WILLAMETTE RIVER FLOODPLAIN RESTORATION STUDY
FLOODPLAIN HABITAT INDEX

PLANNING MODELS DOCUMENTATION

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1. PURPOSE

The purpose of this multi-species floodplain restoration habitat index is to evaluate the potential ecological benefits of restoring and reconnecting floodplain areas along the Willamette River in Oregon. Specifically, the index and its components will address the extent to which floodplain restoration will benefit multiple key fish and wildlife species. The index is comprised of multiple species Habitat Suitability Indices (HSIs) within the Habitat Evaluation Procedures (HEP) framework developed by the U.S. Fish and Wildlife Service (USFWS 1980).

The index will be used for the Willamette River Floodplain Study being conducted by the U.S. Army Corps of Engineers, Portland District and its local sponsors, the Willamette Partnership, the Nature Conservancy, the Coast Fork Willamette Watershed Council and the Middle Fork Willamette Watershed Council. There are several federal authorities for the Willamette River Floodplain Restoration Study.

- Section 202 of the Water Resources Development Act of 2002 (P.L. 106-541, 11 December 2000). Titled "Watershed and River Basin Assessments". Section 202 amended Section 729 of the Water Resources Development Act of 1986 (100 Stat. 4164), authorizing the Secretary of the Army to assess the water resources needs of river basins and watersheds of the United States, including needs relating to: (1) ecosystem protection and restoration; (2) flood damage reduction; (3) navigation and ports; (4) watershed protection; (5) water supply; and (6) drought preparedness.
- The Senate Committee on Public Works resolution for the Willamette River Basin Comprehensive Study, adopted November 15, 1961, authorized the Chief of Engineers to determine "…whether any modification of the existing project is advisable at the present time, with particular reference to providing additional improvements for flood control, navigation, hydroelectric power development, and other purposes, coordinated with related land resources, on the Willamette River and Tributaries, Oregon."
- House Committee on Public Works resolution for the Willamette Basin Review Study, adopted September 8, 1988, authorized the Chief of Engineers to determine "…whether modifications to the existing projects are warranted and determine the need for further improvements within the Willamette River Basin (the Basin) in the interest of water resources improvements."

Floodplain habitats have been significantly reduced and degraded along the Willamette River since Euro American settlement began (Hulse 2002). Floodplains have been modified for agricultural, industrial, residential and urban land uses and the natural hydrology of various tributaries has been significantly changed as a result of the construction and operation of federal and non-federal dams. The Willamette River no longer experiences frequent peak events that form and sustain in-channel, off-channel, and floodplain habitats.

2. BACKGROUND

Initial planning for a comprehensive ecological response model was discussed in several previous reports for this study including the *Willamette River Basin Floodplain Restoration Feasibility Study Ecological Response Model Recommendations* (Primozich, *et al*. 2004); *An Approach for Synthesis of Willamette Floodplain Aquatic and Terrestrial Attributes* (McConnaha, *et al*. 2005); and the *Analysis of the Potential Benefits of Floodplain Habitats in the Middle Fork Willamette River Using Geomorphic Splice Analysis* (McConnaha, *et al*. 2006). These previous reports defined functions that floodplains provide and included the use of expert panels to recommend the types of indicators that could be used to represent those functions. It was recommended that indicators of geomorphic functions, terrestrial and aquatic habitats be used in the model to provide a comprehensive evaluation of the potential benefits that could be gained by restoring floodplain habitats. Indicators are fish and wildlife species, plant communities, or functions. Indicator attributes are the actual physical or biological features or processes that can be measured either in the field or via GIS analysis. Attributes can include channel length, floodplain habitat types, temperature, pieces of large woody debris, etc.

The approach recommended by those previous reports was deemed to be to time consuming and costly to apply to both the Coast and Middle Forks watershed. Thus, our approach has been to identify riverine and floodplain environments into major habitat types and address the response of each habitat type through Habitat Suitability Indices for species closely associated with each habitat type (Figure 1). The results from each of the component suitability indices can be examined independently and/or combined into a single overall index of floodplain function we have termed the Floodplain Habitat Index. Each of the component HSIs are described in detail below.

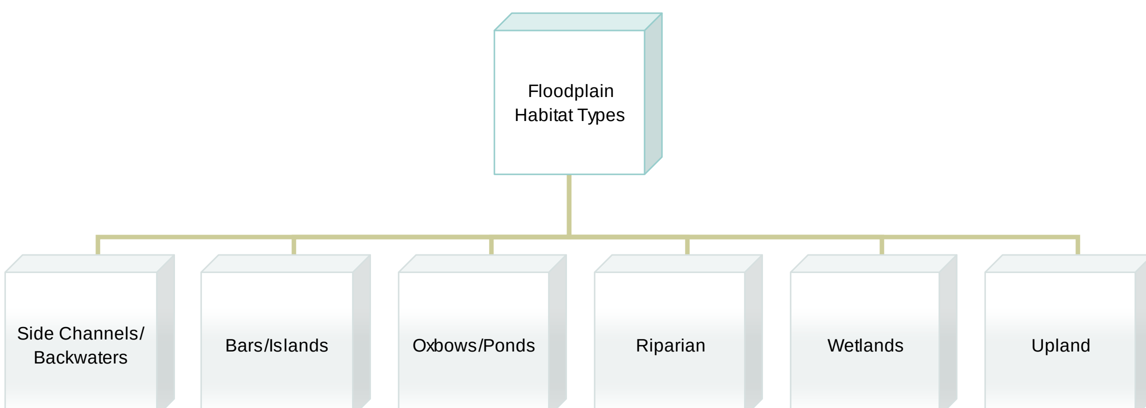

Figure 1. Floodplain Habitat Types.

The floodplain habitat index will assess the existing and proposed future condition of riverine and floodplain habitats and their relationships to fish and wildlife species production and survival.

3. FLOODPLAIN HABITAT INDEX

3.1 Habitat Evaluation Procedure (HEP)

The Habitat Evaluation Procedure (HEP) is a procedure developed by the U.S. Fish and Wildlife Service (1980a and 1980b) to facilitate the identification of impacts from various types of actions on fish and wildlife habitat. The basic premise of HEP is that habitat quantity and quality can be numerically described. HEP can provide a comparison of habitat quality between different sites or between different times at one site (for example, pre-construction versus post-construction). A key assumption in HEP is that an individual species "prefers" (or survives/reproduces better) in habitats with certain physical characteristics that can be measured. For example, if yellow warblers typically nest in deciduous shrubs, then sites with greater deciduous shrub cover are more suitable for yellow warblers than sites which have little or no deciduous shrub cover.

