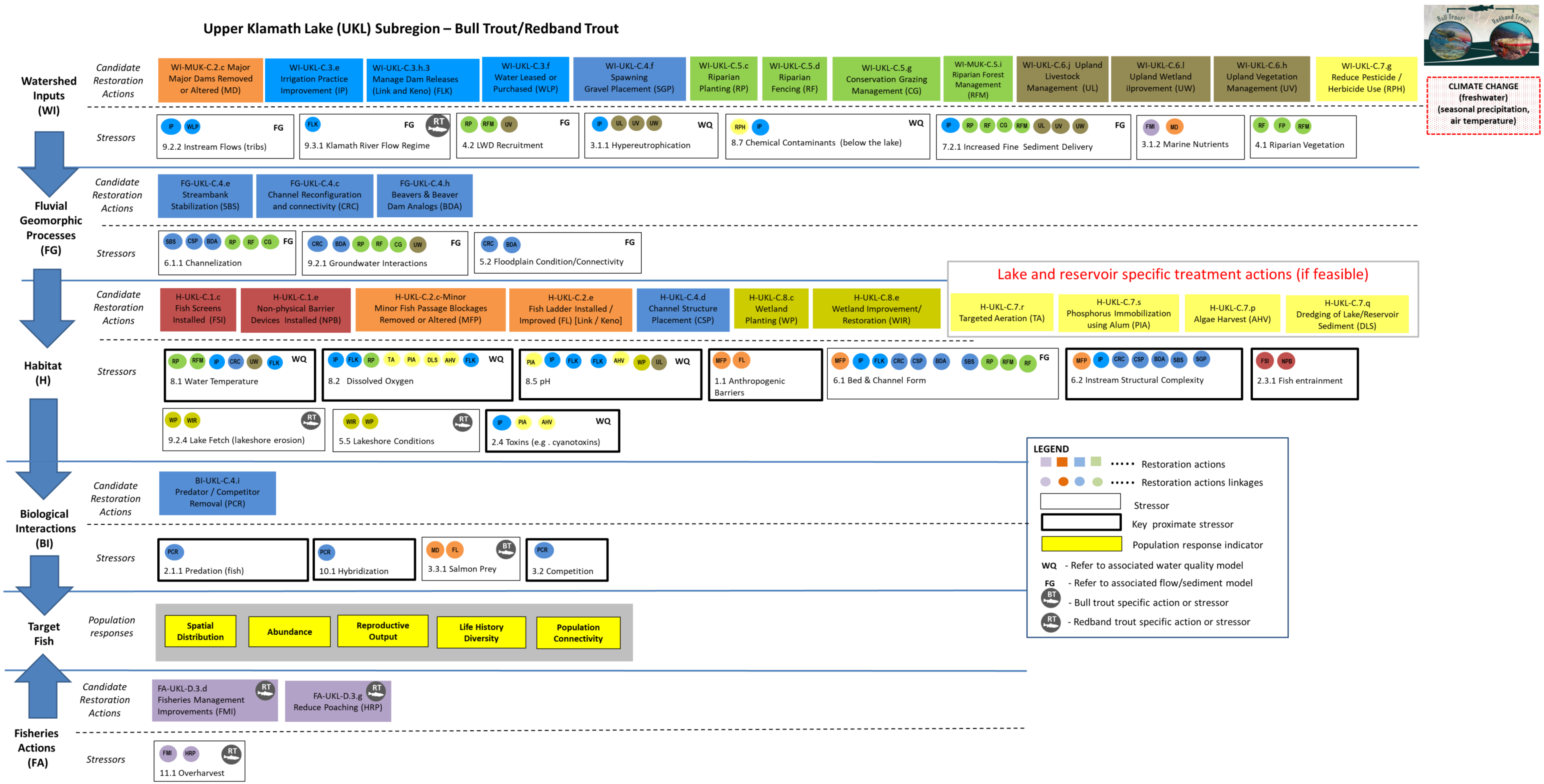
Superimposed on dam removal is climate change. Among potential changes shown in climate models, less snowpack may have greatest influence in the MUK sub-region. Freshet flows may decline with reduced amount of snow although it is unknown if mean annual flow in the Klamath River will be modified. If annual amounts of precipitation decline, river flow may decline proportionately. Climate variation may shift the timing of the annual hydrograph, but this change is small compared to change from lentic to lotic conditions that would be caused by the removal of dams in the MUK sub-region.

Lower Klamath River sub-region (LKR)

With respect to water quality issues in the Lower Klamath River sub-region (LKR), episodic cooling flows from the Trinity River can be applied as a directed restoration action. Benefit from this action will be dependent on the amount of water available to supply cooling given concurrent water needs for irrigation in the Trinity River basin. Reduced amounts of precipitation that may result from future climate change may mean that offsetting flows from the Trinity River may be less reliable in the future than at present for assistance in cooling the lower Klamath River.

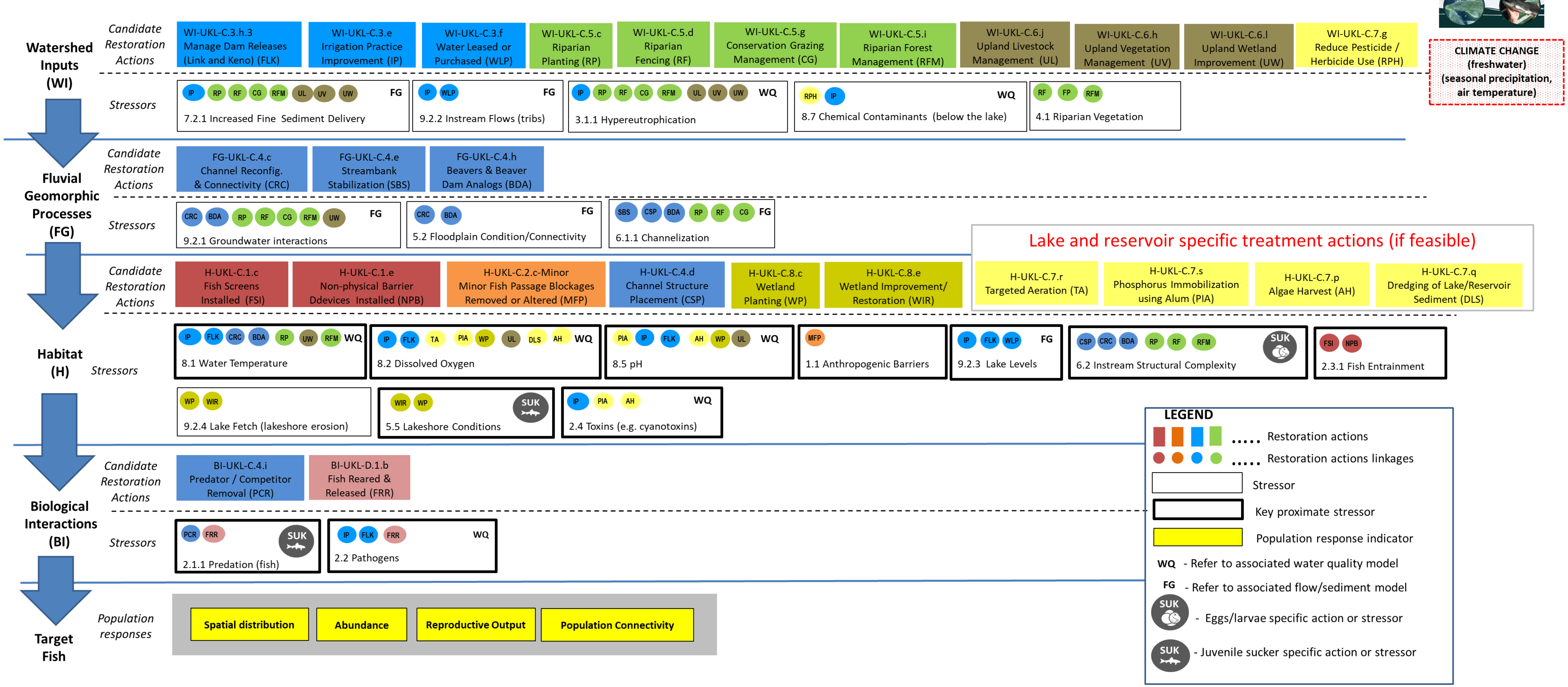
Critical water quality uncertainties

There is little uncertainty about the causes of the hypereutrophic state of Klamath River waterways or about the need to reduce nutrient loading to improve water quality. There is also little uncertainty about potential downstream water quality benefits from the proposed removal of the Klamath mainstem dams because the effects of such dam removal projects have been assessed previously in other jurisdictions (e.g., Elwa dam removal, Peters et al. 2017). In contrast, there is much uncertainty about the broader effectiveness of the many restoration actions that have or could be applied to the Upper Klamath sub-region. For example, one action dealing with water return to a single cattle grazing field is unlikely to be detectable with respect to change to water quality in Upper Klamath Lake and may only be detectable in a stream immediately downstream of the field. Even effects from many such actions may not be detectable in the short term or even long term. While the water quality-related actions in each of the UKL conceptual models are considered important and practically useful, much uncertainty remains in regard to broader effectiveness. As with dam removal, a large and forceful action or group of actions will be required to generate a broad effect, particularly in Upper Klamath Lake that has a built-in latency of response to nutrient loading. Uncertainty about detecting broad response can be reduced by assessing effects of cumulative restoration actions, not just one or two but across many actions covering the entire upper watershed. Multiple lines of evidence may be required to determine potential change in nutrient loading downstream, as nothing may be detectable in that regard over several years in Upper Klamath Lake itself. Separation of assessments of effects of change in land uses vs. effects of internal lake biogeochemistry is required for long term lake management and in support of broader decisions on managing water quality and fish populations further downstream.

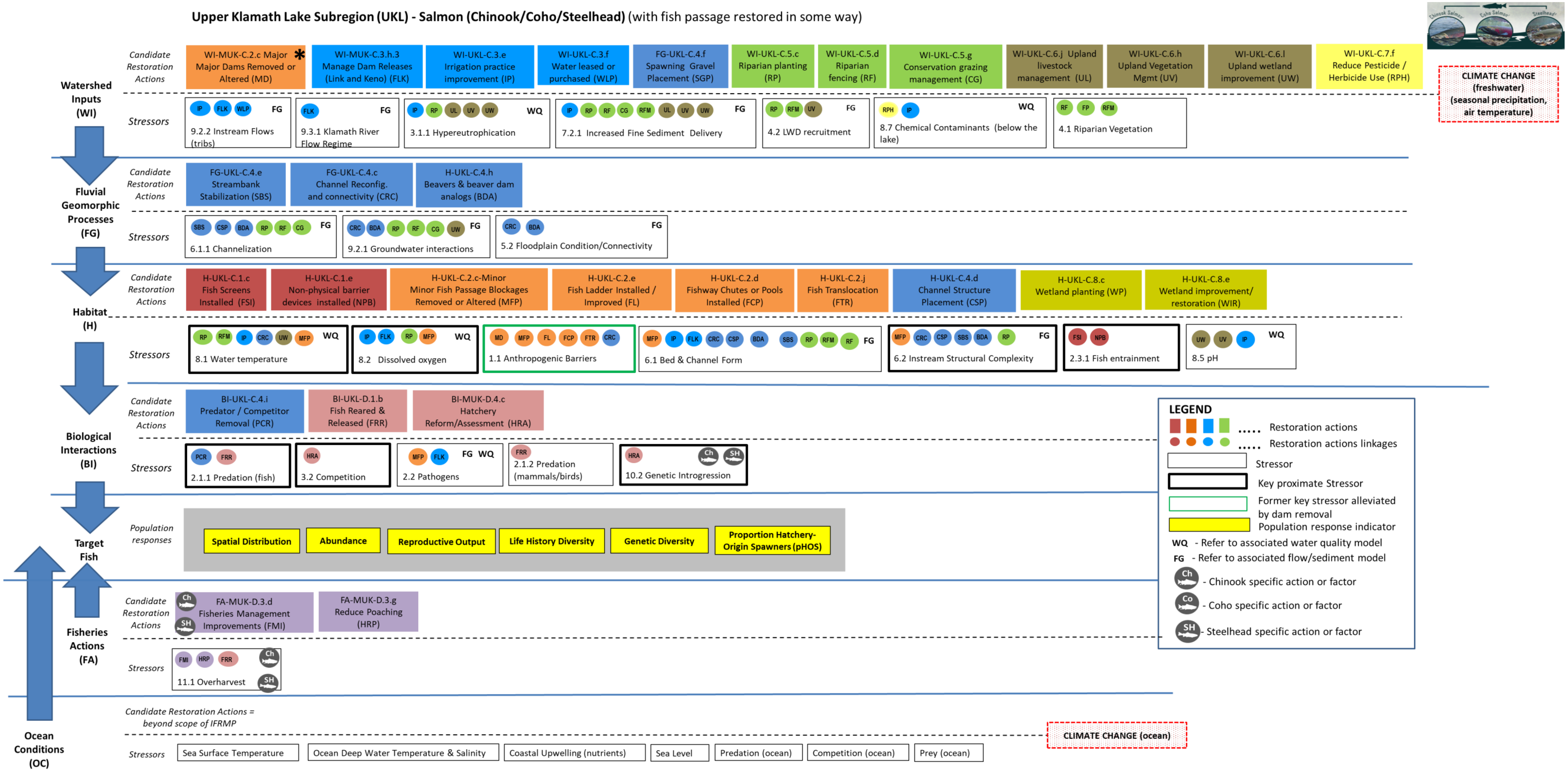


All actions of this conceptual model could still be beneficial to trout in the UKL subregion regardless of whether or not mainstem dams are removed.

