A combined hydraulic-habitat model for assessing restoration of fish passage at a low head dam

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Abstract

This project developed a combined hydraulic-habitat model for assessing fish passage options for the Long Tom River located in the Willamette Valley of western Oregon. This work was undertaken as part of a habitat restoration feasibility study in collaboration with the City of Monroe and the Confederated Tribes of Siletz Indians. In the 1940's, the Long Tom River channel rectification and improvement project included channel dredging, straightening, channel embankments, and construction of three drop structures to improve channel capacity and limit erosion for receiving outflows from Fern Ridge Dam (river mile 23.6). The Monroe drop structure (river mile 6.9) is the first impediment to upstream fish passage by several salmonid species and Pacific lamprey. A city-owned park with wetland areas connected to the main channel via a network of culverts is adjacent to the drop structure. Restoring fish passage was the primary goal, and we also sought options for improving the connectivity between the channel and wetland areas in the city park. Alternatives considered included dam removal, several bypass-channel options, rock ramp variations, and combinations of these features. A two-dimensional hydraulic model was developed for a 5-mile river reach covering 2.5 square miles consisting of approximately 48,000 grid cells. Cell sizes of the unstructured grid ranged from 15 feet in the river channel up to 100 feet in floodplain regions. Upstream fish passage potential was greatest during the winter months. Model flows included 72, 800, and 4,360 cubic feet per second, the 95%, 50%, and 5% daily flow duration values, respectively, based on nearby gage data over an 80-year period. Habitat suitability index (HSI) curves were obtained from literature and focused on adult cutthroat trout and juvenile Chinook salmon preferences with respect to water depth and velocity. At each model grid cell, the hydraulic model's output of velocity and depth were used to calculate a corresponding habitat value based on the HSI curves. Habitat scores were normalized by the area of the individual model cells and then summed over the total model domain for each HSI curve. The fish passage efficiency of each alternative, represented by a factor ranging from 0.5 for no action to 0.95 for alternatives that included full removal of the drop structure, was qualitatively assessed based on the degree to which each alternative would likely accommodate fish passage. The passage efficiency factor was multiplied by the total habitat score to estimate the overall benefit to fish. Non-adjusted habitat scores typically scaled with the length of bypass channel added under each alternative for the median and high winter flows. Rock ramp features scored better under low flows where bypass channels no longer offered adequate flow-through capacity. Application of fish passage scaling factors favored alternatives that included removal of the drop structure, with greater overall scores for those that also increased access to side channel habitat. Results of our combined hydraulic-habitat model allowed us to implement a tiered approach in evaluating habitat restoration alternatives. The model-predicted habitat values for the top five ranking alternatives typically increased two-fold over the no action alternative.

Introduction

Low head dams are common in low gradient rivers in the United States that were installed for milling operations, flood protection, hydropower generation, water supply, irrigation, and navigation. Negative impacts associated with low head dams relate to the disruption in ecological connectivity and safety concerns (ASCE 2022; Wohl et al. 2015). River restoration efforts at low head dams typically focus on restoring connectivity by removal or fishway options (Aadland 2010; Major et al. 2017; Zielinski and Freiburger 2021) and the U.S. Army Corps of Engineers (USACE) engages in such restoration efforts using a planning process that involves a cost effectiveness and incremental cost analysis (Fischenich 2011; Oliver et al. 2018).

One of the primary inputs to the USACE's planning process is the quantification of environmental benefits of potential alternatives. Models to quantify environmental benefits need to have an ecologically relevant output metric, measure both quality and quantity of the ecological value, and have an output resolution that allows discernment among alternatives considered (Stakhiv et al. 2003). Models that quantify environmental benefits of fish passage primarily use hydraulic variables to assess habitat conditions, which does not produce a direct output of fish utilization of the passage alternative but rather an index of potential preference of the fish. However, the correlation between hydraulic conditions and habitat preferences of various species of fish have been established through the extensive development of habitat suitability index (HSI) curves (Stakhiv et al. 2003). Furthermore, habitat index models spatially linked with process-based hydraulic models have been extensively used to evaluate how changes in flow regimes affect habitat conditions and fish populations (Crowder and Diplas 2006; Clark et al. 2008; Baki et al. 2014; Haro et al. 2015; Tang et al. 2021).

A combined hydraulic-habitat index model was developed for this study to assess fish passage alternatives at a low head dam on the Long Tom River located in western Oregon. This effort was a part of a USACE Section 1135 Ecosystem Restoration project in collaboration with the City of Monroe, Oregon, and the Confederated Tribes of Siletz Indians. The two goals of this project were to facilitate upstream passage of three target fish species (adult cutthroat trout, juvenile Chinook salmon, and Pacific lamprey) at the Monroe drop structure (low head dam), as well as improve aquatic habitat of the Long Tom River and adjacent floodplain in the vicinity of the dam. In developing the evaluation criteria used to assess alternatives, it was specified that the modeling approach for quantifying environmental benefits be able to assess both local and river reach spatial scales. The combined hydraulic-habitat model developed for this project combined the depth and velocity results from a two-dimensional (2D) hydraulic model, four HSI curves, and a fish passage utilization factor that mimics some of the functionality of the Hydrologic Engineering Center's Ecosystem Functions Model (HEC-EFM, USACE 2020).

Study Area

The Long Tom River is a tributary of the Willamette River located in western Oregon (Figure 1). Fern Ridge Dam (river mile 23.6) was completed in 1941 and captures approximately 70% of the 410 square mile watershed of mixed forest and agricultural lands. The Long Tom River downstream of Fern Ridge Dam was extensively modified between 1943 and 1951 to increase the flow conveyance capacity of the river so that it could better accommodate releases from Fern Ridge Dam. Modifications included channel dredging, straightening, building of embankments along the channel, and the construction of three drop structures (low-head dams) that effectively reduced the Lower Long Tom River's length from 36 to 23 miles.