A Habitat Suitability Index (HSI) is the typical format used in HEP 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 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 Suitability Indices that represent key habitat requisites for the species during one or more life history stages are combined into an overall Habitat Suitability Index (HSI) by adding or multiplying the individual indices. The attributes are measured in the field or via GIS analysis and their corresponding index values are inserted into the model to produce a score that describes existing habitat suitability. The overall HSI value is also an index score between 0 and 1. This index value can be multiplied by the area of the site to yield Habitat Units (HUs), or it can be used as an index score for a habitat quality comparison only.

A number of HSIs have been published for either individual species or guilds or other attributes, including those that may occur in Oregon (both native and non-native): bald eagle, beaver, black-capped chickadee, black bullhead, bullfrog, brook trout, carp, channel catfish, cutthroat, downy woodpecker, great blue heron, hairy woodpecker, belted kingfisher, long nose dace, marsh wren, mink, osprey, red-winged blackbird, smallmouth bass, and wood duck. HSIs can be created or modified using literature and other data. Local or draft models have been developed for green heron (USFWS 1980c), native amphibians (WDFW 1997), Oregon chub (Scheerer 2006) and western pond turtle (Tetra Tech 2000), and are based on the literature for the species.

HEP has typically been used on a site-specific basis. The indicator attributes selected will need to be appropriate for the scale of analysis. A more detailed monitoring plan should be developed that will compare species diversity and abundance before and after the project is implemented, and to also compare the validity of the HEP model in predicting habitat improvements.

4. DESCRIPTION OF MODEL

As identified previously, the proposed model will be a combination of multiple individual species HSIs. The resultant indices may be averaged or geometrically combined, and during the use of the model, it will be tested and documented which combination of components provides the most meaningful estimation of the quality of habitat.

4.1 Description of Input Data

Input data for a HEP model almost always should be collected specifically at the project site or by the use of aerial photographs or a GIS database for the project area. The input data required varies substantially from one Habitat Suitability Index to another. It is important to utilize or develop an HSI where the variables can be measured within the cost and time constraints of a particular study or project. Typical variables that are measured include percent canopy cover, diameter of trees, water depth, water velocity, number of pieces of downed wood, vegetation composition, etc. These measured variables are then assigned a Suitability Index based on the Suitability Curve or discreet Suitability Values developed in the model.

Typically, input variables are measured at multiple locations on the project site and then averaged to yield an overall percent canopy cover or similar value. If the project site is comprised of several distinctly different vegetation communities, then variables can be measured specifically for each community to yield multiple scores for the overall site. Users must be capable of using basic ecological data collection techniques and, depending upon the model, capable of identifying plant species on the site.

4.2 Description of Output Data

The output data from a HSI is one or several individual suitability indices (unit less number from 0 to 1) that are then entered into the HSI model equation to yield an overall habitat suitability index for the species. For example, the yellow warbler model includes four variables: 1) V1, percent deciduous shrub crown cover; 2) V2, percent overall canopy cover; 3) V3, average height of deciduous shrub cover; and 4) V4, percent shrub canopy comprised of hydrophytic vegetation. The equation for combining these variables is an average as shown below, because none of the variables are limiting factors (such that a score of zero should render the habitat completely unsuitable for yellow warbler), and it appears that the variables are compensatory (such that while a low suitability score for one variable will reduce the overall habitat suitability, the other variables can somewhat compensate and still provide suitable habitat).

$$HSI = (V_1 + V_2 + V_3 + V_4) / 4$$

4.3 Capabilities and Limitations of the Model

A major assumption of HEP 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 the majority of observations of yellow warbler nests were in deciduous shrubs ranging from 1.5 to 4 meters, then deciduous shrubs of that height are assumed to provide optimal nesting habitat, and thus yield a high index score (in the range of 0.8 to 1.0). Shrubs of lesser height are assumed to be less suitable and yield lower index scores.

Specific limitations have been observed in the use of HEP and 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. (Barry, *et al*. 2006; O'Neil, *et al*. 1988; Wakeley 1988)

These limitations have been recognized in the development of this integrated model. Because it may be inaccurate to represent habitat suitability for large guilds or assemblages of species, multiple species were selected for the HEP portion of this model (and are described later) to encompass the habitat requirements for relatively small guilds or individual species of interest. This proposed model has also been reviewed by a number of fish and wildlife biologists in the watershed with specific expertise with the species of interest to solicit feedback on the species selected and the relationships between variables and habitat suitability.

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 species 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.

This study will not be used to restore or manage habitat for a single species, nor is it intended to specifically increase the population of a single species. This project is intended to allow the Willamette River to form floodplain habitats over time, rather than creating a specific static habitat type. The models have been modified or created to reflect local or regional data, as well as to simplify the models so that only the variables (and habitat types) likely to change as a result of the restoration project are included.

4.4 Model Development Process

All HSIs proposed for use in this model have been documented and reviewed. The Oregon chub and amphibian models were developed by multi-agency teams based on regional literature and expert opinions. The western pond turtle model was developed based on regional literature and reviewed and modified based on expert reviews. Testing and validation of the models is more limited. A recommendation for future use of these models is that the monitoring plan developed for this project should incorporate many of the parameters included in the HSI models to test and validate assumptions on habitat suitability. This monitoring data could inform future refinements or changes to the models and improve their predictive capability.

4.5 Identification of Formulas and Proof Computations are Done Correctly

All equations used in the HEP model are specifically stated and described below, as well as the Suitability Curves. Calculations are done in standard spreadsheet software (i.e. Microsoft Excel). The models are completely transparent and all assumptions can be verified.

4.6 Availability of Input Data

Input data used for this model will be collected from on-site field surveys and from the use of aerial photography.

4.7 Proposed HSI Models

Primozich, *et al.* (2004) proposed the use of plant communities and wildlife species as indicators. Published HSIs for the following species or guilds were reviewed for potential inclusion in the HEP including: beaver, mink, yellow warbler, belted kingfisher, green heron, great blue heron, hairy woodpecker, downy woodpecker, red-winged blackbird, wood duck, mallard, lesser scaup, osprey, bald eagle, black-capped chickadee, marsh wren, cutthroat trout, Oregon chub, native amphibians, native salmonids, American kestrel, and bullfrog.

