US Army Corps
of Engineers ®
Walla Walla District

YAKIMA RIVER DELTA ECOSYSTEM RESTORATION

Final Feasibility Report with Integrated Environmental Assessment

Appendix C

Habitat Evaluation Model

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PURPOSE

The purpose of the Yakima Delta Ecosystem Restoration Project habitat evaluation process is to evaluate the increase in ecological function and habitat benefits as a result of restoring aquatic habitats within the Yakima Delta located in Richland, Washington. Specifically, the model and components address the extent to which aquatic habitat restoration will benefit anadromous salmonids. The model used is the General Salmonid Habitat (GSH) Model developed by the US Army Engineer Research and Development Center (ERDC) (Herman et. al. 2020).

The GSH model was developed by the ERDC to assist in the plan formulation process for ecosystem restoration and mitigation projects. The model generates a Habitat Suitability Index (HSI) to evaluate relative differences in habitat quality between proposed alternative future scenarios. The GSH model is proposed for use for the Yakima Delta Ecosystem Restoration Project (Project) being conducted by the U.S. Army Corps of Engineers (USACE), Walla Walla District, and its cost-share partner, the Washington Department of Fish and Wildlife (WDFW). The model was used to evaluate habitat gains resulting from the restoration for salmonid species. Habitat units (HU) derived from the restoration area and HSI scores were evaluated with a Cost Effectiveness/Incremental Cost Analysis (CE/ICA) model that identified the “best buy” Project Alternatives based on net HU benefit per unit cost.

The GSH model was certified for regional use within all watersheds that support anadromous Pacific salmon species along the northwest coast of the continental United States (northern California, Oregon, and Washington) by Gary L. Young, Planning and Policy and Director, National Ecosystem Restoration Planning Center of Expertise, Mississippi Valley Division on 7 May 2020.

BACKGROUND

This document summarizes the modeling used for estimating ecological benefits of the proposed Alternatives of the Yakima Delta Ecosystem Restoration Project (Project). These models were used to assess the future without (FWOP) project conditions of aquatic habitats and their relationships to salmonid species production and migration and the conditions that would be likely to occur following implementation of the tentatively selected plan (TSP). The intent of the model is to provide a set of quantitative tools for evaluating and comparing a broad set of potential outcomes associated with various alternatives. To evaluate and compare restoration alternatives, it was necessary to assign a numeric value to the habitat benefits for each alternative. The GSH model provides a means for designing a mathematical model based on the HSI of the existing and proposed restored habitats for salmonid species in the Pacific Northwest. The output of the model provides a quantitative value (HUs) to be used for further evaluation and comparison of the proposed alternatives. This quantitative or numeric scoring method further facilitates comparisons of potential habitat impacts and benefits among alternatives using the HUs in conducting a Cost Effectiveness and Incremental Cost Analysis (CE/ICA).

Study Area and Proposed Project

The Yakima River Delta is located at the confluence of the Columbia and Yakima Rivers, near Columbia River Mile 335. It is situated near Richland, Washington. Bateman Island sits to the east of the Delta, with an earthen causeway running from the south side of the Delta to Bateman Island.

Columbia Park Marina also sits along the south side of the Delta and is protected from wave action by the causeway. The zone of influence from McNary Dam extends up the Yakima River to just past the Interstate 82 (I-82) Bridge (around Yakima River Mile 2). The Yakima River flows into the Columbia River by going under the I-82 Bridge, down into the Delta, and then back up around the northern tip of Bateman Island. Approximately 17 miles of Federal levees lay along the banks of the Columbia River to protect the Tri-Cities of Kennewick, Richland, and Pasco, Washington. The assumed area of effect for the model evaluation was the aquatic areas of the delta, from the WA Highway 240 Bridge to a point drawn from the southeast tip of Columbia Point to Bateman Island and then from Bateman Island to the Shoreline, a total of 360.4 acres.

Prior to the construction of McNary Lock and Dam and the Federal levee system in the 1950s, the Yakima River Delta supported a variety of woody vegetation and shallow water channels that were inundated seasonally. The Yakima River flowed into the Delta and mixed freely with the Columbia River during both high and low flows, and then flowed along the south side of Bateman Island into the Columbia River.

Many problems exist within the Yakima River Delta because of the construction of McNary Dam and the Federal levees throughout the Tri-Cities in the 1950s. The impoundment of Lake Wallula has completely changed the flows within the Delta, with the effects felt approximately 2 miles into the Yakima River. These problems are compounded by a 500-foot causeway between the mainland and Bateman Island, which stops flow from moving around the south side of the island. The main two problems that this study focuses on solving are as follows:

- Impoundment of the Columbia River reduced the energy and volume of flows entering the Yakima River Delta.
- Blocked flows south of Bateman Island and increased sedimentation created a large, shallow backwater environment.

These factors create poor conditions for both returning adult salmonids and outmigrating juveniles. Returning adults often encounter lethally high temperatures in the Delta, frequently above 25°C in summer months, while juveniles find a Delta lacking in flushing flows and full of warm water predators.

The proposed project is to restore aquatic habitat in areas of the Yakima Delta by removing the causeway to Bateman Island. Project implementation would include the complete removal of the 560 ft Bateman Island causeway with the intent of improving mixing of Columbia River flows to reduce temperatures in the area west of Bateman Island. Grading for the full removal would blend adjacent grades and would transition to adjacent bank lines by flattening with limited fill (versus excavation) and revegetation.

Only removal of the causeway without any accompanying riparian restoration is proposed for multiple reasons. If natural riparian habitat development does not occur, supplemental plantings are proposed as part of the Monitoring and Adaptive Management Plan, as appropriate. Riparian restoration at several areas along Bateman Island was examined as a means of improving habitat for migrating salmonids. However, given uncertainty regarding the reactions of the island shoreline to an altered flow regime, benefits from riparian restoration were seen as highly speculative, especially by the project sponsor, the WDFW. Riparian restoration was also seen to have limited benefits in the GSH model. Furthermore, the existing shoreline habitat in the Yakima Delta is of relatively high quality in terms of cover and composition. The primary factors degrading aquatic habitat in the delta are driven by poor flows and mixing within the delta due to the impoundment of the Columbia River and the construction of the Bateman Island causeway.

The removal of the Bateman Island causeway will benefit numerous salmonid species which migrate through the delta including Endangered Species Act (ESA)-listed Threatened Mid-Columbia steelhead (*Oncorhynchus mykiss*), spring and fall run Chinook salmon (*O. tshawytscha*), and reestablished populations of coho salmon (*O. kisutch)* and sockeye salmon (*O. nerka*).

HABITAT EVALUATION MODEL

The GSH model is an HSI-based procedure developed by the ERDC to assist in the plan formulation process for ecosystem restoration and mitigation projects focus on salmonid habitats. The basic premise of the GSH model is that salmonid habitat quantity and quality can be numerically described. The GSH model can provide a comparison of salmonid habitat quality between different sites or between different times at one site (e.g. before and after action). A key assumption in the GSH model is that salmonid species "prefer" (i.e. survives/reproduces better) habitats with certain physical characteristics that can be measured. For example, if juvenile Chinook salmon prefer to rear among gravel and cobble substrates along shorelines with riparian habitat adequate to provide complex bank cover and woody debris, then sites characterized by riparian inputs of woody debris and bank cover are more suitable for juvenile Chinook salmon relative to sites with little riparian habitat.

An HSI is the framework used in the GSH model which is a mathematical relationship between a physical, chemical, or biological habitat attribute and its suitability for a single species or assemblage of species. The Suitability Index (SI) is a unit-less number between 0 and 1 that describes the requirements of a species for certain attributes such as cover, distance to foraging, water temperature, etc. A set of one or more SIs that represent key habitat requisites for the species during one or more life history stages are combined into an overall HSI by adding or multiplying the individual indices. The attributes may be measured in the field or via Geographic Information System (GIS) analysis where appropriate. Their corresponding index values are inserted into the model to produce a score between 0 and 1 that describes existing habitat suitability. This index value can be multiplied by the area of the site to yield HUs, or it can be used as an index score for a habitat quality comparison only.

The GSH model was selected under guidance from the USACE Northwest Division due to its explicit applicability to a salmonid-focused planning study in the region.

DESCRIPTION OF UTILIZED MODEL

Model Development Process

The GSH model was developed through a mediated modeling workshop, resulting in consensus on a conceptual model and quantification of parameters (Herman et.al 2018). Challenges overcome during the mediated model development workshop included integrating new members of the model development team, cultivating a collective understanding of the applications and limitations of the model (for example, general enough to be applied in a variety of project types and sensitive enough to generate relative differences between proposed future alternative scenarios), and finding a group consensus with the final conceptual model and model framework.

The mediated model development workshop was held in July of 2016 in Seattle, Washington, which included USACE planners, modelers, biologists, and non-USACE academics. Mediated modeling is a process wherein facilitators and stakeholders find consensus at each model development phase, which results in a collective understanding of the model's assumptions, limitations, and applications (Van den Belt et al. 2006). The first step in the workshop was to develop a refined conceptual model (Figure 1) and reach consensus on which parameters to carry forward into the quantification phase.

