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US Army Corps of Engineers®
Engineer Research and Development Center

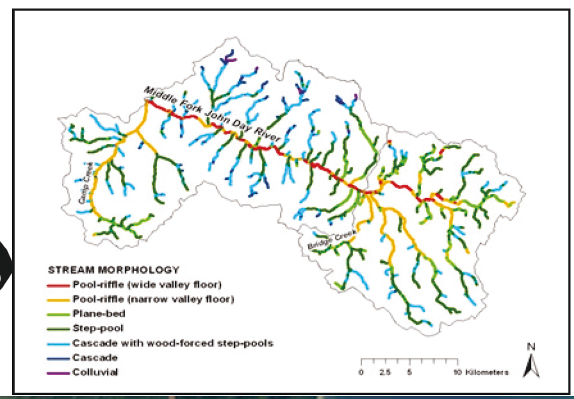
Ecosystem Management and Restoration Research Program

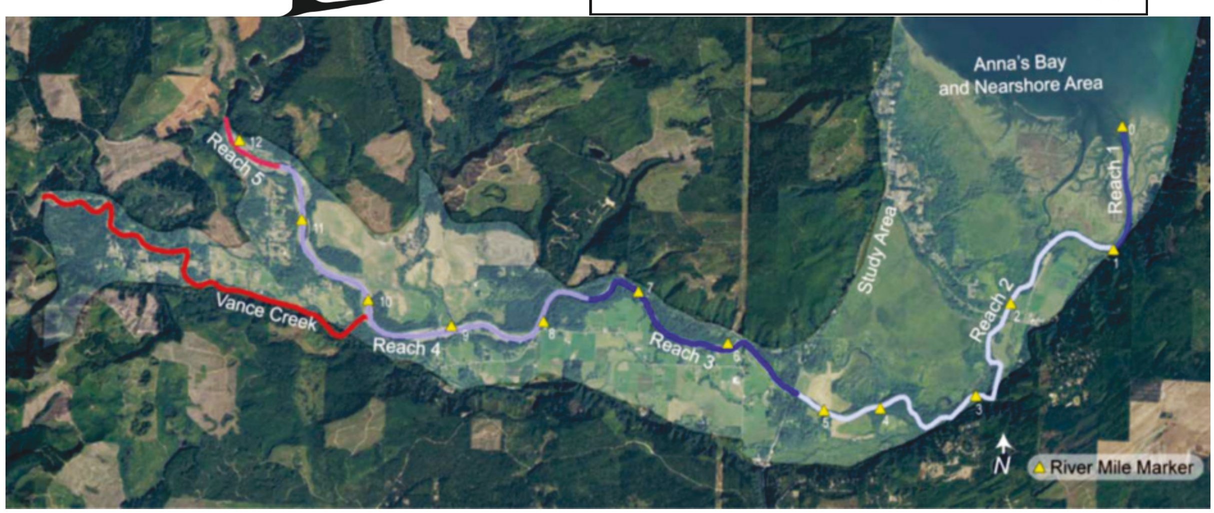
Framework for a General Restoration Model for Ecosystems with Anadromous Fish for U.S. Army Corps of Engineers

Phase 1: Conceptual Model Development

Brook D. Herman, Todd M. Swannack, Molly K. Reif, Nathan Richards, Tomma Barnes, and Candice D. Piercy

December 2018





Environmental Laboratory

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Final Report

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Under Project 01-2013 “Critical Species Modeling: Methods Development, Standardization, and Certification for USACE Restoration and Planning”

Abstract

Salmonid species are critically important ecologically, socially, and economically for North American coastal regions. Alterations to the structure (e.g., channelization) and function (e.g., sediment transport) of estuaries, rivers, and streams have greatly impacted these species, many are now listed as federally threatened or endangered. As part of environmental compliance procedures and policy, the U.S. Army Corps of Engineers (USACE) is required to assess the impacts and/or benefits of proposed water resource projects (e.g., levee maintenance, ecosystem restoration, etc.) to the environment. The USACE is required to predict and quantify environmental benefits using models to justify federal investment in ecosystem restoration projects. The purpose of this effort is to develop a general model or model framework that can be used during the USACE planning process that will serve as a unified standard Salmonid model. The primary purpose of the model will be to project future environmental benefits that will result from proposed restoration measures. Additionally, the model needs to be sensitive to different combinations of restoration measures in order to assist the USCAE in the planning and decision making process. This report presents the results of the first phase of model development using the mediated model development process.

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Preface

This study was conducted for the Ecosystem Management and Restoration Research Program (EMRRP) under Project FY2013 "Critical Species Modeling: Methods Development, Standardization, and Certification for USACE Restoration and Planning." The technical monitor was Dr. Trudy J. Estes.

The work was performed by the Wetlands and Coastal Ecology Branch (CEERD-EEW) and Environmental Sensing Branch (CEERD-EEC) of the Ecosystem Evaluation and Engineering Division (CEERD-EE), U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Ms. Patricia Tolley was Branch Chief, CEERD-EEW, Mr. Mark Graves was Branch Chief, CEERD-EEC, Dr. Mark D. Farr was Division Chief, CEERD-EE, Dr. Al Cofrancesco, CEERD-EMW, was the Technical Director, and Dr. Trudy J. Estes, CEERD-EPE, was Program Manager, for the EMRRP. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director was Dr. Ilker Adiguzel.

Thank you to the participants of the workshop that included: Mr. Todd Swannack (ERDC), Ms. Tomma Barnes (USACE Pittsburgh District), Ms. Candice Piercy (ERDC), Ms. Molly Reif (ERDC), Mr. Nathan Richards, Mississippi River Valley, Rock Island (MVR), Ms. Nancy Gleason Northwest, Seattle, (NWS), Mr. Frederick Goetz, (NWS), Mr. Michael Scuderi (NWS), and Mr. William Brostoff, South Pacific, San Francisco (SPN).

COL Ivan P. Beckman was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
fathoms	1.8288	meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

Acronyms and Abbreviations

DPS	Distinct Population Segment
DO	Dissolved Oxygen
DoD	Department of Defense
EE	Ecosystem Evaluation and Engineering Division
EEC	Environmental Sensing Branch
EEW	Wetlands and Coastal Ecology Branch
EL	Environmental Laboratory
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
ELAM	Eulerian Lagrangian Agent Method
EMRRP	Ecosystem Management and Restoration Research Program
ERDC	Engineer Research Development Center
ECO-PCX	National Ecosystem Planning Center of Expertise
Fldpln	Floodplain
HEP	Habitat Evaluation Procedure
LWD	Large Woody Debris
MVR	Mississippi River Valley, Rock Island District
NWS	Northwest, Seattle District
SPN	South Pacific, San Francisco District
USACE	U.S. Army Corps of Engineers

1 Introduction

1.1 Project background

Salmonid species are critically important ecologically, socially, and economically for the North American Pacific Northwest region. Alterations to the structure (e.g., channelization) and function (e.g., sediment transport) of estuaries, rivers, and streams have greatly impacted these species, such that many are now listed as federally threatened or endangered. The first salmon species to be listed as endangered was the Snake River Sockeye in 1991. Over the next few decades, a number of distinct subpopulations and evolutionary significant units were listed. By 1999, wild salmon populations had been extirpated from around 40% of their historic spawning/breeding ranges within the Pacific Northwest. Table 1 lists the salmonid species listed under the Endangered Species Act (ESA).

Table 1. Threatened and endangered salmonid species in the Pacific Northwest.

Common Name	Scientific Name	# of Subpopulations
Bull Trout	*Salvelinus confluentus*	1-DPS** and one-non-essential experimental population
Chinook	*Oncorhynchus tshawytscha*	9-ESU* and two-non-essential experimental populations
Chum	*Oncorhynchus keta*	2-ESU*
Coho	*Oncorhynchus kisutch*	4-ESU*
Sockeye	*Oncorhynchus keta*	2-ESU*
Steelhead Trout	*Oncorhynchus mykiss*	11-DPS**

*-evolutionarily significant unit

**-distinct population segment

The U.S. Army Corps of Engineers (USACE) is currently operating and maintaining water resource structures within many of the waterways that salmonids depend on for successful reproduction. As part of environmental compliance and planning procedures, the USACE is required to assess the impacts of proposed water resource projects (e.g., levee maintenance or construction) to the environment. In addition, the USACE has partnered with local sponsors to address the loss of salmonid habitats through ecological restoration. The USACE is required to predict and quantify environmental benefits using models to justify federal investment in restoration projects.

Many methods have been developed to assess impacts of proposed projects to salmonids with varying degrees of complexity (Lower Willamette River 2014; Klimas and Yuill 2013; Willamette River 2012; and Skagit River 2011). This has resulted in multiple models that seemingly have the same purpose, but measure different ecosystem or species specific attributes at different spatial and temporal scales. Each model that was developed was fairly site specific. The specificity of these models make them inappropriate to be used in different areas and/or for different types of projects. The problem is that there is no general standard salmonid model that can be used in different areas and for different projects, thus the cost and labor associated with building a new model for each new project continues to undermine the efficiency of the USACE planning process. The purpose of this effort is to develop a general model, or model framework, that can be used during the USACE planning process and will serve as a unified standard salmonid model. Potential purposes of the model will include assessing impacts from navigation, flood risk reduction and hydroelectric operations, and projecting environmental benefits from ecosystem restoration projects. Overall, the primary purpose of the model will be to project future environmental benefits that will result from proposed restoration measures. Additionally, the model needs to be sensitive to different combinations of restoration measures in order to assist the USACE in the planning and decision making process.

1.2 Purpose

The purpose of this report is to describe and document the first phase of the development process of the standard salmonid model. The first phase included an intensive workshop that resulted in the first draft of the conceptual model and a parameter refinement exercise that resulted in a second conceptual model, albeit a simpler version of the first draft. This report describes the work completed as part of the workshop and the methods and results of the parameter refinement exercise. Follow on reports will document future steps in the model development process.

1.3 Overview of previous USACE models

Studies looking at the relationship between species presence/absence and abundance of different life stages (e.g., egg vs. fry vs. smolt), coupled with environmental variables, have generated a plethora of data on the life requisites of salmonid species. Previous studies have also the identified many of the ecosystem processes (e.g., hydroperiod) that maintain their environmental needs. Table 2 presents an overview of the ecosystem attributes/processes (labeled parameters for this purpose) that have been found to be the most influential for successful salmonid reproduction (Klimas and Yuill 2013). The identified system parameters have formed the basis for previous USACE model development efforts. Note that previous efforts by the USACE to assess impacts of potential water resource projects on salmonid species have focused on freshwater habitat, generally excluding estuarine and oceanic habitat. Table 3 lists previous models developed by the USACE and the parameters used to characterize important ecosystem attributes.