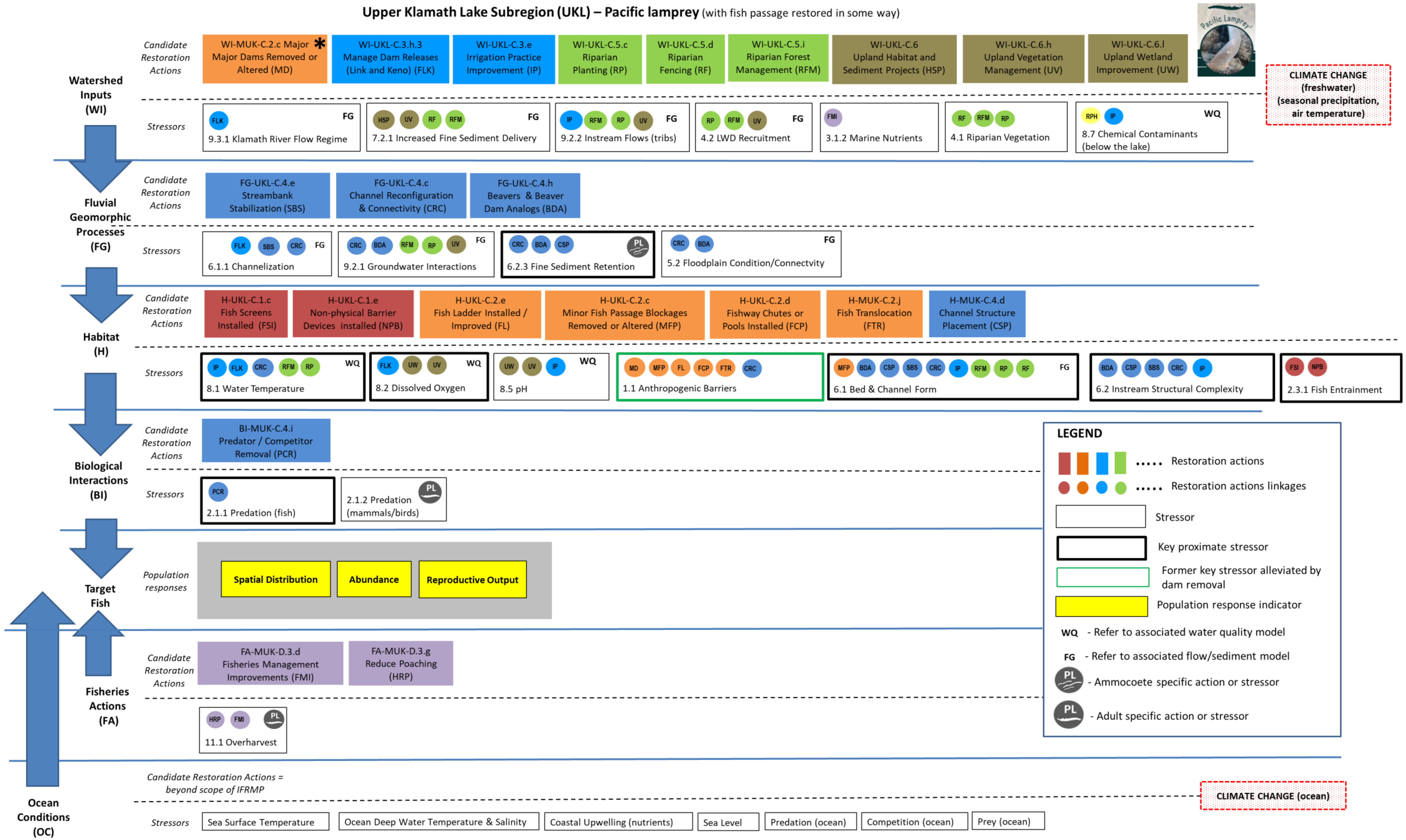
Upper Klamath Lake (UKL) Subregion – Endangered Suckers (Lost River Sucker and Shortnose Sucker)



Upper Klamath Lake Subregion (UKL) - Salmon (Chinook/Coho/Steelhead) (with fish passage restored in some way)



***All actions of this conceptual model could still be beneficial to restored salmon in the UKL subregion regardless of whether or not mainstem dams are removed.**



All actions of this conceptual model could still be beneficial to restored Pacific Lamprey in the UKL subregion regardless of whether or not mainstem dams are removed.

Figure A - 6. Conceptual diagrams and supporting table for stressors and potential restoration actions across model framework tiers for focal fish species in the Upper Klamath Lake (UKL) sub-region: Bull Trout & Redband Trout, Endangered Suckers (Lost River Sucker, and Shortnose Sucker); and potential future species in the UKL - Chinook, Coho, & Steelhead, and Pacific Lamprey. See Figure A - 1 for explanation of abbreviations.

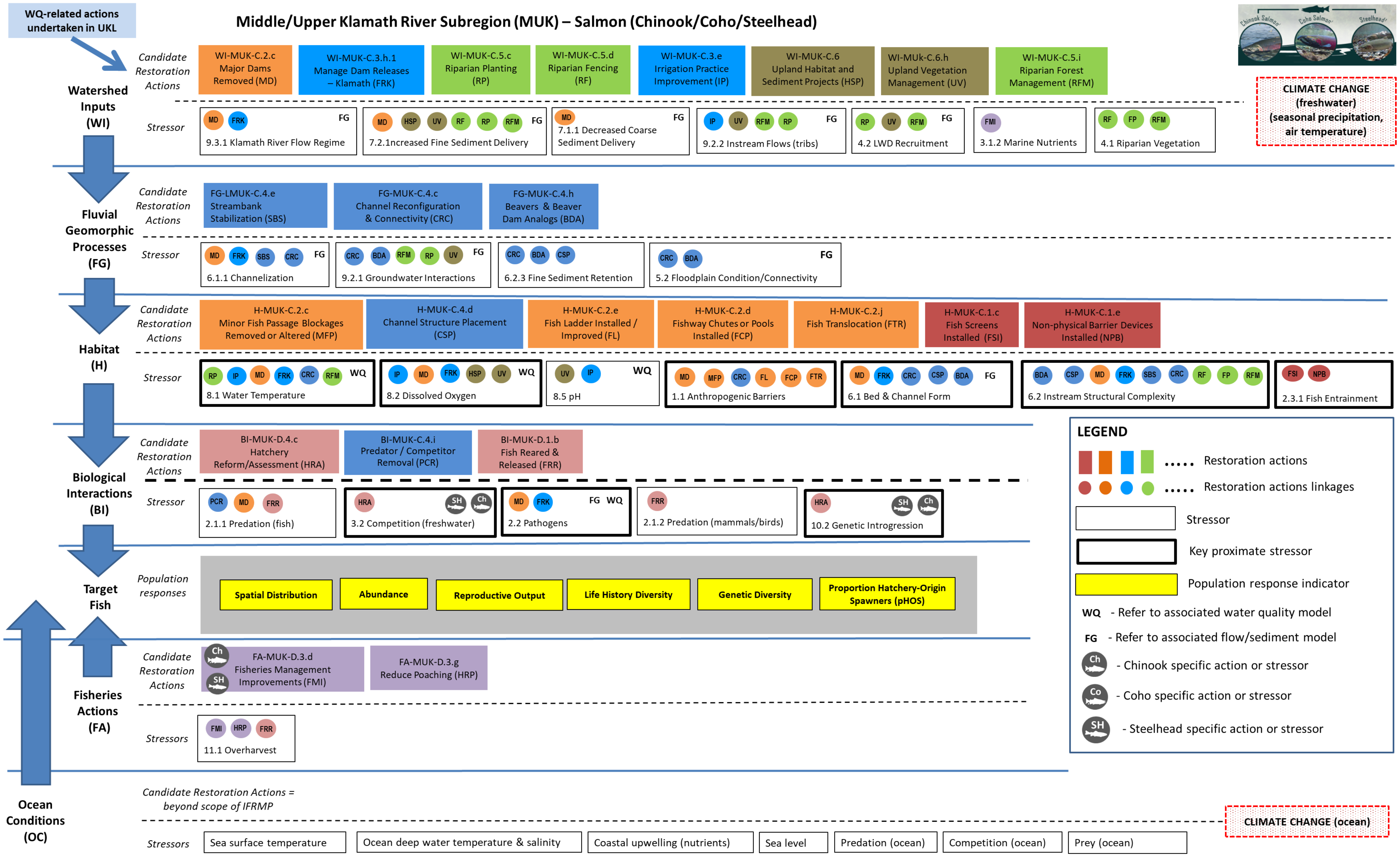
Table A - 4. Stressors affecting the focal fish species/functional groups in the Upper Klamath Lake (UKL) sub-region and the candidate restoration actions that could help alleviate/mitigate each stressor (codes in table match with those for stressors and restoration actions in UKL species conceptual diagrams. Critical uncertainties around each restoration action are described in the Klamath IFRMP Master Restoration Actions Dictionary.

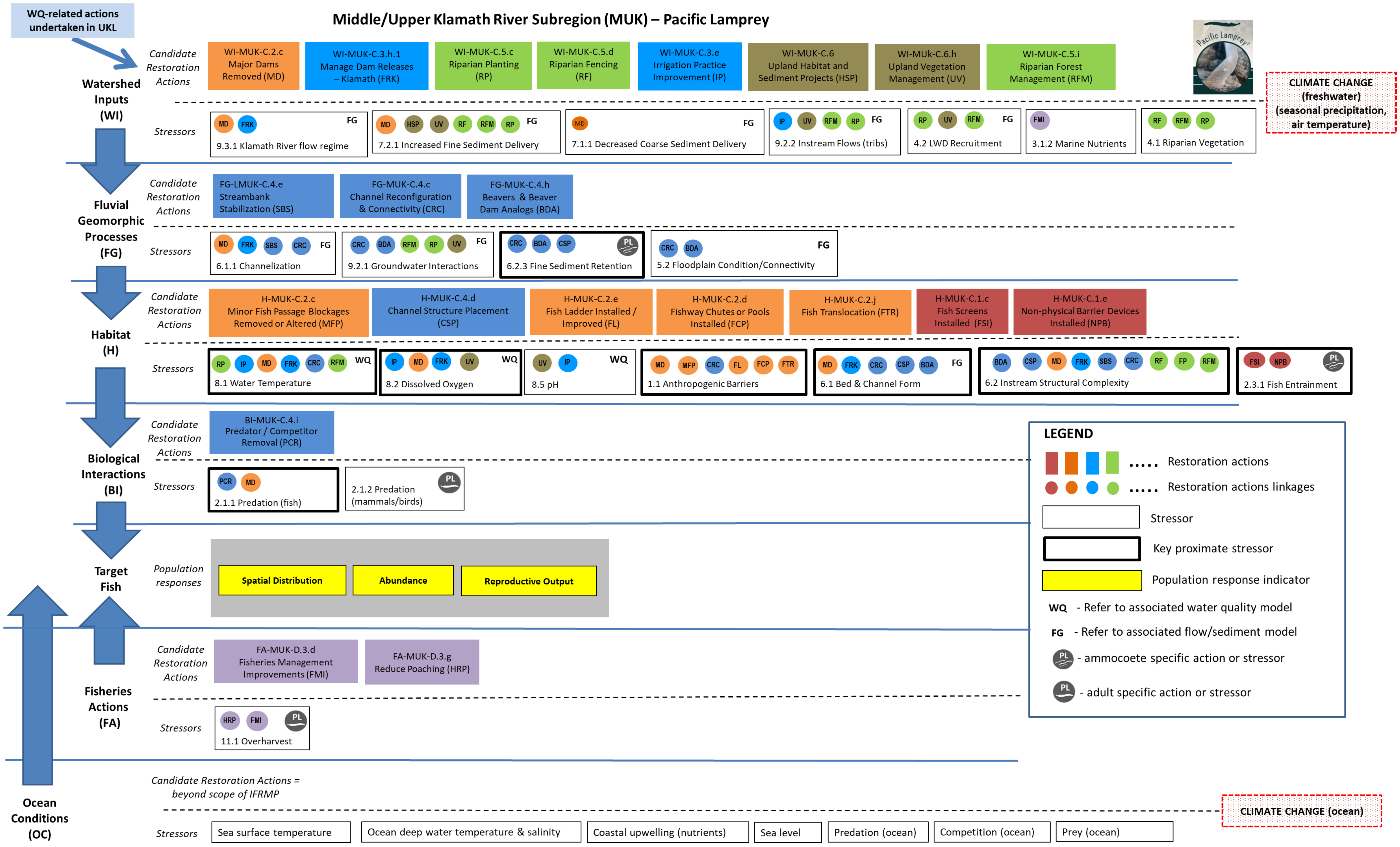
Upper Klamath Lake Focal Species Models Summary (Stressors and Candidate Restoration Actions)			
Tier	**Stressors**	**Candidate Restoration Actions to Alleviate Stressor**	**Restoration Action Code**
Watershed Inputs	7.2.1 Increased fine sediment input/delivery	Upland livestock management (UL)	FG-UKL-C.6.j
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Upland vegetation management (UV)	WI-UKL-C.6.h
	9.2.2 Instream flow (tribs)	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Water leased or purchased (WLP)	WI-UKL-C.3.f
	3.1.1 Hypereutrophication	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Upland livestock management (UL)	WI-UKL-C.6.j
		Upland vegetation management (UV)	WI-UKL-C.6.h
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
		Riparian forest management (RFM)	WI-UKL-C.5.i
	8.7 Chemical contaminants (below the lake)	Reduce pesticide/herbicide use (RPH)	WI-UKL-C.7.g
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
	4.1 Riparian vegetation	Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
	9.3.1 Klamath River flow regime	Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
	4.2 LWD recruitment	Riparian planting (RP)	WI-UKL-C.5.c
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Upland vegetation management (UV)	WI-UKL-C.6.h
	3.1.2 Marine nutrients	Fisheries management Improvements (FMI)	FA-UKL-D.3.d