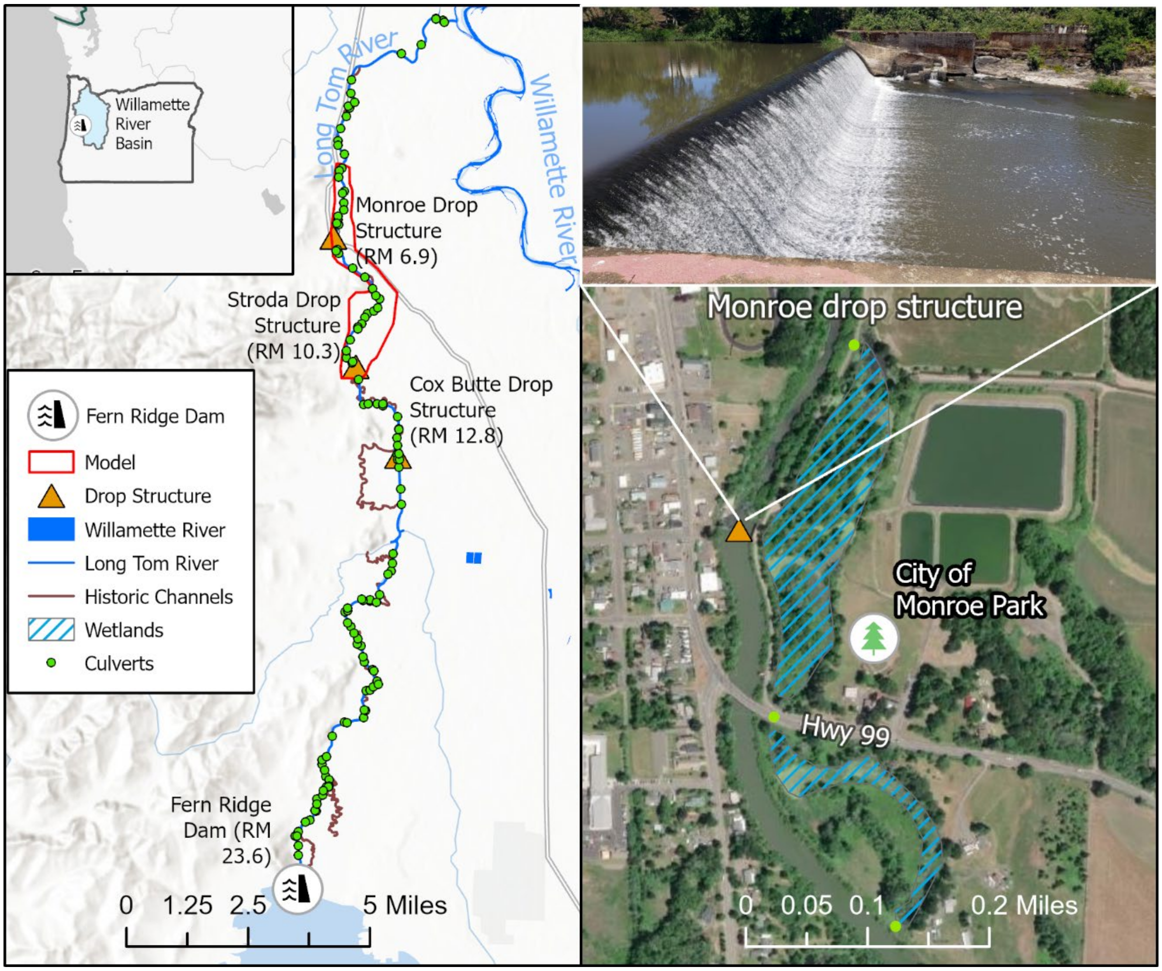

Figure 1. Map of study area including the Long Tom River downstream of Fern Ridge Dam and the Monroe drop structure

The Monroe drop structure (river mile 6.9) is the most downstream of the low head dams and was constructed at the site of an existing mill dam. It is the first impediment to upstream fish passage encountered on the Long Tom, and there are current and planned restoration efforts for the two upstream drop structures once there is passage at Monroe. The Long Tom Watershed Council (LTWC) estimates that approximately 106 miles of riverine habitat will be available once upstream fish passage is available at these three drop structures (LTWC 2022). The height of the Monroe drop structure is 9.5 feet with a crest elevation of 277.5 feet (NAVD88, North American Vertical Datum of 1988). The historic headrace and fish ladder features from the mill dam were incorporated into the Monroe drop structure, but they are currently located on private land, considered non-functional for fish passage, and were ruled out as a viable option for restoration in this study.

The channel modifications from the 1940s included the installation of 144 culverts with diameters ranging between one and four feet being installed through the embankments. The culverts connect to relic oxbow channels, small tributaries, and allow for water to enter in and out of the floodplain during high flows providing hydrodynamic stability on both sides of the embankments but limited ecological connectivity. Near the Monroe drop structure, there are two embankment culverts (river mile 6.6 and 7.2) that connect to the wetland features, and a culvert under the

Highway 99 roadway (Figure 1) creates a potential flow path through the City of Monroe Park's wetlands. One of the desired outcomes expressed by the project sponsors was to improve the floodplain connectivity in the vicinity of the City of Monroe Park.