Table 2. Freshwater system parameters that affect anadromous fish species of the Pacific Northwest.*

System Parameters	Significant Effects When Degraded or Lost	Affected Life Stage
Winter High Flow	Redd scour, sediment transport	incubation
Summer Low Flow	Reduced upstream access/reduced spawning area	migration/spawning
Water Temperature	Impeded adult passage, mortality, accelerated development, reduced survivorship	migration/spawning/incubation
Dissolved Oxygen (DO)	Egg suffocation, reduced survivorship	Incubation
Fine Sediment**	Suffocation of embryos, bury fry and spawning beds	spawning/incubation
Coarse Sediment	Bury egg/fry, redd dislocation	spawning/incubation
Large Woody Debris (LWD)	Low levels increase redd scour, increase channel instability, limit adult pools and rearing	migration/spawning/incubation/ rearing
Channel Condition	Reduced pool quality and increased predation, reduced channel complexity increases redd scour, limits rearing	migration/spawning/incubation/ rearing
Side Channels	Limits adult holding areas, limits spawning, limits rearing habitat	migration/spawning/incubation/ rearing
Channel Stability	Increased redd scour/bury or de-watering of redd	migration/spawning/incubation
Riparian Condition	Removal/impair native forest increases temp, reduces stability of floodplain, reduces LWD input	migration/spawning/incubation
Floodplain/Wetland Area	Concentrated main stem flows, high peak, increased redd scour, reduces summer low flow	migration/spawning/incubation
Fish Passage	In-channel structures obstruct or impede passage, limits juvenile access to rearing and feeding habitats	migration/rearing

*Benefits Analysis (Klimas and Yuill 2013). **Fine suspended sediments and fine sediment that settles out.

Table 3. Parameters previously used in habitat evaluation procedure (HEP) models to measure critical needs of anadromous fish in freshwater systems.

System Attributes*	Skokomish Restoration	Lower Willamette Restoration		Willamette Floodplain	Skagit Mitigation
		Tributary	Mainstem		
	Parameters	Parameters	Parameters	Parameters	Parameters
Winter High Flow	flood return interval				Velocity (fish bench, weirs, groins, lifts)
Summer Low Flow	flood return interval			Percent pools during low water	Velocity (fish bench, weirs, groins, lifts)
Water Temperature		Max Temp	Percent Cover Bank Veg	Max water temp during low flow	
Dissolved Oxygen					
Fine Sediment	flood return interval	Substrate composition	Substrate	Predominant substrate type in riffle/runs	
Coarse Sediment	flood return interval	Substrate composition	Substrate	Predominant substrate type in riffle/runs	
LWD	Percent surface areas in pools, LWD pieces per meter	LWD present		Instream cover present	Woody Debris type
Channel condition	Percent surface areas in pools, LWD pieces per meter, flood return interval	Percent of area as pools in low water, substrate composition	Depth, Depth from shore	Percent pools during low water	Bank condition (layback)
Side Channels	Percent of original fldpln connection remaining e.g., how much still floods (how much still floods)	Percent of area as backwaters/pools			Slough creation
Channel Stability					Velocity (fish bench, weirs, groins, lifts)
Riparian Condition	Percent of area w/big buffer (relative to reach)	Percent of area as backwaters/pools	Percent Cover Bank Veg	Instream cover present	Bank condition (layback, levee set back), native cover
Floodplain/wetland Area	Percent fldpln connection remaining	Percent total backwaters/pools			Slough creation
Fish passage	Percent fldpln connection remaining				

*System attributes are ecosystem structures, functions or processes that parameters measure and quantify. Fldpln – Floodplain, LWD – Large Woody Debris.

The review of USACE models, and the parameters used therein, was used as part of the shared information that formed the basis of the workshop. The work completed as part of the workshop that will be described in the upcoming sections.

2 Synthesis of Progress

2.1 Workshop purpose

A Salmon Model Workshop was convened in Seattle, WA, on 15–16 September 2014. The purpose of the workshop was to develop the first draft of the conceptual model for a unified, standard salmonid model suitable for USACE planning purposes. Attendees agreed that the USACE needs one overall model, or model framework, that is widely applicable not only to salmonids, but also, to other *sensitive* species (e.g., such as species of concern that are associated with salmonid habitat). This supports that all ecosystem restoration activities should be focused on restoring the entire system of interest. Restoration of salmonid habitat should benefit the vast majority of all native species (both common and rare) that use the same habitat. In addition, the general, all-purpose model has the potential to be used for impact assessments, (i.e., Essential Fish Habitat Assessments and benthic recovery assessments). The eventual model should be able to be applied in a variety of contexts, assist in the assessment of a spectrum of water resource management projects, and help inform decision makers. Section 3 contains the results of the work completed at the workshop, including workshop goals and objectives.

2.2 Workshop goals

The objectives of the model are:

- to be able to distinguish between proposed project alternatives,
- to be able to include input from other agencies once a conceptual model or model framework has been developed,
- to be scalable, considering different points along a regional system/landscape (estuary-to-tributary), and considering life cycle requirements (i.e., spatially and temporally hierarchical - along geography/habitat structure and life cycle lines),
- to be relevant to habitats of interest and at the ecosystem level, not just the species
- to be used to better communicate benefits derived from a recommended plan.

These objectives were developed to encompass the varied challenges associated with the modeling and planning decision-making process. The information further clarifies some of the objectives. For example, the ability to distinguish between proposed project alternatives is referring to differences in potential benefits derived from different, proposed plans. The ability to take into consideration comments and suggestions from our partner agencies during model development, such as the U.S. Fish and Wildlife Service, is key to better communication and collaboration between the USACE and other regulatory agencies. Finally, being able to apply the model at different spatial scales will help the USACE overcome deficiencies in previous salmonid models.

3 Model Parameters Discussed in Workshop

3.1 Model development

The workshop was intended to begin the first phase of model development by bringing together a group of people with common goals with a diverse set of skills and experiences. Participants were guided through the steps of model development with presentations on the dos and don'ts of model development (e.g., conceptualization, quantification, evaluation, etc.) followed by breakout sessions where the group discussed the critical components (parameters) needed for the next steps of mode development. The group discussed all environmental (biotic and abiotic) parameters that are known to affect salmonid populations to better understand critical physical, chemical, and biological components that affect different stages of the salmonid life cycle and determine reproductive output. The parameters were delineated per defined landscape units, such as, estuary, mainstem and tributary, and by life stage. It is important to note, that each parameter has different significance in the landscape units, within each life cycle stage, and is seasonally influenced. Table 4 presents the environmental parameters that were identified as important as adults migrate from the sea, through the estuary, and into the tributaries. Table 5 lists parameters progressing from the tributaries to the estuary assuming egg incubation, fry hatch/rearing, and juvenile/smolt development in estuary. Prior to fry hatch and juvenile migration to estuary, egg placement is an important precursor with its own relevant parameters. Note that in Table 4, the mainstem section is not shown separately, since parameters are largely the same as in the tributary. However, there is greater importance for lateral connectivity (i.e., side channels, floodplain) in the mainstem. Also, in the estuary, it is important to point out that although parameters are the same for both life stages (juveniles and smolts), there are different value ranges and priorities within the individual parameters, requiring different model curves or grades depending on age/life cycle stage. For example, juveniles can handle higher flow velocities and greater depths. In addition to the estuary, it is important to consider the role of the nearshore environment, including shoreline habitats, such as beach, reef, and terrace complexes.

Table 4. Environmental parameters important for anadromous fish in different landscape units for reproducing adults.

Tributary	Mainstem	Estuary
Structure	*Structure*	*Structure*
Gradient	Gradient	Gradient
Complexity	Complexity	Channelization
Sinuosity	Sinuosity	Complexity
Pools/Riffles	Pools	Sinuosity
Channel Shape	Channel Shape	Distributary Channels
Floodplain	Side Channels	Lacustrine wetlands
	Floodplain	
Connectivity	**Connectivity**	**Connectivity**
Longitudinal	Longitudinal	Longitudinal
Lateral (floodplain)	Lateral (floodplain)	
Landscape	**Landscape**	**Landscape**
Riparian Edge Type	Riparian Edge Type	Riparian Edge Type
Refuge Cover	**Refuge Cover**	**Refuge Cover**
Undercut Banks	Undercut Banks	Undercut Banks
Woody Debris	Woody Debris	Woody Debris
Aquatic Veg		
Predators	**Predators**	**Predators**
Predatory fish	Predatory fish	Sea Lions
Other (e.g., birds)	Other (e.g., birds)	Other (e.g., birds)
Substrate	**Substrate**	**Substrate**
Size	Size	
	Transport	
Hydroperiod	**Hydroperiod**	**Hydroperiod**
Flood Interval	Flood Interval	High/Low Flow
Seasonality	Seasonality	Seasonality
Water	**Water**	**Water**
Suspended Sediments	Suspended Sediments	Suspended Sediments
DO	DO	DO
pH	pH	Contaminants
Contaminants	Contaminants	Depth
Depth	Depth	Temp
Temp	Temp	Velocity (tidal)
Velocity	Velocity	Clarity
Clarity	Clarity	Salinity (?)

Table 5. Environmental parameters important for anadromous fish life cycle stages per landscape unit.