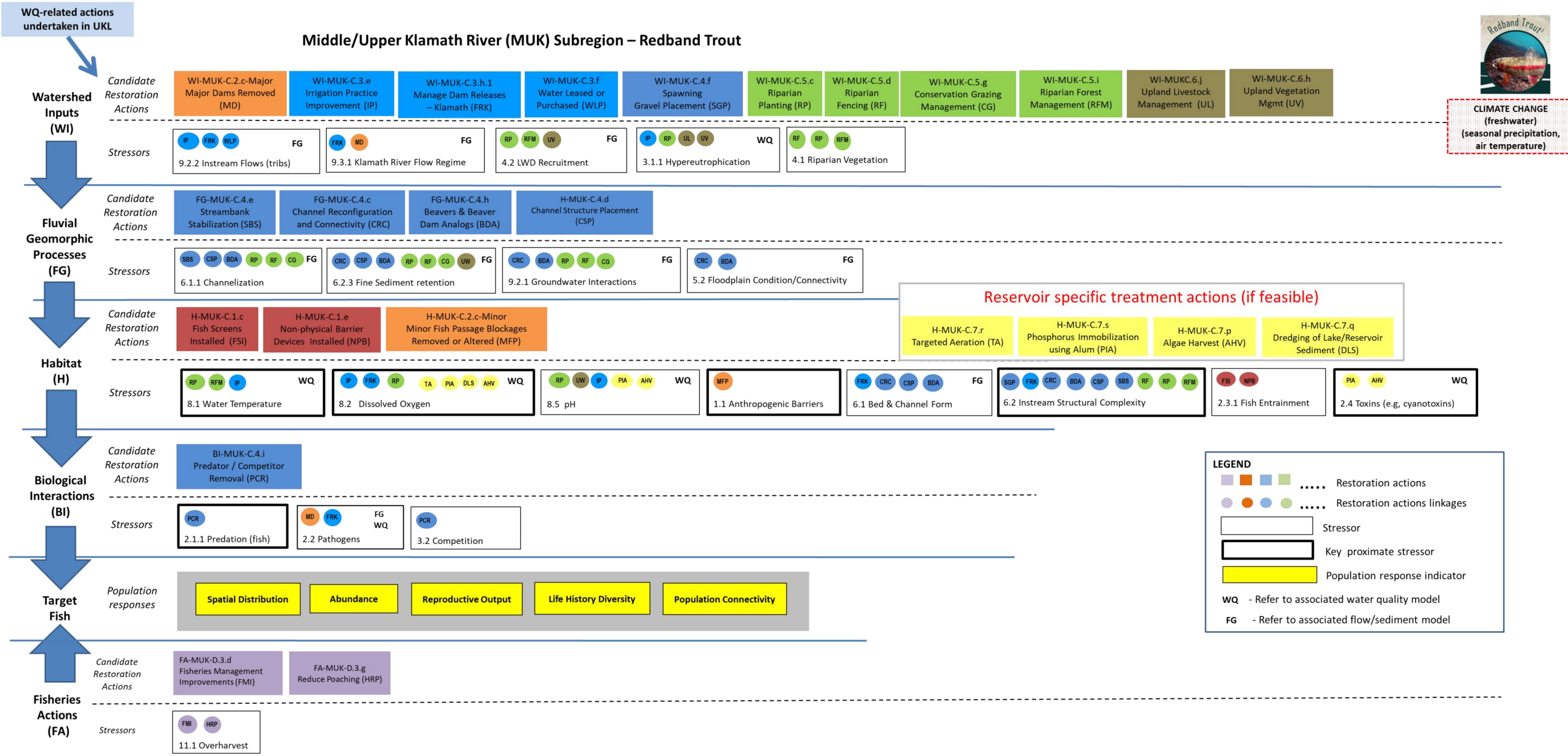
		Major dams removed or altered (MD)	WI-MUK-C.2.c Major
Fluvial Geomorphic Processes	9.2.1 Groundwater interactions	Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers and beaver dam analogues (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Conservation grazing management (CG)	WI-UKL-C.5.g
		Upland wetland improvement (UW)	WI-UKL-C.6.l
	5.2 Floodplain condition/connectivity	Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
	9.2.3 Channelization	Streambank stabilization (SBS)	FG-UKL-C.4.e
		Channel structure placement (CSP)	H-UKL-C.4.d
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Conservation grazing management (CG)	WI-UKL-C.5.g
Habitat	8.1 Water temperature	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Riparian planting (RP)	WI-UKL-C.5.c
		Upland wetland improvement (UW)	WI-UKL-C.6.l
		Riparian forest management (RFM)	WI-UKL-C.5.i
	8.2 Dissolved oxygen	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Targeted aeration (TA)	H-UKL-C.7.r
		Phosphorus immobilization using alum (PIA)	HI-UKL-C.7.s
		Wetland planting (WP)	H-UKL-C.8.c
		Dredging of lake/reservoir sediment (DLS)	H-UKL-C.7.q
		Algae harvest (AHV)	H-UKL-C.7.p
	8.5 pH	Phosphorus immobilization using alum (PIA)	H-UKL-C.7.s
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Algae harvest (AHV)	H-UKL-C.7.p

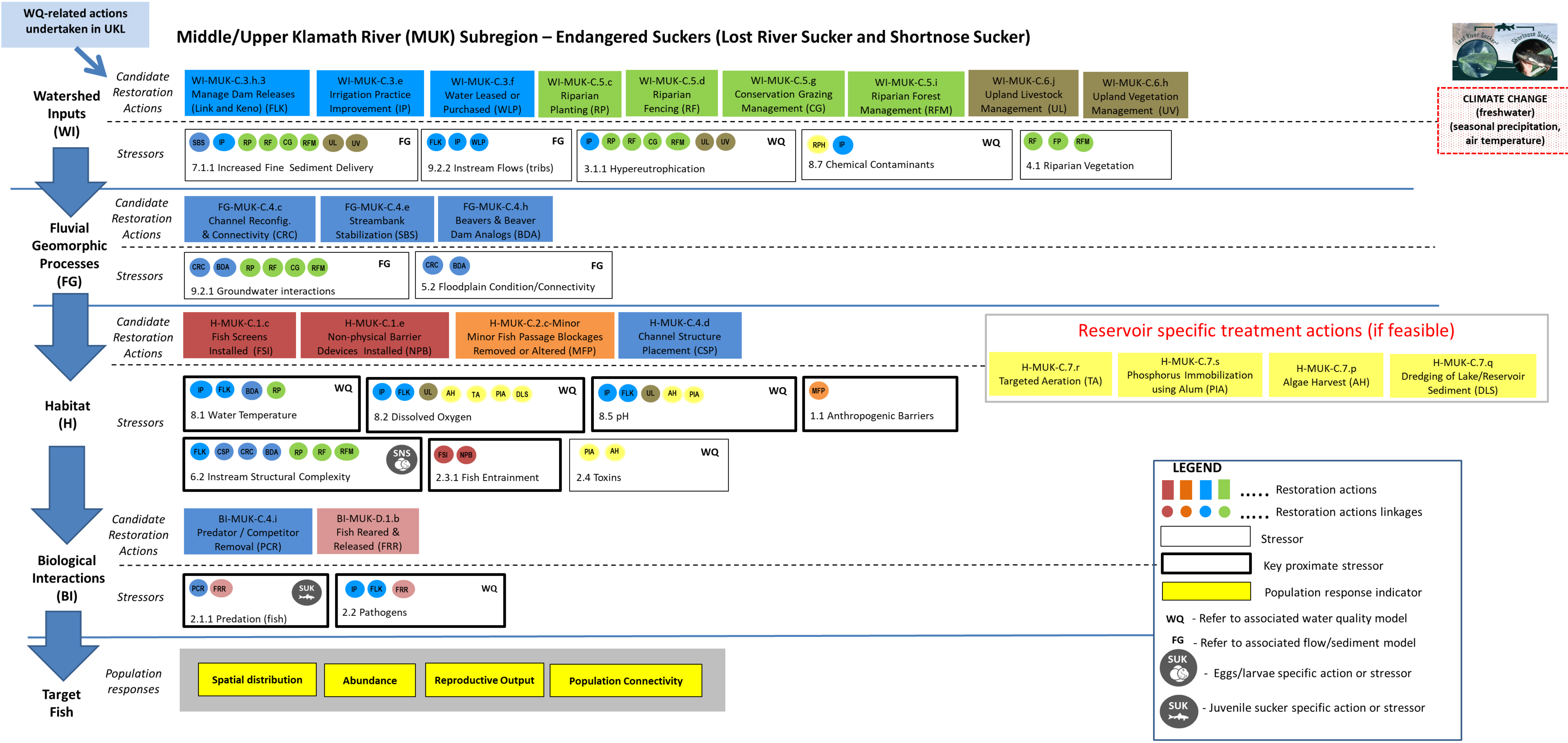
		Wetland planting (WP)	H_UKL-C.8.c
		Upland livestock management (UL)	WI-UKL-C.6.j
	1.1 Anthropogenic barriers	Minor fish passage blockages removed or altered (MFP)	H-UKL-C.2.c-Minor
		Fish ladder installed/improved (FL) (Link/Keno)	H-UKL-C.2.e
	9.2.3 Lake levels	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Water leased or purchased (WLP)	WI-UKL-C.3.f
	6.1 Bed & channel form	Minor fish passage blockages removed or altered (MFP)	H-UKL-C.2.c-Minor
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-UKL-C.3.h.3
		Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Streambank stabilization (SBS)	FG-UKL-C.4.e
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
	6.2 Instream structural complexity	Channel structure placement (CSP)	H-UKL-C.4.d
		Channel reconfiguration and connectivity (CRC)	FG-UKL-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-UKL-C.4.h
		Riparian planting (RP)	WI-UKL-C.5.c
		Riparian fencing (RF)	WI-UKL-C.5.d
		Riparian forest management (RFM)	WI-UKL-C.5.i
		Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Minor fish passage blockages removed or altered (MFP)	H-UKL-C.2.c-Minor
		Streambank stabilization (SBS)	FG-UKL-C.4.e
		Spawning gravel placement (SGP)	WI-UKL-C.4.f
	2.3.1 Fish entrainment	Fish Screens Installed (FSI)	H-UKL-C.1.c
		Non-physical barrier devices installed (NPB)	H-UKL-C.1.e
	9.2.4 Lake fetch	Wetland planting (WP)	H_UKL-C.8.c
		Wetland improvement (WIR)	H-UKL-C.8.e
	5.5 Lakeshore conditions	Wetland planting (WP)	H_UKL-C.8.c
		Wetland improvement (WIR)	H-UKL-C.8.e
	2.4 Toxins (e.g., cyanotoxins)	Irrigation practice improvement (IP)	WI-UKL-C.3.e

		Phosphorus immobilization using alum (PIA)	H-UKL-C.7.s
		Algae harvest (AHV)	H-UKL-C.7.p
Biological Interactions	2.1.1 Predation (fish)	Predator / competitor removal (PCR)	BI-UKL-C.4.i
		Fish reared and released (FRR)	BI-UKL-D.1.b
	3.2 Competition	Predator / competitor removal (PCR)	BI-UKL-C.4.i
	3.3.1 Salmon prey	Major dams removed or altered (MD)	WI-MUK-C.2.c Major
		Fish ladder installed/improved (Link/Keno)	H-UKL-C.2.e
	10.1 Hybridization	Predator / competitor removal (PCR)	BI-UKL-C.4.i
	2.2 Pathogens	Irrigation practice improvement (IP)	WI-UKL-C.3.e
		Manage Dam Releases (Link and Keno) (FLK)	WI-UKL-C.3.h.1
		Fish Reared & Released (FRR)	BI-UKL-D.1.b
Fisheries Actions	11.1 Overharvest	Fisheries management Improvements (FMI)	FA-UKL-D.3.d
		Reduce poaching (HRP)	FA-UKL-D.3.g