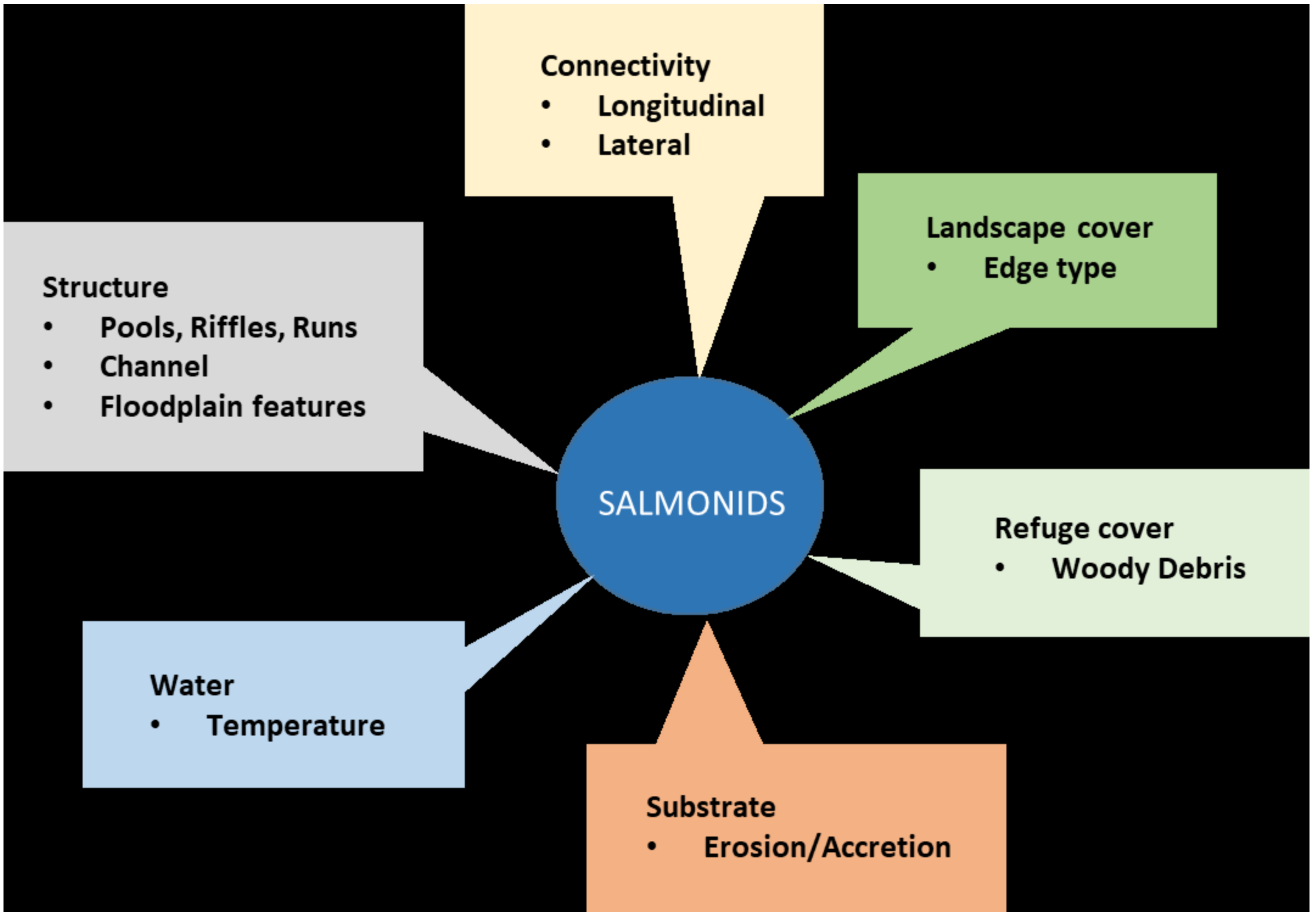

Figure 1. The Conceptual Framework of the Genera Salmonid Habitat Model.

Quantification involves defining the mathematical relationship each parameter has to the system of interest. Typically, this is conducted by agreeing on how the parameter should be measured (for example, mg1/L, average depth, ft/s2, etc.) and mathematically describing the response of this parameter to a change in the system (for example, linear, logistic, truncated). For the purposes of this effort, the expected change in the system is a potential future action undertaken by the USACE (for example, restoration of woody debris). The group then quantified the maintained parameters through a consensus process, where the workshop participants were encouraged to talk about their experiences (for example, data collection and analysis) and observations of these parameters (Schmolke et al. 2010). After the discussion, the group then reached a consensus about how to measure the parameters and how to mathematically describe each parameter's relationship to a change in the system. The model development team used a combination of published literature and best professional judgment to create the response curves.

Description of Input and Output

The GSH model includes six categories and nine parameters of environmental features to represent ideal salmonid habitats (Table 1). Several of these parameters are further broken out by life-stage.

Table 1. GSH Model Categories and Parameters

Parameter	Description
Structure	
Channel	Considers the diversity of in-stream habitat types that result from the shape and geomorphic contours of a channel.
Pools, Riffles, Runs	Considers the relationship of specific in-stream features (for example, pools) to the quality of anadromous fish habitat.
Floodplain features	Considers the relationship of specific floodplain features (for example, wall-based ponds, oxbows, and wetlands) to the quality of anadromous fish habitat.
Connectivity	
Longitudinal connectivity	Considers the ability of an organism to access areas within a stream or river network (for example, watershed).
Lateral connectivity	Considers the ability of organisms to access habitat adjacent to stream and river reaches within floodplain and surge plain areas.
Edge-type Landscape Cover	
Edge Cover 1	Considers the relationship between percent cover in the riparian buffer area to the quality of anadromous salmonid habitat.
Edge Cover 2	Considers the relationship between the percent of the riparian buffer area covered by native species to the quality of anadromous salmonid habitat.
Refuge Cover	
Woody Debris	Considers the relationship between the quantity of large woody debris in the channel to the quality of anadromous salmonid habitat
Substrate	
Sediment	Considers the sedimentation processes that form critical substrate for a variety of different life stages of anadromous fish species.
Water	
General Temperature	Describes the general range of water temperature and its associated habitat suitability.
Bioenergetics Temperature	Describes the predicted performance of individuals in terms of successful migration, breeding, and rearing.
Survival Temperature	Describes predictive survival ranges.

Structure

Channel Diversity

The channel parameter quantifies the diversity of in-stream habitat types that result from the shape and geomorphic contours of a channel. When a channel is straightened, the diversity of habitats is lost. This parameter represents diversity of in-stream habitats, including secondary and main stem channels, alcoves, sloughs, backwaters, and sinuosity of shoreline. The parameter is measured as an index of diversity (for example, habitat diversity). As the richness (number of total features) and evenness (abundance of features) of channel features increases, so does the quality of anadromous fish habitat. Evenness is calculated as the abundance of one feature in relation to other habitat features in the area of concern. As the abundance of each feature becomes similar to the abundance of the other features, the diversity will increase.

This parameter was assessed as a Shannon's (H´) Index of Diversity. The outputs from the Shannon Index range between 1.5 and 3.5, rarely above 4 (Magurran 1988). The curve describes an increase from 0 to 2.5 along the y axis, then plateaus, with the reason being that any increase beyond 60%–75% maximum habitat diversity (~2.5) may not be as significant as the increase between 0 and 60%–75% (Figure 2).

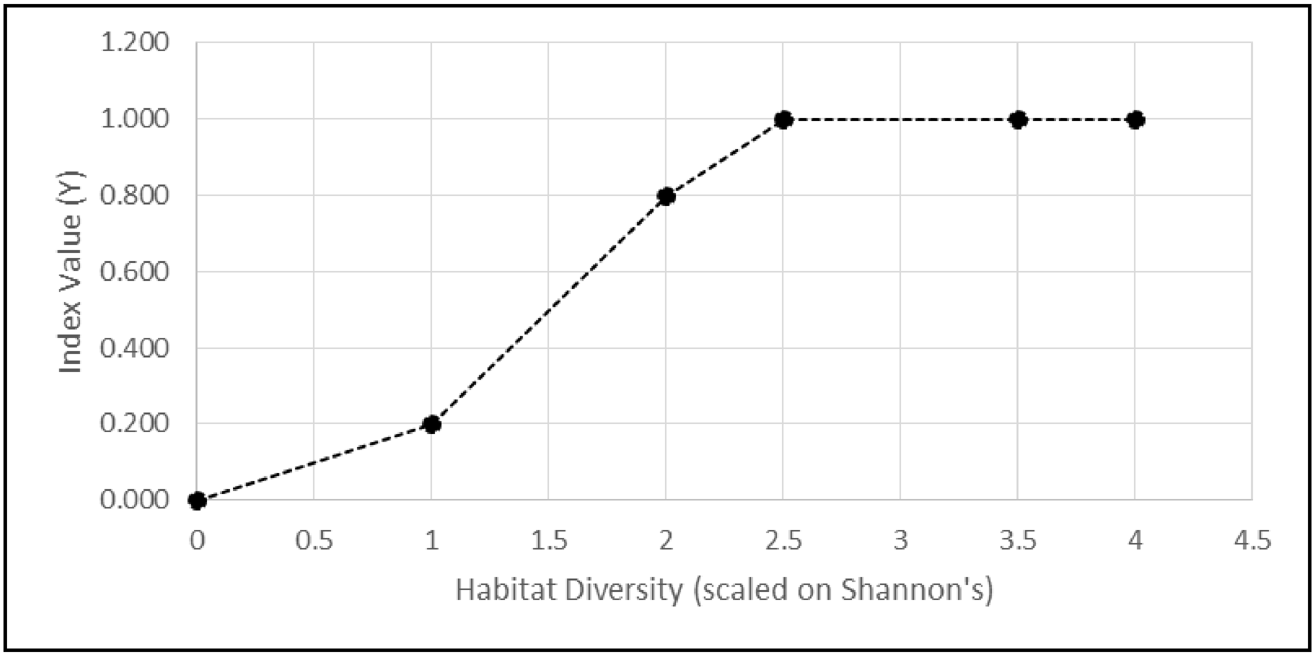

Figure 2. Channel Diversity Index Value Curve.

Channel Diversity can be assessed in the GSH model at the scale of a tributary, watershed, or estuary. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. Channel features were digitized from aerial imagery and Shannon's H was calculated for the APE. For the purposes of the Channel Diversity parameter, the Bateman Island causeway itself is not considered a habitat type. There were no forecasted changes to Channel Diversity in either the Future Without Project (FWOP) condition or via any of the proposed alternatives due to the regulation of the project area by McNary Dam, and this parameter was scored consistently across the range of alternatives.

References: Langler and Smith (2001), Rosenfeld, Porter, and Parkinson (2000), Anlauf-Dunn et al. (2014), Smorkorowski and Pratt (2007), Geist and Daubble (1998), Wippelhauser and Squiers (2015), and McMahon and Hartman (1989).

Pools, Riffles, Runs

Similar to the parameter pools-to-riffles ratio, this parameter quantifies the relationship of specific in-stream features (for example, pools) to the quality of anadromous fish habitat. The group decided that the most appropriate way to measure this parameter is to measure the amount of area each feature covers within a reach and calculate the ratio of area of features. As the ratio becomes more even, the quality of habitat increases, with a plateau in suitability at 0.5. This parameter was developed for the tributary reach scale and is not applicable to a river delta. It was not modeled here.

References: Rosenfeld (2014), Muhlfeld, Bennett and Marotz (2001), Bell, Duffy, and Roelofs (2001), and Roper et al. (1994).