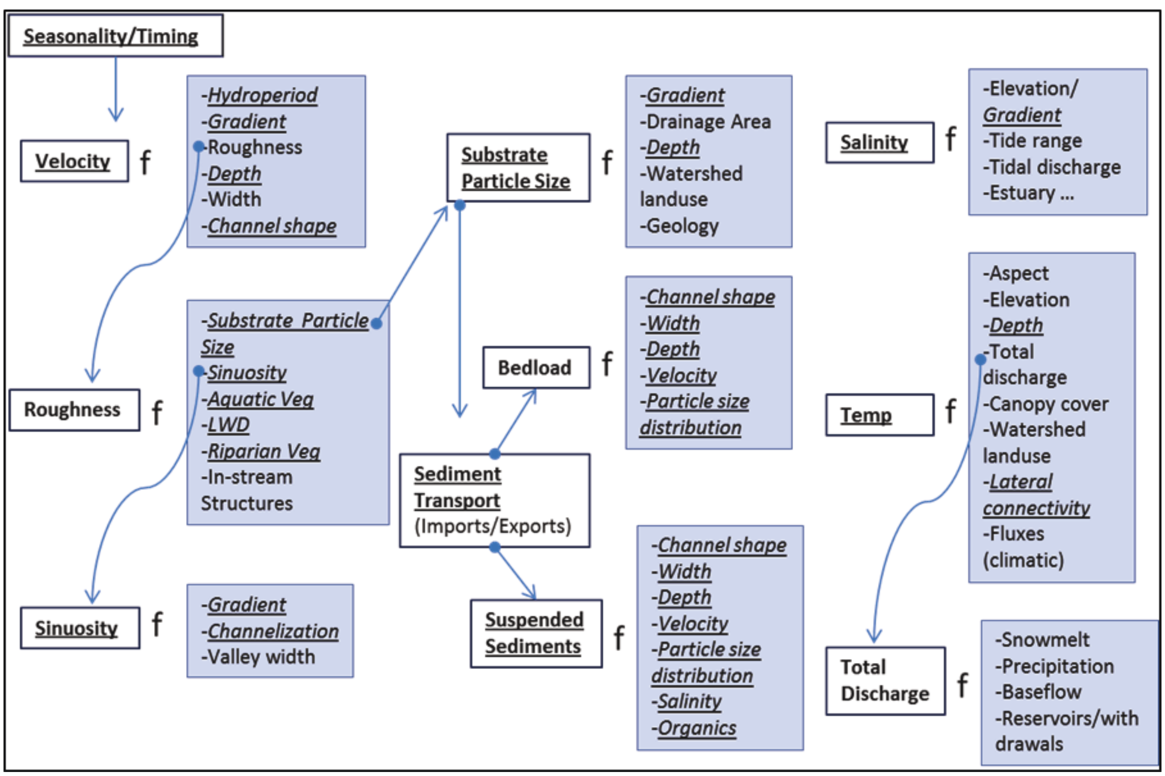
Tributary Egg Incubation	Tributary Fry	Estuary Juvenile/Smolts
Structure	*Structure*	*Structure*
Pools/Riffles	Gradient	Gradient
	Complexity	Sinuosity
	Sinuosity	Pools
	Pools/Riffles	Side Channel
	Channel Shape	Channel Shape
		Tidal Channels
Connectivity	Connectivity	Connectivity
	Longitudinal	Longitudinal
	Lateral (floodplain	Lateral (floodplain)
Landscape	Landscape	Landscape
		Riparian Edge Type
Refuge Cover	Refuge Cover	Refuge Cover
	Undercut banks	Undercut banks
	Woody Debris	Woody Debris
	Aquatic Veg	
Predators	Predators	Predators
Predatory fish	Predatory fish	Sea Lions
Other	Other	
Substrate	Substrate	Substrate
Embeddedness	Size	Size
Size		Transport
Hydroperiod	Hydroperiod	Hydroperiod
high/low flow	Flood interval	Flood interval
Seasonality	Seasonality	Seasonality
Water	Water	Water
Suspended Sediments	Suspended Sediments	Suspended Sediments
DO	DO	DO
Contaminants	pH	Contaminants
Depth	Contaminants	Depth
Temp	Depth	Temp
Velocity (tidal)	Temp	Velocity
Nutrients	Nutrients	Nutrients (?)
	Food	Clarity

This report will not attempt to provide detailed explanations of each of the listed parameters that was discussed during the workshop. However, the following references provide more information on why these parameters are important, and should be considered during this phase of model development: Groot and Margolis. (1998), Lichatowich (1999), Quinn (2005), and Stokes and White (2014).

3.2 Ecosystem drivers of environmental parameters

The driving forces behind some of the identified critical parameters were explored in order to highlight relationships and interconnectedness between parameters. This will be useful in the conceptual model development as it relates to reducing parameter redundancy and isolating those parameters that are most influential. Because of the extensive nature of this exercise, such as the number of parameters that were explored and documented, a number of figures were produced to visually present the interconnectedness of many of the parameters (Figures 1–3).

Figure 1. Ecosystem drivers for velocity, substrate roughness, sinuosity, substrate particle size, sediment transport, salinity, and temperature.



*Note: arrows between parameters illustrates relationship/interconnectedness. Also, the words underlined and in italics indicate parameters previously identified as influential to salmonids.

Figure 2. Ecosystem drivers for dissolved oxygen (DO), nutrients, pH, water clarity, and contaminants.

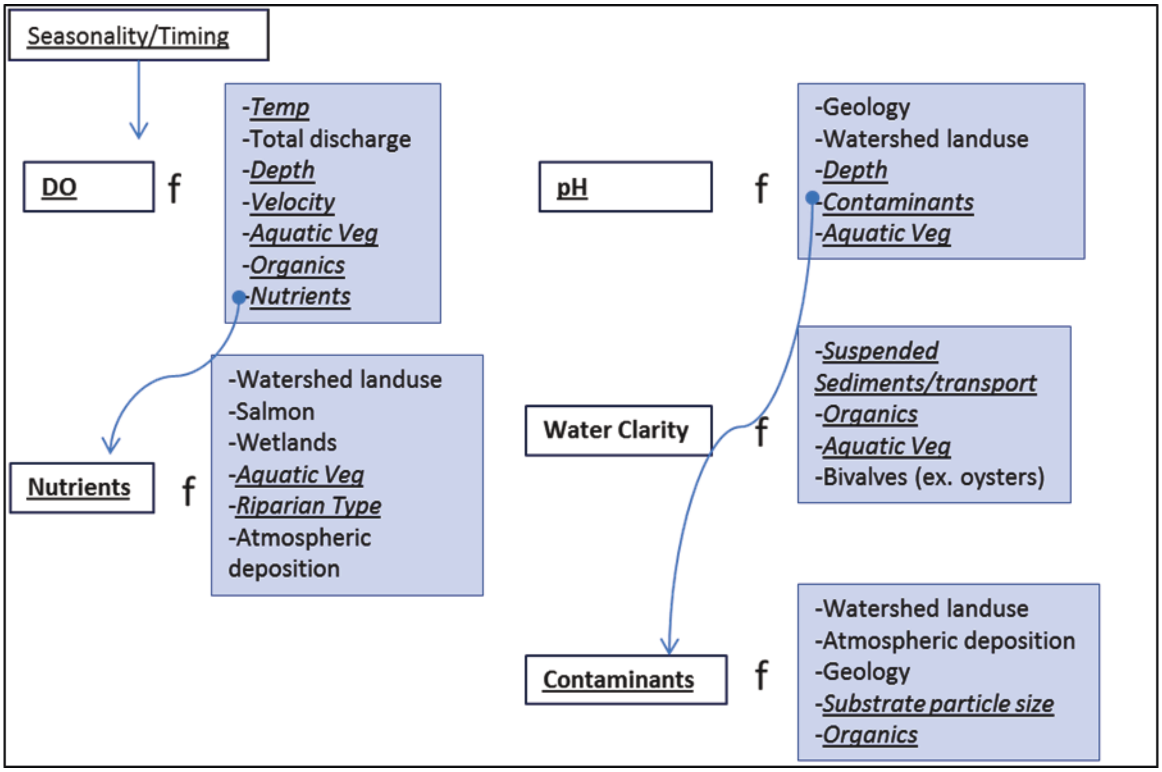
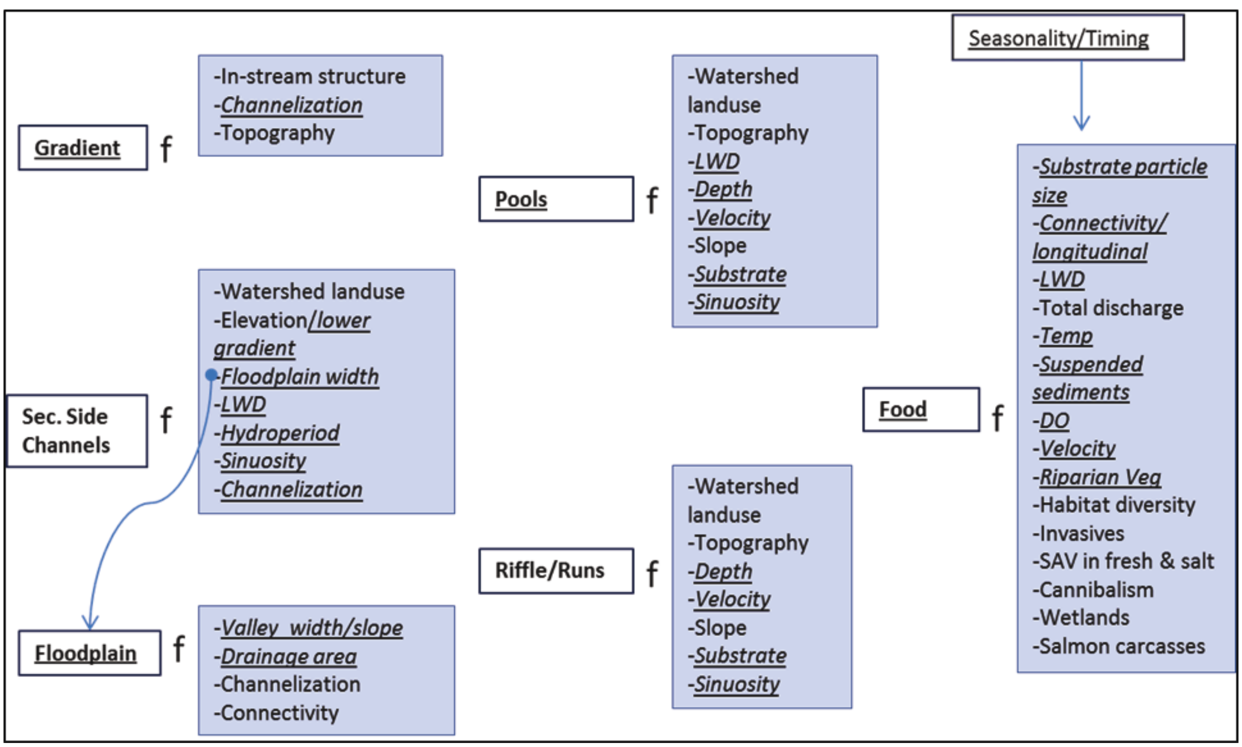


Figure 3. Driving forces for channel gradient, secondary side channels, floodplain, pools, riffles/runs, and food.