WQ-related actions undertaken in UKL
Middle/Upper Klamath River Subregion (MUK) – Salmon (Chinook/Coho/Steelhead)
Chinook Salmon
Coho Salmon
Steelhead
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.2.c Major Dams Removed (MD)
WI-MUK-C.3.h.1 Manage Dam Releases – Klamath (FRK)
WI-MUK-C.5.c Riparian Planting (RP)
WI-MUK-C.5.d Riparian Fencing (RF)
WI-MUK-C.3.e Irrigation Practice Improvement (IP)
WI-MUK-C.6 Upland Habitat and Sediment Projects (HSP)
WI-MUK-C.6.h Upland Vegetation Management (UV)
WI-MUK-C.5.i Riparian Forest Management (RFM)
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Stressor
MD FRK FG 9.3.1 Klamath River Flow Regime
MD HSP UV RF RP RFM FG 7.2.1ncreased Fine Sediment Delivery
MD FG 7.1.1 Decreased Coarse Sediment Delivery
IP UV RFM RP FG 9.2.2 Instream Flows (tribs)
RP UV RFM FG 4.2 LWD Recruitment
FMI 3.1.2 Marine Nutrients
RF FP RFM 4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
Candidate Restoration Actions
FG-LMUK-C.4.e Streambank Stabilization (SBS)
FG-MUK-C.4.c Channel Reconfiguration & Connectivity (CRC)
FG-MUK-C.4.h Beavers & Beaver Dam Analogs (BDA)
Stressor
MD FRK SBS CRC FG 6.1.1 Channelization
CRC BDA RFM RP UV FG 9.2.1 Groundwater Interactions
CRC BDA CSP 6.2.3 Fine Sediment Retention
CRC BDA FG 5.2 Floodplain Condition/Connectivity
Habitat (H)
Candidate Restoration Actions
H-MUK-C.2.c Minor Fish Passage Blockages Removed or Altered (MFP)
H-MUK-C.4.d Channel Structure Placement (CSP)
H-MUK-C.2.e Fish Ladder Installed / Improved (FL)
H-MUK-C.2.d Fishway Chutes or Pools Installed (FCP)
H-MUK-C.2.j Fish Translocation (FTR)
H-MUK-C.1.c Fish Screens Installed (FSI)
H-MUK-C.1.e Non-physical Barrier Devices Installed (NPB)
Stressor
RP IP MD FRK CRC RFM WQ 8.1 Water Temperature
IP MD FRK HSP UV WQ 8.2 Dissolved Oxygen
UV IP WQ 8.5 pH
MD MFP CRC FL FCP FTR 1.1 Anthropogenic Barriers
MD FRK CRC CSP BDA FG 6.1 Bed & Channel Form
BDA CSP MD FRK SBS CRC RF FP RFM 6.2 Instream Structural Complexity
FSI NPB 2.3.1 Fish Entrainment
Biological Interactions (BI)
Candidate Restoration Actions
BI-MUK-D.4.c Hatchery Reform/Assessment (HRA)
BI-MUK-C.4.i Predator / Competitor Removal (PCR)
BI-MUK-D.1.b Fish Reared & Released (FRR)
Stressor
PCR MD FRR 2.1.1 Predation (fish)
HRA SH Ch 3.2 Competition (freshwater)
MD FRK FG WQ 2.2 Pathogens
FRR 2.1.2 Predation (mammals/birds)
HRA SH Ch 10.2 Genetic Introgression
Target Fish
Population responses
Spatial Distribution
Abundance
Reproductive Output
Life History Diversity
Genetic Diversity
Proportion Hatchery-Origin Spawners (pHOS)
Fisheries Actions (FA)
Candidate Restoration Actions
Ch SH FA-MUK-D.3.d Fisheries Management Improvements (FMI)
FA-MUK-D.3.g Reduce Poaching (HRP)
Stressors
FMI HRP FRR 11.1 Overharvest
Ocean Conditions (OC)
Candidate Restoration Actions = beyond scope of IFRMP
CLIMATE CHANGE (ocean)
Stressors
Sea surface temperature
Ocean deep water temperature & salinity
Coastal upwelling (nutrients)
Sea level
Predation (ocean)
Competition (ocean)
Prey (ocean)
LEGEND
..... Restoration actions
..... Restoration actions linkages
Stressor
Key proximate stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
Ch - Chinook specific action or stressor
Co - Coho specific action or stressor
SH - Steelhead specific action or stressor


Middle/Upper Klamath River Subregion (MUK) – Pacific Lamprey
WQ-related actions undertaken in UKL
Pacific Lamprey
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.2.c Major Dams Removed (MD)
WI-MUK-C.3.h.1 Manage Dam Releases – Klamath (FRK)
WI-MUK-C.5.c Riparian Planting (RP)
WI-MUK-C.5.d Riparian Fencing (RF)
WI-MUK-C.3.e Irrigation Practice Improvement (IP)
WI-MUK-C.6 Upland Habitat and Sediment Projects (HSP)
WI-MUk-C.6.h Upland Vegetation Management (UV)
WI-MUK-C.5.i Riparian Forest Management (RFM)
Stressors
MD FRK FG 9.3.1 Klamath River flow regime
MD HSP UV RF RFM RP FG 7.2.1 Increased Fine Sediment Delivery
MD FG 7.1.1 Decreased Coarse Sediment Delivery
IP UV RFM RP FG 9.2.2 Instream Flows (tribs)
RP UV RFM FG 4.2 LWD Recruitment
FMI 3.1.2 Marine Nutrients
RF RFM RP 4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
Candidate Restoration Actions
FG-LMUK-C.4.e Streambank Stabilization (SBS)
FG-MUK-C.4.c Channel Reconfiguration & Connectivity (CRC)
FG-MUK-C.4.h Beavers & Beaver Dam Analogs (BDA)
Stressors
MD FRK SBS CRC FG 6.1.1 Channelization
CRC BDA RFM RP UV FG 9.2.1 Groundwater Interactions
CRC BDA CSP PL 6.2.3 Fine Sediment Retention
CRC BDA FG 5.2 Floodplain Condition/Connectivity
Habitat (H)
Candidate Restoration Actions
H-MUK-C.2.c Minor Fish Passage Blockages Removed or Altered (MFP)
H-MUK-C.4.d Channel Structure Placement (CSP)
H-MUK-C.2.e Fish Ladder Installed / Improved (FL)
H-MUK-C.2.d Fishway Chutes or Pools Installed (FCP)
H-MUK-C.2.j Fish Translocation (FTR)
H-MUK-C.1.c Fish Screens Installed (FSI)
H-MUK-C.1.e Non-physical Barrier Devices Installed (NPB)
Stressors
RP IP MD FRK CRC RFM WQ 8.1 Water Temperature
IP MD FRK UV WQ 8.2 Dissolved Oxygen
UV IP WQ 8.5 pH
MD MFP CRC FL FCP FTR 1.1 Anthropogenic Barriers
MD FRK CRC CSP BDA FG 6.1 Bed & Channel Form
BDA CSP MD FRK SBS CRC RF FP RFM 6.2 Instream Structural Complexity
FSI NPB PL 2.3.1 Fish Entrainment
Biological Interactions (BI)
Candidate Restoration Actions
BI-MUK-C.4.i Predator / Competitor Removal (PCR)
Stressors
PCR MD 2.1.1 Predation (fish)
PL 2.1.2 Predation (mammals/birds)
Target Fish
Population responses
Spatial Distribution
Abundance
Reproductive Output
Fisheries Actions (FA)
Candidate Restoration Actions
FA-MUK-D.3.d Fisheries Management Improvements (FMI)
FA-MUK-D.3.g Reduce Poaching (HRP)
Stressors
HRP FMI PL 11.1 Overharvest
Ocean Conditions (OC)
Candidate Restoration Actions = beyond scope of IFRMP
CLIMATE CHANGE (ocean)
Stressors
Sea surface temperature
Ocean deep water temperature & salinity
Coastal upwelling (nutrients)
Sea level
Predation (ocean)
Competition (ocean)
Prey (ocean)
LEGEND
Restoration actions
Restoration actions linkages
Stressor
Key proximate stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
PL - ammocoete specific action or stressor
PL - adult specific action or stressor


WQ-related actions undertaken in UKL
Middle/Upper Klamath River (MUK) Subregion – Redband Trout
Redband Trout
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.2.c-Major Major Dams Removed (MD)
WI-MUK-C.3.e Irrigation Practice Improvement (IP)
WI-MUK-C.3.h.1 Manage Dam Releases – Klamath (FRK)
WI-MUK-C.3.f Water Leased or Purchased (WLP)
WI-MUK-C.4.f Spawning Gravel Placement (SGP)
WI-MUK-C.5.c Riparian Planting (RP)
WI-MUK-C.5.d Riparian Fencing (RF)
WI-MUK-C.5.g Conservation Grazing Management (CG)
WI-MUK-C.5.i Riparian Forest Management (RFM)
WI-MUKC.6.j Upland Livestock Management (UL)
WI-MUK-C.6.h Upland Vegetation Mgmt (UV)
Stressors
9.2.2 Instream Flows (tribs)
9.3.1 Klamath River Flow Regime
4.2 LWD Recruitment
3.1.1 Hypereutrophication
4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
FG-MUK-C.4.e Streambank Stabilization (SBS)
FG-MUK-C.4.c Channel Reconfiguration and Connectivity (CRC)
FG-MUK-C.4.h Beavers & Beaver Dam Analogs (BDA)
H-MUK-C.4.d Channel Structure Placement (CSP)
6.1.1 Channelization
6.2.3 Fine Sediment retention
9.2.1 Groundwater Interactions
5.2 Floodplain Condition/Connectivity
Reservoir specific treatment actions (if feasible)
H-MUK-C.7.r Targeted Aeration (TA)
H-MUK-C.7.s Phosphorus Immobilization using Alum (PIA)
H-MUK-C.7.p Algae Harvest (AHV)
H-MUK-C.7.q Dredging of Lake/Reservoir Sediment (DLS)
Habitat (H)
H-MUK-C.1.c Fish Screens Installed (FSI)
H-MUK-C.1.e Non-physical Barrier Devices Installed (NPB)
H-MUK-C.2.c-Minor Minor Fish Passage Blockages Removed or Altered (MFP)
8.1 Water Temperature
8.2 Dissolved Oxygen
8.5 pH
1.1 Anthropogenic Barriers
6.1 Bed & Channel Form
6.2 Instream Structural Complexity
2.3.1 Fish Entrainment
2.4 Toxins (e.g, cyanotoxins)
Biological Interactions (BI)
BI-MUK-C.4.i Predator / Competitor Removal (PCR)
2.1.1 Predation (fish)
2.2 Pathogens
3.2 Competition
Target Fish
Population responses
Spatial Distribution
Abundance
Reproductive Output
Life History Diversity
Population Connectivity
Fisheries Actions (FA)
FA-MUK-D.3.d Fisheries Management Improvements (FMI)
FA-MUK-D.3.g Reduce Poaching (HRP)
11.1 Overharvest
LEGEND
Restoration actions
Restoration actions linkages
Stressor
Key proximate stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model


WQ-related actions undertaken in UKL
Middle/Upper Klamath River (MUK) Subregion – Endangered Suckers (Lost River Sucker and Shortnose Sucker)
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.3.h.3 Manage Dam Releases (Link and Keno) (FLK)
WI-MUK-C.3.e Irrigation Practice Improvement (IP)
WI-MUK-C.3.f Water Leased or Purchased (WLP)
WI-MUK-C.5.c Riparian Planting (RP)
WI-MUK-C.5.d Riparian Fencing (RF)
WI-MUK-C.5.g Conservation Grazing Management (CG)
WI-MUK-C.5.i Riparian Forest Management (RFM)
WI-MUK-C.6.j Upland Livestock Management (UL)
WI-MUK-C.6.h Upland Vegetation Management (UV)
Stressors
SBS IP RP RF CG RFM UL UV FG 7.1.1 Increased Fine Sediment Delivery
FLK IP WLP FG 9.2.2 Instream Flows (tribs)
IP RP RF CG RFM UL UV WQ 3.1.1 Hypereutrophication
RPH IP WQ 8.7 Chemical Contaminants
RF FP RFM 4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
Candidate Restoration Actions
FG-MUK-C.4.c Channel Reconfig. & Connectivity (CRC)
FG-MUK-C.4.e Streambank Stabilization (SBS)
FG-MUK-C.4.h Beavers & Beaver Dam Analogs (BDA)
Stressors
CRC BDA RP RF CG RFM FG 9.2.1 Groundwater interactions
CRC BDA FG 5.2 Floodplain Condition/Connectivity
Habitat (H)
Candidate Restoration Actions
H-MUK-C.1.c Fish Screens Installed (FSI)
H-MUK-C.1.e Non-physical Barrier Ddevices Installed (NPB)
H-MUK-C.2.c-Minor Minor Fish Passage Blockages Removed or Altered (MFP)
H-MUK-C.4.d Channel Structure Placement (CSP)
Reservoir specific treatment actions (if feasible)
H-MUK-C.7.r Targeted Aeration (TA)
H-MUK-C.7.s Phosphorus Immobilization using Alum (PIA)
H-MUK-C.7.p Algae Harvest (AH)
H-MUK-C.7.q Dredging of Lake/Reservoir Sediment (DLS)
Stressors
IP FLK BDA RP WQ 8.1 Water Temperature
IP FLK UL AH TA PIA DLS WQ 8.2 Dissolved Oxygen
IP FLK UL AH PIA WQ 8.5 pH
MFP 1.1 Anthropogenic Barriers
FLK CSP CRC BDA RP RF RFM SNS 6.2 Instream Structural Complexity
FSI NPB 2.3.1 Fish Entrainment
PIA AH WQ 2.4 Toxins
Biological Interactions (BI)
Candidate Restoration Actions
BI-MUK-C.4.i Predator / Competitor Removal (PCR)
BI-MUK-D.1.b Fish Reared & Released (FRR)
Stressors
PCR FRR SUK 2.1.1 Predation (fish)
IP FLK FRR WQ 2.2 Pathogens
Target Fish
Population responses
Spatial distribution
Abundance
Reproductive Output
Population Connectivity
LEGEND
Restoration actions
Restoration actions linkages
Stressor
Key proximate stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
SUK - Eggs/larvae specific action or stressor
SUK - Juvenile sucker specific action or stressor