It is recommended that HSIs for several species be utilized to capture the range of benefits that could be provided by a floodplain restoration project. The recommended HEP model includes the following species or guild: (1) Western pond turtle; (2) Oregon chub; (3) beaver; (4) wood duck; (5) yellow warbler (highly riparian associated); (6) native amphibians (red-legged frog, Oregon spotted frog, Pacific tree frog, rough-skinned newt, Northwestern salamander, long-toed salamander); (7) native salmonids (Chinook, steelhead, cutthroat); and (8) American kestrel (grasslands/ag lands). The Western pond turtle and Oregon chub are both species of concern in the study area and utilize backwaters and ponds. The beaver is a mammal species dependent on native riparian species for food (cottonwood, willow, and alder). The wood duck is a cavity nesting waterfowl species that utilizes riparian areas for nesting. The yellow warbler is highly associated with riparian habitat for nesting. The six amphibians are native amphibians that primarily represent aquatic amphibians utilizing riparian and wetland habitats. Chinook salmon, steelhead and cutthroat trout utilize off-channel aquatic habitats for rearing and refuge. American kestrel are raptors that utilize open grasslands and agricultural lands for foraging, as well as riparian and woodlands for nesting and perching.

Primozich, *et al* (2004) proposed using geomorphic features for aquatic habitats and the following terrestrial indicators/species/guilds: 1) native riparian shrub and forest community; 2) off-channel marsh and pond community; 3) turtles and amphibians; 4) riverbank wildlife; and 5) bar/flat wildlife. The model recommended here includes species that can represent all of those indicators. For example, the native riparian shrub and forest community can be represented by the riparian dependent yellow warbler. Table 3 shows the species/guilds selected and the habitat types and physical parameters (attributes) they will represent.

Table 1. Recommended species for HEP model.

Species/Guild Selected	*Variables/Attributes*	*Habitat Type Associated With*
Western pond turtle	**Water depth, water temperature, percent cover, availability of nesting sites**	**Off-channel ponds, sloughs, and backwaters**
Oregon chub	**Waterbody type, velocity, submergent and emergent vegetation, water depth, substrate type, slope, woody debris, riparian, marsh, water temperature, non-native fish, habitat isolation**	**Off-channel ponds, sloughs, and backwaters**
Beaver	**Tree canopy closure, tree size class, shrub crown cover, height of shrub canopy, species composition**	**Riparian and floodplain vegetation communities (particularly cottonwood and willow)**
Wood duck	**Cover**	**Riparian and floodplain vegetation communities and near shore aquatic habitats**
Yellow warbler	**Deciduous shrub crown cover, canopy cover, height of shrub canopy, hydrophytic shrubs, velocity**	**Riparian and floodplain vegetation communities (particularly cottonwood and willow)**
Native amphibians	**Permanent water, water velocity, emergent and submergent vegetation, ground cover along water's edge, riparian zone width, water temperature, land use**	**Slow velocity stream reaches/alcoves, off-channel ponds, sloughs, and backwaters and other wetlands**
Native salmonids	**Maximum water temperature, percent pools, instream cover, predominant substrate size**	**Side channels, backwaters, oxbows/ponds**
American kestrel	**Distance to woodland, distance to suitable perch sites, distance to open land, average dbh of trees**	**Grasslands, ag lands, riparian forest, woodland**

Several of the existing HSI models do not appear appropriate to use in their current condition and the reasons for not selecting the species and models are briefly described in Table 4.

Table 2. Species not selected for HEP model.

Species	*Description of Variables*	*Reason for Not Selecting*
Bald eagle	Size of waterbody for foraging; morphoedaphic index; distance from nest to foraging area	Model designed for breeding season at lacustrine habitats and based on volume of forage base. Not relevant to project area or proposed alternatives. Could have created new model for wintering habitat, but primarily based on availability of perching habitat and proximity to waterbodies, which will not change significantly as a result of proposed restoration measures.
Black-capped chickadee	% Tree canopy closure, average height of trees, # of snags	Restoration of floodplain and riparian habitats will benefit these attributes and habitat requirements, but are not directly predictable from proposed changes.
Black bullhead	% Pools/backwaters, % cover, average current velocity, temp, DO, pH, salinity, turbidity, substrate, % cover objects	Could use as a negative HEP because it is a non-native warmwater species, but currently using bullfrog as the negative HEP that requires similar attributes.
Brook trout	Average thalweg depth, %	Non-native species likely present in the project area,

Species	*Description of Variables*	*Reason for Not Selecting*
	instream cover, % pools, pool class, % substrate size, % riffle fines, average maximum temperature, average minimum DO, average water velocity, pH, average annual base flow, dominant substrate type, average % vegetation, % streamside vegetation, % midday shade	but similar requirements to cutthroat trout. All attributes are in-channel, may not see significant change.
Channel catfish	% Cover, substrate type, % pools, average current velocity, temperature, DO, turbidity, salinity, length of growing season	Could use as a negative HEP because it is a non-native warmwater species, but currently using bullfrog as the negative HEP that requires some similar attributes.
Cutthroat trout	Average thalweg depth, % adult cover, % pools, pool class, % juvenile cover, % substrate size, % riffle fines, average maximum temperature, DO, water velocity, average gravel size, % fines, pH, base flow, dominant substrate, % vegetation, % vegetation erosion, midday shade	Could use as a comparison to EDT model for in-channel attributes.
Downy woodpecker	Basal area per hectare, # snags/ha	Will likely benefit from floodplain/riparian restoration, but attributes are not directly relevant.
Great blue heron	Distance between foraging areas and heronry sites, shallow clear water, distance from human activities	Attributes not likely to show a significant change from future without-project to future with-project condition.
Hairy woodpecker	# of snags, mean dbh of overstory trees, % canopy cover	Will likely benefit from floodplain/riparian restoration, but attributes are not directly relevant.
Belted kingfisher	% of shoreline subject to severe wave action, average water transparency, % water surface obstructed, % water area < 60 cm, % riffles, number of stream reaches with 1 or more perches, distance to suitable soil bank	Will likely benefit from floodplain/riparian restoration, but attributes are not directly relevant to project site.
Longnose dace	Average current velocity, maximum depth of riffles, % riffles, substrate type, average maximum temperature, % cover	In-channel attributes that will not likely show a significant change. Also, primarily a species of swift flowing smaller tributaries.
Marsh wren	Growth form of emergent hydrophytes, % canopy cover of emergents, mean water depth, % canopy cover of woody vegetation	Will benefit from wetland restoration, but attributes not directly relevant.
Osprey	Obstructions over water, transparency, human activities	Attributes will not show a significant change.
Red-winged blackbird	Dominant emergent vegetation type, water present/absent, carp present/absent, larvae of odonates, patchiness of vegetation, layers of wetland vegetation	Will benefit from floodplain wetland restoration, but attributes not directly relevant.
Smallmouth bass	Substrate type, % pools, % cover, depth of pools, pH, DO, turbidity,	Could use as a negative HEP, but in-channel attributes are not likely to show a significant change.