Floodplain Features

Floodplains provide important habitat features for anadromous fish, especially salmonid species. Floodplain includes the following features: wall-based ponds, oxbows, wetlands, and others. Once floodplain features are destroyed through development or agriculture, they are lost as habitat. As a floodplain is restored, the number of different habitat features available increases, and the quality of habitat increases. The parameter is measured as a Shannon’s index of diversity (Figure 3). There is a positive relationship between the diversity of floodplain features and suitability of habitat.

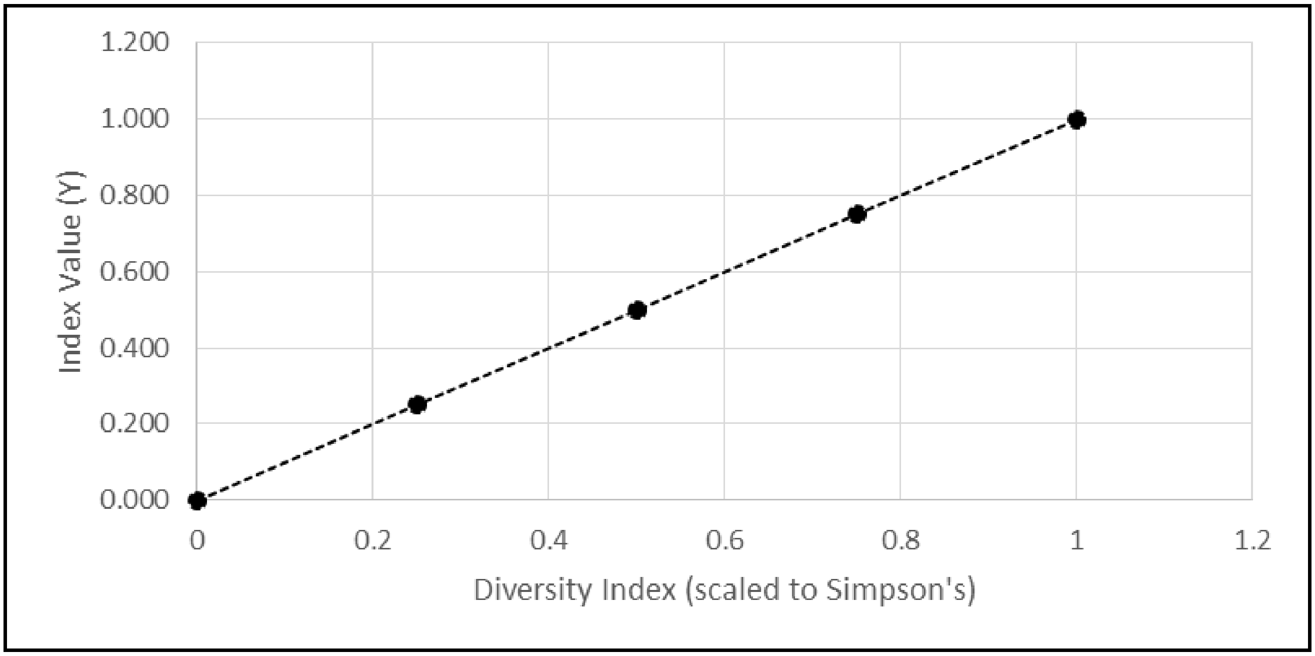

Figure 3. Floodplain Features Diversity Index Value Curve.

Floodplain features may be assessed in the GSH model at tributary, mainstem, or estuary scales, but the type, number, and evenness of floodplain features differ between landscape units. Mainstem floodplain features include small intermittent tributaries, ponds, lakes, various wetlands, natural levees, and natural upland edges. Tributaries contain oxbows, wall-based ponds, various wetlands, and natural upland ridges. Estuaries contain different various wetlands, tidal channels, panes, natural upland ridges, and tributaries.

For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. The APE is considered a mainstem for the purposes of the Project and the GSH model. Floodplain Features were digitized from aerial imagery and Shannon's H was calculated for the APE.

For the purposes of the Floodplain Features parameter, the Bateman Island causeway itself is not considered a habitat type. Floodplain Features in the proposed action area consist primarily of upland edges, small intermittent streams, and wetlands. There were no forecasted changes to Floodplain Features in either the FWOP condition or via any of the proposed alternatives due to the regulation of the project area by McNary Dam. Because the surface elevation of the delta and lower Yakima River is controlled by McNary Dam, the floodplain is rarely accessed, and is not subjected to substantial velocity when it is. As such the Floodplain Features are not subject to the intensity of flow that would be required to drive change in these characteristics, and this parameter was scored consistently across the range of alternatives. References: Branton and Richardson (2014), Beechie, et al. (2012), Roni et al. (2006), and Smokorowski and Pratt (2007).

Connectivity

Longitudinal connectivity

Longitudinal connectivity is the ability of an organism to access areas within a stream or river network (for example, watershed). Barriers to movement create disconnected habitat. Barriers to movement may manifest during different times (for example summer low flow) of the year. Longitudinal connectivity is a critical ecosystem component for anadromous species that need to access different habitat types within an aquatic network during different life stages and during different times of the year. As the percent of time increases for the ability of a species to access formerly disconnected habitat, the suitability of the aquatic network or system as a whole increases. The parameter is measured as the percentage of time that all habitat types are accessible (Figure 4).

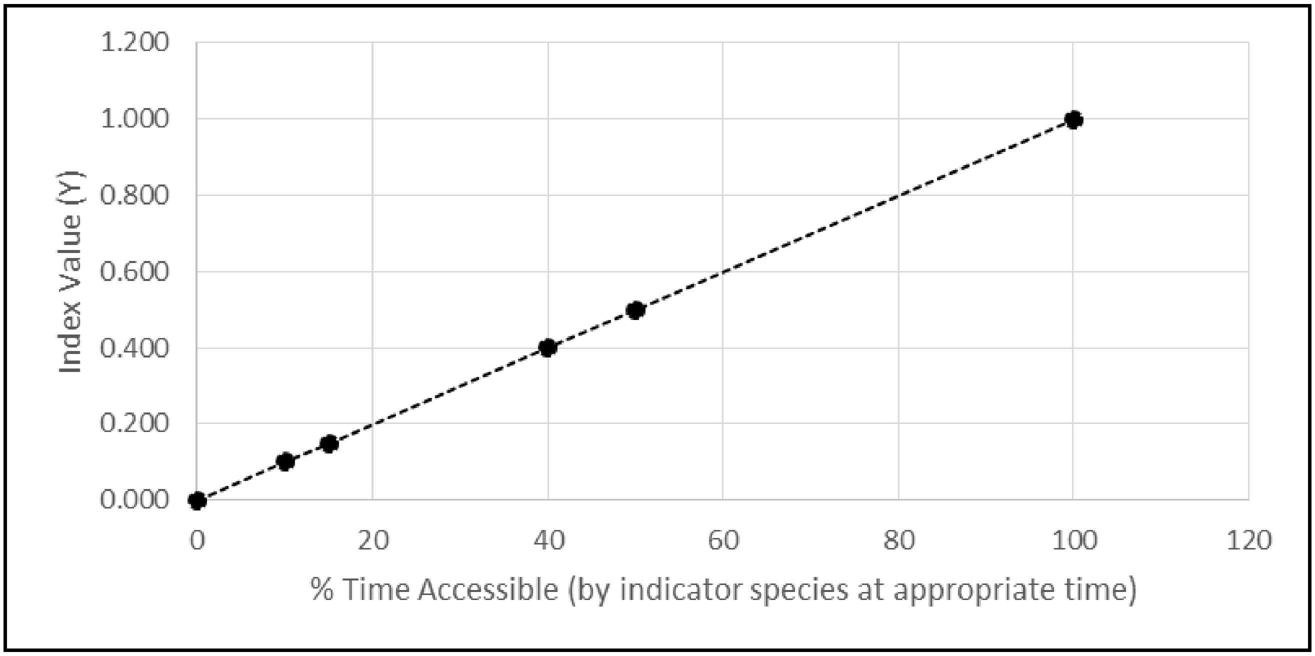

Figure 4. Lateral Connectivity Value Curve.

Lateral Connectivity may be assessed in the GSH model at tributary, mainstem, or estuary scales. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. There are no absolute physical barriers to passage in the Yakima Delta; the causeway blocks passage along the southern side of Bateman Island, but migrating salmonids are able to enter the Delta from the North side of the island. However, conditions created by the causeway result in extreme temperatures which prevent returning adult salmon and steelhead from entering the delta during the summer. To estimate Lateral Connectivity, USACE calculated the number of days per year that elevated temperatures in the Yakima Delta are so high that salmonids will not enter the Delta, or would be subject to severe injury if they did so. USACE used available water temperature data, literature-derived estimates, and professional judgement to estimate the number of days per year that thermal extremes to limit connectivity in the Yakima Delta.

The APE is considered a mainstem for the purposes of the Project and the GSH model.

References: Beechie, Beamer, and Wasserman (1994), Cote et al. (2009), and Buddendorf et al. (2017).

Lateral connectivity

Lateral connectivity is the ability of organisms to access habitat adjacent to stream and river reaches within floodplain and surge plain areas. Lateral connectivity is driven by river fluctuations that allow access to floodplain habitat during portions of the year. Lateral connectivity is impacted when barriers (for example, levees) no longer allow species to access floodplain habitat. This parameter was developed for the tributary reach scale and is not applicable to a river delta. It was not modeled here.

Edge-type landscape cover

The type and amount of vegetation that occur along the network of streams and rivers within a watershed is an important indicator of suitable habitat. As riparian vegetation is converted or lost due to human activities, there is an overall decrease in the quality of habitat. Additionally, in some areas non-native plant species have replaced native plant species. In some cases, the non-native plant species provide similar functions as native plant species. However, non-native species largely negatively impact the ecosystem function and structure that support suitable habitat.