Phytoplankton and macrophytes are most influential in the availability of dissolved oxygen (DO), and they are a source for decomposing carbon-based organisms that form the base of organic input into the system that drive DO rates as well (Mellina and Hinch 2009, Collins et al. 2014). During the growing season, aquatic vegetation (temporary or semi-permanent) contributes to driving the level of nutrients in the system and the type of vegetation growing within the riparian areas (e.g., plant uptake and leaf litter-input). All of these can increase or decrease nutrients entering system (Wootton 2012 and Roberts and Bilby 2009). In terms of water clarity, aquatic vegetation includes abundance of phytoplankton and marophytes.

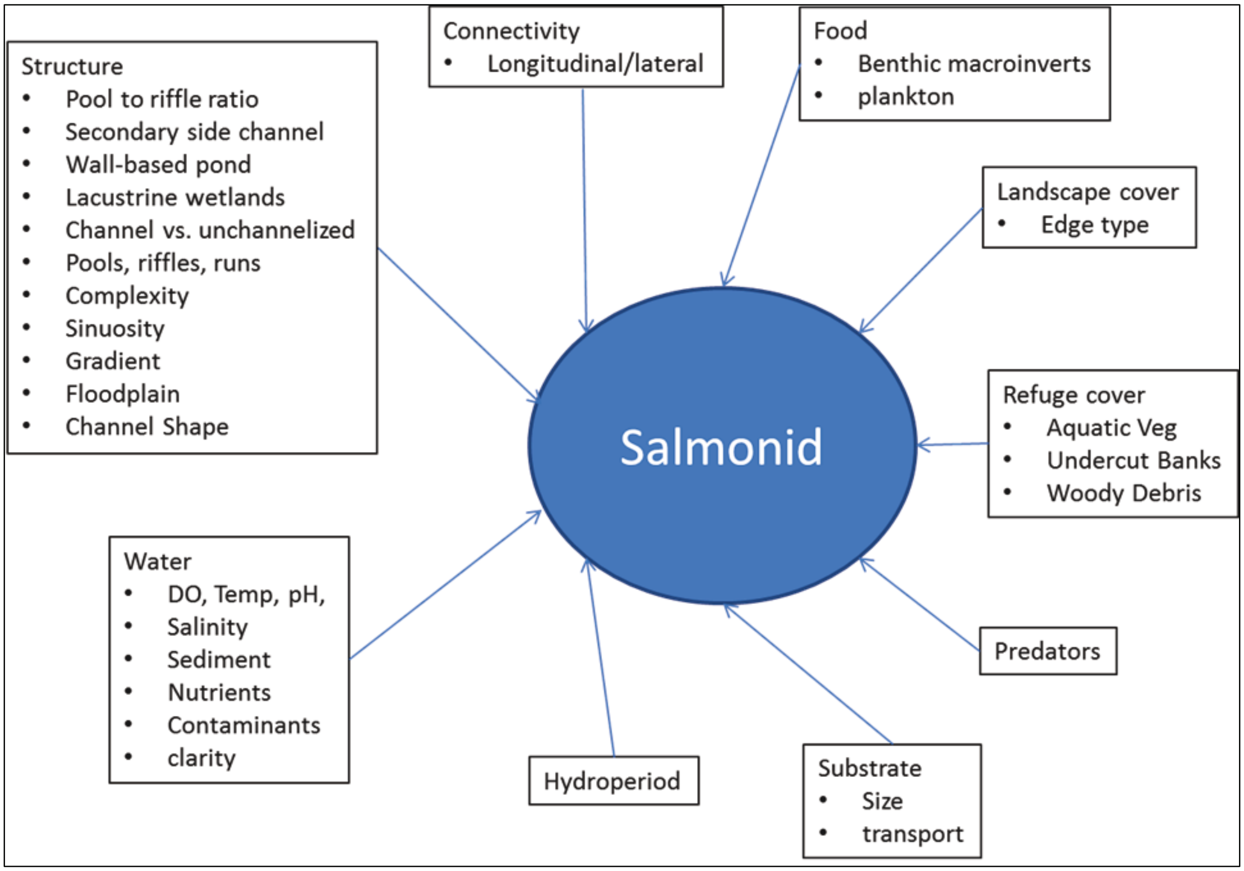
4 Workshop Recommendations

4.1 Discussions and recommendations

After the preliminary list of potential model parameters was synthesized, a parameter prioritization was conducted through group discussion. The group discussion included revaluating model priorities and potential strategies for managing multiple scales across the landscape and life cycle stage. Scalar issues were addressed by illustrating the current state of the model science. Currently, there are three model scales: individual fish, species/reach, and estuary/watershed. The individual fish scale is computationally intensive and is being addressed in other ERDC research efforts (e.g., the Eulerian Lagrangian Agent Method (ELAM)). The eventual goal is to link all three scales. However, the priority for this model framework is to capture both the species/reach scale and estuary/ watershed scale. The USACE has available data on species/reach interactions. Various reports have established metrics to quantify impacts, such as number of fish per linear foot (carrying capacity over a season) (Gleason and McClain 2011), pool/riffle ratio or linear foot of pool, and density of fish supported (empirical data from fish surveys or literature values (Klimas and Yuill 2013). Current model approaches, such as habitat suitability indices, are limited in that they can only address one scale or the other (not both). Thus, it will be important to build a robust and flexible model that can be applied at different landscape scales.

A hierarchical nested approach that allows flexibility to turn on/off parameters and/or select appropriate parameter value ranges, as they relate to landscape and life cycle stage scales, will be important for addressing complex and sometimes competing priorities. The workshop participants decided that the first priority is the estuary/watershed scale with the secondary priority being the species/reach scale. The estuary/watershed scale is important to include because this has largely been neglected in previous models. The species/reach scale is important because this is the scale that planners use to formulate and design potential restoration actions. The conceptual model (Figure 4) encompasses all parameters deemed to be important as a result of consensus by the workshop participants. The next step of model development will involve refinement of the conceptual model based on model development objectives.

Figure 4. Workshop derived salmonid conceptual model.



In terms of priorities, it may be beneficial to exclude factors that are not in the USACE authority (i.e., watershed land use contributing to habitat degradation), because it would be very difficult to buy out properties and change land use for ecosystem restoration purposes. Nevertheless, understanding watershed level land use and/or assessing restoration of certain areas would be useful for better understanding how far benefits can be claimed for a restored area (i.e., quantifying benefits of changed land use practice on a restored property). There is a need for models to better assess connectivity over the entire watershed system versus just focusing on an individual area or footprint. A variety of methods exist to quantify watershed connectivity benefits and link reach and watershed scales (Cote et al. 2009). The challenge is to integrate these methods into a general standard model that will be sensitive to restoration actions associated within USACE authority.

In addition to scalar issues, participants at the workshop brought up another important priority to consider, the rarity or scarcity of critical landforms (i.e., lacking a particular habitat). It is important to identify critical habitat types needed for various life cycle stages, such as transfer areas during smoltification. Rarity of a critical landform can sometimes result in setting a particular project goal at a higher priority level or giving a higher weight to certain parameters because of their overwhelming importance to the system. Table 6 lists critical landforms characteristic of lakes, littoral, estuary, and nearshore zones found in the Pacific Northwest (e.g., geographic region). Workshop participants felt it was important to include this information for model development documentation as this provides justification for the inclusion of some parameters that measure unique aspects of these landforms.

Table 6. Critical landforms and spatial considerations.

Geographic Region	Lake
California	Floodplain
Washington	Reservoir
Oregon	Natural
Littoral	**Estuary**
Side Channel	Lower
Tributary	Middle
Main Channel	Upper
Backwater	
Reach	**Nearshore**
Riffle	Beach
Run	Embayments
Pool	Pocket Lagoons
Site	

4.2 Workshop conclusion

The results of the workshop included formulating model goals and objectives, a first draft of a conceptual model, and a path forward for further model development. Next steps in the model development process include refining the conceptual model, quantifying the parameters, model evaluation, and application. Parameter refinement is described in section five, and follow on reports will present the results for the next steps in the model development process.

5 Parameter Refinement

The goal of this model development process is to unify the current multiple salmonid models while addressing issues of scale (temporal and spatial) and being acceptable for the USACE's Planning and Environmental Compliance processes. The next step is to refine the parameters identified within the conceptual model in order to reduce redundancy and ensure sensitivity of model outputs to potential USACE projects.

5.1 Evaluating parameters

A number of comparisons were employed to understand the importance of each parameter in relation to the other parameters (i.e., identifying redundancy) and to determine how well each parameter would satisfy the modeling objectives. Parameters must be shown to be critically important for salmonid species, must not have a high degree of overlap with other parameters, must be readily available and cost efficient to measure, and must show a measurable response to changes resulting from proposed USACE project actions.

The first draft of the conceptual model contains nine modules and thirty parameters. The Structure Module contains eleven parameters, the Water Module contains eight parameters, the Refuge Module contains three parameters, the Connectivity, Food and Substrate Modules contain two parameters, and the Landscape, Predators and Hydroperiod Modules contain one parameter. Table 7 presents the list of parameters chosen to form the first conceptual model and the influence of each parameter to specific landscape units and life stages of salmonids. Note, the adult stage is not indicated because all parameters listed are important for the adult life stage. Additionally, the table presents potential methods used to measure each parameter and how sensitive these parameters would be to changes as a result of USACE activity. A clarification of what constitutes a restoration action: restoration actions are defined as actions the USACE has the authority to undertake (e.g., aquatic ecosystem restoration, flood risk reduction, etc.). This is an important point because the USACE is limited in ability to address every stressor or disturbance that may be detrimental to salmonids (e.g., upland land use, impact to navigation, flood risk). However, non-USACE organizations can undertake these same restoration actions in abstentia or in partnership.

As described in Table 7, the Measurement column description of each parameter was based on referenced literature and personal experiences. The evaluation of parameters based on their availability and accuracy of measurement helps to remove parameters that would be costly or hard to accurately measure. Inefficient and hard to accurately measure parameters are contrary to an efficient and cost effective planning process. They may have a negative impact on model outputs, and consequently, on effective decision-making. Also, insensitive parameters should also be removed, especially since the USACE is somewhat limited in its ability to fully address all identified stressors and disturbances to the system. The column Sensitivity to Action and Ability to Detect Change describes the type of potential USACE action likely to be considered and whether the parameter would be sensitive to potential USACE action coupled with the ability to accurately detect any change. Lastly, parameter redundancy should be reduced. Parameters that are correlated, or show a similar response to system changes, would be considered redundant. Table-7 lists potential redundancies under the column of Interrelatedness.