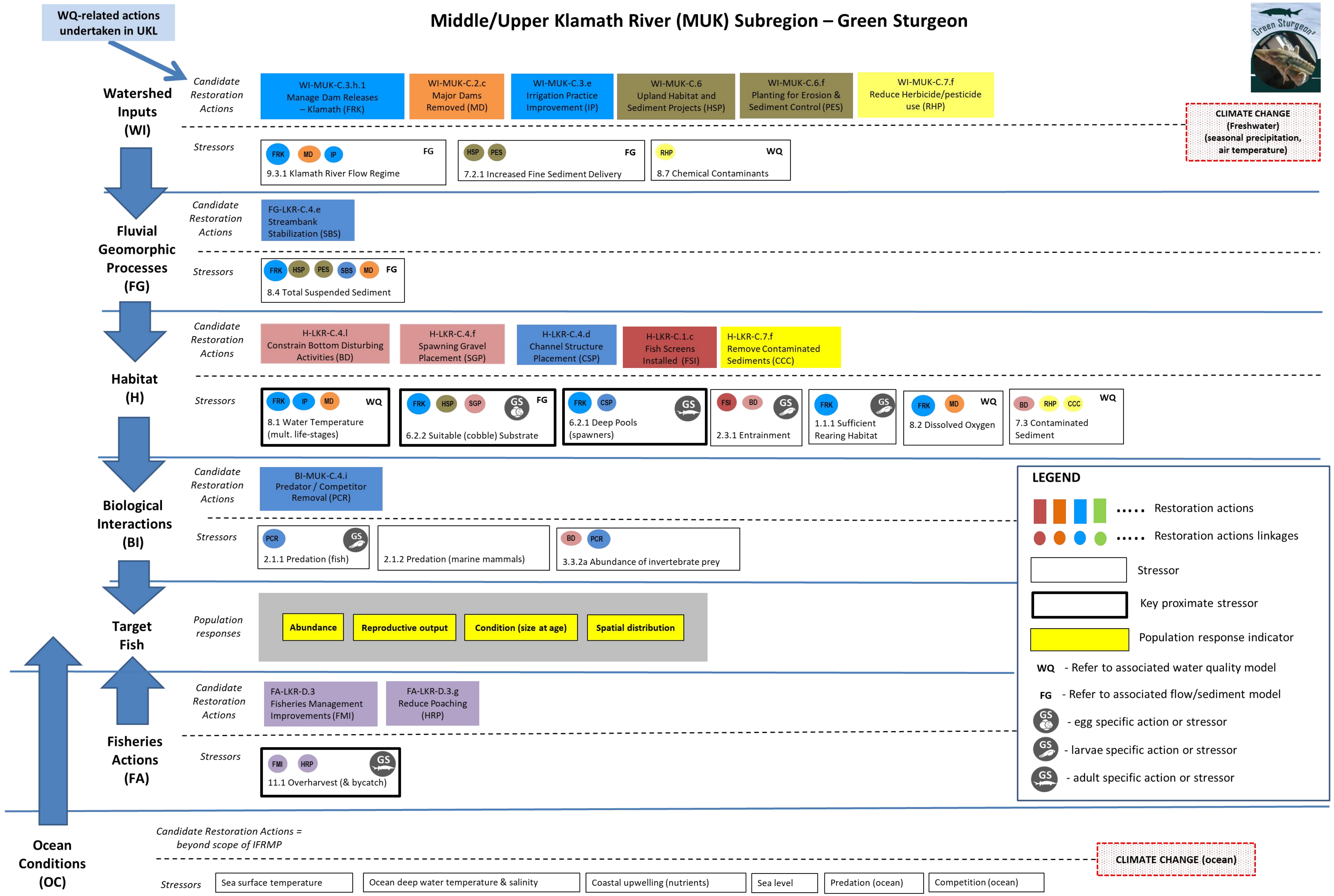


Figure A - 7. Conceptual diagrams for stressors and potential restoration actions across model framework tiers for focal species in the Mid/Upper Klamath River (MUK) sub-region: Chinook, Coho, & Steelhead, Pacific Lamprey, Redband Trout, Endangered Suckers (Lost River Sucker and Shortnose Sucker), and Green Sturgeon. See Figure 2 for explanation of abbreviations.

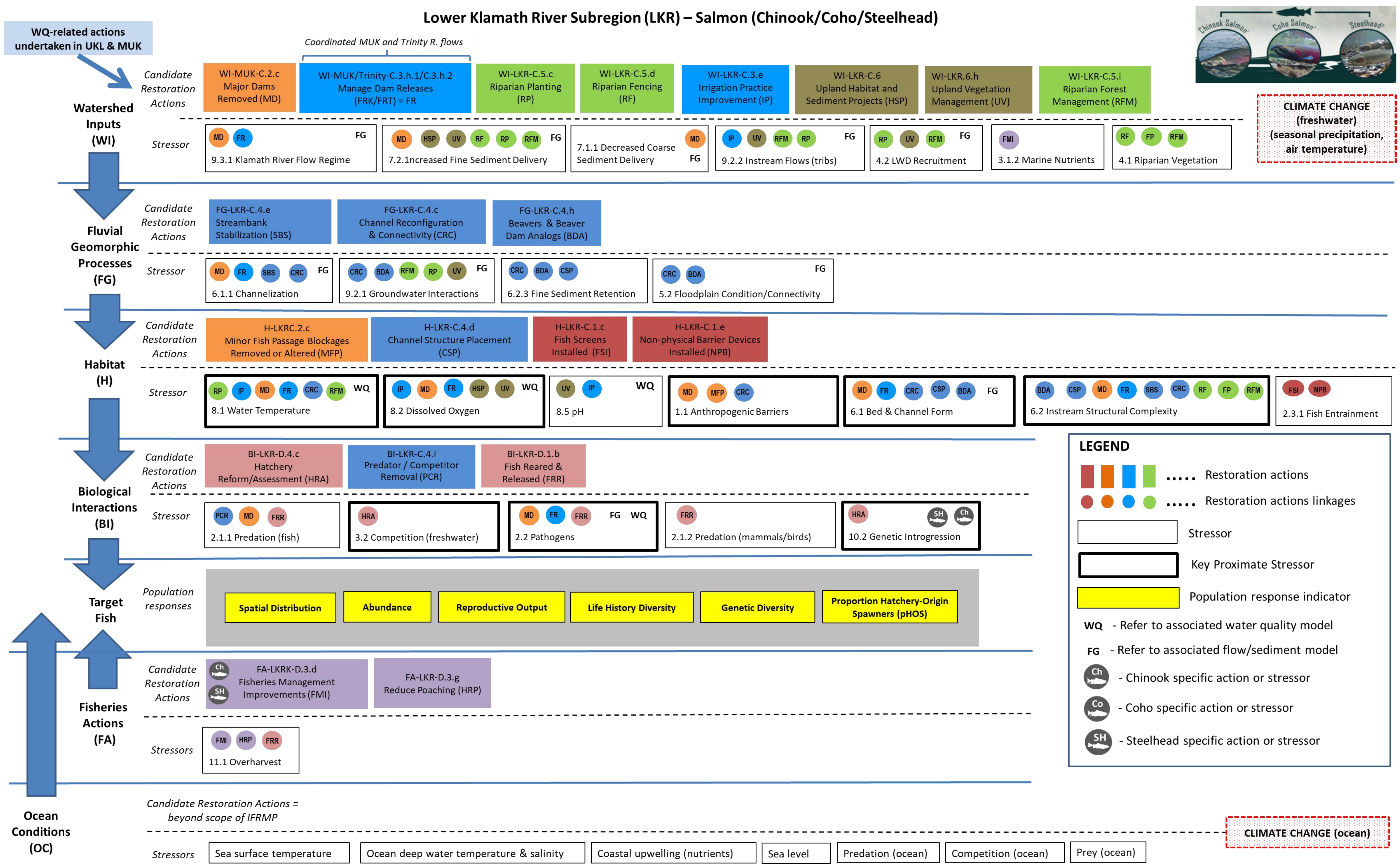
Table A - 5. Stressors affecting the focal fish species/functional groups in the Mid/Upper Klamath River (MUK) sub-region and the candidate restoration actions that could help alleviate/mitigate each stressor (codes in table match with those for stressors and restoration actions in MUK focal species conceptual diagrams. Critical uncertainties around each restoration action are described in the Klamath IFRMP Master Restoration Actions Dictionary.

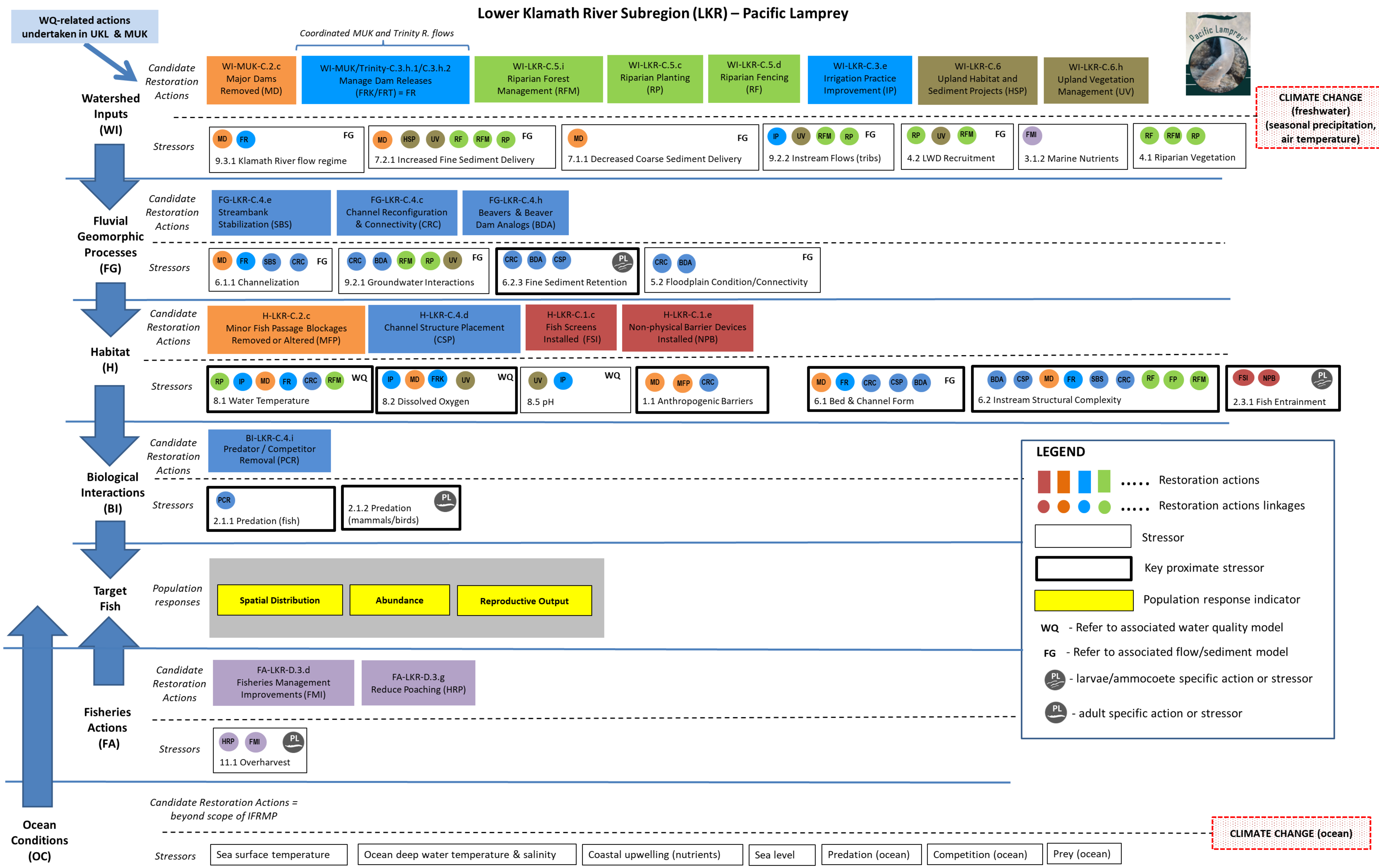
Tier	Stressor	Candidate Restoration Actions to Alleviate Limiting Factor	Restoration Action Code
Watershed Inputs	9.3.1 Klamath River flow regime	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
	7.2.1 Increased fine sediment delivery	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Upland Habitat and Sediments Projects (HSP)	WI-MUK-C.6
		Irrigation practice improvement (IP)	WI-MUK-C.3.e
		Riparian forest management (RFM)	WI-MUK-C.5.i
		Riparian fencing (RF)	WI-MUK-C.5.d
		Riparian planting (RP)	WI-MUK-C.5.c
		Upland livestock management (UL)	WI-MUK-C.6.j
		Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
	7.1.1. Decreased coarse Sediment Delivery	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
	9.2.2 Instream flow (tribs)	Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Riparian Planting (RP)	WI-MUK-C.5.d
		Riparian Forest Management (RFM)	WI-MUK-C.5.i
		Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
		Water leased or purchased (WLP)	WI-MUK-C.3.f
	3.1.1 Hypereutrophication	Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Riparian Fencing (RF)	WI-MUK-C.5.d
		Riparian planting (RP)	WI-MUK-C.5.c
		Conservation grazing management (CG)	WI-MUK-C.5.g
		Riparian forest management (RFM)	WI-MUK-C.5.i
		Upland livestock management (UL)	WI-MUK-C.6.j
		Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
	8.7 Chemical contaminants	Irrigation practice improvement (IP)	WI-MUK-C.3.e
	4.2 LWD recruitment	Riparian planting (RP)	WI-MUK-C.5.c
		Riparian Forest Management (RFM)	WI-MUK-C.5.i