Fish Passage Alternatives

The alternatives considered in this study included full and partial removal of the drop structure, removal of portions of the river embankment, as well as fishway features with the constructed features boundary limited to the river channel and the City of Monroe Park. After an initial screening, the alternatives considered in this study included complete removal of the drop structure, a rock ramp at the drop structure, and various bypass channels that connected to the wetland features on the City of Monroe Park. Brief descriptions of the alternatives considered are listed in Table 1.

Table 1. Fish passage alternatives assessed in this study

Alternative	ID	Description
No action	EC	Existing conditions and assumed future without project
Removal of drop structure	T	Removal of the drop structure (leaving historic fish ladder) and channel regrading
Rock ramp at drop structure	R1	Notching of the drop structure (1.5 feet height by 70 feet wide) with concrete ramp and rock riffle extending 650 feet downstream.
Short bypass channel	B1	Approximately 650-foot channel through City of Monroe Park. Inlet and outlet close to drop structure
Long bypass channel	B2	Approximately 2,600-foot channel through City of Monroe Park. Inlet and outlet close to drop structure
Medium bypass channel with downstream rock ramp	B3DR	Approximately 1,400-foot channel with outlet 900 feet downstream of drop structure with small rock ramp (riffle) in channel and bypass outlet
Downstream rock ramp with removal of drop structure	DRT	Removal of the drop structure with downstream rock ramp (riffle) in same location as B3DR
Short bypass channel with removal of drop structure	B1T	Combination of B1 and T
Long bypass channel with removal of drop structure	B2T	Combination of B2 and T
Medium bypass channel, downstream rock ramp, and removal of drop structure	B3DRT	Combination of B3DR and T

Methods

Hydraulic Model

The development of the 2D hydraulic model involved creating several model components that include a hydrologic analysis of design flows, terrain model, numerical grid, hydraulic structures, and an unsteady flow model. These model components were developed using existing data sources. The level of detailed applied to hydraulic model components were performed at a level suited for this feasibility study and do not represent any significant restoration design considerations. The hydraulic models used for this study were developed using HEC's River Analysis System (HEC-RAS, version 6.1).

Three flow regimes were simulated based on guidance set by the National Marine Fisheries Service (NMFS 2022) that represented winter low, median, and high flows defined by flow duration analysis of daily average flows that are exceeded 95%, 50%, and 5% of the time, respectively. Information provided by the LTWC suggested that winter months had the greatest potential for upstream fish passage at Monroe. Daily average flow data from 6-Sep-1939 to 14-Dec-2021 was obtained from the U.S. Geological Survey (USGS) streamflow gage at Monroe, Oregon, gage number 14170000 (USGS 2022). Flow duration exceedances were calculated for both the year-round and the winter (01-October to 01-April) periods using HEC-Statistical Software Package (HEC-SSP, version 2.2) with results listed in Table 2. The 95%, 50%, and 5% exceedance flows were 72, 800, and 4,360 cubic feet per second, respectively, that represent winter low, medium, and high flow events.

Table 2. Flow duration exceedance values

Percent time exceeded (%)	Flow, year-round (cubic feet per second)	Flow, winter (cubic feet per second)
99	20	26
95	30	72
90	37	142
80	50	240
50	230	800
20	1,080	2,160
10	2,240	3,500
5	3,540	4,360
2	4,550	5,080
1	5,110	5,730
0.5	5,740	6,340
0.2	6,540	7,380

The existing conditions terrain model was developed from a variety of topographic data sources that include Light Detection and Ranging (LiDAR) data from 2008 covering the entire watershed, cross section surveys from 1988 and 2013 on the lower 20 river miles of the Long Tom River, and single beam sonar survey of the pool behind the Monroe drop structure in 2021. The various topographic data sources were combined into a single digital elevation model (DEM) using tools available in ArcGIS and HEC-RAS Mapper and resampled into a single DEM with a spatial resolution of 3 feet and all elevations are referenced to the NAVD88 datum.

Terrain models for the alternatives listed in Table 1 were made using the existing conditions terrain model as the starting point. DEM editing tools in HEC-RAS Mapper were used to create three individual bypass channels through the City of Monroe Park, create wedge features representing rock ramps, and smooth the river channel slope in the vicinity of the drop structure for alternatives where the drop structure was removed. The alignments of the bypass channels were developed with consultation with the project sponsors and stakeholders. Elevations along the Long Tom River centerline were extracted for each terrain model that depicts the magnitude of slope changes created by rock ramp features and channel smoothing applied to alternatives with the drop structure removed (Figure 2).

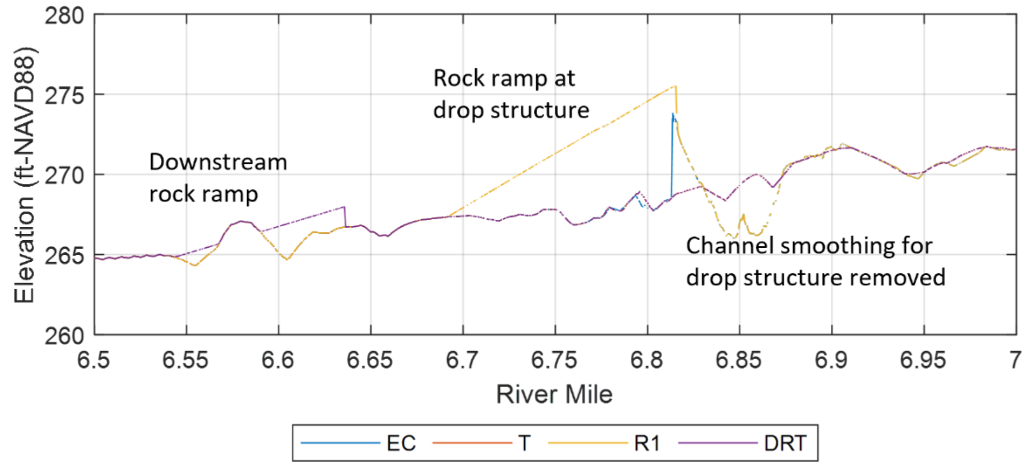

Figure 2. Longitudinal profile of terrain models along the centerline of the Long Tom River