Table 7. Parameter comparison.

Parameter	Landscape Unit*	Life Stage**	Measurement	Sensitivity to Action and Ability to Detect Change	Interrelatedness
Structure					
1. Pool to riffle ratio	T	E, F, JS	Area of pools in relation to area of riffles	Direct change (install riffles and pools, reestablish flow regime), easy to detect change	6. Pools, riffles, runs, 7. Complexity, 16. Edge cover, 23. Hydroperiod-related to discharge for sustainability
2. Secondary side channel	M, E	JS	Length, depth	Direct change (excavate side channel), easy to detect change	10. Floodplain, 12. Longitudinal
3. Wall-based pond	T	F, JS	Area, Volume, Presence/absence, or number of ponds	Direct change (build pond, reconnect pond), easy to detect change	7. Complexity
4. Lacustrine wetlands	M, E	JS	Percent cover, or Acres	Direct change (build wetland shelf, or reconnect right hydrology), easy to detect change	23. Hydroperiod-related to discharge for sustainability
5. Channelization	M, E	F, JS	Length of channelized reach, or percent length of reach channelized	Direct change (remeander channel, reestablish flow regime), easy to detect change	7. Complexity, 8. Sinuosity, 9. Gradient, 11. Channel shape

Parameter	Landscape Unit*	Life Stage**	Measurement	Sensitivity to Action and Ability to Detect Change	Interrelatedness
6. Pools, riffle, runs	T	E, F, JS	Length of pool/riffle complex, or presence/absence of pool/riffle complex	Direct change (install riffles and pools, reestablish flow regime), easy to detect change	1. Pools to riffles ratio, 7. Complexity, 23. Hydroperiod-related to hydroperiod for sustainability
7. Complexity	T, M, E	F, JS	Measure the No. and variety of geomorphic structures w/in and along river, Index of Complexity?	Direct change (install riffles, pools, LWD, reestablish flow regime), easy to detect change	1. Pools to riffles ratio, 6. Pools, riffles, runs, 5. Channelization, 8. Sinuosity, 11. Channel Shape, 23. Hydroperiod- related to hydroperiod for sustainability, and Refuge cover
8. Sinuosity	T, M, E	F, JS	Ratio of sinuous length to straight-line length,	Direct change (remeander channel, reestablish flow regime), easy to detect change	5. Channelization, 7. Complexity, 9. Gradient, 11. Channel shape
9. Gradient	T, M, E	F, JS	Difference in elevation along distance of river/stream reach	Direct change (remeander channel, reestablish flow regime), easy to detect change	5. Channelization, 8. Sinuosity, 11. Channel shape
10. Floodplain	T, M, E	F, JS	Presence/absence of 10-yr, 25-yr, etc. or percent connected historical floodplain	Direct change (remove levee), easy to detect change	2. Sec Side channel, 12. Longitudinal
11. Channel shape	T, M	F, JS	Measure of width, mean depth, mean velocity, suspended sediment load and water discharge, measured by category?	Direct change (remeander channel, reestablish flow regime), easy to detect change	5. Channelization, 8. Sinuosity, 9. Gradient
			Connectivity		
12. Longitudinal	T, M	F, JS	Length of upstream accessible, or percent river/stream accessible, or Index of Dendritic Connectivity	Direct change (remove obstruction), easy to detect change	23. Hydroperiod
13. Lateral	T, M	F, JS	Acres of accessible floodplain, Percent of accessible floodplain	Direct change (remove levee/obstruction), easy to detect change	2. Sec Side channel, 10. Floodplain, 23. Hydroperiod
			Food		
14. Benthic macroinverts	T, M, E	JS	Abundance, or Index of Biotic Integrity, or Index of Diversity (Cole et al 2009)	Direct change by installation of substrate, easy to detect change. Indirect by changes in water quality/velocity, may be difficult to detect change if not all stressors are removed	1. Pool to riffle ratio 4. Lacustrine wetlands 6. Pools, riffles, runs, 7. Complexity, 9. Gradient, 19. Woody debris, 21. Size, 24. DO, 27. Sediments, 28. nutrients

Parameter	Landscape Unit*	Life Stage**	Measurement	Sensitivity to Action and Ability to Detect Change	Interrelatedness
15. Plankton	T	F	Abundance, or Index of Biotic Integrity or Index of Diversity (Cole et al 2009)	Indirect change, may or may not be sensitive to action	4. Lacustrine wetlands 6. Pools, riffles, runs, 7. Complexity, 23. Sediments
			Landscape Cover		
16. Edge Cover	T, M, E	F, JS	Percent cover of area, or diversity of cover within area, and/or categorical type of cover (Deciduous, Evergreen, Shrub, Grassland, etc.)	Direct change (plant target species), easy to detect change	17. Aquatic veg, 18. Undercut banks, 19. Woody debris
			Refuge Cover		
17. Aquatic veg	T	F	Percent cover, or Type of cover (native vs. non-native)	Direct change (plant target species), easy to detect change	16. Edge cover, 19. Woody debris
18. Undercut banks	T, M, E	F, JS	Presence/absence, or Percent of banks undercut	Direct change (build ledge and under shelf, reestablish channel forming processes), easy to detect change	16. Edge cover
19. Woody debris	T, M, E	F, JS	Presence/absence, or Percent cover, or Type, or Pieces per meter	Direct change (install rootwads, revegetate riparian area), easy to detect change	16. Edge cover
			Predators		
20. Predators	T, M, E	E, F, JS	Presence/absence, or Abundance	Indirect change, may not be sensitive to action	14. Benthic macoinvert.
			Substrate		
21. Size	T, M	E, F, JS	Presence/absence of substrate size class, or Percent cover of substrate size class, or Average size of substrate	Direct change (install target substrate, reestablish natural sediment transport), easy to detect change	16. Edge cover, 19. Woody debris, 22. Particle, 23. Hydroperiod-related to sediment transport for sustainability
22. Particle	T, M	E, F,	Dominant substrate composition	Direct change (install target substrate, reestablish natural sediment transport), easy to detect change	16. Edge cover, 19. Woody debris, 21. Size, 23. Hydroperiod-related to sediment transport for sustainability

Parameter	Landscape Unit*	Life Stage**	Measurement	Sensitivity to Action and Ability to Detect Change	Interrelatedness
Hydroperiod					
23. Hydroperiod	T, M, E	E, F, jS	Flood return interval	May not have direct change depending on if actions restore upstream permeability and retention, direct change by reconnecting floodplain wetlands, easy to detect change	7. Complexity, 10. Floodplain, 11. Channel shape
Water					
24. DO	T, M, E	E, F, JS	Average percent DO per reach	Indirect change, may not be sensitive to action	1. Pools to riffles ratio, 6. Pools, riffles, runs, 17. Aquatic veg, 19. Woody debris, 25. Temp
25. Temp	T, M, E	E, F, JS	Average Temp per reach, or Avg temp at depth per reach or pool, or Avg summer temp in pool	Indirect change, restore riparian canopy cover, may not be sensitive to action or at small reach scale	1. Pools to riffles ratio, 7. Complexity, 16. Edge Cover, 17. Aquatic veg, 18. Undercut banks, 19. Woody debris,
26. pH	T, M	E, F	Average pH per reach, or Avg pH summer per reach	Indirect change, restore carbon sources for buffering, may not be sensitive to action	17. Aquatic veg, 27. Sediments, 28. Nutrients, 29. Contaminants
27. Sediments	T, M, E	E, F, JS	Percent suspended fine sediment, or Percent suspended sediments low flow	Direct change (remove sources of sediments or change sediment load through installation of settling pools, etc.), easy to detect change	9. Gradient, 16. Edge Cover, 19. Woody debris, 21. Substrate size, 22. Substrate particle
28. Nutrients	T, M	E, F, JS	Percent N and P, or Algal indicator species	Direct or indirect change add fertilizer, restore organic matter input from riparian areas, reconnect spawning runs, may not be sensitive to indirect action	4. Lacustrine wetlands, 7. Complexity, 16. Edge cover, 17. Aquatic veg, 19. Woody debris
29. Contaminants	T, M, E	E, F, JS	Presence/absence, or Percent coverage	Direct change (remove source of contaminants), easy to detect change	
30. Clarity	T, M, E	JS	Turbidity	Indirect change, may not be sensitive to action, depends on the source of the problem	9. Gradient, 16. Edge Cover, 19. Woody debris, 21. Substrate size, 22. Substrate particle, 27. Sediments, 28. Nutrients

5.2 Parameter recommendations

5.2.1 Structure

5.2.1.1 Pool to Riffle Ratio

This parameter is important for egg placement, incubation, and fry development, mainly in the tributaries and in the mainstem for some rivers (Geist and Dauble 1998). This is measured as the area of pools to area of riffles within a reach. Installation of riffle structures and/or excavating out deeper areas for pool formation would directly impact this parameter. Additionally, pools/riffle complexes can be restored with natural processes, reducing excess sediment input, aggrading incised streams and reestablishing essential geomorphic form-building, and maintaining flow regimes (Beechie et al. 2012). The Pool to Riffle ratio is related to the following parameters in Table 7: (6) Pools, Riffles, Runs, (7) Complexity, (16) edge cover, and (23) Hydroperiod. This parameter is related to the structural complexity of a reach. The number of different geomorphic forms found within a reach, including pools and riffles, can be measured as Complexity. In addition, pools and riffles are highly impacted by sediment transport, and sediment transport is influenced by edge cover (e.g., sediment sources) and flow regimes. Because of the high degree of overlap with other parameters that measure structure, this parameter is recommended to be removed from further consideration. Of note is that pools and riffles are discussed again in (6) Pools, Riffles, Runs because of the strong correlation between the survivorship of multiple life stages (e.g., fry, juveniles, adults) with pools and riffles (Rosenfeld 2014; Muhlfeld et al. 2001; Bell et al. 2001; Ropper et al. 1994).

5.2.1.2 Secondary Side Channel

This parameter is important for juveniles and smolt life stages primarily within the mainstem and estuary (Bell et al. 2001). One method of measuring Secondary Side Channel is length (e.g., feet or miles) of accessible Secondary Side Channel within project area. The Secondary Side Channel could be directly affected by excavating out a new channel or reconnecting a previous channel by removing an obstruction/barrier. This is related to (7) Complexity, (10) Floodplain, and (12) Longitudinal Connectivity (Beechie et al. 2012). As Secondary Side Channels are reconnected to either the mainstem or the estuary, the connectivity of the surrounding floodplain increases. Accessible Secondary Side Channels also add to complexity of reach or basin. Although this parameter is related to

Floodplain and Longitudinal Accessibility (e.g., connectivity), this parameter is recommended to be maintained to the next model development step because of the important uniqueness of this feature that greatly influences the suitability of the watershed for salmonids.