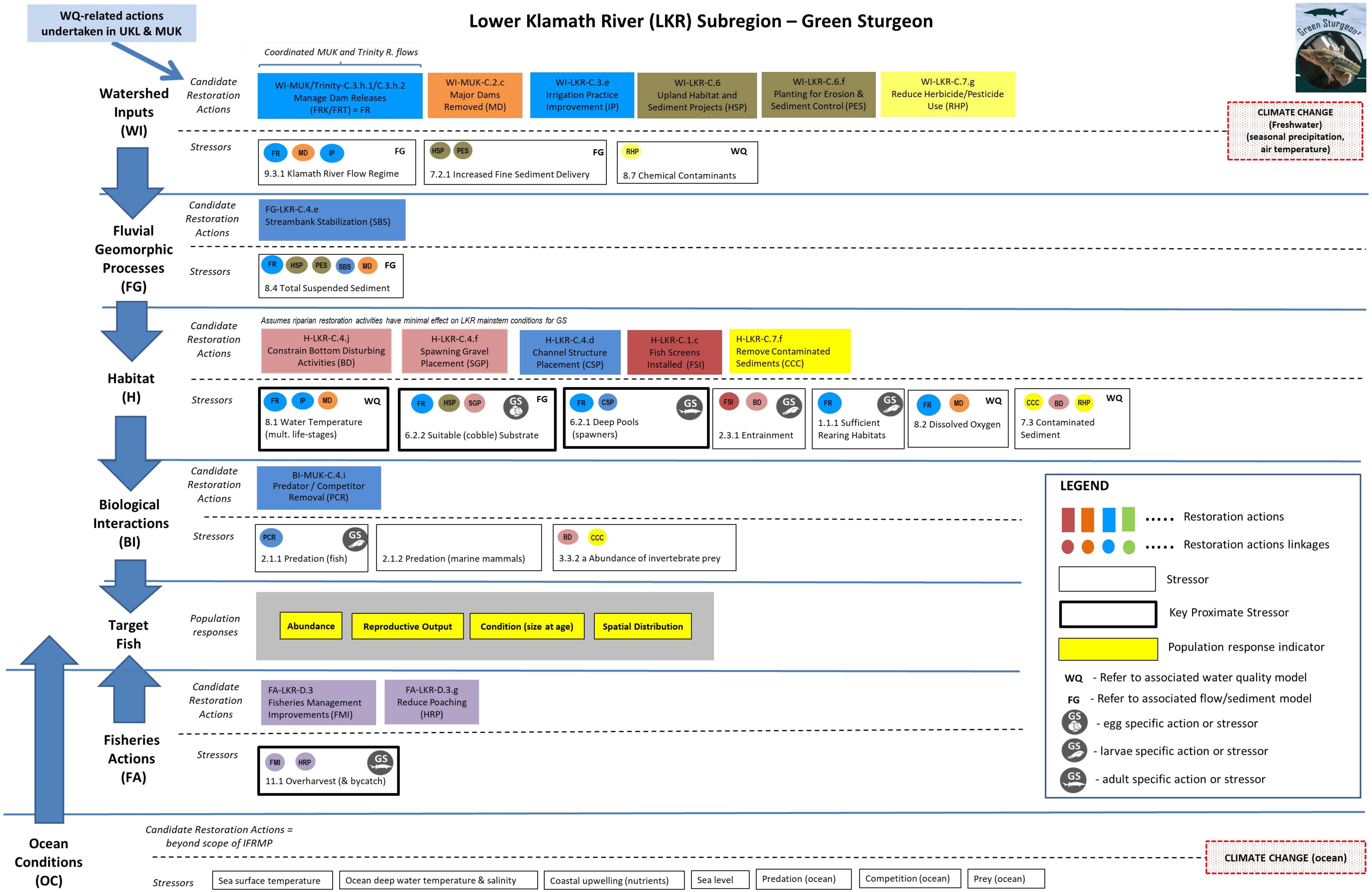
		Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
	3.1.2 Marine nutrients	Fisheries Management Improvement (FMI)	WI-MUK-D.3.d
	4.1 Riparian vegetation	Riparian Forest Management (RFM)	WI-MUK-C.5.i
		Riparian Fencing (RF)	WI-MUK-C.5.d
		Riparian planting (RP)	WI-MUK-C.5.c
Fluvial Geomorphic Processes	6.1.1 Channelization	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Streambank Stabilization (SBS)	FG-MUK-C.4.e
		Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Channel structure placement (CSP)	H-MUK-C.4.d
		Riparian planting (RP)	WI-MUK-C.5.c
		Riparian fencing (RF)	WI-MUK-C.5.d
		Conservation grazing management (CG)	WI-MUK-C.5.i
	9.2.1 Groundwater interactions	Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Riparian planting (RP)	WI-MUK-C.5.c
		Riparian fencing (RF)	WI-MUK-C.5.d
		Riparian forest management (RFM)	WI-MUK-C.5.i
		Upland Vegetation Management (UV)	WI-MUK-C.6.h
		Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h
		Conservation grazing management (CG)	WI-MUK-C.5.i
	6.2.3 Fine sediment retention	Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h
		Channel Structure Placement (CSP)	H-MUK-C.4.d
	5.2 Floodplain condition/connectivity	Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h
Habitat	8.1 Water temperature	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Manage dam releases (Link and Keno) (FLK)	WI-MUK-C.3.h.3
		Riparian Forest Management (RFM)	WI-MUK-C.5.i
		Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c

		Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Riparian Planting (RP)	WI-MUK-C.5.c
		Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h
	8.2 Dissolved oxygen	Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Upland Habitat and Sediments Projects (HSP)	WI-MUK-C.6
		Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
		Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Manage dam releases (Link and Keno) (FLK)	WI-MUK-C.3.h.3
		Upland livestock management (UL)	WI-MUK-C.6.j
		Targeted aeration (TA)	H-UKL-C.7.r
		Phosphorus immobilization using alum (PIA)	HI-UKL-C.7.s
		Wetland planting (WP)	H-UKL-C.8.c
		Dredging of lake/reservoir sediment (DLS)	H-UKL-C.7.q
		Algae harvest (AHV)	H-UKL-C.7.p
	8.5 pH	Upland Vegetation Mgmt (UV)	WI-MUK-C.6.h
		Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-MUK-C.3.h.3
		Wetland planting (WP)	H-UKL-C.8.c
		Upland livestock management (UL)	WI-MUK-C.6.j
		Phosphorus immobilization using alum (PIA)	HI-UKL-C.7.s
		Algae harvest (AHV)	H-UKL-C.7.p
		Riparian planting (RP)	WI-MUK-C.5.c
	1.1 Anthropogenic barriers	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Minor Fish Passage Blockages Removed or Altered (MFP)	H-MUK-C.2.c-Minor
		Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Fish ladder installed/improved (FL)	H-MUK-C.2.e
		Fishway chutes or pools installed (FCP)	H-MUK-C.2.d
		Fish translocation (FTR)	H-MUK-C.2.j
	6.1 Bed & channel form	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h

		Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Channel Structure Placement (CSP)	H-MUK-C.4.d
	6.2 Instream structural complexity	Beaver and beaver dam analogs (BDA)	H--MUK-C.4.h
		Channel Structure Placement (CSP)	H-MUK-C.4.d
		Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Manage dam releases (Link and Keno) (FLK)	WI-MUK-C.3.h.3
		Streambank Stabilization (SBS)	FG-MUK-C.4.e
		Channel Reconfiguration and Connectivity (CRC)	FG-MUK-C.4.c
		Riparian planting (RP)	WI-MUK-C.5.c
		Riparian fencing (RF)	WI-MUK-C.5.d
		Riparian forest management (RFM)	WI-MUK-C.5.i
	2.3.1 Fish entrainment	Fish screens installed (FSI)	WI-MUK-C.1.c
		Non-physical barrier devices installed (NPB)	WI-MUK-C.1.e
	2.4 Toxins	Phosphorus immobilization using alum (PIA)	HI-UKL-C.7.s
		Algae harvest (AHV)	H-UKL-C.7.p
Biological Interactions	2.1.1 Predation (fish)	Predator / Competitor Removal (PCR)	BI-MUK-C.4.i
		Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Fish reared & released (FRR)	BI-MUK-D.1.b
	2.2 Pathogens	Major Dams Removed (MD)	WI-MUK-C.2.c-Major
		Manage Dam Releases - Klamath (FRK)	WI-MUK-C.3.h.1
		Irrigation Practice Improvement (IP)	WI-MUK-C.3.e
		Manage dam releases (Link and Keno) (FLK)	WI-MUK-C.3.h.3
	2.1.2 Predation (mammals/birds)	Fish reared & released (FRR)	BI-MUK-D.1.b
	3.2 Competition	Hatchery reform/assessment (HRA)	BI-MUK-D.4.c
		Predator/competitor removal (PCR)	BI-MUK-C.4.i
	10.2 Genetic introgression	Hatchery reform/assessment (HRA)	BI-MUK-D.4.c
Fisheries Actions	11.2 Overharvest	Fisheries Management Improvement (FMI)	BI-MUK-D.3.d
		Reduce Poaching (HRP)	BI-MUK-D.3.g
		Fish reared & released (FRR)	BI-MUK-D.1.b


Lower Klamath River Subregion (LKR) – Salmon (Chinook/Coho/Steelhead)
WQ-related actions undertaken in UKL & MUK
Coordinated MUK and Trinity R. flows
Chinook Salmon
Coho Salmon
Steelhead
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.2.c Major Dams Removed (MD)
WI-MUK/Trinity-C.3.h.1/C.3.h.2 Manage Dam Releases (FRK/FRT) = FR
WI-LKR-C.5.c Riparian Planting (RP)
WI-LKR-C.5.d Riparian Fencing (RF)
WI-LKR-C.3.e Irrigation Practice Improvement (IP)
WI-LKR-C.6 Upland Habitat and Sediment Projects (HSP)
WI-LKR.6.h Upland Vegetation Management (UV)
WI-LKR-C.5.i Riparian Forest Management (RFM)
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Stressor
MD FR FG 9.3.1 Klamath River Flow Regime
MD HSP UV RF RP RFM FG 7.2.1ncreased Fine Sediment Delivery
MD FG 7.1.1 Decreased Coarse Sediment Delivery
IP UV RFM RP FG 9.2.2 Instream Flows (tribs)
RP UV RFM FG 4.2 LWD Recruitment
FMI 3.1.2 Marine Nutrients
RF FP RFM 4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
Candidate Restoration Actions
FG-LKR-C.4.e Streambank Stabilization (SBS)
FG-LKR-C.4.c Channel Reconfiguration & Connectivity (CRC)
FG-LKR-C.4.h Beavers & Beaver Dam Analogs (BDA)
Stressor
MD FR SBS CRC FG 6.1.1 Channelization
CRC BDA RFM RP UV FG 9.2.1 Groundwater Interactions
CRC BDA CSP 6.2.3 Fine Sediment Retention
CRC BDA FG 5.2 Floodplain Condition/Connectivity
Habitat (H)
Candidate Restoration Actions
H-LKRC.2.c Minor Fish Passage Blockages Removed or Altered (MFP)
H-LKR-C.4.d Channel Structure Placement (CSP)
H-LKR-C.1.c Fish Screens Installed (FSI)
H-LKR-C.1.e Non-physical Barrier Devices Installed (NPB)
Stressor
RP IP MD FR CRC RFM WQ 8.1 Water Temperature
IP MD FR HSP UV WQ 8.2 Dissolved Oxygen
UV IP WQ 8.5 pH
MD MFP CRC 1.1 Anthropogenic Barriers
MD FR CRC CSP BDA FG 6.1 Bed & Channel Form
BDA CSP MD FR SBS CRC RF FP RFM 6.2 Instream Structural Complexity
FSI NPB 2.3.1 Fish Entrainment
Biological Interactions (BI)
Candidate Restoration Actions
BI-LKR-D.4.c Hatchery Reform/Assessment (HRA)
BI-LKR-C.4.i Predator / Competitor Removal (PCR)
BI-LKR-D.1.b Fish Reared & Released (FRR)
Stressor
PCR MD FRR 2.1.1 Predation (fish)
HRA 3.2 Competition (freshwater)
MD FR FRR FG WQ 2.2 Pathogens
FRR 2.1.2 Predation (mammals/birds)
HRA SH Ch 10.2 Genetic Introgression
Target Fish
Population responses
Spatial Distribution
Abundance
Reproductive Output
Life History Diversity
Genetic Diversity
Proportion Hatchery-Origin Spawners (pHOS)
Fisheries Actions (FA)
Candidate Restoration Actions
Ch SH FA-LKRK-D.3.d Fisheries Management Improvements (FMI)
FA-LKR-D.3.g Reduce Poaching (HRP)
Stressors
FMI HRP FRR 11.1 Overharvest
Ocean Conditions (OC)
Candidate Restoration Actions = beyond scope of IFRMP
Stressors
Sea surface temperature
Ocean deep water temperature & salinity
Coastal upwelling (nutrients)
Sea level
Predation (ocean)
Competition (ocean)
Prey (ocean)
CLIMATE CHANGE (ocean)
LEGEND
..... Restoration actions
..... Restoration actions linkages
Stressor
Key Proximate Stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
Ch - Chinook specific action or stressor
Co - Coho specific action or stressor
SH - Steelhead specific action or stressor