Species	*Description of Variables*	*Reason for Not Selecting*
	temperature, fluctuations in water level, gradient	

Western Pond Turtle Life History and Habitat Requirements

The western pond turtle (*Clemmys marmorata*) is found in the Pacific northwest generally west of the Cascade Range from Puget Sound south to Baja California Norte. There are two subspecies: the northern subspecies occurs north of the American River in California (C. *marmorata marmorata*) and the southern subspecies occurs south of the American River (C. *marmorata pallida*). In Oregon, the species occurs in the western Cascades, the Willamette Valley, Coast Range, and Klamath Mountains and possibly east of the Cascades in the Deschutes and John Day drainages (likely from introductions, Holland, 1994). Western pond turtles are in the family of Emydidae that includes many species of semi-aquatic pond and marsh turtles including slider turtles. Life history requirements of the turtles in this family have many similarities (Rosenberg et al. 2009). The model described herein was based on the slider turtle model developed by the U.S. Fish and Wildlife Service (Morreale and Gibbons 1986) with the addition of key parameters identified by regional Western pond turtle experts. Based on the co-occurrence of Western pond turtles and red eared sliders in most habitats in the Willamette Valley and similar life history uses of habitats, the parameters included in the model appear appropriate for Western pond turtle (K. Beale, USACE, 2012, pers. comm.).

Western pond turtles are very wary and sensitive to human disturbance, particularly movements of pedestrians even as far as 100 meters away (Holland, 1994). They forage in water and eat a wide variety of aquatic invertebrates, and terrestrial insects. Pond turtles likely eat small fish, crayfish and frogs as well, but much less frequently, and possibly only via scavenging. Scavenging of carrion may also be an important food source, particularly seasonally (early spring). Pond turtles typically overwinter in the northern part of the range from one to six months, but may frequently emerge on sunny days to bask. Overwintering can occur in mud on the bottom of ponds, under overhanging banks, or in forested areas under a thick layer of leaf litter. Pond turtles may also use terrestrial habitats if their aquatic habitat seasonally dries up (Rosenberg et al 2009). During the rest of the year, turtles generally occur in aquatic habitats, with a slow to moderate current. A significant amount of time is used for basking on rocks, logs or emergent vegetation. Nesting habitat is a key terrestrial component of Western pond turtle life history. Terrestrial nesting habitat is typically sparsely vegetated with grass and/or forbs. It is typically on south-facing gentle slopes or other areas with good sun exposure and typically fairly compact soil with silt or clay, although sandy loam and gravel/cobble mixed with soil have also been used (Rosenberg et al. 2009). Nesting habitat within approximately 200 meters to aquatic habitats may be preferred. The various studies cited in Rosenberg et al. (2009) generally found that solar exposure and warmer temperature soils were the most consistent trait. It appears that hatchlings remain in the nest over the winter and emerge the following spring. Predation on eggs and hatchlings is typically very high by raccoons, fox, coyote, and skunks as well as domestic dogs. Small turtles may also fall prey to largemouth bass, bullfrogs, trout, other resident fish and waterfowl. Larger turtles typically do not have many predators, but may occasionally be taken by the mammals listed above, and also by bear, river otter, dogs and humans. Minimizing habitat for bullfrogs and other non-native predators will benefit western pond turtles, although unfortunately the turtles typically prefer warm waters that bullfrogs also prefer. Some significant limiting factors to western pond turtle survival in the Willamette Valley appear to be: 1) predation of nests; 2) hatchling predation by bullfrogs; and 3) lack of nesting habitat (B. Castillo, ODFW, pers. comm.). Loss of aquatic habitat and road mortality are also major threats to this species (Rosenberg et al. 2009).

Oregon Chub Life History and Habitat Requirements

The Oregon chub (*Oregonichthys crameri*) was listed as endangered under the federal Endangered Species Act in 1993. This small minnow is endemic to the Willamette River system from Oregon City to Oakridge, Oregon. Currently, there are estimated to be 15 populations of Oregon chub with at least 500 individuals. Eight of these populations are stable, with 6 populations in the Middle Fork system, 1 in the Santiam, and 1 in the mainstem Willamette (Scheerer, *et al* 2003 cited in draft HSI). The Oregon chub prefers off-channel habitats including sloughs, oxbows, beaver ponds and flooded marshes. The habitat requirements for this species include low- or zero-velocity water with depths of less than 2 meters (6.6 feet), silty and organic substrates, and considerable aquatic or overhanging riparian vegetation for cover (USFWS 1993). Spawning occurs from the end of April through early August when water temperatures range from 15° C to 21° C. Spawning activity in Oregon has only been observed at temperatures exceeding 16° C (Scheerer 1999). Off-channel habitats have been nearly eliminated from the Willamette Basin due to changes in hydrology as a result of the construction of dams, channelization of the Willamette River and its tributaries, removal of large woody debris (LWD), and agricultural and other development (USFWS 1998; Scheerer and McDonald 2003). Remaining off-channel habitats have been invaded by non-native predators and competitors introduced into the Willamette River. Species such as bass, mosquito fish and bullfrogs may present the largest obstacle to the recovery of the Oregon chub (Scheerer 2002). Habitats that currently support healthy populations of Oregon chub are isolated from adjacent aquatic habitats and do not typically have non-native fish species present. However, the fragmentation of populations has likely reduced the viability of the species as a whole reducing genetic exchange and the potential for recolonization of new habitats.

A key area that should be considered for future research and monitoring is the potential effects of non-native invasive plant species on Oregon chub habitat. In areas of dense aquatic plant growth, the senescence of the plants each fall/winter can cause low dissolved oxygen conditions that might prohibit fish use of certain habitats.

Beaver Life History and Habitat Requirements

Beaver are herbivorous aquatic mammals found throughout North America wherever suitable riparian and wetland habitats occur. Beaver were once so numerous (50-100 million) those most aquatic habitats in North America were shaped by beaver activity (do we have a citation for this?). The HSI model for beaver is described in Allen (1982) and habitat requirements are summarized below. Beaver are generalized herbivores, but have strong preferences for specific plant species and size classes. Aspen, willow, cottonwood, and alder are the preferred species. Woody stems less than 10 centimeters in diameter near water are preferred and herbaceous vegetation and leaves are consumed during the summer. Aquatic vegetation is also utilized.