5.2.1.3 Wall-Based Pond

This parameter is important for overwintering juvenile salmon (Wright 2010; Sandercock 1991). Wall-Based Ponds cans be measured by the number of ponds per reach or presence/absence of ponds within a reach. Wall-Based Ponds can be directly restored by excavating a deep area within the in-stream or off of a side channel (Roni et al. 2006a), installing a water control structure that would form lentic conditions (Roni et. al. 2010), or reconnecting flow to depressional areas within floodplains (Branton and Richardson 2014). Wall-Based Pond is related to (7) Complexity, such that a Wall-Based Pond can be considered to be a geomorphic structure, similar to a riffle or pool, and would be measured as part of the complexity of a reach. Additionally, Wall-Based Ponds can also be measured as part of landscape complexity as well. Wall-Based Ponds are related to structural complexity and restricted to the tributaries and the juvenile life stage. Given these redundancies and limitations, the Wall-Based Pond parameter is recommended to be removed from further consideration.

5.2.1.4 Lacustrine Wetlands

Lacustrine Wetlands are equally important for the juvenile rearing and adult life stage within the estuary (David et al. 2016) and mainstem as a floodplain feature (Pess et al. 2002). Wetlands provide refuge and food resources. Lacustrine Wetlands can be measured as percent cover within an area or as number of acres within an area. Lacustrine Wetlands can be directly restored by installing a wetland shelf or reconnecting a low lying area with the appropriate hydrology to maintain appropriate hydrology and hydrophytic plant species. The presence of wetlands is highly influenced by the soils and hydrology of an area. Sustaining previous and newly established wetlands requires the correct hydrology to maintain a sufficient hydroperiod. This parameter is one of a few parameters that is related directly to the estuary and the adult life stage and it does meet the requirements of sensitivity to potential project actions. Lacustrine Wetlands is recommended to be maintained to the next stage of model development.

5.2.1.5 Channelization

Channelization is important for all life stages, especially within the estuary and mainstem where channels can be natural or man-made. Natural channels are more suitable for salmonid species (Chapman and Knudson 1980). Channelization can be measured as length or percent of reach channelized, compared to historical length of meandering channel, or compared to potential future length of meandering/sinuosity (Jackels et al. 2012). Channelization would be directly affected by removing man-made structures and allowing the channel to naturalize. Channelization is related to Table-7 (7) Complexity, (8) Sinuosity, (9) Gradient and (11) Channel shape. Complexity of the channel is also related to sinuosity and shape. When a channel is straightened (e.g., channelized) through man-made actions, sinuosity and shape are reduced, and therefore, complexity is reduced (Langler and Smith 2001). Although Channelization is related to Structural Complexity and Sinuosity, it is also the driving force behind critical impairments in many poor quality reaches that can be rectified through the modification of this parameter (Beechie et al. 2012), and it can be efficiently measured through remote technology (e.g., Satellite imagery, LiDar) (Jackels et al. 2012). Thus, this parameter is recommended to be maintained to the next stage of model development.

5.2.1.6 Pools, Riffles, and Runs

Pools, Riffles, and Runs are important for egg placement, incubation, and fry development, mainly within the tributaries. Pools, Riffles, and Runs can be measured by length of pool/riffle complex or presence/absence of a pool/riffle complex. Pools, Riffles, and Runs would be directly affected by installing riffles/runs, and/or excavating pools, and by restoring processes that would form and maintain structures (e.g., flow regime). The sustainability of pools and riffles are dependent on flow regime (e.g., Parameter (23) Hydroperiod - Wash Out) and sediment transport (e.g., Parameter (27) Sediments - Aggradations). This is related to (1) Pools to Riffles Ratio, (7) Complexity, (23) Hydroperiod with particular overlap of (1) Pools to Riffles Ratio. Even though Pools, Riffles, and Runs are redundant to (7) Complexity and (23) Hydroperiod, it is has been found to have strong correlations with multiple life stages (e.g., fry, juveniles, adults) survivorship (Rosenfeld 2014; Muhlfeld et al. 2011; Bell et al. 2001; Ropper et al. 1994), therefore, Pools, Riffles and Runs is recommended to be maintained to the next stage of model development.

5.2.1.7 Complexity

Complexity is important for fry and juvenile development and adult refuge in all landscape units, tributary, mainstem, and estuary (Langler and Smith 2001). Measurements of Complexity include a number and variety of geomorphic structures (e.g., pools, LWD, side channels, substrate, etc) (Rosenfeld et al. 2000) at multiple spatial scales (channel unit, reach, stream network) (Anlauf-Dunn et al. 2014). Complexity would be directly affected by remeandering, installation of pools, riffles, LWD, etc. Complexity is related to almost all of the parameters identified within the structure module. Although Complexity is a limiting factor (Anauf-Dunn et al. 2014; Smorkorowski and Pratt 2007; Geist and Daubble 1998; McMahon and Hartman 1989), it is a parameter that encompasses many aspects of structure (e.g., pools, riffles, runs, secondary side channel, etc.) that are better measured as stand-alone parameters, based what is an appropriate restoration measure for a specific unit of habitat (watershed, channel unit, reach). Based on the interrelatedness of many of the structural parameters, Complexity is recommended to be removed from further consideration.

5.2.1.8 Sinuosity

Sinuosity is important for spawning (main stem and tributaries) (Geist and Daubble 1998), fry and adult development in all landscape units (tributary, mainstem and estuary). Measurement of Sinuosity is the ratio of sinuous length to straight-line length. Sinuosity would be directly affected by remeandering length of stream/river reach either through earth moving or restoration of natural processes that allow the channel to naturalize (Beechie et al. 2012). Sinuosity is related to parameter (5) Channelization, (7) Complexity, (9) Gradient, and (11) Channel Shape. Based on the relatedness to complexity and other structural parameters, it is recommended that Sinuosity be removed from further consideration.

5.2.1.9 Gradient

Gradient is important to adult fry development, and juvenile and smolt development in all landscape units, tributary, mainstem, and estuary (Burnett et al. 2007; Steel et al. 2012; Scheuerell et al. 2006). Measurement of gradient is the change in elevation divided by length of reach. Gradient would be directly affected by removing barriers that prevent meandering of a reach (Beechie et al. 2012). Gradient is related to

(5) Channelization, (7) Complexity, (8) Sinuosity, and (11) Channel Shape. Although this parameter is closely related (5) Channelization and (11) Channel Shape, both parameters that will be maintained, and they respond in a similar fashion to restoration actions as Gradient, it is recommended that Gradient be maintained for the next step in model development. Gradient is recommended to be maintained in order to better understand the differences between parameters (e.g., (5) Channelization) and if a parameter should be included at a different scale than the other parameters.

5.2.1.10 Floodplain

Floodplain is important to fry development and juvenile and smolt development in the tributary and mainstem. Measurement of Floodplain can be presence/absence of fish access to aquatic features of 10-year, 25-year, etc. connected floodplain or as percent connected floodplain within the area of concern. Floodplain would be directly affected by levee removal (e.g., lateral connectivity), removal of side channel obstruction (e.g., longitudinal connectivity) or pulling back of banks. Floodplain is related to (2) Side Channel, (12) Longitudinal Connectivity, and (13) Lateral Connectivity. Because Floodplain is related to other connectivity based parameters (e.g. (12) Longitudinal Connectivity), Floodplain is recommended to be removed from further consideration.

5.2.1.11 Channel Shape

Channel Shape is important to fry development and juvenile and smolt development in the tributary and mainstem (Rosenfeld et al. 2000). Measurement of Channel Shape can be width to depth ratio or as a category and each category can be rated to suitability for salmonid species. As Channel Shape evolves and changes based on the balance between sediment transport, properties of substrates forming the bed and banks, and water input. During low flow, the shape of a channel can have a critical influence on water depths, resulting barriers to migration upstream, (NOAA Fisheries 2004). Channel Shape would be directly affected by remeandering (e.g., gradient and velocity), excavating pools (e.g., depth), installing riffles (e.g., velocity), and/or installing LWD/boulders (House and Boehner 1985), and/or grading back banks that would change the depth of water and allow upstream passage. Channel Shape is related to (1) Pools to Riffles, (6) Pools/Riffles/Runs, (5) Channelization, (8) Sinuosity, (9) Gradient, (12) Longitudinal

Connectivity, and (19) Woody Debris. Because of the potential redundancies to many other measures of structure (e.g., (9) Gradient), Channel Shape is recommended for removal from further consideration.

5.2.2 Connectivity

5.2.2.1 Longitudinal

This parameter is important for almost all life stages, adult migration, fry, and juvenile/smolt development occurring mainly within the mainstem and tributaries, although problems can arise in estuaries as well (e.g., installation of tidegates). Measurement of Longitudinal connectivity can be the length of an accessible reach or percent of river/stream accessible or by the Index of Dendritic Connectivity. Longitudinal connectivity can be directly affected by removal of a dam or fish passage obstruction or can be a temporally variable parameter such as accessibility of certain reaches only available during a high-flow event. Longitudinal connectivity is somewhat unique, the parameter most related is (23) Hydroperiod. Because of the unique nature of this parameter, its ability to be directly impacted by USACE action, and its influence on multiple life stages, it is recommended that Longitudinal connectivity be maintained for the next stage of model development.

5.2.2.2 Lateral

Lateral connectivity is important for adult migration (e.g., stranding), fry development and juvenile/smolt development within the estuary, mainstem, and tributary. Lateral connectivity can be measured as acres of accessible floodplain or percent of accessible floodplain within the study area. Lateral connectivity would be directly affected by removal of levee or excavating of side channel to reconnect floodplain. Lateral connectivity is also temporally influenced by (23) Hydroperiod and can be a positive connection (e.g., access a more diverse food resources) or a negative connection (e.g., adults become cut off from mainstem after flood event). In addition to (23) Hydroperiod, this parameter is related to (2) Secondary Side Channel and (10) Floodplain. Because this is a more encompassing parameter than either (2) Secondary Side Channel and (10) Floodplain, and it is unique in that it can have a positive or negative effect, Lateral connectivity is recommended to be maintained for the next stage of model development.