Lower Klamath River Subregion (LKR) – Pacific Lamprey
WQ-related actions undertaken in UKL & MUK
Coordinated MUK and Trinity R. flows
Watershed Inputs (WI)
Candidate Restoration Actions
WI-MUK-C.2.c Major Dams Removed (MD)
WI-MUK/Trinity-C.3.h.1/C.3.h.2 Manage Dam Releases (FRK/FRT) = FR
WI-LKR-C.5.i Riparian Forest Management (RFM)
WI-LKR-C.5.c Riparian Planting (RP)
WI-LKR-C.5.d Riparian Fencing (RF)
WI-LKR-C.3.e Irrigation Practice Improvement (IP)
WI-LKR-C.6 Upland Habitat and Sediment Projects (HSP)
WI-LKR-C.6.h Upland Vegetation Management (UV)
Pacific Lamprey
CLIMATE CHANGE (freshwater) (seasonal precipitation, air temperature)
Stressors
9.3.1 Klamath River flow regime
7.2.1 Increased Fine Sediment Delivery
7.1.1 Decreased Coarse Sediment Delivery
9.2.2 Instream Flows (tribs)
4.2 LWD Recruitment
3.1.2 Marine Nutrients
4.1 Riparian Vegetation
Fluvial Geomorphic Processes (FG)
FG-LKR-C.4.e Streambank Stabilization (SBS)
FG-LKR-C.4.c Channel Reconfiguration & Connectivity (CRC)
FG-LKR-C.4.h Beavers & Beaver Dam Analogs (BDA)
6.1.1 Channelization
9.2.1 Groundwater Interactions
6.2.3 Fine Sediment Retention
5.2 Floodplain Condition/Connectivity
Habitat (H)
H-LKR-C.2.c Minor Fish Passage Blockages Removed or Altered (MFP)
H-LKR-C.4.d Channel Structure Placement (CSP)
H-LKR-C.1.c Fish Screens Installed (FSI)
H-LKR-C.1.e Non-physical Barrier Devices Installed (NPB)
8.1 Water Temperature
8.2 Dissolved Oxygen
8.5 pH
1.1 Anthropogenic Barriers
6.1 Bed & Channel Form
6.2 Instream Structural Complexity
2.3.1 Fish Entrainment
Biological Interactions (BI)
BI-LKR-C.4.i Predator / Competitor Removal (PCR)
2.1.1 Predation (fish)
2.1.2 Predation (mammals/birds)
Target Fish
Population responses
Spatial Distribution
Abundance
Reproductive Output
Fisheries Actions (FA)
FA-LKR-D.3.d Fisheries Management Improvements (FMI)
FA-LKR-D.3.g Reduce Poaching (HRP)
11.1 Overharvest
Ocean Conditions (OC)
Candidate Restoration Actions = beyond scope of IFRMP
Sea surface temperature
Ocean deep water temperature & salinity
Coastal upwelling (nutrients)
Sea level
Predation (ocean)
Competition (ocean)
Prey (ocean)
CLIMATE CHANGE (ocean)
LEGEND
Restoration actions
Restoration actions linkages
Stressor
Key proximate stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
PL - larvae/ammocoete specific action or stressor
PL - adult specific action or stressor


Lower Klamath River (LKR) Subregion – Green Sturgeon
WQ-related actions undertaken in UKL & MUK
Green Sturgeon
Watershed Inputs (WI)
Candidate Restoration Actions
Coordinated MUK and Trinity R. flows
WI-MUK/Trinity-C.3.h.1/C.3.h.2 Manage Dam Releases (FRK/FRT) = FR
WI-MUK-C.2.c Major Dams Removed (MD)
WI-LKR-C.3.e Irrigation Practice Improvement (IP)
WI-LKR-C.6 Upland Habitat and Sediment Projects (HSP)
WI-LKR-C.6.f Planting for Erosion & Sediment Control (PES)
WI-LKR-C.7.g Reduce Herbicide/Pesticide Use (RHP)
CLIMATE CHANGE (Freshwater) (seasonal precipitation, air temperature)
Stressors
FR MD IP FG 9.3.1 Klamath River Flow Regime
HSP PES FG 7.2.1 Increased Fine Sediment Delivery
RHP WQ 8.7 Chemical Contaminants
Fluvial Geomorphic Processes (FG)
Candidate Restoration Actions
FG-LKR-C.4.e Streambank Stabilization (SBS)
Stressors
FR HSP PES SBS MD FG 8.4 Total Suspended Sediment
Habitat (H)
Assumes riparian restoration activities have minimal effect on LKR mainstem conditions for GS
Candidate Restoration Actions
H-LKR-C.4.j Constrain Bottom Disturbing Activities (BD)
H-LKR-C.4.f Spawning Gravel Placement (SGP)
H-LKR-C.4.d Channel Structure Placement (CSP)
H-LKR-C.1.c Fish Screens Installed (FSI)
H-LKR-C.7.f Remove Contaminated Sediments (CCC)
Stressors
FR IP MD WQ 8.1 Water Temperature (mult. life-stages)
FR HSP SGP GS FG 6.2.2 Suitable (cobble) Substrate
FR CSP GS 6.2.1 Deep Pools (spawners)
FSI BD GS 2.3.1 Entrainment
FR GS 1.1.1 Sufficient Rearing Habitats
FR MD WQ 8.2 Dissolved Oxygen
CCC BD RHP WQ 7.3 Contaminated Sediment
Biological Interactions (BI)
Candidate Restoration Actions
BI-MUK-C.4.i Predator / Competitor Removal (PCR)
Stressors
PCR GS 2.1.1 Predation (fish)
2.1.2 Predation (marine mammals)
BD CCC 3.3.2 a Abundance of invertebrate prey
Target Fish
Population responses
Abundance
Reproductive Output
Condition (size at age)
Spatial Distribution
Fisheries Actions (FA)
Candidate Restoration Actions
FA-LKR-D.3 Fisheries Management Improvements (FMI)
FA-LKR-D.3.g Reduce Poaching (HRP)
Stressors
FMI HRP GS 11.1 Overharvest (& bycatch)
Ocean Conditions (OC)
Candidate Restoration Actions = beyond scope of IFRMP
CLIMATE CHANGE (ocean)
Stressors
Sea surface temperature
Ocean deep water temperature & salinity
Coastal upwelling (nutrients)
Sea level
Predation (ocean)
Competition (ocean)
Prey (ocean)
LEGEND
Restoration actions
Restoration actions linkages
Stressor
Key Proximate Stressor
Population response indicator
WQ - Refer to associated water quality model
FG - Refer to associated flow/sediment model
GS - egg specific action or stressor
GS - larvae specific action or stressor
GS - adult specific action or stressor

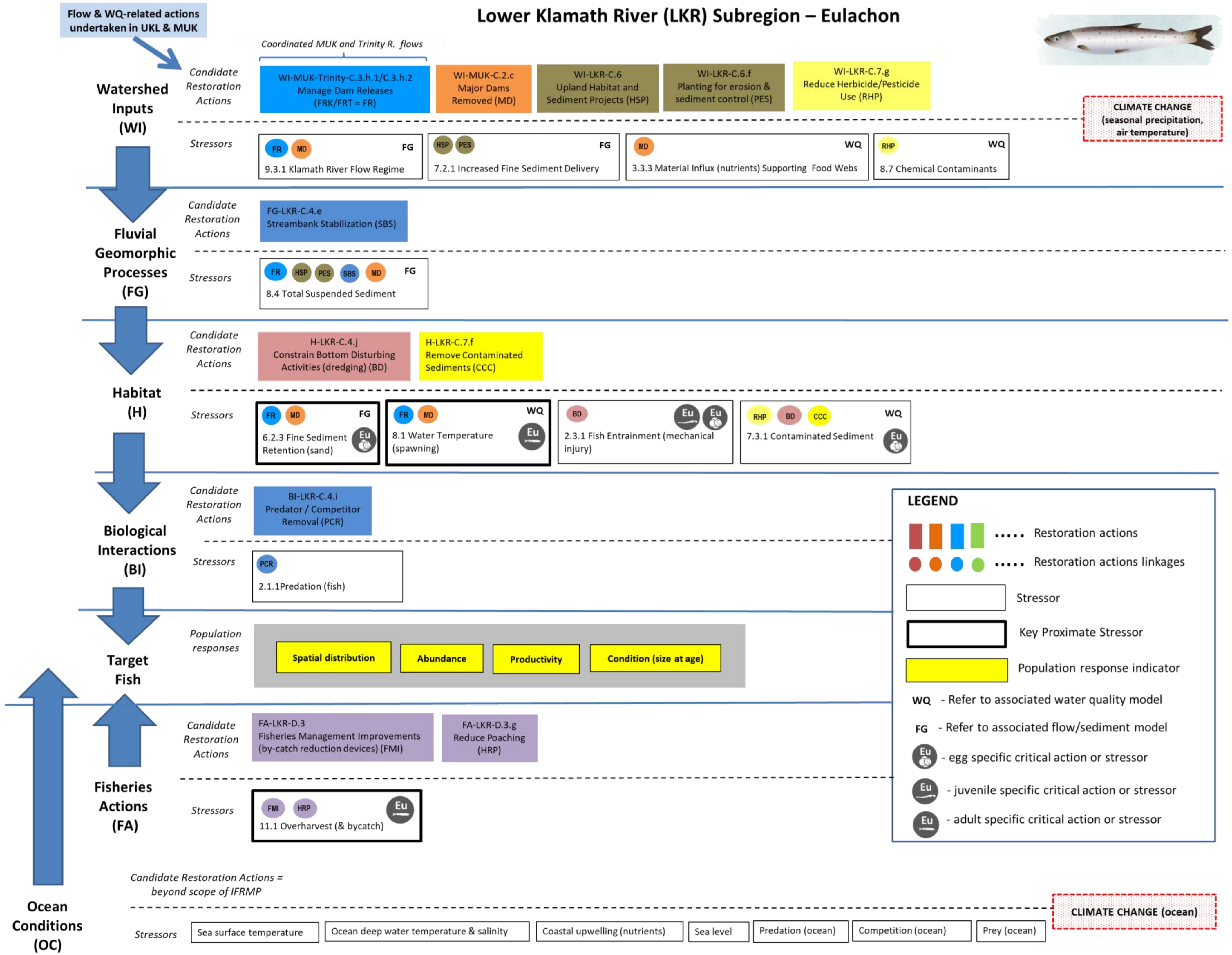


Figure A - 8. Conceptual diagrams for stressors and potential restoration actions across model framework tiers for focal species in the Lower Klamath River (LKR) sub-region: Chinook, Steelhead, Coho, Pacific Lamprey, Green Sturgeon, and Eulachon. See Figure 2 for explanation of abbreviations.

Table A - 6. Stressors affecting the focal fish species/functional groups in the Lower Klamath River (LKR) sub-region and the candidate restoration actions that could help alleviate/mitigate each stressor (codes in table match with those for stressors and restoration actions in LKR focal species conceptual diagrams. Critical uncertainties around each restoration action are described in the Klamath IFRMP Master Restoration Actions Dictionary.

Tier	Stressors	Candidate Restoration Actions to Alleviate Limiting Factor	Restoration Action Code
Watershed Inputs	9.3.1 Klamath River flow regime	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Major Dams removed (MD)	WI-MUK-C.2.c
		Irrigation practice improvement (IP)	WI-LKR-C.3.e
	7.2.1 Increased fine sediment delivery	Upland Habitat and Sediment Projects (HSP)	WI-LKR-C.6
		Upland Vegetation Management (UV)	WI-LKR-C.6.h
		Major Dams removed (MD)	WI-MUK-C.2.c
		Riparian planting (RP)	Wi-LKR-C.5.c
		Riparian fencing (RF)	WI-LKR-C.5.d
		Riparian forest management (RFM)	WI-LKR-C.5.i
		Planting for erosion & sediment control (PES)	WI-LKR-C.6.f
	8.7 Chemical contaminants	Reduce herbicide/pesticide use (RHP)	Wi-LKR-C.7.g
	3.1.2 Marine nutrients	Fisheries Management Improvements (FMI)	WI-LKR-D.3.d
	7.1.1 Decreased coarse sediment delivery	Major Dams removed (MD)	WI-MUK-C.2.c
	9.2.2 Instream flows (tribs)	Irrigation practice improvement (IP)	WI-LKR-C.3.e
		Upland vegetation management (UV)	WI-LKR-C.6.h
		Riparian forest management (RFM)	WI-LKR-C.5.i
		Riparian planting (RP)	WI-LKR-C.5.d
	4.2 LWD recruitment	Riparian planting (RP)	WI-LKR-C.5.d
		Upland vegetation management (UV)	WI-LKR-C.6.h
		Riparian forest management (RFM)	WI-LKR-C.5.i
	4.1 Riparian vegetation	Riparian forest management (RFM)	WI-LKR-C.5.i
		Riparian planting (RP)	WI-LKR-C.5.d
		Riparian planting (RP)	WI-LKR-C.5.d