The numerical model domain spanned 5 river miles covering an area of 2.5 square miles starting at the Stroda drop structure (river mile 10.3) and extending downstream to river mile 4.5 (2.4 miles downstream of Monroe). The downstream extent was chosen to be far enough downstream of the project area as to not affect the results of the hydraulic model and to avoid backwater effects from the Willamette River that would add complexity in selecting boundary conditions for the model. The 2D unstructured grid consisted of approximately 48,000 cells with cell sizes ranging from 15 feet in the river channel up to 100 feet in floodplain regions.

A hydraulic roughness layer was developed based on the 2016 National Land Cover Dataset (NLCD) where the Long Tom River channel and a 100-foot riparian buffer were digitized into the NLCD data. Manning's roughness values were assigned to land cover classifications based on guidance provided in HEC-RAS 2D User's Manual (USACE 2022) and user defined land cover polygons were added to represent the City of Monroe Park wetlands, as well as rock ramp features. The relevant Manning's n values were set to 0.035 in the river channel, 0.07 in the riparian region (embankments are heavily vegetated), 0.06 in the City of Monroe Park, 0.04 in the wetlands, and 0.05 for rock ramp features.

Hydraulic structures included in the model were the Monroe and Stroda drop structures, the Highway 99 bridge, and three embankment culverts with diameters larger than 1.5 feet (located at river miles 6.5, 8.4, and 8.5). The Monroe and Stroda drop structures were specified in the model as weirs and were simulated using 2D flow equations. The flow under the Highway 99 bridge was simulated using the 1D energy method with the bridge geometry consisting of three pier bents and a 5-foot-thick bridge deck with a curved alignment inferred from aerial imagery. The Highway 99 roadway and embankment culverts were simulated as 1D concrete pipe culverts with entrance and loss coefficients assumed to be 0.5 and 1, respectively, Manning's n values were assumed to be 0.015, and invert elevations were inferred from the terrain model.

The 2D hydraulic model simulations used the diffusive wave approximation for computational expedience based on initial simulations comparing results to simulations using the full shallow water equations. The Courant number approximation suggested a time step of 12 seconds, which was increased to 30 seconds based on sensitivity simulations. The upstream flow boundary condition was based off a simulated hydrograph developed for a dam breach model scaled down to the desired flows for this study. The simulations occurred over a six-day period where the flow was ramped up to the peak flow over three days and then maintained at the peak flow for the remaining three days. The downstream flow boundary condition was set as a normal flow condition with an assumed river slope of 0.001. Initial conditions were established by running a simulation with a steady flow of 30 cubic feet per second for six days. The ending water surface elevation throughout the model domain was used as the initial condition file for subsequent simulations. The simulated flow variables such as water depth and velocity all reached steady state conditions during the three-day period where the flows were held at the desired flow. The steady state flow conditions of the last simulated time step were used to calculate habitat value in the combined hydraulic-habitat index model.

Habitat Suitability Index Curves

HSI curves used to quantify habitat value were selected in consultation with the project co-sponsors. Four HSI curves were selected with two representing preferred flow depth and velocity for adult cutthroat trout, *Oncorhynchus clarki* (Braithwaite 2011) and two representing preferred flow depth and velocity for juvenile Chinook salmon, *Oncorhynchus tshawytscha* (White, et al. 2022). Water depth and velocity preferences for Pacific lamprey, *Entosphenus tridentatus*, passage would be met using the same criteria as those for the juvenile Chinook salmon, as their optimal ranges overlap (LTW 2020). Thus, there was no separate HSI curve evaluated for Pacific lamprey in the combined hydraulic-habitat index model.

The HSI curve based on flow velocity for adult cutthroat trout in the Braithwaite (2011) study was developed using near bed velocity measurements, whereas the White et al. (2022) study used average velocity values from a hydraulic model. Typically, near bed velocity measurements are lower than the average velocities calculated in a hydraulic model as vertical velocity profiles theoretically approach zero at the river bed and increase subtantially over centimeters away from the bed. The velocity values used in the HSI curves of the Braithwaite (2011) study were adjusted to represent average velocity values using information from a separate study (Al-Chokhachy and Budy 2007) that listed both near bed and average velocities and was cited by the Braithwaite (2011) study. The near-bed velocities were multipled by a factor of 2.1 to estimate the average flow velocities for the adult cutthroat trout HSI curve.

The HSI curves used in the combined hydraulic-habitat index model are depicted in Figure 3. Optimal water depth ranged from 1.3 to 2.3 feet for adult cutthroat trout and from 0.15 to 2.3 feet for juvenile Chinook salmon. Unsuitable water depth for adult cutthroat trout occurred for depths greater than 2.8 feet whereas the juvenile Chinook salmon had usable habitat at depths greater than 4 feet. The optimal flow velocity range was similar between the adult cutthroat trout and juvenile Chinook salmon, with ranges between 0 to 1.4 and 0.7 to 1.3 feet per second, respectively. Unsuitable habitat was associated with flow velocities of greater than 2.1 and 3.3 feet per second for the adult cutthroat trout and juvenile Chinook salmon, respectively.