In order to capture the changes from loss of overall edge cover and conversion of native species to non-native species, GSH model implements two measures of edge cover. Edge Cover 1 scores the quantity of vegetated cover in the riparian buffer area while Edge Cover 2 scores the composition of that cover. For both parameters the riparian buffer is measured from toe of bank to the high water level, which allows the measurement of the high water level to accommodate specifics of a project area Edge cover 1 is measured as a response curve exhibiting a mostly linear relationship with percent cover in the riparian buffer area and a plateau of suitability around 75% cover (Figure 5)

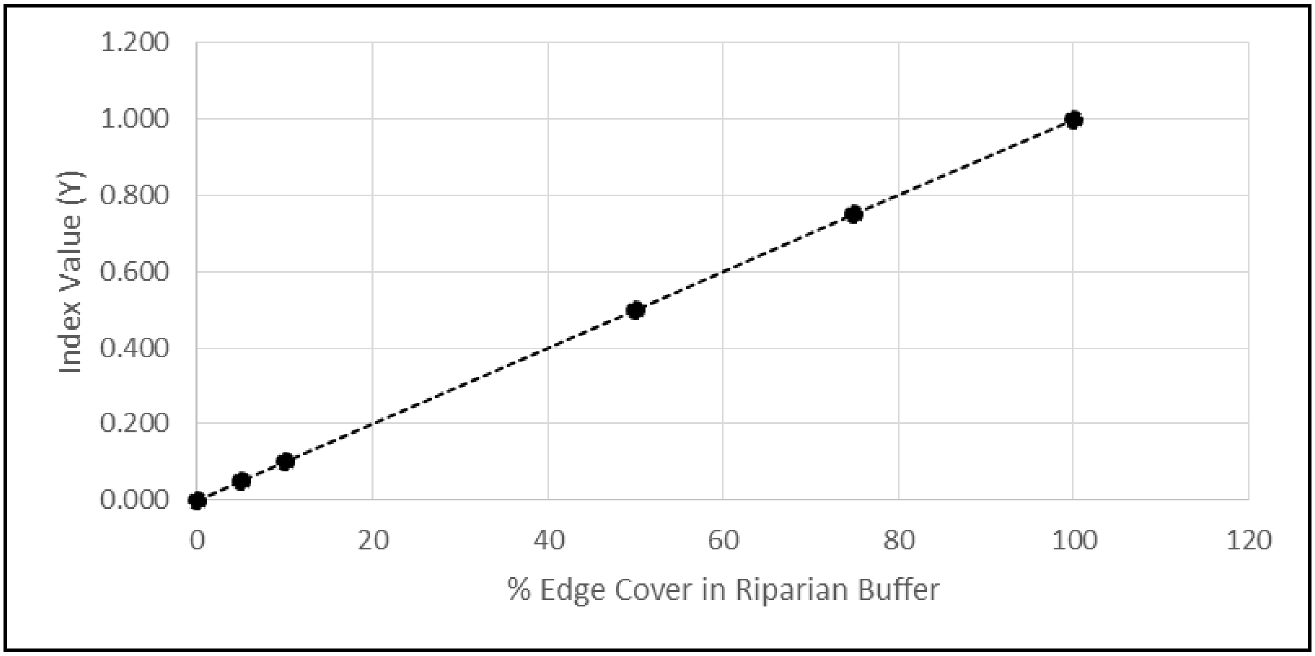

Figure 5. Percentage Edge Cover Value Curve.

Edge Cover 1 may be assessed in the GSH model at tributary, mainstem, or estuary scales, although the parameter evaluation does not change across scales. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. To score the parameter, the riparian buffer and visible cover were digitized from aerial imagery in GIS. For alternatives that included riparian planting, professional judgement was used to estimate that amount of cover in the planted areas and its persistence over the 50-year evaluation period. For alternatives that included a full or partial causeway breach, the (full or partial) causeway was removed from the edge cover analysis.

Edge cover 2 is scored as a response curve exhibiting a mostly linear relationship with percent native cover in the riparian buffer area and a plateau of suitability around 75% cover (Figure 6).

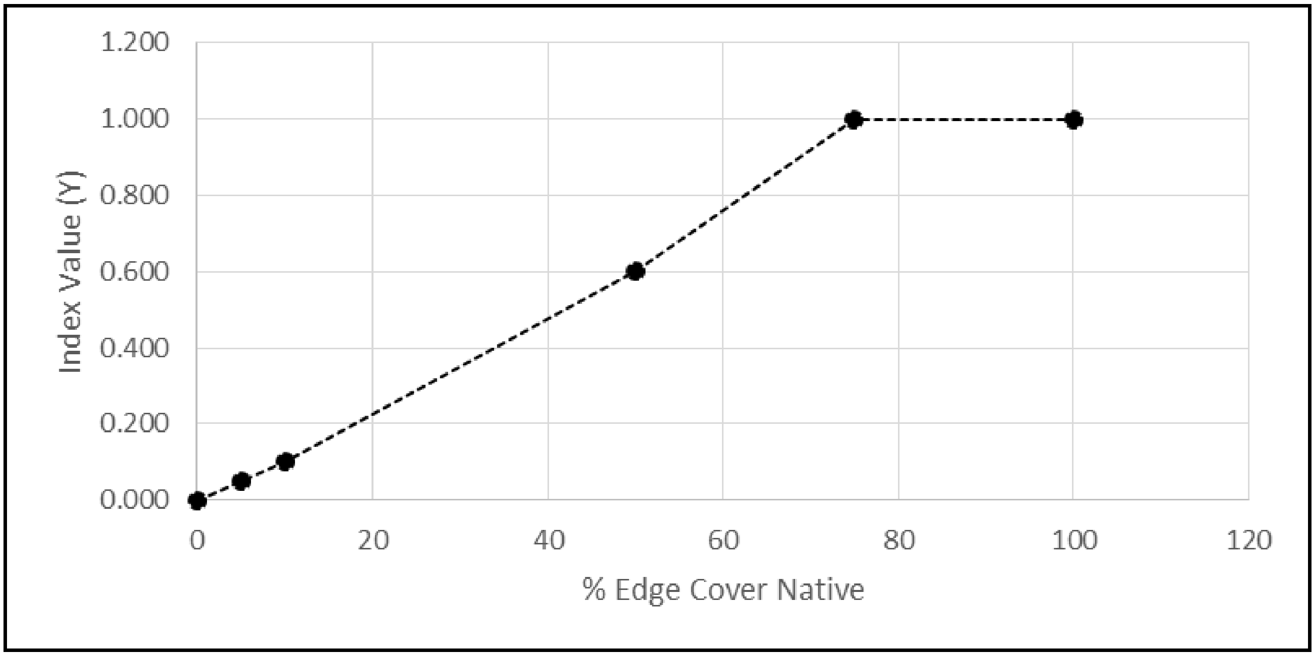

Figure 6. Percentage Native Cover Value Curve.

Edge Cover 2 may be assessed in the GSH model at tributary, mainstem, or estuary scales, although the parameter evaluation does not change across scales. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. To score the parameter, the composition of vegetation in the riparian buffer was assessed at multiple points during sites visits and then used to guide digitization of aerial imagery in GIS. For alternatives that included riparian planting, professional judgement was used to estimate that amount of native cover in the planted areas and its persistence over the 50-year evaluation period. For alternatives that included a full or partial causeway breach, the (full or partial) causeway was removed from the edge cover analysis.

References (edge cover 1 and 2): Burnett et al. (2007), Pess et al. (2012), Klimas and Yuill (2013), del Tanago and de Jalon (2006), Battin et al. (2007), Mellina and Hinch (2009), Wootton (2012).

Refuge cover

Woody Debris

Woody debris that falls or is washed into an aquatic system forms critical structures for anadromous fish species at different life stages and during different seasons. As the number of woody debris pieces or multiple piece jams are found within a reach, the quality of habitat for fish species. This parameter is measured by the number of pieces found within the bankful width of a reach at the scale of concern (tributary, mainstem, and estuary). There are different optimum number of pieces found within different landscape units (for example, tributary vs. mainstem), and they may differ between watersheds, according to research in Fox and Bolton (2007). After the optimal number of pieces are present within a reach at the scale of concern, any increase in the number of pieces does not increase suitability of habitat. Mainstem is measured as the number of pieces within the bankfull width along a kilometer of a reach (Figure 7).

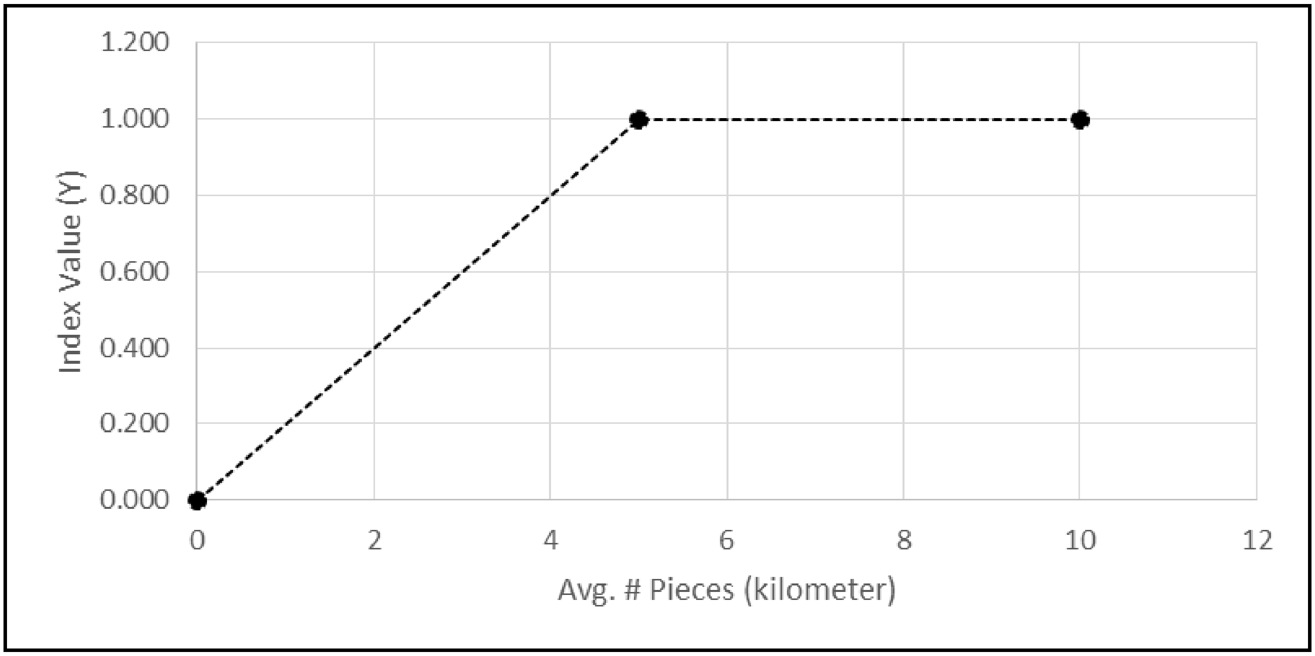

Figure 7. Woody Debris Value Curve.