5.2.3 Food

5.2.3.1 Benthic Macroinvertebrates

This parameter is important for juvenile and smolt development in all landscape units to include: estuary, mainstem, and tributary (Rosenfeld et al. 2005). Benthic Macroinvertebrates can be measured as average abundance per reach (e.g., dried weight or number of individuals), species richness, Index of Diversity (e.g., Simpson's, Shannon's, etc.) or Index of Biotic Integrity. Benthic Macroinvertebrates are highly influenced by a number of environmental variables (e.g., sediment type, (23) Hydroperiod, velocity, (7) Complexity) that may or may not be sensitive to USACE restoration actions. However, there is potential for a temporary direct impact from such actions as sediment placement that could smother some invertebrates, although, most would detach and drift away. USACE restoration actions can have a positive effect on the benthic macroinvertebrate community and their distribution by improving substrate, velocity, (8) Gradient, (1) Pool to Riffle Ratio, and (28) Nutrient Input (Diefenderfer et al. 2016). Overall benefits to Benthic Macroinvertebrates may be limited by the USACEs inability to affect systemic water quality issues. This parameter is related to other parameters such as (4) Lacustrine Wetlands, (6) Pools, Riffles, Runs and (7) Complexity. Benthic Macroinvertebrates are recommended to be removed from further consideration because of the potentially limited ability the USACE has to affect benthic macroinvertebrates and potential redundancies with other environmental parameters.

5.2.3.2 Plankton

This parameter is important for fry development in the tributaries (Mazumder and Edmundson 2002). Plankton has many similarities with (14) Benthic Macroinvertebrates in the way it can be measured and its predicted response to potential USACE actions. Plankton can be measured as average abundance per reach (e.g., wet weight), species richness, Index of Diversity (e.g., Simpson's, Shannon's, etc.) or Index of Biotic Integrity. Plankton are highly influenced by a number of environmental variables (e.g., (28) Nutrients, (23) Hydroperiod, (7) Complexity) that USACE actions could affect, but rarely would a project have more than a temporary, direct impact from such actions as sediment placement (e.g., would smother some plankton, or increase turbidity) (Gregory and Northcote 1993). Thus, USACE actions may alter Plankton through indirect means. Detecting a measurable change may be difficult if USACE actions are not specifically calibrated to influence plankton. Plankton is related to other environmental parameters such as (4) Lacustrine Wetlands, (6) Pools, Riffles, Runs, and (27) Sediments. Plankton is recommended to be removed from further consideration because of the indirect nature that USACE action would have on Plankton and the potential redundancies with other environmental parameters.

5.2.4 Landscape/edge cover

Edge Cover is important for juvenile/smolt development in all landscape units including: estuary, mainstem, and tributary (Burnett et al. 2007; Pess et al. 2012). Edge Cover can be measured by percent length of cover along reach, diversity of cover types along reach, weighted percent cover type along a reach based on suitability of cover, and/or area of buffer width (Klimas and Yuill 2013). Edge Cover type can be classified as herbaceous, shrubs, trees (e.g., alder, deciduous or evergreen dominated etc.), USACE actions would have a direct effect on Edge Cover through either removal, or installation of target edge cover type. Edge Cover is related to (17) Aquatic Vegetation, (18) Undercut Banks, and (19) Woody Debris (e.g., some cover types more likely to introduce woody debris into stream than others). Although Edge Cover is closely related to the parameters for Refuge Cover (e.g., (19) Woody debris), this parameter is more encompassing than any single parameter and would be sensitive to USACE actions (del Tanago and de Jalon 2006). Therefore, Edge Cover is recommended to be maintained for the next stage of model development.

5.2.5 Refuge cover

5.2.5.1 Aquatic Vegetation

Aquatic Vegetation is important for fry development within the tributary. Measurement of Aquatic Vegetation can be presence/absence, percent cover, and/or type of cover (native vs. non-native). USACE action would have a direct affect to this parameter by directly removing aquatic vegetation through levee construction or increase in coverage through direct plantings. The change in Aquatic Vegetation would be easy to measure and detect either visually or remotely (e.g., LiDar, etc.). Aquatic Vegetation is related to (12) Edge Cover via sources of seed or reproductive parts that disperse through the landscape and (19) Woody Debris via providing suitable habitat through reducing flow and allowing sedimentation and root development. Aquatic vegetation is highly correlated to (12) Edge Cover and (19) Woody Debris (Wootton 2012; Steel et al. 2012; Scheuerell et al. 2006; Pess et al. 2012; Mellina and Hinch 2009). Aquatic Vegetation is recommended to be removed from further consideration because of the high degree of redundancy with other parameters that will be maintained.

5.2.5.2 *Undercut Banks*

This parameter is important for fry development and juvenile/smolt for refuge and food resources, as well as, for refuge during adult upstream migration within all landscape units including: estuary, mainstem, and tributary (House and Boehne 1985). Undercut Banks can be measured as presence/absence, relative length of undercut compared to potential for a reach, or percent undercut banks along reach. Undercut Banks would be directly affected by USACE actions through levee maintenance and repair, levee construction, and/or bank stabilization and would be easy to measure and detect change as a result of actions. Undercut banks are related to (16) Edge Cover (e.g., hardened vs. natural), (7) Complexity, because undercut banks can be classified as an in-stream geomorphic feature, and (27) Sediments. Also, Undercut Banks are related to flow/ velocity and (11) Channel Shape. In addition, Undercut Banks are correlated to both (16) Edge Cover (e.g., vegetation stabilizes undercut bank and decreasing collapse) (Tschaplinski and Hartman 1983), and, if undercut banks are considered a geomorphic feature, (7) Complexity, at the channel unit and reach scale. Undercut Banks is closely related to other landscape, structural and functional parameters, and restoration actions that target these parameters (e.g., (16) Edge Cover) will address this parameter as well (e.g., Smokorowski and Pratt 2007). Thus, Undercut Banks is recommended to be removed from further consideration.

5.2.5.3 *Woody Debris*

Woody Debris is important for fry development and juvenile/smolt in all landscape units including: estuary, mainstem, and tributary (House and Boehne 1985; Smokorowski and Pratt 2007; and Louhi et al. 2016). Woody Debris can be measured as presence/absence or percent cover or category of woody debris (e.g., logs, root wads, etc.), or pieces per reach. USACE actions would have a direct effect on Woody Debris by projects that would either directly install for habitat or remove to reduce flood damages. Also, changes to Woody Debris sources can be directly impacted, such as

(16) Edge Cover by levee construction. Additionally, overall stream conditions can be improved by installation of woody debris for accumulation of more debris or sediment trapping and pool formation (Beechie et al. 2012; Roni et al. 2010). Woody Debris is related to (7) Complexity. Woody debris can also be thought of as a geomorphic in-stream feature related to (11) Channel Shape, as woody debris collects in bends of natural river shapes, and (16) Edge Cover, which provides sources of material. Although Woody Debris is closely related to other landscape and structural parameters, Woody Debris is a critical need in all landscape units, is sensitive to USACE actions, and is easy to measure. Woody Debris is recommended to be maintained for the next step in model development.

5.2.6 Predators

5.2.6.1 Predators

Predators is important for all life stages, egg incubation, fry development, juvenile/smolt, and migrating adults in all landscape units including: estuary, mainstem, and tributary (Peterman and Gatto 1978; Ruggerone et al. 2000; Ward et al. 2007). Predators can be measured by presence/absence, abundance, or density of predators relative to salmon population size. Since it is unlikely the USACE would engage in direct predator removal, it is likely any USACE action would have an indirect effect on Predators, such as through altering habitat suitability of the project area for the predator of concern. For example, removal of a dam would remove suitable habitat for predatory warm water fish (Lawrence et al. 2014) or the removal of rip rap would remove hiding spaces for predatory fish in rivers and estuaries. There are also a number of environmental and biotic variables that control the density or presence of Predators (e.g., competition) that the USACE would be unlikely to alter. The Predators parameter may be difficult to appropriately and accurately measure since a change in predators may not be related to USACE actions. Predators are related to (14) Benthic Macroinvertebrates, which includes a suite of predators that feed on egg/embryo/juvenile life stages. Predators is recommended to be removed from further consideration because of potential insensitivity to USACE actions.

5.2.7 Substrate

5.2.7.1 Size

Size of substrate is important for egg placement, egg incubation, fry development, and juvenile/smolt development, primarily within the tributaries (Reiser and White 1988; Collins et al. 2014). Substrate Size can be measured as presence/absence of size classes, percent cover of size classes, average size of substrate within reach, or greater than/less than threshold of 11% fines. Size of substrates would be directly affected by USACE actions through dredging, dredge material placement, direct installation of target size class, or by altering (8) Gradient and/or velocity of a reach. The sustainability of a targeted size class would be highly dependent on future sediment transport dynamics of the system (NOAA 2004). Substrate Size is related to (16) Edge Cover (e.g., sediment source), (19) Woody Debris (e.g., sediment sink), (23) Substrate Particle and (23) Hydroperiod (e.g., frequent flooding may change sediment transport dynamics). Although substrate Size is related to other parameters it represents a unique set of conditions for critical life stages, therefore, Size of substrate is recommended to be maintained for the next stage of model development.

5.2.7.2 Particle

Particle is important for egg incubation and fry development, mainly in the mainstem and tributary. Substrate Particle can be measured as dominant substrate composition. Similar to substrate (21) Size, substrate Particle can be directly affected by USACE actions. It is unclear how substrate Particle is significantly different from (21) Size. Also, substrate Particle is related to (16) Edge Cover, (19) Woody Debris and (23) Hydroperiod. Because of the clear redundancies with other environmental parameters, namely (21) Size, Particle is recommended to be removed from further consideration.