Quantification of Habitat Value

An algorithm was developed to quantify habitat value for all combinations of alternatives, flows, and HSI curves. For each simulation, habitat value was calculated for each grid cell in the model. The habitat value for each grid cell was divided by the area of each cell and then summed over the model domain for each HSI curve. The summed values for each HSI curve were added together to give a total habitat value in units of habitat units per square foot. The HSI curves depicted in Figure 3 only address preferred habitat for the target fish species and do not factor in upstream passage efficiency. A fish passage factor was multiplied by the total habitat value to get the scaled total habitat value (in habitat units per square feet). The fish passage scaling factor was established in consultation with USACE and sponsor fish biologists involved with the project. Scalar values were 0.5 for the no action, 0.7 for the long and medium bypass channels, 0.75 for the short bypass channel, 0.85 for the rock ramp, and 0.95 for alternatives where the drop structure was removed.

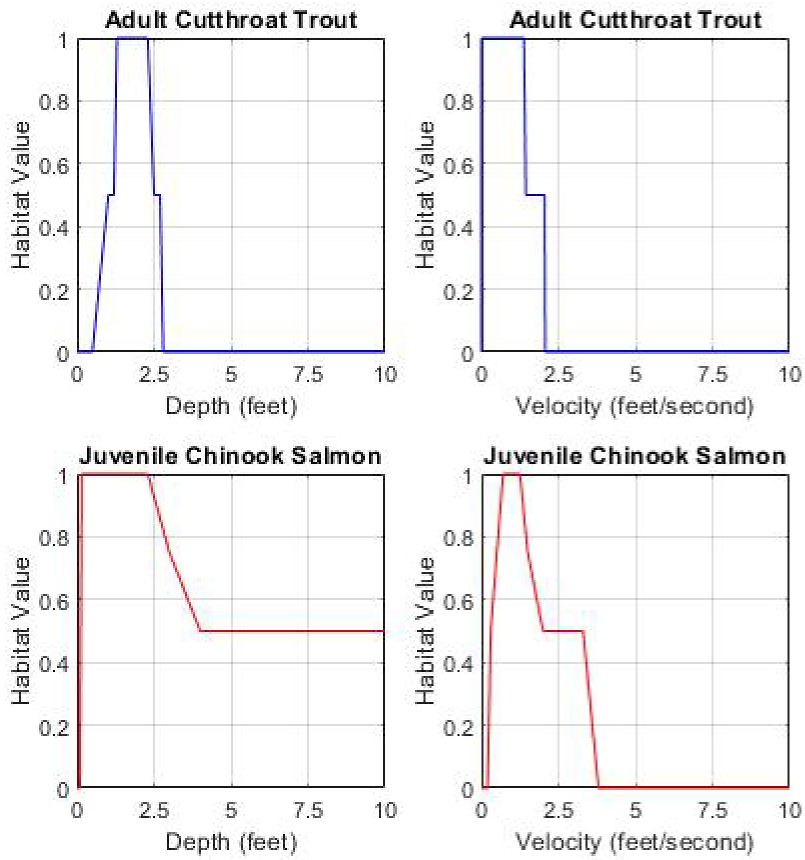

Figure 3. Habitat suitability index curves for adult cutthroat trout and juvenile Chinook salmon

There was a total of 120 simulations representing various combinations of the ten alternatives (Table 1), three flows rates (72, 800, and 4,360 cubic feet per second), and four HSI curves (Figure 3). The algorithm gathered all the inputs, performed calculations, exported GIS files of habitat value results, and generated summary tables of the total habitat value and scaled total habitat values. The input files included the HEC-RAS plan file for each simulation (a hierarchical data format, .hdf file), a GIS shape file (.shp file) of the numerical grid that was exported from HEC-RAS (one for each alternative), and text files that tabulated the HSI curves. The outputs were saved as GIS shape files of the habitat values and tables of the total and scaled total habitat scores.

Results

The no action alternative consists of no change in the drop structure with flow regimes forecasted to largely mimic current conditions. Maps of habitat value for the four HSI curves at 800 cubic feet per second (median winter flow) suggest that suitable water depths for adult cutthroat trout are limited to the river channel edges, whereas there are generally suitable conditions for the juvenile Chinook salmon throughout the channel both upstream and downstream of the Monroe drop structure (Figure 4-a,c). Flow velocities were segmented with suitable habitat for the adult cutthroat trout found upstream of the drop structure in the slower pool region and downstream of the drop structure for the juvenile Chinook salmon in the more natural river conditions (Figure 4-b,d). The total habitat value score is mathematically the same as the mean value when mapped for individual cells that depicts a habitat value of less than 0.5 upstream of the drop structure, as well as a large portion of the river downstream of the drop structure. There were some intermittent regions with values less than 0.75 typically along the riverbanks (Figure 4-e).