For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole, assessed using the mainstem framework. To score the parameter, aerial imagery was used to identify woody debris in the channel. Due to the rapid loss in energy in the system upon reaching the delta, there is an abundance of woody debris in the Yakima Delta and therefore LWD parameter does not affect alternative selection.

References (woody debris 1–3): House and Boehne (1985), Smokorowski and Pratt (2007), Louhi et al. (2016), Beechie et al. (2012), Roni et al. (2010), Fox and Bolton (2007), and Mellina and Hinch (2009)

Substrate

Sediment

The parameter sediment refers to the sedimentation processes that form critical substrate for a variety of different life stages of anadromous fish species. Rather than measure substrate size directly, the GSH model measures a proxy of sediment transport processes that indicates suitable habitat. The ratio of accretion to erosion is indicative of a process that. forms and maintains critical substrate for different life stages of anadromous fish species. As the rate of accretion exceeds erosion, or erosion exceeds accretion, habitat suitability decreases. Sediment is measured as the ratio of accretion vs deposition within a reach (Figure 8).

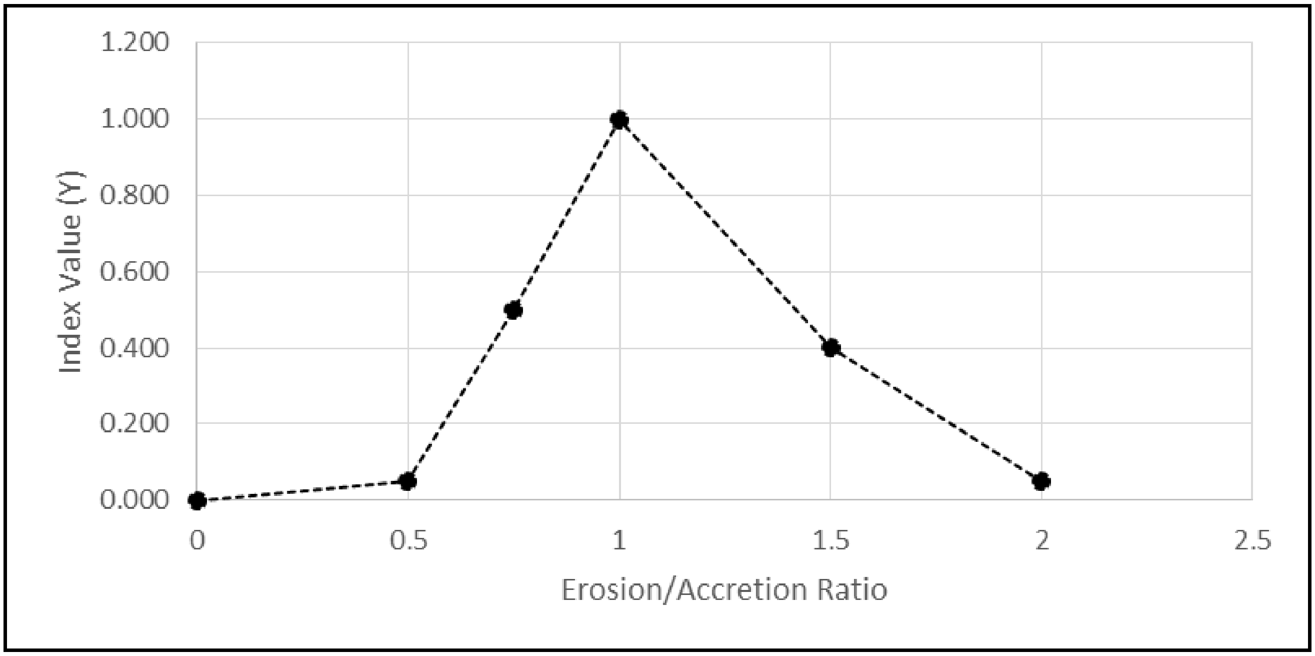

Figure 8. Sediment Value Curve

While the Sedimentation parameter is intended for use on the tributary scale, it was included in this evaluation to aid in capturing the sediment transport problems within the impounded Yakima Delta. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. To score the parameter hydrological models and professional judgement was used to estimate the effects of the alternatives on sediment transport.

References: Reiser and White (1988), Collins et al. (2014), and the National Oceanic and Atmospheric Administration (NOAA) Fisheries (2004).

Water

Temperature

High water temperatures (>25^{o}C) within the summer months are known to have adverse impacts on anadromous fish species, particularly salmonids. Water temperature is measured as a function of habitat suitability. Just one measure of temperature, such as mean daily summer temperature, would not capture all the possible scenarios of restoring water temperature to a more suitable range. Different life stages of fish species have different tolerances related to time of exposure, seasonality, and landscape unit type. In order to accommodate potential future restoration scenarios, the GSH model employs three different mathematical relationships for representing different aspects of how temperature is a function of habitat. In addition, each of the three curves was calibrated for west coast anadromous fish species.

General Temperature

General Temperature describes the general range of water temperature and its associated habitat suitability. As temperature increases for the WC, from the expected low of 15ºC to greater than 25ºC, the suitability of habitat decreases (Figure 9).

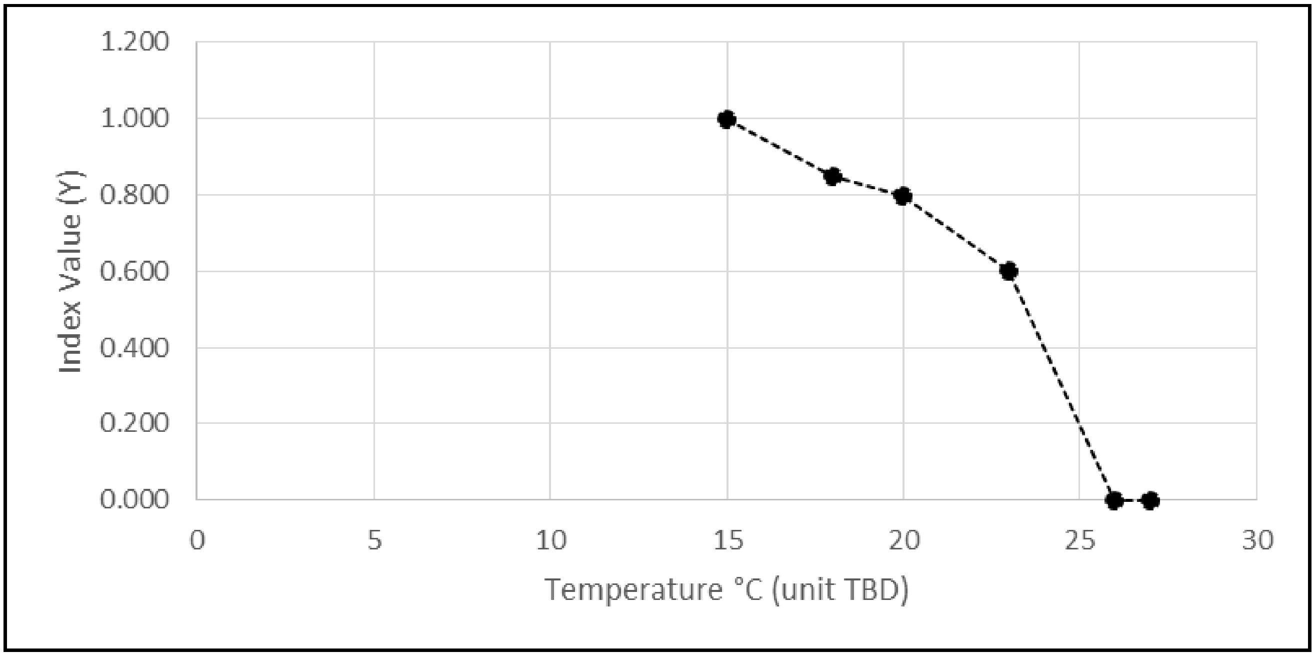

Figure 9. General Temperature Value Curve.

The way in which temperature is measured for each relationship (for example, mean annual temperature, mean daily temperature) is intentionally undescribed by the GSH model to allow for flexibility. For implementation in the Project, it was determined that the appropriate scale for evaluation was the area of potential affect (APE) as a whole. Parameter scoring was derived from hydrological models built to evaluate the alternatives and FWOP (see Appendix B. Hydrologic & Hydraulic Feasibility Assessment).

Bioenergetics Temperature

Bioenergetics Temperature describes the predicted performance of individuals in terms of successful migration, breeding, and rearing. There is an optimum range of bioenergetics that sits around 15ºC, and anything lower or higher is not as suitable (Figure 10).

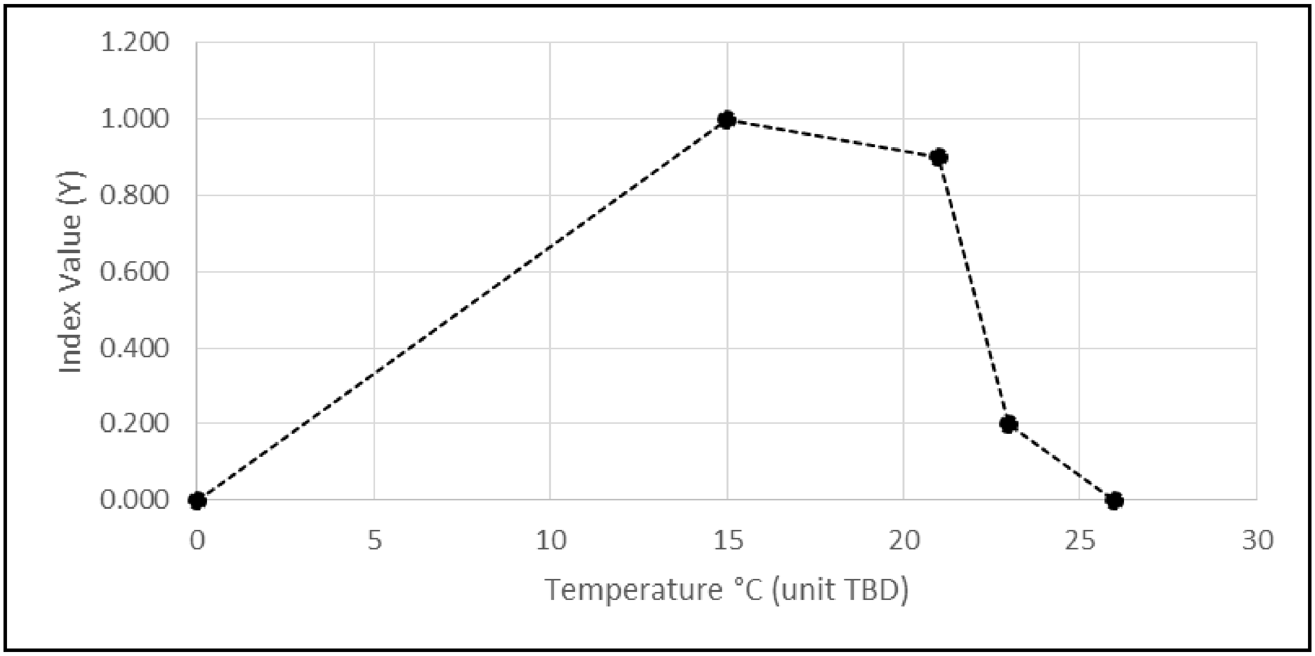

Figure 10. Bioenergetics Temperature Value Curve.