5.2.8 Hydroperiod

5.2.8.1 Hydroperiod

Hydroperiod is related to all life stages including: adult migration, egg placement, egg incubation, fry development, and juvenile/smolt development that occurs within all landscape units to include estuary, mainstem, and tributary (Mantua et al. 2010; Groves and Chandler 1999;

Burnett et al. 2007). For purposes of this effort, Hydroperiod is defined as the seasonal pattern of the water level that results from water inputs and wetland capacity. Hydroperiod can be measured by frequency and duration of wetness at a specific elevation. Specific aspects of Hydropreiod may influence one or more salmonid life stage. Salmonid species are adapted to a certain extent to a dynamic hydrologic regime, but less so to contemporary flooding frequencies that are 2–3 times greater than historic conditions over the course of a year (Burnett et al. 2007). USACE actions would directly affect Hydroperiod through installation of levees that would decrease flooding to floodplain wetlands and/or installing reservoirs to reduce flood height downstream. The USACE authorities are limited to the floodplain and buffer areas. In order to reduce flood frequency and duration, the uplands within a watershed need to be able to retain more water through converting impervious to pervious surfaces or installing more water retention structures. Detecting a change in Hydroperiod as a result of a single USACE action may be difficult if the action is limited in scope. However, combined actions, such as removal of levees and dams and installation of water control structures, would directly impact Hydroperiod (Diefenderfer et al. 2016). Hydroperiod is related to (7) Complexity (e.g., roughness), (10) Floodplain, (11) Channel shape, (12) Longitudinal Connectivity, and (13) Lateral Connectivity. Because Hydroperiod might be difficult to significantly change through a single USACE action, and its redundancies to other environmental parameters that will be maintained, Hydroperiod is recommended to be removed from further consideration.

5.2.9 Water

5.2.9.1 Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is important for many life stages including: adult migration, egg incubation, fry development and juvenile/smolt and within all land-scape units including estuary and mainstem tributary (Peterson and Quinn 1996; Geist et al. 2006). DO can be measured as average percent per reach or average percent at depth per reach. USACE actions would most likely have an indirect impact on DO in lotic waters and any change in DO may be unrelated to USACE actions. DO is related to an array of environmental parameters: (1) Pools to Riffle Ratio, (6) Pools, Riffles, Runs, (17) Aquatic Vegetation, (19) Woody Debris and (25) Temperature. DO is recommended to be removed from further consideration because of the potential insensitivity to USACE actions and redundancies with other environmental parameters.

5.2.9.2 Temperature (Temp)

Temperature is important for all life stages including: adult migration, egg incubation, fry development, and juvenile/smolt, and within all landscape units including: estuary, mainstem, and tributary (Geist et al. 2006; Groves and Chandler 1999). Temperature can be measured as average temperature per reach, average temperature at depth per reach, average seasonal temperature per reach or per geomorphic feature (e.g., pool). USACE actions are likely to have an indirect effect on this parameter, such as, restoring (16) Edge Cover and over-hanging canopy for small tributaries that reduces direct sunlight to water surface (Mellina and Hinch 2009). A paired study of riparian restorations (e.g., (16) Edge Cover) did not show a significant difference in temperature between restored and control site (Wootton et al. 2012). This could indicate that the length of riparian area manipulated was not large enough, or the width of the river was too wide to significantly change water temperature. Temperature is related to (1) Pools to Riffles Ratio, (6). Pools, Riffles, Runs, (16) Edge Cover, (17) Aquatic Vegetation, (18) Undercut Banks, and (19) Woody Debris. Although, this parameter is related to a number of other structural parameters and may not be sensitive to restoration actions at a larger scale (e.g., mainstem). Temperature is a critical component of survival for many life stages, therefore, Temperature is recommended to be maintained for the next step of model development.

5.2.9.3 pH

Spawning (Nelson et al. 2015) and fry development in tributaries and mainstem are dependent on pH (Kennedy and Picard 2012). Usually, pH can be measured as average pH per reach or average pH per season per reach. The USACE actions are likely to have an indirect effect on pH by way of installation of aquatic vegetation (e.g., dissolved carbon buffering) or removal of containments. This is related to (17) Aquatic Vegetation, (27) Sediments, (28) Nutrients, and (29) Contaminants. Because of the potential insensitivity to USACE actions and redundancies with other environmental parameters, it is recommended that pH be removed from further consideration.

5.2.9.4 Sediments

Sediments is important for egg incubation, fry development, and juvenile/smolt development in all landscape units including: estuary, mainstem, and tributary (Collins et al. 2014). Sediments can be measured as percent suspended sediments or percent suspended sediments during low flow. USACE actions would have a direct effect on Sediments via projects that install structures to sequester sediments, remove sources of sediments and/or change the sediment load. Sediments are related to (9) Gradient, (16) Edge Cover, (19) Woody Debris, (21) Substrate Size, and (22) Substrate Particle. Restoration actions aimed at restoring structure and function such as, (19) Edge Cover, (19) Woody Debris, and (21) Substrate Size would also benefit areas experiencing excessive suspended sediments and sedimentation. Sediments is recommended to be removed from consideration because it is closely related to other parameters that will be maintained.

5.2.9.5 Nutrients

Nutrients are important for egg incubation, fry development, and juvenile/smolt development, primarily in the tributary (Roberts and Bilby 2009). Nutrients can be measures by percent available Nitrogen and/or Phosphorus or certain algal indicator species. Levels of nutrients in lotic systems are usually the result of geology, land use, and (19) Edge Cover within the watershed of concern. It is also linked to marine-derived nutrients in the Pacific Northwest (e.g., salmon carcasses) (Gende et al. 2002). USACE actions could directly impact nutrient levels by seeding reaches with fertilizers to stimulate algal growth (Sterling et al. 2000), restore riparian vegetation to reestablish sources of organic matter (Roberts and Bilby 2009) or removing barriers to historical spawning runs to restore influx of marine-derived nutrients (Gende et al. 2002) Nutrients are related to (4) Lacustrine Wetlands, (7) Complexity (e.g., provide areas for organic matter accumulation and breakdown) (Richardson et al. 2005), (16) Edge Cover, (17) Aquatic Vegetation, and (19). Woody Debris. Although Nutrients may be sensitive to USACE projects, it is highly related to other environmental parameters that will be maintained. Therefore, Nutrients is recommended to be removed from further consideration.

5.2.9.6 Contaminants

Contaminants is important for egg incubation, fry development, and juvenile/smolt development in all landscape units including estuary, mainstem, and tributary. Contaminants can be measured as presence/absence, percent coverage of area, or milligrams per kilogram in sediment. USACE actions can directly change this parameter by removal of contaminants. However, the USACE authorities to do so are very limited in scope and rarely are allowed outside of deepening of navigation channels. Although Contaminants can be directly impact through USACE action, this action is typically undertaken by another entity (e.g., Environmental Protection Agency). Contaminants are not directly related to other environmental parameters, but disturbance/erosion and subsequent movement of contaminants downstream is of concern during assessments of proposed actions. Contaminants is recommended to be removed from further consideration because Contaminants is most likely not going to be directly impacted through USACE actions.

5.2.9.7 Clarity

Clarity is important for the juvenile/smolt development life stage within all landscape units including estuary, mainstem, and tributary (Gregory and Northcote 1993). Clarity can be measured as turbidity with secci disk. Clarity is likely to be indirectly impacted by USACE actions and may be difficult to correlate change in Clarity to a USACE project. Clarity is related to (9) Gradient, (16) Edge Cover, (19) Woody Debris, (21) Substrate Size, (22) Substrate Particle, (27) Sediments, and (28) Nutrients. Because of the potential insensitivity between Clarity and USACE actions, and redundancies with other environmental parameters, Clarity is recommended to be removed from further consideration.

5.3 Parameter refinement summary

As a result of the parameter refinement process (evaluation and comparison), the number of recommended parameters is eleven out of the original thirty. The parameter refinement was able to clearly delineate any potential issues with being able to effectively and accurately measure parameters, whether the parameter would be sensitive to potential USACE actions and potential redundancies with other parameters. Table 8 lists the recommendations from the parameter refinement process.

Table 8. Recommended parameters.

Parameter	Recommendation
A. Structure	
1. Pool to riffle ratio	Remove
2. Secondary side channel	**Maintain**
3. Wall-based pond	Remove
4. Lacustrine wetlands	**Maintain**
5. Channelization	**Maintain**
6. Pools, riffle, runs	**Maintain**
7. Complexity	Remove
8. Sinuosity	Remove
9. Gradient	**Maintain**
10. Floodplain	Remove
11. Channel shape	Remove
B. Connectivity	
12. Longitudinal	**Maintain**
13. Lateral	**Maintain**
C. Food	
14. Benthic macroinverts	Remove
15. Plankton	Remove
D. Landscape Cover	
16. Edge Cover	**Maintain**
E. Refuge Cover	
17. Aquatic veg	Remove
18. Undercut banks	Remove
19. Woody debris	**Maintain**
F. Predators	
20. Predators	Remove
G. Substrate	
21. Size	**Maintain**
22. Particle	Remove
H. Hydroperiod	
23. Hydroperiod	Remove
I. Water	
24. DO	Remove
25. Temp	**Maintain**
26. pH	Remove
27. Sediments	Remove
28. Nutrients	Remove
29. Contaminants	Remove
30. Clarity	Remove

6 Conclusion

The focused mediated model development workshop was successful at taking the first step in the general standard salmonid model development process. The workshop participants were able to fully explore all the numerous environmental and biotic variables (i.e., potential model parameters) that influence suitable salmonid habitat and how they interact with one another. It is clear that salmonid life history requisites are complicated and complex, and that coming to consensus on model parameters that are most appropriate to meet the model goals and objectives are challenging. As discussed throughout the report, future model development steps will need to take into consideration system complexities, and differing temporal and spatial scales.

Next steps in the model development process will be to organize another mediated model development workshop that will focus on coming to consensus on the final parameters of the model, how the parameters interact with one another and the system as a whole, and quantifying the relationship the parameters have to suitable salmonid habitat.

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14. ABSTRACT

Salmonid species are critically important ecologically, socially, and economically for North American coastal regions. Alterations to the structure (e.g., channelization) and function (e.g., sediment transport) of estuaries, rivers, and streams have greatly impacted these species, many are now listed as federally threatened or endangered. As part of environmental compliance procedures and policy, the U.S. Army Corps of Engineers (USACE) is required to assess the impacts and/or benefits of proposed water resource projects (e.g., levee maintenance, ecosystem restoration, etc.) to the environment. The USACE is required to predict and quantify environmental benefits using models to justify federal investment in ecosystem restoration projects. The purpose of this effort is to develop a general model or model framework that can be used during the USACE planning process that will serve as a unified standard Salmonid model. The primary purpose of the model will be to project future environmental benefits that will result from proposed restoration measures. Additionally, the model needs to be sensitive to different combinations of restoration measures in order to assist the USCAE in the planning and decision making process. This report presents the results of the first phase of model development using the mediated model development process.

15. SUBJECT TERMS

Restoration ecology
Stream restoration
Environmental protection--Planning
Rivers--Regulation
Salmonidae--Mathematical models

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