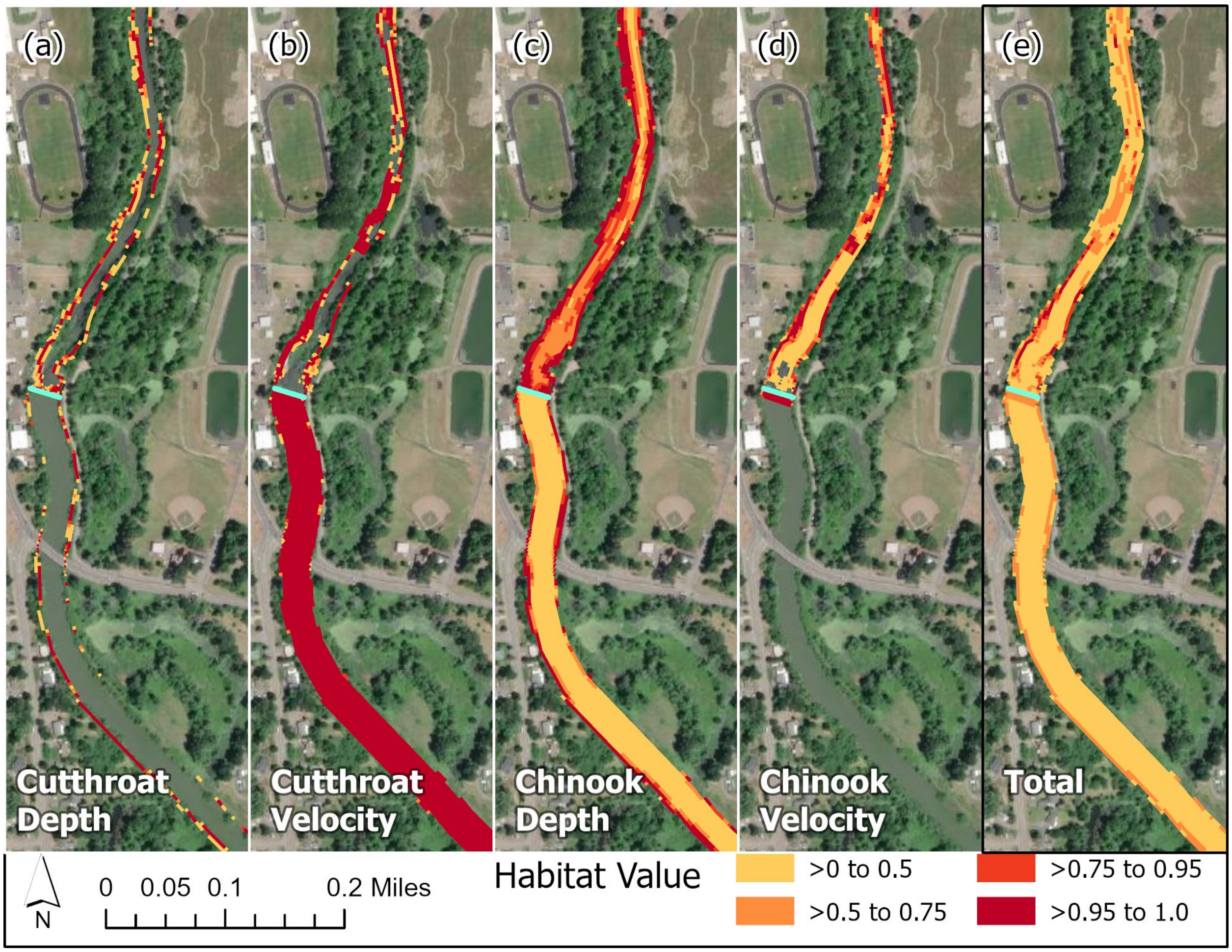

Figure 4. Maps of habitat value of each habitat suitability index curve for the no action alternative at the median winter flow of 800 cubic feet per second

The nine alternatives that included fish passage all increased the suitable habitat area upstream and downstream of the Monroe drop structure relative to the no action alternative for the three flow regimes assessed. Mapped results of the total habitat value at the median winter flow of 800 cubic feet per second depicted high values along the channel edges of the Long Tom River and bypass channels (Figure 5). Alternatives that retained the Monroe drop structure (R1, B1, B2, and B3DR, Figure 5-a,b,c,d) depict patches of good habitat between the pooled area of the Long Tom River and the bypass channels. The long bypass alternative (B2) had the highest value habitat among alternatives that extended throughout the bypass channel in the wetland region (Figure 5-c).