Parameter scoring was derived from hydrological models built to evaluate the alternatives and FWOP (see Appendix B. Hydrologic & Hydraulic Feasibility Assessment). To score Bioenergetics Temperature a “typical freshet condition” (June 16, 2012) was selected to model a two-dimensional temperature profile for the APE for each of the alternative conditions. This model was then sampled along a 25-meter mesh in GIS and the mean value calculated for the APE. The mean value was chosen to preserve the influence of outlying values.

Survival Temperature

Survival Temperature describes predictive survival ranges. West coast anadromous salmonids are expected to survive temperatures between 0°C to 25°C; anything greater than 25°C is considered lethal to most life stages and in most landscape units (Figure 11).

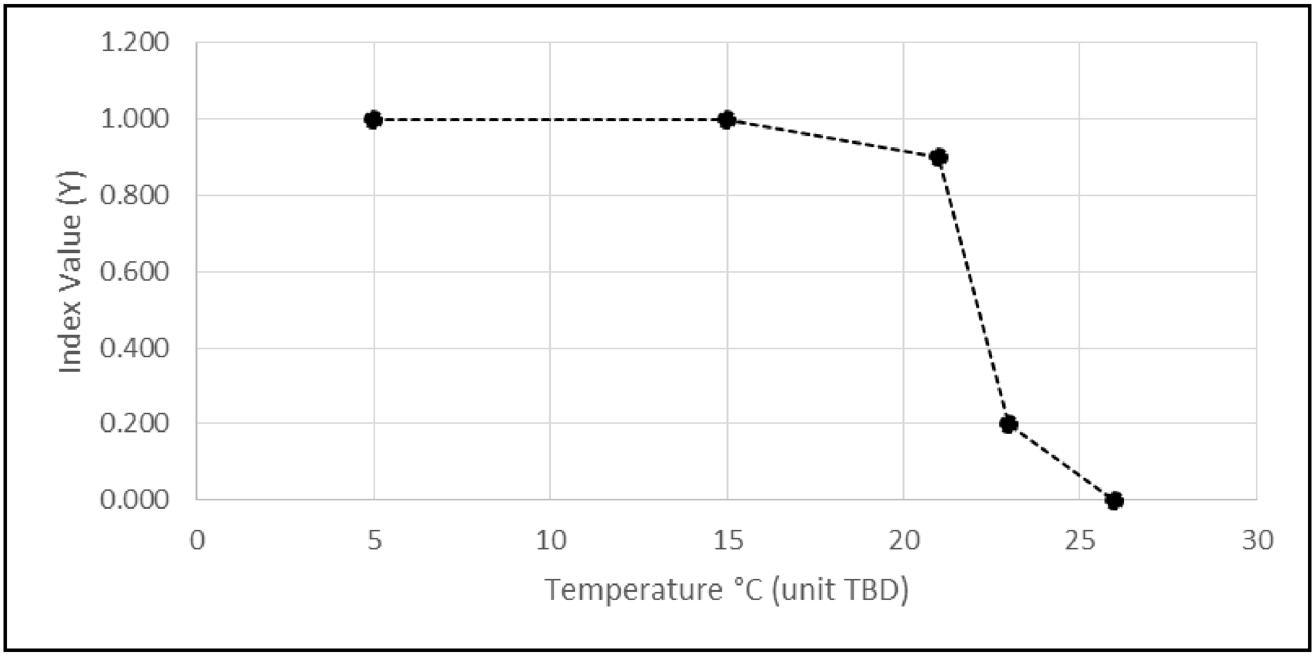

Figure 11. Survival Temperature Value Curve.

Parameter scoring was derived from hydrological models built to evaluate the alternatives and FWOP (see Appendix B. Hydrologic & Hydraulic Feasibility Assessment). To score Survival Temperature a “hot summer condition” (August 9, 2009) was selected to model a two-dimensional temperature profile for the APE for each of the alternative conditions. This model was then sampled along a 25-meter mesh in GIS and the mean value calculated for the APE. The mean value was chosen to preserve the influence of outlying values.

References (temperature 1–3 WC): Branton and Richardson (2014), Geist et al. (2006), Groves and Chandler (1999), Mellina and Hinch (2009), Honea et al. (2009), and Wootton (2012).

Model Scoring

The GSH model uses a geometric mean of all parameters to derive a cumulative HSI score. For this study, a total of 10 parameters were used, so the total score is the 10th root of the product of the ten parameters.

Or:

$$\boldsymbol{HSI} = \sqrt[10]{\boldsymbol{v1} * \boldsymbol{v2} * \boldsymbol{v3} * \boldsymbol{v4} * \boldsymbol{v5} * \boldsymbol{v6} * \boldsymbol{v7} * \boldsymbol{v8} * \boldsymbol{v9} * \boldsymbol{v10}}$$

A geometric mean lets the GSH model function as a limiting factor model at the extremes. This is because if any individual parameter has a value of zero, then the product of all the parameter values must also be zero. Therefore, if any of the GSH model parameters are entirely outside the range of suitable for salmonids, then the entire APE is unsuitable.

Capabilities and Limitations of Models

The GSH model poses no apparent limitations in relevance and ability to capture holistic present and future site conditions, but there are several clear limitations that affect the representation of project-level benefits and quality control.

- The GSH model overall sensitivity to minor changes in parameter scoring are lost among the myriad variables and calculation weighing. This is especially true with this Project in that the survival temperature parameters scores at or near zero for multiple alternatives. This is perfectly acceptable in the context of biological condition and relevance but plays a more significant role in the cost effective/incremental cost analysis modeling to identify best-buy and cost-effective plans.
  We did not find this to be problematic for this study due to the acknowledged outsized role temperature plays in the Yakima Delta. However, this model may not be suitable for projects with multiple stressors or low scoring variables, such that improving one variable could make notable improvements to the habitat that may not be captured due to a consistent low score in another variable.
- This model does not project changes in population numbers of any life stage or species. The model captures changes in the ecosystem as result of USACE activities. Also, it does not project absolute system changes but rather relative differences between proposed restoration alternative actions. While this allows easy ranking of alternatives, it may not be telling us much about the system independent of planning outcomes.
- The GSH model is designed to work well with remotely sensed parameters and aerial imagery. This is convenient for staff and minimizing field time is an important concern in CAP level studies. This may not be able to substitute for careful on-site documentation of habitat parameters.
- The GSH model looks at all juvenile habitat as rearing habitat, not migratory habitat, so may be ill suited to environments with severe but localized impairment. Ultimately juvenile salmon are effectively “rearing” during their entire outmigration, but do not persist in all habitats for similar time periods. Alternatives that, for example, help to quickly move outmigrating salmonids to nearby habitats that may be more suitable but do not notably improve model parameters, would score poorly.
- The GSH model does not capture predation, which is possibly the most significant threat to juvenile salmon in the Yakima Delta. While high scored location should contain habitat parameters that favor salmonids, in an altered system with numerous introduced predators, it is likely that those same conditions may be at least somewhat suitable to one of those predators. For example, reducing stream temperatures below those favored by smallmouth bass may make the aquatic environment more favorable to walleye.

Generally, a major assumption of habitat suitability modelling is that there is a linear relationship between the HSI and either carrying capacity for a species or an observed preference/requirement for a specific habitat feature. When developing specific HSI models it is necessary to define varying qualities of habitat (i.e., optimum, good, fair, poor) based on observed relationships in the literature. For example, if shoreline seining efforts result in most observations of juvenile Chinook salmon rearing over mixed gravel, cobble, and boulder substrates relative to silty substrates, then substrates characterized by a mix of stone sizes are assumed to provide optimal rearing habitat, and thus yield a high index score (in the range of 0.8 to 1.0). Substrates of smaller particle size are assumed to be less suitable and yield lower index scores. Specific limitations have been observed in the use of HSIs and include: 1) many of the developed models have not been tested sufficiently to match observed “preferred” habitats by the various species or to match species experts’ knowledge of optimal habitat; 2) high values generated from the HSIs do not necessarily match observed higher species diversity or abundance than sites with lower values; 3) difficulty in collecting sufficient data to use the models (particularly when models have numerous variables); 4) use of one species model to represent suitability for wider guilds or assemblages may not accurately represent those other species; and 5) lack of variables that describe landscape scale effects on species diversity and abundance (O’Neil, et al. 1988; Wakeley 1988; Barry et al. 2006).

Another limitation in the use of ecological models is that other factors beyond the specific parameters evaluated in the models could have greater effects on populations. Examples could be infectious diseases that could wipe out a localized population, climate change effects on temperatures and hydrology, and invasive species. These are important considerations for the success of any habitat restoration project, and while not amenable to analysis in this proposed model, they should be considered by the project team during design development and implementation. Specifically:

- *Climate change:* Although Earth’s climate is clearly changing (IPCC 2014), insufficient data exists to accurately predict the effects this process will have on parameters that directly affect salmonid species whose life stages were used to prepare this model. Increasing atmospheric temperature may cause warmer water temperature, higher base flows in the winter and spring and lower base flows in the summer and fall. Although this same lack of data means that the effects of climate change cannot be measured in the HSI models, long-term monitoring and adaptive management strategies can be developed to measure these effects and respond to them effectively.