Wood Duck Life History and Habitat Requirements

Wood duck range and life history are summarized in Sousa and Farmer (1983). Wood ducks inhabit creeks, rivers, floodplain lakes, swamps, and beaver ponds. A Pacific population breeds from British Columbia south to California and east to Montana of which, a majority winters in the Sacramento Valley. Wood ducks have been referred to as primarily herbivorous, although invertebrates also make up a part of their annual diet. Suitable cover for wood ducks may be provided by trees or shrubs overhanging water, flooded woody vegetation, or a combination of these two types. For nesting, wood ducks utilize bottomland hardwood forests with trees of sufficient size to contain usable cavities that are near water.

Yellow Warbler Life History and Habitat Requirements

The yellow warbler is a riparian dependent neotropical migratory songbird that breeds throughout Oregon and much of North America. The existing model and habitat requirements are described in Schroeder (1982). The yellow warbler prefers riparian habitats composed of abundant, moderately tall, deciduous shrubs ranging in height from 1.5 to 4 meters. Shrub densities between 60 and 80% are considered optimal and coniferous areas are avoided. Greater than 90% of prey are insects and foraging takes place primarily on small limbs in deciduous foliage. Nests are generally located 0.9 to 2.4 meters above the ground in willows, alders, and other hydrophytic shrubs and trees, including box elders and cottonwoods. Male yellow warblers have greater mating success in shrubs less than 3 meters tall.

Native Amphibians Life History and Habitat Requirements

This habitat suitability index is a combination of the habitat requirements of both aquatic and terrestrial amphibians that commonly occur in Western Washington and Oregon including; Northwestern salamander (*Ambystoma gracile*), long-toed salamander (*Ambystoma macrodactylum*), roughskin newt (*Taricha granulosa*), red-legged frog (*Rana aurora*), Oregon spotted frog (*Rana pretiosa*) and the Pacific treefrog (*Hyla regilla*). The habitat requirements of these species in the HSI for native amphibians are summarized below (WDFW 1997; Corkran & Thoms 1996). This model was developed by an interagency team and has been used on a number of project sites in the lower Willamette and lower Columbia Rivers. While these amphibian species included in the model are considered aquatic, they also use adjacent riparian areas extensively for wintering and feeding. Due to the multiple species included, additional parameters such as water depth requirements for breeding are not applicable across all species and have not been included.

Northwestern salamanders occur in western Oregon, Washington and British Columbia, and are considered to be aquatic salamanders that breed in ponds and stream backwaters. They live in moist forest or woodlands as juveniles and adults. They lay their eggs in moderately deep water (0.5-2 m) attached to small sticks or rigid stems. Larvae live in surface sediments or under debris or logs in their natal waterbodies.

Long-toed salamanders occur throughout much of Oregon, Washington and British Columbia, are are also considered to be aquatic salamanders that breed in seasonal ponds, lake shores and slow-moving streams through wet meadows. They live in a variety of terrestrial habitats (grasslands, woodlands, disturbed areas) as juveniles and adults. They lay their eggs in shallow water (<0.5 m) attached to stems, leaves, or pebbles. Larvae live in surface sediments or under debris in shallow water.

Roughskin newts occur in most of Oregon, and are also considered to be aquatic salamanders, which utilize ponds and slow-moving streams for most of the year or year-round. They prefer forested or partially wooded habitats adjacent to ponds, lakes or sloughs, often where there is extensive aquatic vegetation. They lay their eggs in moderately deep water (0.5-2 m) in mid to late spring, attaching the eggs to stems or floating vegetation. Juveniles and adults live in and under rotting logs and forage in the ponds or moist forest floors.

Red-legged frogs occur on the west side of the Cascade crest in Oregon, Washington and British Columbia. They prefer moist coniferous or deciduous forest and forested wetland habitats. They breed in cool slow-moving waters such as shaded ponds and sloughs in winter to early spring. They lay their eggs in moderately deep water (0.5 - 2 m) and attach the eggs to submerged branches or aquatic vegetation. Juveniles and adults will live in emergent wetlands, logs, or brush adjacent to pond edges. During the rainy season, they move into forest habitats and live under logs and debris, foraging on the forest floor. A major limiting factor for native amphibian survival is lack of adjacent moist forest habitat (B. Castillo, ODFW, pers. comm.).

Oregon spotted frogs occur in British Columbia, western Washington and the Cascade Mountains of Washington and Oregon. Historically they were found in the Willamette Valley, but they appear to have been eliminated from this habitat (Leonard et al. 1993). Oregon spotted frogs are aquatic and require water for breeding, foraging and wintering habitats. They use seasonal waterbodies such as ponds or flooded sloughs/overflows that dry up by summer. However, connections to permanent water must be present to allow tadpoles to metamorphose. Juveniles and adults inhabit marshes, and marshy edges of ponds, streams and lakes with abundant vegetation.

Pacific treefrogs are the most common frog in the northwest and can live in a variety of habitats including marshes, wet meadows, forests and brushy disturbed areas. They breed in shallow water (<0.5 m) attaching their eggs to grasses or twigs. Adults live in wet meadows and riparian areas.

Native Salmonid Life History and Habitat Requirements

Chinook Salmon

Spring and fall Chinook occur in the Willamette River, although the fall run is considered to be entirely derived from plantings of hatchery fish from 1964-1994. Wild spring-run Chinook are listed as a threatened species for the Upper Willamette River (upstream of Willamette Falls). Spring Chinook enter the Willamette River from approximately April through early July and then migrate upstream to spawning grounds, spawning later in the year from August to October. Fall Chinook enter the Willamette River from August to October, spawning immediately from early September through early October. Fry emerge from the spawning grounds from January through April. Spring Chinook are frequently stream-type, in that juveniles may rear in freshwater streams for up to a year or more before migrating to the ocean. Some spring Chinook and most fall Chinook are typically ocean-type, and only rear for 2-6 months in freshwater before migrating to the ocean. Some ocean-type Chinook migrate as fry to estuarine areas and rear for extended periods there. Chinook fry and juveniles rear along stream margins, back eddies, behind woody debris and in side channels. As juveniles become larger, they move into higher velocity areas. Chinook juveniles appear to prefer areas with slow to moderate velocities, <30 cm/s (Healey 1991). The channelization of the Willamette River has drastically reduced off-channel and other low velocity rearing habitats for juvenile Chinook (Kostow 1995).