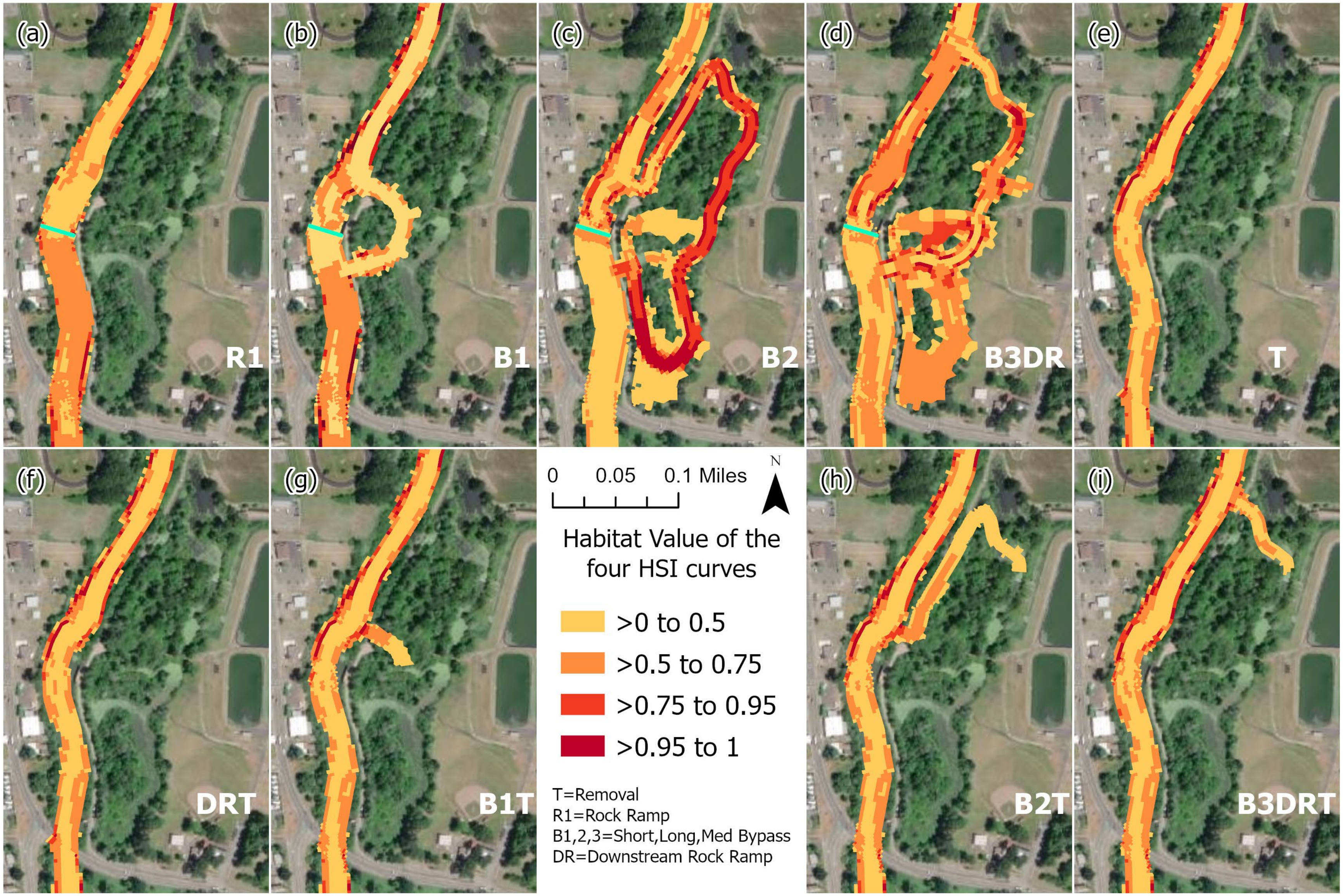

Figure 5. Maps of the total habitat value among alternatives at the median winter flow of 800 cubic feet per second

Alternatives that removed the drop structure (T, DRT, B1T, B2T, and B3DRT Figure 5-e,f,g,h,i) were similar with respect to habitat value in the vicinity of the City of Monroe. The alternatives that included removal of the drop structure and a bypass channel (B1T, B2T, and B3DRT) did not have connecting flow in the bypass channels at 800 cubic feet per second (Figure 5-g,h,i), but they did connect under high winter flows of 4,360 cubic feet per second (data not shown). When the flow did not connect through the bypass channels, there was a backwater pool formed on the downstream side of the removed drop structure that connected to the wetland regions of the City of Monroe Park.

The scaled total habitat values with the passage scalar applied were ultimately used to compare alternatives. At the low winter flow of 72 cubic feet per second, the medium bypass with downstream rock ramp (B3DR) had the largest scaled habitat value but was mainly driven by the large habitat value for velocity HSI curves for both the adult cutthroat trout and the juvenile Chinook salmon (Table 3). Remaining alternatives all had similar total habitat values, so the passage factor was the driver for final rankings based on the scaled total habitat values.

Table 3. Habitat value results at the low winter flow (72 cfs)

Alternative	Trout Depth (HU/ft^2)	Trout Velocity (HU/ft^2)	Salmon Depth (HU/ft^2)	Salmon Velocity (HU/ft^2)	Total Habitat (HU/ft^2)	Passage Factor	Scaled Total Habitat (HU/ft^2)
B3DR	21.8	51.9	47.5	26.5	147.7	0.70	103.4
B1T	20.8	13.5	42.6	7.4	84.3	0.95	80.1
B3DRT	21.6	13.1	43.5	6.0	84.2	0.95	79.9
B2T	20.8	13.3	42.6	7.1	83.8	0.95	79.6
DRT	20.3	9.2	41.1	6.0	76.6	0.95	72.8
T	20.3	9.3	41.0	6.0	76.6	0.95	72.7
R1	20.4	12.2	44.8	7.2	84.6	0.85	71.9
B1	20.9	9.0	45.4	5.1	80.4	0.75	60.3
B2	21.9	8.5	48.6	3.3	82.2	0.70	57.6
No Action	20.1	10.0	45.1	3.9	79.1	0.50	39.5

Notes: Alternatives ranked from high to low based on the Scaled Total Habitat score; HU/ft^2 = habitat value per square feet, cfs = cubic feet per second

At the median winter flow of 800 cubic feet per second, the top three ranked alternatives were B2T, B3DRT, and B1T, all of which would remove the Monroe drop structure and include a bypass channel (Table 4). These alternatives achieved the highest habitat value by restoring fish passage using the most efficient means of removing the drop structure, and increased habitat area by connecting to wetland regions adjacent to the City of Monroe Park. The largest total habitat values were associated with the median and long bypass channels (B3DR and B2), but the upstream scaling factor greatly reduced their scaled total habitat value relative to the other alternatives (Table 4). At the high winter flow of 4,360 cubic feet per second, the total habitat value among alternatives were relatively similar and the upstream passage factor drove the scaled total habitat values (Table 5).