Model variable input values for the Future with project (FWP) conditions are generally speculated based on the expected outcome of restoration actions.

Identification of Formulas and Appropriate Calculation

All equations and SIs used in the HSI models are specifically stated and described above. Calculations were made in standard GIS (ESRI ArcGIS) or spreadsheet software (Microsoft Excel). The models are completely transparent, and all assumptions can be verified.

Availability of Inputs

Input data used for this model was collected from onsite field observations and from the use of aerial photography and GIS data. Inputs to the GSH model are described in Table 2.

Table 2. Model Inputs and Approach

Parameter	**Source**	**Approach**
Channel	1-meter National Agricultural Imagery Program (NAIP) Orthoimagery captured 30 July 2019 and 16 July 2017	Channel features were hand digitized, and Shannon's H calculated in GIS
Floodplain Features	1-meter NAIP Orthoimagery captured 30 July 2020 and 17 July 2017	Floodplain features were hand digitized, and Shannon's H calculated in GIS
Longitudinal Connectivity	USACE hydrologic models	The number of days with average water temperature in the Delta above 25 degrees C per year was estimated using professional judgment from existing annual thermal profiles and future conditions modeled by USACE hydrologist
Edge Cover (1)	1-meter NAIP Orthoimagery captured 30 July 2020 and 17 July 2017	The riparian buffer zone and vegetated areas within that buffer were hand digitized from NAIP orthoimagery. Cover was calculated as area vegetated divided by total riparian buffer area.
Edge Cover (2)	1-meter NAIP Orthoimagery captured 30 July 2020 and 17 July 2018	Vegetated areas were hand digitized as native or invasive based on NAIP orthoimagery and surveys collected during site visits.
Woody Debris Mainstem (2)	1-meter NAIP Orthoimagery captured 30 July 2020 and 17 July 2019	Large woody debris was hand digitized from NAIP orthoimagery.
Sediment	Professional judgement	Sediment deposition was estimated using professional judgement and knowledge of both present and expected future hydrological conditions within the Delta.
General Temperature (1) WC	USACE hydrologic models	General temperature was estimated from existing conditions and USACE hydrologic models, for "typical" conditions outside spring freshet and late summer.
Bioenergetics Temperature (2)	USACE hydrologic models	Bioenergetics Temperature was modeled by USACE hydrologist as a typical freshet condition.
Survival Temperature (3) WC	USACE hydrologic models	Survival temperature was modeled by USACE hydrologist as a typical hot day in late summer.

RESULTS

The GSH model was calculated for the proposed Project, both for existing and future conditions and for each Alternative. The GSH model was scored for conditions at 50 years With-Project (project life span). The HSI scores were then used to calculate Habitat Units (HUs). The HUs were then summed and compared to the FWOP condition to produce an overall net benefit (Average Annual Habitat Units or AAHUs) to compare FWP and FWOP conditions suitable for use in a CE/ICA (as follows).

Data → HSI → HUs → AAHUs

The CE/ICA evaluated the HU benefits for the full range of project measures and alternatives. The following assumptions were made when scoring each variable for FWP and FWOP conditions, the following assumptions were made presently and at 50 years.

FWOP Assumptions

- *Structure:* The structure and diversity of habitat types in the channel would remain similar to existing conditions. Although rivers are dynamic ecosystems, the hydrologic regime of the Yakima Delta is controlled by impounding conditions created by McNary Dam and the Bateman Island causeway. The river processes that create and change channel structures and habitats are largely muted in this impounded system. Therefore, it is assumed that the channel structure would not change significantly within 50 years.
- *Connectivity:* There are no absolute existing physical barriers to longitudinal connectivity in the Yakima Delta and none are likely to be constructed in the next 50 years. Current barriers to passage are driven by extreme summertime temperatures generated by impounded Yakima River flows and poor mixing with cooler Columbia River water in the delta. These conditions are not expected to change, and therefore Connectivity parameters would be expected to remain stable over the next 50 years.
- *Refuge Cover (LWD):* LWD accumulation is expected to remain similar to existing conditions. Lack of flow within the delta is assumed to be unable to flush accumulated LWD into the mainstem Columbia River. Although additional woody debris may accumulate over the projected time period, adequate LWD already exists within the system to optimally support salmonids. A net loss of woody debris would not be expected.
- *Substrate*: River deltas are inherently depositional areas. This tendency is exaggerated in the Yakima Delta due to the presence of McNary Dam and the Bateman Island causeway. The dam impounds the river and saps flow velocity required to flush sediments while causeway inhibits mixing with Columbia River flows in the delta. It is assumed the sediment would continue to accrete in the delta over the next 50 years.
- *Water Temperature:* The water temperature in the delta is controlled by the incoming temperature of the Yakima River and the degree of mixing with the cooler Columbia River in the delta. It is assumed that conditions in the mainstem Yakima and Columbia Rivers would continue to warm gradually in the summer low flow periods over the next 50 years, but this does not affect the model scoring as Survival Temperature (summer, low flow conditions) is well above the threshold of a 0 score in the GSH model at existing conditions.

FWP Assumptions

- *Structure:* The structure and diversity of habitat types in the channel would remain similar to existing conditions. Even with the causeway removed and improved mixing with the delta, impoundment of the river by McNary Dam would limit the sort of high energy flows required to create new channel structure or habitat types. Therefore, it is assumed that the channel structure would not change significantly within 50 years.
- *Connectivity:* There are no existing absolute physical barriers to longitudinal connectivity in the Yakima Delta and none are likely to be constructed in the next 50 years. Current barriers to passage are driven by extreme summertime temperatures generated by impounded Yakima River flows and poor mixing with cooler Columbia River water in the delta. USACE hydrological models indicate that with the removal of at least half of the Bateman Island causeway, mixing within the delta would be sufficient to prevent thermal passage barriers to adult migration. The cooling is driven by cool Columbia River water, it is assumed that the Columbia River would not warm notably over the next 50 years.
- *Refuge Cover (LWD):* LWD accumulation is expected to remain similar to existing conditions. Lack of flow within the delta is assumed to be unable to flush accumulated LWD into the mainstem Columbia River. An increase of mixing with the Columbia River may create conditions to promote the movement of LWD out of the delta, although most mixing would occur along Bateman Island. Presently the delta contains significantly more LWD than is required for an optimal score in the GSH model. It is assumed, that even if greater LWD transport were to occur, it would not be so great as to strip debris from the system.
- *Substrate*: River deltas are inherently depositional areas. This tendency is exaggerated in the Yakima Delta due to the presence of McNary Dam and the Bateman Island causeway. The dam impounds the river and saps flow velocity required to flush sediments while causeway inhibits mixing with Columbia River flows in the delta. It is assumed that there will be an initial flush of accumulated sediments following the breach of the causeway. This would likely lead to a system that is rapidly losing sediment over the first year following the breach. Following the initial flush, it is assumed that the system would return to a more stable, but still depositional state.
- *Water Temperature:* The water temperature in the delta is controlled by the incoming temperature of the Yakima River and the degree of mixing with the cooler Columbia River in the delta. USACE hydrological models indicate that with the removal of at least half of the Bateman Island causeway, mixing within the delta would be sufficient to lower water temperature in the causeway. It is assumed that conditions in the mainstem Yakima and Columbia Rivers would continue to warm gradually in the summer low flow periods over the next 50 years.

Existing and Future Habitat Conditions

Habitat data were used to derive GSH model scores for the Yakima Delta. Table 3 summarizes the scoring for the FWOP and Table 4 summarizes the scoring for the TSP. For each year, the “data” column is the raw score calculated from the inputs described in Table 2. The HSI column indicates the value derived from that raw score via the curves illustrated in the model description section above. The Overall HSI row is the geometric mean of the individual HSI values, and the Quantity row indicates the area over which the model is scored, 360.4 acres. The output is HUs by Year for the year 0, 1, 5, 10, 25, and 50 conditions. These can then be annualized to AAHUs. The highest possible index score of 1 indicates the best possible conditions for each parameter. Scores ≥ 0.7 indicate good to excellent quality for that parameter. Parameters with scores approaching 0 are not considered to have suitable habitat for the salmonid species. It was assumed that the Without-Project future condition would reflect the existing condition and remain virtually unchanged with slight variation within the parameters on an immeasurable level relative to the present.

Table 3. HSI Scores and Habitat Units for the FWOP.

	Year	0	Year	1	Year	5	Year	10	Year	25	Year	50
Description	Data	HSI	Data	HSI	Data	HSI	Data	HSI	Data	HSI	Data	HSI
Channel	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42
Floodplain	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Longitudinal Con	76	0.76	76	0.76	76	0.76	76	0.76	76	0.76	76	0.76
Edge Cover 1	35	0.35	35	0.35	35	0.35	35	0.35	35	0.35	35	0.35
Edge Cover 2	56	0.70	56	0.70	56	0.70	56	0.70	56	0.70	56	0.70
Woody Debris	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00
Sediment	1.5	0.40	1.5	0.40	1.5	0.40	1.5	0.40	1.5	0.40	1.5	0.40
General T	20	0.80	20	0.80	20	0.80	20	0.80	20	0.80	20	0.80
Bioenergetics T	14.1	0.94	14.1	0.94	14.1	0.94	14.1	0.94	14.1	0.94	14.1	0.94
Survival T	25.5	0.03	25.5	0.03	25.5	0.03	25.5	0.03	25.5	0.03	25.5	0.03
Overall HSI		**0.47**		**0.47**		**0.47**		**0.47**		**0.47**		**0.47**
Quantity	360.4		360.4		360.4		360.4		360.4		360.4	
HUs by Year		168.9		168.9		168.9		168.9		168.9		168.9

Habitat units were derived by multiplying the overall HSI scores by the area of habitat that may be affected by each Project alternative. The area of habitat was determined by estimating aquatic habitat within the delta. For this study, the APE was the permanently wetted waters within the delta from the Highway 240 bridge to a line drawn from Columbia Point to Bateman Island and from Bateman Island to the shore, a total of 360.4 acres.

Table 4. HSI Scores and Habitat Units for the Tentatively Selected Plan.