Fluvial Geomorphic Processes	6.1.1 Channelization	Major Dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Streambank stabilization (SBS)	WI-LKR-C.4.e
		Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
	9.2.1 Groundwater interactions	Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-LKR-C.4.h
		Riparian forest management (RFM)	WI-LKR-C.5.i
		Riparian planting (RP)	WI-LKR-C.5.d
		Upland vegetation management (UV)	WI-LKR-C.6.h
	6.2.3 Fine sediment retention	Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-LKR-C.4.h
		Streambank stabilization (SBS)	WI-LKR-C.4.e
		Major Dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	5.2 Floodplain condition/connectivity	Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Beavers & beaver dam analogs (BDA)	FG-LKR-C.4.h
	8.4 Total suspended sediment	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Upland Habitat and Sediment Projects (HSP)	WI-LKR-C.6
		Planting for erosion & sediment control (PES)	WI-LKR-C.6.f
		Streambank stabilization (SBS)	WI-LKR-C.4.e
		Major Dams removed (MD)	WI-MUK-C.2.c
Habitat	8.1 Water temperature (spawning)	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Major Dams removed (MD)	WI-MUK-C.2.c
		Riparian planting (RP)	Wi-LKR-C.5.c
		Irrigation practice improvement (IP)	WI-LKR-C.3.e
		Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Riparian forest management (RFM)	WI-LKR-C.5.i
	8.2 Dissolved oxygen	Irrigation practice improvement (IP)	WI-LKR-C.3.e
		Major Dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Upland Habitat and Sediment Projects (HSP)	WI-LKR-C.6

		Upland vegetation management (UV)	WI-LKR-C.6.h
	8.5 pH	Upland vegetation management (UV)	WI-LKR-C.6.h
		Irrigation practice improvement (IP)	WI-LKR-C.3.e
	1.1 Anthropogenic barriers	Major Dams removed (MD)	WI-MUK-C.2.c
		Minor fish passage blockages removed or altered (MFP)	WI-MUK-C.2.c
		Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
	6.1 Bed & channel form	Major Dams removed (MD)	WI-MUK-C.2.c
		Major Dams removed (MD)	WI-MUK-C.2.c
		Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Channel structure placement (CSP)	H-LKR-C.4.d
		Beavers & beaver dam analogs (BDA)	FG-LKR-C.4.h
	6.2 Instream structural complexity	Beavers & beaver dam analogs (BDA)	FG-LKR-C.4.h
		Channel structure placement (CSP)	H-LKR-C.4.d
		Major Dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Streambank stabilization (SBS)	WI-LKR-C.4.e
		Channel reconfiguration & connectivity (CRC)	WI-LKR-C.4.c
		Riparian planting (RP)	Wi-LKR-C.5.c
		Riparian forest management (RFM)	WI-LKR-C.5.i
		Riparian fencing (RF)	WI-LKR-C.5.d
	2.3.1 Fish entrainment (mechanical injury)	Fish screens installed (FSI)	WI-LKR-C.1.c
		Non-physical barrier devices installed (NPB)	WI-LKR-C.1.e
		Constrain bottom disturbing activities (BD)	H-LKR-C.4.j
	7.3. Contaminated sediment	Reduce herbicide/pesticide use (RHP)	WI-LKR-C.7.g
		Constrain bottom disturbing activities (BD)	H-LKR-C.4.j
		Remove Contaminated Sediments (CCC)	H-LKR-C.4.k
	6.2.2 Suitable (cobble) substrate	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Upland Habitat and Sediment Projects (HSP)	WI-LKR-C.6
		Spawning gravel placement (SGP)	H-LKR-C.4.f
	6.2.1 Deep pools (GS spawners)	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Channel structure placement (CSP)	H-LKR-C.4.d

	1.1.1 Sufficient rearing habitats	Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
Biological Interactions	2.1.1 Predation (fish)	Predator / Competitor Removal (PCR)	BI-LKR-C.4.i
		Major Dams removed (MD)	WI-MUK-C.2.c
		Fish reared & released (FRR)	BI-LKR-D.1.b
	3.2 Competition (freshwater)	Hatchery reform/assessment (HRA)	BI-LKR-D.4.c
	2.2 Pathogens	Major Dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Fish reared & released (FRR)	BI-LKR-D.1.b
	2.1.2 Predation (mammals)	Fish reared & released (FRR)	BI-LKR-D.1.b
	10.2 Genetic introgression	Hatchery reform/assessment (HRA)	BI-LKR-D.4.c
	3.3.2a Abundance of invertebrate prey	Constrain bottom disturbing activities (BD)	H-LKR-C.4.j
		Remove Contaminated Sediments (CCC)	H-LKR-C.4.k
Fisheries Actions	11.2 Overharvest (& bycatch)	Harvest Management (HMI)	FA-LKR-D.3.d
		Fish reared & released (FRR)	BI-LKR-D.1.b
		Reduce poaching (HRP)	FA-LKR-D.3.g

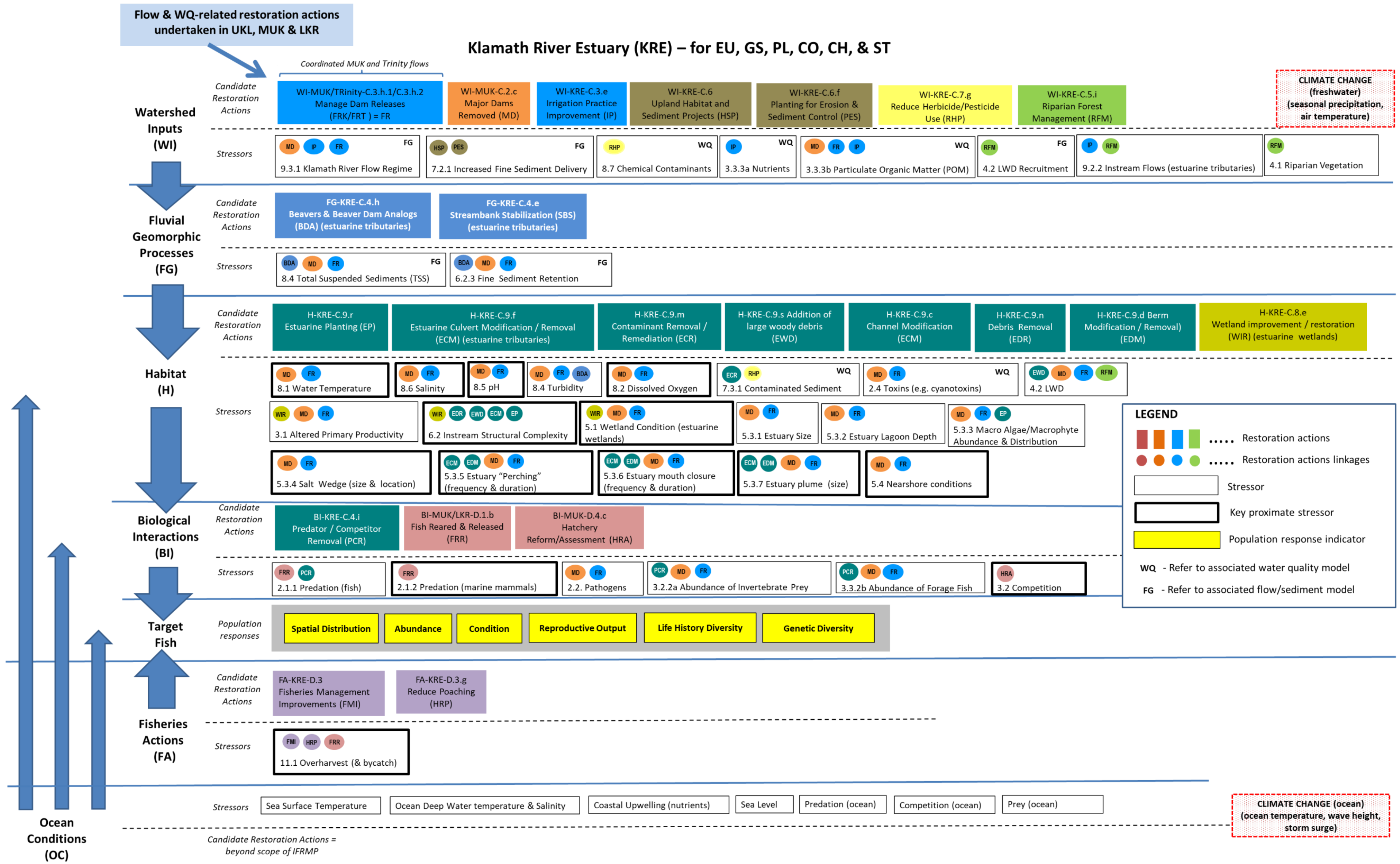


Figure A - 9. Conceptual diagrams for stressors and potential restoration actions across model framework tiers for focal species in the Klamath River Estuary (KRE) sub-region: Eulachon, Green Sturgeon, Pacific Lamprey Chinook, Coho, & Steelhead. See Figure A - 1 for explanation of abbreviations.

Table A - 7. Stressors affecting the focal fish species/functional groups in the Klamath River Estuary (KRE) sub-region and the candidate restoration actions that could help alleviate/mitigate each stressor (codes in table match with those for stressors and restoration actions in KRE focal species conceptual diagrams. Critical uncertainties around each restoration action are described in the Klamath IFRMP Master Restoration Actions Dictionary.

Tier	Stressors	Candidate Restoration Actions to Alleviate Limiting Factor	Restoration Action Code
Watershed Inputs	9.3.1 Klamath River flow regime	Major dams removed (MD)	WI-MUK-C.2.c
		Irrigation practice improvement (IP)	WI-KRE-C.3.e
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	7.2.1 Increased fine sediment delivery	Upland habitat and sediment projects (HSP)	WI-KRE-C.6
		Planting for erosion and sediment control (PES)	WI-KRE-C.6.f
	8.7 Chemical contaminants	Reduce herbicide/pesticide use (RHP)	WI-KRE-C.7.g
	3.3.3a Nutrients	Irrigation practice improvement (IP)	WI-KRE-C.3.e
	3.3.3b Particulate organic matter (POM)	Irrigation practice improvement (IP)	WI-KRE-C.3.e
		Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	4.2 LWD recruitment	Riparian forest management (RFM)	Wi-KRE-C.5.i
	9.2.2 Instream flows (estuarine tributaries)	Irrigation practice improvement (IP)	WI-KRE-C.3.e
		Riparian forest management (RFM)	Wi-KRE-C.5.i
	4.1 Riparian vegetation	Riparian forest management (RFM)	Wi-KRE-C.5.i
Fluvial Geomorphic Processes	8.4 Total suspended sediment (TSS)	Beavers & beaver dam analogs (BDA) (estuarine tributaries)	WI-KRE-C.4.h
		Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	6.2.3 Fine sediment retention	Beavers & beaver dam analogs (BDA) (estuarine tributaries)	WI-KRE-C.4.h
		Major dams removed (MD)	WI-MUK-C.2.c

		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
Habitat	8.1 Water temperature	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	8.6 Salinity	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	8.5 pH	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	8.4 Turbidity	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Beavers & beaver dam analogs (BDA) (estuarine tributaries)	WI-KRE-C.4.h
	8.2 Dissolved oxygen	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	7.3.1 Contaminated sediment	Reduce herbicide/pesticide use (RHP)	WI-KRE-C.7.g
		Contaminant removal/remediation (ECR)	WI-KRE-C.9.n
	2.4 Toxins (e.g. cyanotoxins)	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	4.2 LWD	Addition of large woody debris (EWD)	H-KRE-C.9.s
		Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Riparian forest management (RFM)	WI-KRE-C.5.i
	3.1 Altered primary productivity	Wetland improvement/restoration (WIR) (estuarine wetlands)	H-KRE-C.8.e
		Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	Instream structural complexity	Wetland improvement/restoration (WIR) (estuarine wetlands)	H-KRE-C.8.e
		Debris removal (EDR)	H-KRE-C.9.n
		Addition of large woody debris (EWD)	H-KRE-C.9.s
		Channel modification (ECM)	H-KRE-C.9.c
		Estuarine planting (EP)	H-KRE-C.9.r
	Wetland condition (estuarine wetlands)	Wetland improvement/restoration (WIR) (estuarine wetlands)	H-KRE-C.8.e
		Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2

	Estuary size	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	Estuary lagoon depth	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	Macro algae/macrophyte abundance & distribution	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Estuarine planting (EP)	H-KRE-C.9.r
	Salt wedge (size & location)	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	Estuary "perching" (frequency & duration)	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Channel modification (ECM)	H-KRE-C.9.c
		Berm modification/removal	H-KRE-C.9.d
	Estuary mouth closure (frequency & duration)	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Channel modification (ECM)	H-KRE-C.9.c
		Berm modification/removal	H-KRE-C.9.d
	Estuary plume (size)	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Channel modification (ECM)	H-KRE-C.9.c
		Berm modification/removal	H-KRE-C.9.d
	Nearshore conditions	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
Biological Interactions	Predation (fish	Fish reared & released (FRR)	BI-MUK/LKR-D.1.b
		Predator/competitor removal (PCR)	BI-KRE-C.4.i
	Predation (marine mammals)	Fish reared & released (FRR)	BI-MUK/LKR-D.1.b
	Pathogens	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
	Abundance of invertebrate prey	Major dams removed (MD)	WI-MUK-C.2.c
		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Predator/competitor removal (PCR)	BI-KRE-C.4.i
	Abundance of forage fish	Major dams removed (MD)	WI-MUK-C.2.c

		Manage Dam Releases – Klamath/Trinity (FRK/FRT) = FR	WI-MUK/Trinity-C.3.h.1/C.3.h.2
		Predator/competitor removal (PCR)	BI-KRE-C.4.i
	Competition	Hatchery reform/assessment (HRA)	BI-MUK-D.4.c
Fisheries Actions	Overharvest (& bycatch)	Fisheries Management Improvement (FMI)	FA-KRE-D.3
		Reduce poaching (HRP)	FA-KRE-D.3.g
		Fish reared & released (FRR)	BI-MUK/LKR-D.1.b