Coho Salmon

Coho were introduced to the Upper Willamette River starting in 1952. Releases of hatchery fish continued through 1988, but are no longer conducted, except in the Tualatin River. Adult coho enter the Willamette River from late August through early December, migrating into tributaries all along the length of the River. Adult coho will often hold for extended periods in deep pools, where they are less vulnerable to predation. Spawning occurs typically from September through December. Fry emerge from the spawning grounds from late February through April. Coho fry and juveniles rear in freshwater for one or two years typically, although even longer freshwater residence can occur. Coho typically spend only one year in saltwater. Fry typically congregate after emerging from the gravel and within a few days begin swimming along the bank margins, especially near overhanging vegetation. Coho often hold in pools and periodically come out to capture prey in riffle areas. Coho will also typically settle on the bottom during darkness. Areas with a high percentage of margin habitat (narrow streams) and with woody debris and pools are the most productive for coho. Coho move into side channels and under debris for wintering. Outmigration occurs from March through June.

Steelhead Trout

Summer and winter runs of steelhead trout occur in the Willamette River. The winter run is the most significant run and is listed as a threatened species in the Upper Willamette River, although distribution information indicates that winter steelhead occur only downstream of the Calapooia River. Upstream of the Calapooia River are resident rainbow trout. For the purposes of this HEP, we treat anadromous and resident trout equivalently. Adults typically enter the river from mid-February through mid-May, with spawning occurring from March through May. The summer run is derived from introduced hatchery fish planted in the basin starting in the late 1960s. Summer steelhead adults typically enter the river from late March through July. Juveniles rear in freshwater for one to four years utilizing areas with rubble, woody debris or other cover, and frequently feed in riffles. Areas with dense riparian vegetation and other cover provide the best habitat for steelhead juveniles. Outmigration of smolts typically occurs from April through June.

Cutthroat Trout

Coastal cutthroat trout occur throughout the Willamette River basin and are a polytypic species with multiple life-history forms including resident, fluvial, anadromous, and potamodromous (NOAA 1999). The anadromous life history form was unlikely to have been a major component of the Upper Willamette population historically due to the difficulty of ascending Willamette Falls. The primary form is likely to have been freshwater migratory. Spawning typically occurs from December through June, with a peak in February (NOAA 1999). Cutthroat juveniles migrate within the stream systems and utilize pools, cover, and off-channel habitats. Cover is considered one of the essential elements of cutthroat habitat (Hickman & Raleigh 1982).

American Kestrel Life History and Habitat Requirements

The American kestrel is a small raptor of open country. They typically hunt over open fields, consuming insects, birds and small mammals. Kestrels hunt from perches such as trees. Kestrels nest in tree cavities, banks, cliffs, and structures. Interspersion between open lands and woodland or riparian zones provides suitable habitat for both feeding and nesting. (USFWS 1978)

Table 3. HSI models.	
Western Pond Turtle	V_1 = Percent area with water depth preferred by adults V_2 = Percent cover along water's edge V_3 = Water temperature during low flows V_4 = Percent area with water depth less than 0.3 meters V_5 = Availability of suitable nesting sites $HSI_{W\ Pond\ Turtle} = (V_1 + V_2 + V_3 + V_4 + V_5) / 5$
Oregon Chub	V_1 = Waterbody type V_2 = Water velocity V_3 = % Submergent/emergent vegetation present V_4 = Water depth V_5 = Substrate type V_6 = Slope V_7 = Large woody debris V_8 = Small woody debris V_9 = Riparian V_{10} = Marshes V_{11} = Water temperature V_{12} = Non-native fish V_{13} = Habitat isolation $HSI_{Oregon\ Chub} = [V_1(V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9 + V_{10})/9 * (V_{11} * V_{12})]^{1/4}$
Beaver	V_1 = Percent tree canopy closure V_2 = Percent of trees in 2.5 to 15.2 cm dbh size class V_3 = Percent shrub crown cover V_4 = Average height of shrub canopy V_5 = Species composition of woody vegetation $HSI_{Beaver} = [(V_1 \times V_2)^{1/2} \times V_5]^{1/2} + [(V_3 \times V_4)^{1/2} \times V_5]^{1/2}$ *(within 100 m)* + $0.5[(V_1 \times V_2)^{1/2} \times V_5]^{1/2} + [(V_3 \times V_4)^{1/2} \times V_5]^{1/2}$ *(100-200 m)* / 1.5
Wood Duck	V_4 = Percent of the water surface covered by potential brood cover $HSI_{Wood\ Duck} = V_4$
Yellow Warbler	V_1 = Percent deciduous shrub crown cover V_2 = Percent overall canopy cover V_3 = Average height of deciduous shrub canopy V_4 = Percent of shrub canopy comprised of hydrophytic shrubs $HSI_{Neotropical\ Songbirds} = (V_1 + V_2 + V_3 + V_4) / 4$
Native Amphibians	V_1 = Percent area with permanent water V_2 = Water current in breeding areas during spring V_3 = Percent area with emergent or submergent wetland/aquatic vegetation V_4 = Percent ground cover along the water's edge V_5 = Width of riparian zone V_6 = Maximum temperature during low flows V_7 = Land use within 200 meters of the wetland edge $HSI_{Native\ Amphibians} = (V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7) / 7$
Native Salmonids	V_1 = Maximum water temperature during low flow V_2 = Percent pools during low water period V_3 = Instream cover present V_4 = Predominant substrate type in riffle or run areas $HSI_{Salmonids} = (V_1 + V_2 + V_3 + V_4) / 4$

American Kestrel	V_1 = Distance to woodland V_2 = Distance to suitable perching sites V_3 = Distance to open land V_4 = Average dbh of trees $HSI_{Riparian}$ = the lower of X_1 or X_2; $X_1 = (V_1 * V_2)^{1/2}$; $X_2 = V_2$

Western Pond Turtle HSI

The Habitat Suitability Index for western pond turtle is described in the following equation. None of the variables are considered to be so limiting that a score of zero would render the habitat totally unsuitable.

$$\mathbf{HSI_{WPondTurtle} = (V_1 + V_2 + V_3 + V_4 + V_5) /5}$$

V_1 = % Area with water depth preferred by adults (1-2 m) ***(Morreale & Gibbons, 1986)***

% Area	**SI**
0	0
20	0.5
50	1.0
75	1.0
100	0.2

V_2 = % Cover along water's edge including canopy, LWD, emergent wetland vegetation, etc. ***(Morreale & Gibbons, 1986)***

% Cover	**SI**
0	0
25	0.2
50	0.5
75	1.0
100	1.0

V_3 = Water temperature during low flows ***(Morreale & Gibbons, 1986; Holland, 1994)***

Temperature (°C)	**SI**
5	0
10	0.2
15	0.6
20	1.0
25	1.0
30	0.6

V_4 = % Area with water depth less than 0.3 meters *(Bill Castillo, ODFW, pers. comm.)*