	Year	0	Year	1	Year	5	Year	10	Year	25	Year	50
Description	Data	HSI	Data	HSI	Data	HSI	Data	HSI	Data	HSI	Data	HSI
Channel	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42	1.37	0.42
Floodplain	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Longitudinal Con	76	0.76	95	0.95	95	0.95	95	0.95	95	0.95	95	0.95
Edge Cover 1	35	0.35	37	0.37	37	0.37	37	0.37	37	0.37	37	0.37
Edge Cover 2	56	0.70	58	0.73	58	0.73	58	0.73	58	0.73	58	0.73
Woody Debris	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00
Sediment	1.5	0.40	0.5	0.05	1.1	0.88	1.1	0.88	1.1	0.88	1.1	0.88
General T	20	0.80	20	0.80	20	0.80	20	0.80	20	0.80	20	0.80
Bioenergetics T	14.1	0.94	14.8	0.99	14.8	0.99	14.8	0.99	14.8	0.99	14.8	0.99
Survival T	25.5	0.03	23.4	0.17	23.4	0.17	23.4	0.17	23.4	0.17	23.5	0.16
Overall HSI		**0.47**		**0.47**		**0.63**		**0.63**		**0.63**		**0.63**
Quantity	360.4		360.4		360.4		360.4		360.4		360.4	
HUs by Year		168.91		169.79		226.18		226.18		226.18		225.27

In addition to the FWOP and the Proposed Project Condition, several other alternatives and measures were evaluated in the GSH model. Table 5 presents the total amount of HUs available to salmonids under each measure, as calculated using the GSH model. Table 6 present the marginal HUs (or additional HUs above the baseline condition which are created by the measure) available to salmonids under each measure, as calculated using the GSH model. For each measure net average annual habitat units were calculated by subtracting the existing condition AAHU from the FWP measure AAHU. Complete descriptions of the measures and alternatives are found in the main body of the Feasibility Report with Integrated Environmental Assessment.

Table 5. Habitat Units for Measures Evaluated with the GSH Model.

Measure	Year 0	Year 1	Year 5	Year 10	Year 25	Year 50	AAHU
Existing Condition (No Action)	168.9	168.9	168.9	168.9	168.9	168.9	168.9
Partial Breach (Alt 3b)	168.9	168.9	221.8	221.8	221.8	220.9	218.4
Full Breach (Alt 3a – TSP)	168.9	169.8	226.2	226.2	226.2	225.3	222.6
Partial Breach + All Riparian (Alt 2b)	168.9	173.3	227.3	226.7	226.2	225.3	222.9
Full Breach + All Riparian (Alt 2a)	168.9	173.4	231.2	231.2	231.2	229.6	227.1
In-stream Structures	168.9	150.4	150.4	150.4	150.4	150.4	150.6
Riparian 1 + Partial Breach	168.9	169.8	222.9	222.9	222.9	222.0	219.5
Riparian 2 + Partial Breach	168.9	170.6	224.0	224.0	224.0	223.1	220.5
Riparian 3 + Partial Breach	168.9	169.8	222.9	222.3	221.8	220.9	218.6
Riparian 4 + Partial Breach	168.9	169.8	222.9	222.9	222.9	222.0	219.5
Riparian 1 + Full Breach	168.9	170.6	227.3	227.3	227.3	226.4	223.6
Riparian 2 + Full Breach	168.9	171.4	228.4	228.4	228.4	227.4	224.7
Riparian 3 + Full Breach	168.9	170.2	226.8	226.8	226.8	225.3	223.0
Riparian 4 + Full Breach	168.9	170.6	227.3	227.3	227.3	226.4	223.6

Table 6. Marginal Habitat Units for Measures Evaluated with the GSH Model.

Measure	Year 0	Year 1	Year 5	Year 10	Year 25	Year 50	Net AAHU
Existing Con (No Action)	0.0	0.0	0.0	0.0	0.0	0.0	-
Partial Breach (Alt 3b)	0.0	0.0	52.9	52.9	52.9	52.0	49.5
Full Breach (Alt 3a – TSP)	0.0	0.9	57.3	57.3	57.3	56.4	53.6
Partial Breach + All Riparian (Alt 2b)	0.0	4.4	58.4	57.8	57.3	56.4	54
Full Breach + All Riparian (Alt 2a)	0.0	4.5	62.2	62.2	62.2	60.5	58.5
In-stream Structures	0.0	(18.5)	(18.5)	(18.5)	(18.5)	(18.5)	(18.3)
Riparian 1 + Partial Breach	0.0	0.9	54.0	54.0	54.0	53.1	50.6
Riparian 2 + Partial Breach	0.0	1.7	55.1	55.1	55.1	54.2	51.6
Riparian 3 + Partial Breach	0.0	0.9	54.0	53.4	52.9	52.0	49.7
Riparian 4 + Partial Breach	0.0	0.9	54.0	54.0	54.0	53.1	50.6
Riparian 1 + Full Breach	0.0	1.7	58.4	58.4	58.4	57.4	54.7
Riparian 2 + Full Breach	0.0	2.5	59.4	59.4	59.4	58.5	55.8
Riparian 3 + Full Breach	0.0	1.3	57.9	57.9	57.9	56.4	54.1
Riparian 4 + Full Breach	0.0	1.7	58.4	58.4	58.4	57.4	54.7

Model-Based Project Selection

Aquatic net AAHUs derived from the GSH model scores for the FWP condition estimated for each measure within Yakima Delta were used to perform cost effectiveness and incremental cost analysis (CE/ICA) using IWR Planning Suite (IWR), version 2.0.9. The CE/ICA analysis evaluated 29 possible combinations of measures. Of these, 20 plans, including the No Action Alternative, were identified as cost effective. The incremental cost analysis identified six plans as “Best Buy” plans, defined as those cost-effective plans that provide the greatest incremental increase in benefits for the lowest incremental increase in cost (Figure 12).

The USACE objective in ecosystem restoration planning is to contribute to the national ecosystem restoration (NER) plan. Contributions to the NER plan (outputs) are increases in the net quantity and/or quality of desired ecosystem resources. The NER plan must reasonably maximize ecosystem restoration benefits compared to costs, consistent with the Federal objective. The selected plan must be shown to be cost effective and justified to achieve the desired level of output. In addition to the NER account, the plan that also maximizes benefits for social, environmental, and economic considerations should be identified. This plan is referred to as Comprehensive Benefits Plan.

The evaluation and comparison of alternatives led the PDT to recommend Alternative 3a - Full Breach without Riparian Restoration as the Tentatively Selected Plan (TSP) as well as the National Ecosystem Restoration (NER) plan and the Comprehensive Benefits Plan. This alternative maximizes the study objectives and habitat benefits while still maintaining efficiency and effectiveness. This plan also provides cohesion to the local tribal community, as well as employment from the construction (Refer to Section 5 of feasibility report with integrated environmental assessment for more information).

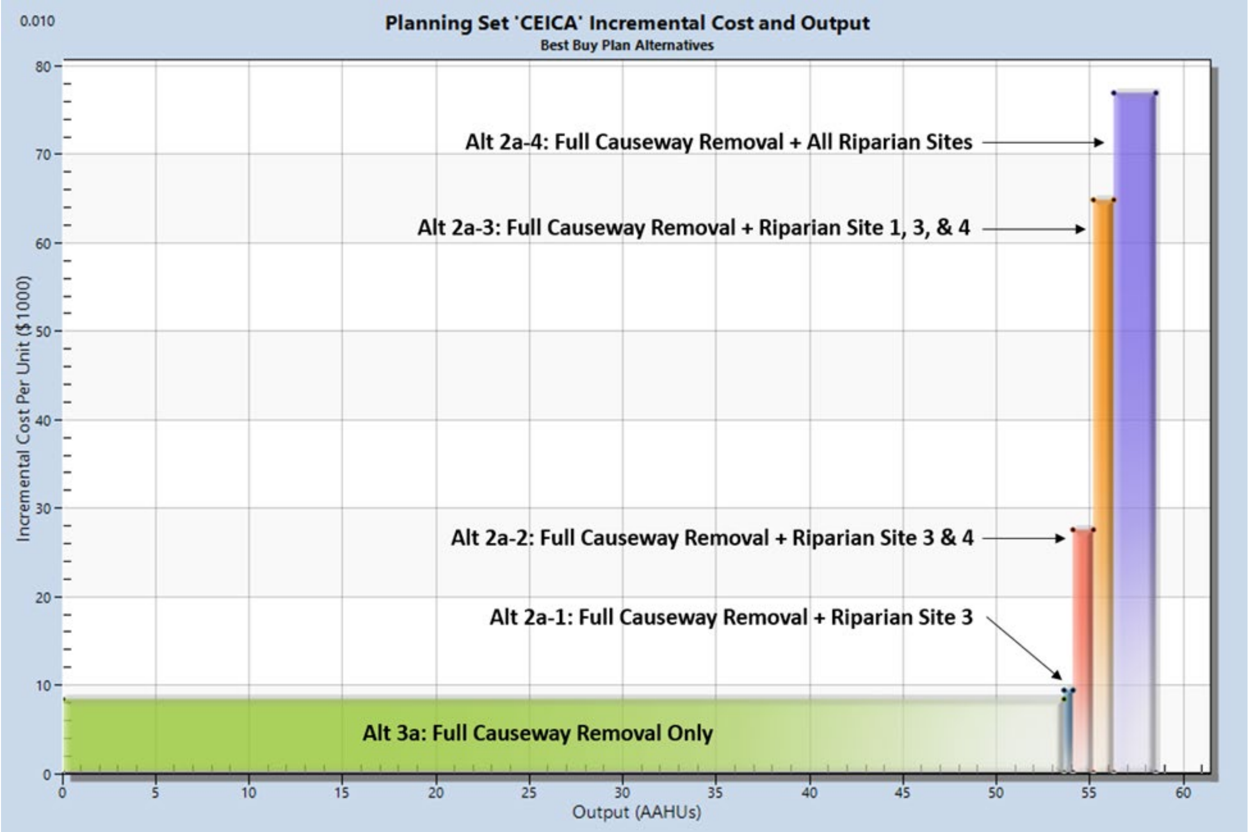

Figure 12. Cost Effectiveness/Incremental Cost Analysis Results.

CONCLUSIONS

Model results suggest that implementation of the proposed Project would restore ecological habitat function for salmonids within Yakima Delta. Use of the HUs calculated through the GSH model to populate the CE/ICA suggests that the proposed Project is a “best buy”, meaning we are proposing a cost-effective ecosystem restoration plan capable of producing a satisfactory outcome for salmonid species. Therefore, our Project removing the Bateman Island causeway will lead to the restored function of aquatic habitat that may be utilized by all species of migrating salmonids.

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