Table 4. Habitat value results at the median winter flow (800 cfs)

Alternative	Trout Depth (HU/ft^2)	Trout Velocity (HU/ft^2)	Salmon Depth (HU/ft^2)	Salmon Velocity (HU/ft^2)	Total Habitat (HU/ft^2)	Passage Factor	Scaled Total Habitat (HU/ft^2)
B2T	15.6	27.2	49.7	34.1	126.6	0.95	120.3
B3DRT	14.7	27.3	48.5	34.5	125.0	0.95	118.8
B1T	14.9	27.2	48.4	34.1	124.7	0.95	118.4
R1	13.8	34.8	47.9	38.5	135.0	0.85	114.7
DRT	13.6	26.2	45.7	33.4	118.9	0.95	113.0
T	13.7	26.2	45.7	33.2	118.8	0.95	112.9
B3DR	14.1	51.3	50.5	37.2	153.1	0.70	107.2
B2	15.4	51.5	52.4	28.3	147.7	0.70	103.4
B1	13.0	35.9	48.2	37.8	135.0	0.75	101.2
No Action	12.4	49.6	47.3	21.5	130.8	0.50	65.4

Notes: Alternatives ranked from high to low based on the Scaled Total Habitat score; HU/ft^2 = habitat value per square feet, cfs = cubic feet per second

Table 5. Habitat value results at the high winter flow (4,360 cfs)

Alternative	Trout Depth (HU/ft^2)	Trout Velocity (HU/ft^2)	Salmon Depth (HU/ft^2)	Salmon Velocity (HU/ft^2)	Total Habitat (HU/ft^2)	Passage Factor	Scaled Total Habitat (HU/ft^2)
B2T	13.9	38.0	65.4	33.1	150.4	0.95	142.9
B3DRT	13.2	35.0	63.8	35.9	148.0	0.95	140.6
B1T	11.8	32.8	61.2	32.3	138.2	0.95	131.2
T	11.2	31.4	58.2	31.0	131.7	0.95	125.1
DRT	11.1	31.4	58.3	30.9	131.7	0.95	125.1
B3DR	12.8	48.1	64.7	41.0	166.6	0.70	116.6
R1	11.1	32.3	60.3	32.6	136.3	0.85	115.9
B1	13.1	33.3	64.5	33.3	144.2	0.75	108.1
B2	13.0	36.7	65.6	36.7	152.0	0.70	106.4
No Action	11.1	45.5	60.1	39.8	156.5	0.50	78.2

Notes: Alternatives ranked from high to low based on the Scaled Total Habitat score; HU/ft^2 = habitat value per square feet, cfs = cubic feet per second

Overall, the total habitat values were similar among alternatives with the passage factor providing significant differentiation among the alternatives. The alternatives that removed the Monroe drop structure had the largest passage factors as it would facilitate the most direct route for passage. The rock ramp and alternatives that included bypass channels had lower passage factors because they would require fish to navigate new river elements that would disorient at least a portion of the fish population transiting the river. The long and median bypass channels had the lowest passage factors due to the length of the new channel segment, but this was offset somewhat by the increase in access to quality wetland habitat. The alternatives that combined removal of the drop structure with a bypass channel typically resulted in high scaled total habitat value even when the bypass channel was not fully connected upstream to downstream at low and median flows. This outcome highlights the added habitat value of connecting to side-channel wetlands that will increase the area of optimal habitat accessible to fish, even if upstream fish passage can be achieved solely by removing the Monroe drop structure.

Discussion

This study used a combined hydraulic-habitat model for evaluating restoration alternatives related to upstream fish passage at a low head dam as a part of a USACE Section 1135 ecosystem restoration project. The feasibility study focused on assessing alternatives to provide upstream fish passage at the Monroe drop structure on the Long Tom River with an additional goal of improving aquatic habitat. A 2D hydraulic model was developed for a 5-mile reach of the Long Tom River that included the City of Monroe Park adjacent to the drop structure that has wetlands currently connected to the main stem by culverts built through the channel embankments in the 1940s. Velocity and depth outputs from the 2D hydraulic model were used to calculate habitat value estimates using four HSI curves for the target species of adult cutthroat trout and juvenile Chinook salmon (Pacific lamprey were also a target species, but their HSI curve preferences overlapped with the other two). The total habitat value scores (sum of the individual HSI curves) were normalized to the numerical model cell size, summed over the model domain, and scaled using a fish passage factor to get the final scaled total habitat value used to assess alternatives. Overall, alternatives that included removing the Monroe drop structure ranked highest for the flow regimes considered. Alternatives with bypass channels that accessed the city park wetlands had high habitat values, but the passage factor favored alternatives where the drop structure was removed.

The scaled total habitat scores (Tables 3 through 5) provided a means to rank alternatives and provide a metric of environmental benefits for the cost effectiveness and incremental cost analysis (CEICA). The spatial mapping of the individual HSI habitat values and the total habitat value allowed for a qualitative assessment of the overall connectivity of suitable habitat among the alternatives. The alternatives that had bypass channels as the primary fish passage measure typically created hot spots of good habitat along bypass channels running through the City of Monroe Park's wetlands. The alternatives that removed the drop structure had more consistent habitat values throughout the river reach. Alternatives that removed the drop structure and included a bypass channel provided some connectivity between the main channel and the wetlands, but redundant bypass channels would only operate as true flow-through options for fish during high winter flows.

Based on preliminary CEICA analyses that included estimated costs for each alternative listed in Table 1, the removal of the Monroe drop structure (T) is the most cost-effective means for restoring fish passage. The incremental analysis suggests there is a substantial increase in the project cost for adding in a short bypass channel (B1T) as a secondary option. Currently, the project is nearing the stage of developing the tentatively selected plan (TSP). Once the TSP is fully articulated, the feasibility study can be completed. Given the high value of the habitat located in the City of Monroe Park's wetland areas, analyses are underway to assess the potential of improving the culvert system that connects the main channel to the wetland areas to determine whether this could further improve the habitat value under the most cost-effective alternative. It is likely that costs associated with culvert improvements will be significantly less than a bypass channel and will provide a more viable option for maximizing habitat benefits for fish as USACE continues working with project sponsors to finalize the plan.

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