% Area	SI
0	0.1
25	1.0
50	1.0
75	0.3
100	0

V_5 = Availability of suitable nesting sites (qualitative) *(Bill Castillo, ODFW, pers. comm.)*

Availability	SI
None	0
Very few (1-2 in project area)	0.2
Sparse (3-4 in project area)	0.5
Moderate (5-7 in project area)	0.8
Abundant (>7 in project area)	1.0

Oregon Chub HSI

The Habitat Suitability Index for Oregon chub is described in the following equation. V_1, V_{11} and V_{12} are considered limiting and a score of zero would render the habitat unsuitable for Oregon chub.

$$\mathbf{HSI_{Oregon\ Chub} = [V_1(V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9 + V_{10})/9 * (V_{11} * V_{12})]^{1/4}}$$

V_1 = Waterbody type (*Scheerer draft HEP 2006*)

Waterbody Type	SI
Oxbows and backwater pools	1.0
Open water and beaver dammed pools	1.0
Pools (incl. secondary channel and lateral scour pools)	0.8
Seeps or springs	0.8
Riverine wetlands	1.0

V_2 = Water velocity (*adapted from Scheerer draft HEP 2006*)

Velocity	SI
<25% of surface area has no velocity	0
25-50% of surface area has no velocity	0.5
>50% of surface area has no velocity	1.0

V_3 = % Submergent or emergent vegetation present *(adapted from Scheerer draft HEP 2006)*

% Vegetation	SI
<25% cover of submergent or emergent vegetation	0
25-50% cover submergent or emergent vegetation	0.5
>50% cover submergent or emergent vegetation	1.0

V_4 = Water depth *(adapted from Scheerer draft HEP 2006)*

Water depth	SI
<25% of site <1 m depth in late summer	0
<25% of site <2 m depth in late summer	0.25
>25% of site <2 m depth in late summer	0.5
>50% of site <2 m depth in late summer	1.0

V_5 = Substrate type *(adapted from Scheerer draft HEP 2006)*

Substrate Type	SI
<25% substrate comprised of silt/organics	**0**
25%-50% substrate comprised of silt/organics	**0.67**
>50% substrate comprised of silt/organics	**1.0**

V_6 = Shallow Water Zone Slope *(adapted from Scheerer draft HEP 2006)*

Shallow Water Zone Slope	SI
> 15:1	**0**
< 15:1	**1**

V_7 = Large woody debris *(adapted from Scheerer draft HEP 2006)*

Large Woody Debris	SI
Common or abundant	**1**
Absent or sparse	**0**

V_8 = Small woody debris *(adapted from Scheerer draft HEP 2006)*

Small Woody Debris	SI
Common or abundant	**1**
Absent or sparse	**0**

V_9 = Riparian zone *(adapted from Scheerer draft HEP 2006)*

Riparian Zone	SI
1. Dominated by native tree and shrub species and at least 100 feet in width	**1**
2. Dominated by native tree and shrub species at less than 100 feet in width	**0.67**
3. Significant presence of non-native species or very narrow width	**0.33**
4. Dominated by herbaceous species	**0**

V_{10} = Marsh habitat ***(adapted from Scheerer draft HEP 2006)***

Marsh Habitat	SI
Marsh habitat present as appropriate for habitat type	1
No marsh habitat present	0

V_{11} = Water temperatures between May 1st and August 31st ***(adapted from Scheerer draft HEP 2006)***

Water temperature	SI
> 29 C (lethal) during summer	0
Daily temperatures commonly between 16 and 25 C	1
Daily temperatures typically < 16 C	0.5

V_{12} = Presence of non-native fish ***(adapted from Scheerer draft HEP 2006)***

Non-Native Fish	SI
Common or abundant	0
Uncommon, rare or absent	1

V_{13} = Habitat isolation ***(adapted from Scheerer draft HEP 2006)***

Habitat Isolation	SI
Perennially connected with watercourses containing non-native fish	0
Intermittently connected with watercourses containing non-native fish (<5 year connection)	0.33
Perennial isolation over multiple years (>5 year connection)	1

Beaver HSI Model

The Habitat Suitability Index for beaver is described in the following equation. All variables are considered limiting and a score of zero would render the habitat unsuitable for winter cover and feeding, which is also the limiting life history stage for beaver.

$$HSI_{Beaver} = [(V_1 \text{ x } V_2)^{1/2} \text{ x } V_5]^{1/2} + [(V_3 \text{ x } V_4)^{1/2} \text{ x } V_5]^{1/2} \textit{ (within 100 m)} + 0.5[(V_1 \text{ x } V_2)^{1/2} \text{ x } V_5]^{1/2} + [(V_3 \text{ x } V_4)^{1/2} \text{ x } V_5]^{1/2} \textit{ (100-200 m)} / 1.5$$

V_1 = Percent tree canopy closure (the percent of the ground surface shaded by a vertical projection of the canopies of woody vegetation ≥5.0 m (16.5 ft) in height) *(Allen 1982)*

Percent canopy closure	SI
0	0
25	0.5
50	1.0

75	0.8
100	0.6

V_2 = Percent of trees in 2.5 to 15.2 cm (1 to 6 inches) dbh size class *(Allen 1982)*

Percent of trees	HSI
0	0.2
25	0.4
50	0.6
75	0.8
100	1.0

V_3 = Percent shrub crown cover (the percent of the ground surface shaded by a vertical projection of the canopies of woody vegetation < 5 m (16.5 ft) in height) *(Allen 1982)*

Percent cover	HSI
0	0
25	0.6
50	1.0
75	0.9
100	0.8

V_4 = Average height of shrub canopy *(Allen 1982)*

Average height (meters)	HSI
0	0
1	0.3
2	1.0
3	1.0
4	1.0

V_5 = Species composition of woody vegetation (trees and/or shrubs) *(Allen 1982)*

Vegetation Class	Description	HSI
A	Woody vegetation dominated (>50%) by one or more of the following species: aspen, willow, cottonwood, alder	1.0
B	Woody vegetation dominated by other deciduous species	0.6
C	Woody vegetation dominated by coniferous species	0.2

Wood Duck HSI

The Habitat Suitability Index for wood duck is described in the following equation and is applicable for winter cover for wood ducks. Wood ducks are year-round residents in Western Oregon, but may move between wintering and nesting areas. It is anticipated that the project area will be most suitable for winter habitat.

$$\mathbf{HSI_{Wood\ Duck} = V_1}$$

V_1 = Percent of the water surface covered by potential brood cover (shrub cover, overhanging tree crowns within 1 m (3.3 ft) of the water surface, woody downfall, and herbaceous) ***(Sousa and Farmer 1983)***

Percent surface covered	HSI
0	0
25	0.4
40	0.8
50-75	1.0
85	0.6
100	0

Yellow Warbler HSI

The Habitat Suitability Index for yellow warbler is described in the following equation. None of the variables are considered to be so limiting that a score of zero would render the habitat totally unsuitable.

$$\mathbf{HSI_{Yellow\ Warbler} = (V_1 + V_2 + V_3 + V_4) / 4}$$

V_1 = Percent deciduous shrub cover ***(Schroeder 1982)***

% Cover	SI
0	0
25	0.4
50	0.75
60	1.0
80	1.0
90	0.8
100	0.6

V_2 = Percent overall canopy cover (*Schroeder 1982*)

% Canopy Cover	SI
0-20	0
20-40	0.1
40-60	0.2
60-70	0.8
70-80	1.0
80-100	0.1

V_3 = Average height of deciduous shrub canopy height *(Schroeder 1982)*

Canopy Height (m)	SI
0	0
1	0.5
2+	1.0

V_4 = Percent canopy comprised of hydrophytic shrubs *(Schroeder 1982)*

% Hydrophytic Shrubs	SI
0	0.1
25	0.3
50	0.55
75	0.8
100	1.0

Native Amphibian HSI

The Suitability Index for native amphibians is described in the following equation. None of the variables are considered to be so limiting that a score of zero would render the habitat totally unsuitable. Both aquatic and riparian variables are included as both components provide habitat for key life history stages.

$$\mathbf{HSI_{Native\ Amphibians} = (V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7) / 7}$$

V_1 = % Area with permanent water *(modified from WDFW 1997)*

% Area of Permanent Water	SI
0	0
10	0.6
25-40	1.0
>50	0.2

V_2 = Water current in breeding areas during spring *(modified from WDFW 1997)*

Water Velocity (m/s)	SI
0	0.6
0.05	1.0
0.1	0.2
>0.25	0

V_3 = % Area with emergent or submergent wetland/aquatic vegetation *(WDFW 1997)*.

% Area Wetland Vegetation*	SI
0	0
25	0.5
>50	1.0

**Areas dominated by reed canary grass and/or purple loosestrife cause HSI = 0.2.*

V_4 = % Ground cover along the water's edge, including debris, overhanging vegetation, undercut banks, etc. ***(WDFW 1997)***

% Cover	SI
0	0
25	0.3
50	0.6
75	0.9
100	1.0

V_5 = Width of riparian zone ***(WDFW, 1997)***

Width (m)	SI
0	0
10	0.2
30	0.6
>60	1.0

V_6 = Maximum water temperature during low flows ***(Graves & Anderson 1987; USFWS 2002; Christensen 2004)***

Temperature (°C)	SI
0	0
5	0.5
10	1.0
15	1.0
20	0.5
25	0

V_7 = Land use within 200 meters of the wetland edge ***(WDFW 1997)***

Land Use	SI
Developed	0
Row Crops	0.1
Managed Pasture	0.5
Fallow Grass/herbs	0.7
Shrubs/trees	1.0

Native Salmonids HSI

The Suitability Index for anadromous salmon is described in the following equation:

$$\mathbf{SI_{fish} = (FV_1 + FV_2 + FV_3 + FV_4) /4}$$

V_1 = Maximum water temperature during low flow *(Raleigh, et al. 1984)*

Temperature (°C)	SI*
0	A = 0, B = 0**
5	A = 0.5, B = 0.3
10	A = 1.0, B = 0.9
15	A = 0.9, B = 1.0
20	A = 0.5, B = 0.9
25	A = 0, B = 0

***A** = prespawning adults, **B** = juveniles
**Average the adult and juvenile values for V_2

V_2 = Percent pools during low water period *(Raleigh, et al. 1986)*

Percent Pools	SI
0	0.2
25	0.6
50	1.0
75	0.9
100	0.2

V_3 = Instream cover (LWD) present *(modified from McMahon, 1983)*

Instream cover (% of surface area)	SI
0	0.1
10	0.2
20	0.4
30	0.8
40	1.0

V_4 = Predominant substrate size in riffle or run areas *(Raleigh, et al. 1984)*

Class	Description	SI
A	Rubble or small boulders predominant; limited amounts of gravel, large boulders, or bedrock	1.0
B	Rubble, gravel, boulders, and fines occur in approximately equal amounts or gravel is predominant	0.6
C	Fines, bedrock, or large boulders are predominant. Rubble and gravel are < 25%	0.3

American Kestrel HSI

The Suitability Index for the American kestrel is described in the following equations. If the site is currently a grassland or agricultural field, use the grasslands equation; if the site is a riparian zone use the riparian equation.

$$\mathbf{SI_{Riparian} = \text{the lower of } X_1 \text{ or } X_2;\ X_1 = (V_1 * V_2)^{1/2};\ X_2 = V_2}$$

V_1 = Distance to woodland (USFWS 1978)

Distance (miles)	SI
1	1.0
2	0.8
3	0.4
4	0.0

V_2 = Distance to suitable perching sites (USFWS 1978)

Distance (miles)	SI
1	1.0
2	0.8
3	0.4
4	0.0

V_3 = Distance to open land (USFWS 1978)

Distance (miles)	SI
1	1.0
2	0.8
3	0.4
4	0.0

V_4 = Average dbh of trees (USFWS 1978)

dbh (inches)	SI
6	0.0
12	0.8
18	1.0
24	1.0

4.8 Combined HSI Model

An HSI will result for each individual species or guild. To combine the individual species' HSIs into one HSI suitable to use in a cost effectiveness and incremental cost analysis, the following equation is recommended:

$$\mathbf{HSI_{Combined} = (HSI_{\mathit{turtle}} + HSI_{\mathit{chub}} + HSI_{\mathit{beaver}} + HSI_{\mathit{wood\ duck}} + HSI_{\mathit{yellow\ warbler}} + HSI_{\mathit{native\ amphibians}} + HSI_{\mathit{salmon}} + HSI_{\mathit{kestrel}}) / 8}$$

5. USE OF MODEL

The intended use of this model is to formulate site-specific restoration actions and collect data at each site for input into the model. Each HSI will be calculated separately and the results will be reported. Then, the results from each HSI will be combined to test the validity of the Floodplain Habitat Index.

Because of the potential limitations of HSI models in predicting improved conditions and hence, survival, of species or guilds, it is recommended that many of the key parameters included in these models be included in the monitoring and adaptive management plan to be developed for the project to provide further data that can be used to validate or modify these models.

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