SAN JOAQUIN RIVER RESTORATION PROGRAM

MINIMUM FLOODPLAIN HABITAT AREA

For Spring and Fall-Run Chinook Salmon

NOVEMBER 2012

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Acronyms and Definitions

1D	One-dimensional (depth and cross-section averaged)
2D	Two-dimensional (depth averaged)
Abundance	Number of fish present
ASH	Area of Suitable Habitat (subset of *TIA*)
Carrying Capacity	Number of fish a certain area can support
cfs	cubic feet per second
Cs	Suitable Cover
Cohort	a group of fish who share particular events during a particular time span
Cover	physical structure providing protection from predators
CV	California Central Valley
Ds	Suitable Depth
DWR	California Department of Water Resources
Emigration	Migrating from the specified location (i.e. emigration from the SJR)
ESHE	Emigrating Salmonid Habitat Estimation model
Existing *ASH*	Area of Suitable Habitat already present in the SJRRP prior to restoration
FL	Fork Length
HEC-RAS	Hydrologic Engineering Center River Analysis System
HSI	Habitat Suitability Index
HSI_C	Cover Habitat Suitability
HSI_D	Depth Habitat Suitability
HSI_T	Total Habitat Suitability
HSI_V	Velocity Habitat Suitability
km	kilometer
LiDAR	Light Detection And Ranging, an optical remote sensing technology
LOWESS	Locally Weighted Scatterplot Smoothing
mi	mile
N	number of grid cells within simulations domain
NAVD	North American Vertical Datum
NMFS	National Marine Fisheries Service
NRDC	Natural Resources Defense Council
Pre-smolt	A fish too young to migrate to the ocean
Rearing Habitat	Habitat that provides physical parameters (such as food and shelter) that support the development and growth of juvenile fish
Required *ASH*	Area of Suitable Habitat required by fish according to ESHE
RKM	River Kilometer
RM	River Mile
RST	Rotary Screw Trap
Settlement	Stipulation of Settlement in *NRDC, et al. v. Kirk Rodgers, et al.*
SH	Suitable Habitat
SJR	upper San Joaquin River from Friant Dam to the Merced confluence
SJRRP	San Joaquin River Restoration Program
Smolt	A young salmon ready to migrate to the ocean

Spawners	reproducing adult fish
SRH-2D	Sedimentation and River Hydraulics Two-Dimensional model
Sub-yearling	A salmon that emigrates from the river less than a year after emergence
TIA	Total Inundated Area
TINV	t-values of the Student's t-distribution
TS	Territory Size
Ts	Suitable Temperature
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
Vs	Suitable Velocity
WDFW	Washington Department of Fish and Wildlife
Yearling	A spring-run Chinook salmon that remained in the river for a year

1 EXECUTIVE SUMMARY

This study recommends a minimum amount of juvenile rearing habitat necessary to meet fall- and spring-run Chinook salmon targets for the San Joaquin River Restoration Program. Rearing habitat includes both main channel and floodplain habitat and provides physical parameters such as food and shelter to support the development and growth of juvenile fish. The results from this report will inform tradeoffs between impacts and benefits on ongoing floodplain alternative work (i.e. levee setbacks) for Phase 1 and 2 projects and long-term restoration efforts.

Four steps were involved in estimating the minimum rearing habitat requirements for fall- and spring-run Chinook salmon within the restoration reaches of the San Joaquin River. Calculating rearing habitat needs first involved applying the Emigrating Salmonid Habitat Estimation (ESHE) model to simulate the juvenile stages of future restored populations of spring-run and fall-run Chinook salmon in the San Joaquin River, and estimating their required reach-specific amount of suitable habitat (required SH). As a second step, 2D hydraulic modeling estimated the amount of already-available habitat in each San Joaquin River restoration reach that meets juvenile salmon stationary growth (rearing) and downstream movement (emigration) habitat requirements (available SH). This study defines suitable habitat, or the inundated area that meets fish needs, as the number of inundated acres meeting juvenile Chinook salmon depth, velocity, and cover requirements. Third, the suitable habitat (SH) deficit was estimated by subtracting the available suitable habitat in each reach from the required suitable habitat.

Suitable Habitat (SH) deficit = required SH – available SH

Only a portion of the total inundated area (TIA) will meet all the requirements for suitable habitat. The levee alignments will need to enclose an area greater than the suitable habitat area to obtain sufficient quantities of suitable habitat (see Figure ES-1). The fourth and final step determined the total inundated area.

Total Inundated Area (TIA) needed = SH deficit / (fraction of TIA that is suitable)

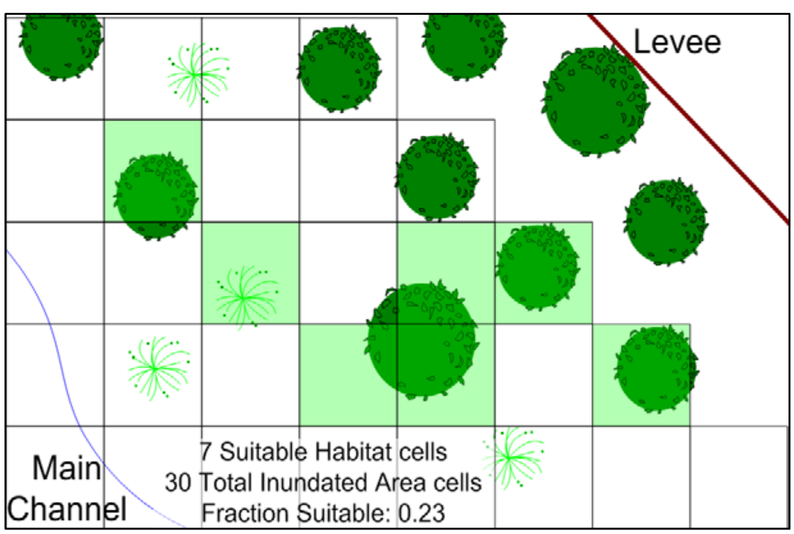

Figure ES-1: Example showing that Suitable Habitat (green) is a fraction of the total inundated area (all cells)

Rearing habitat deficit results by reach could guide habitat creation if floodplain were to be created in each reach. If only the projects specifically identified in the Stipulation of Settlement in *NRDC, et al. v. Kirk Rodgers, et al*. (Settlement) as including floodplain habitat are pursued, the suitable habitat deficit for Reaches 1-3 informs the floodplain acreages for the Reach 2B project and the suitable habitat deficit for Reaches 4-5 informs the floodplain acreage for the Reach 4B project.

No naturally reproducing population of Chinook salmon currently exists in the Restoration Area. Therefore, to address uncertainty in future juvenile Chinook salmon behavior, this study developed scenarios bracketing a reasonable range of potential conditions. Results allow assessment of the sensitivity and tradeoffs of different approaches to each of the calculation steps.

1.1 Required Suitable Habitat

The ESHE model used to calculate required Suitable Habitat simulates stationary growth (rearing) and downstream movement (emigration) of individual daily groups (cohorts) of juvenile spring-run and fall-run Chinook salmon (*Oncorhynchus tschawytscha*). The model tracks their numbers (abundance), average speed, size, the amount of territory needed per fish (territory size), and ultimately the amount of suitable habitat required to sustain the number of juvenile salmon present within a model reach. Model outputs provide daily estimates of the number of juvenile spring-run and fall-run Chinook salmon present in each model reach and the required area of suitable habitat needed to support them throughout the rearing and emigration period.

The ESHE model includes several parameters to track juvenile salmon abundance and habitat needs of daily cohorts. These functions include: (1) *initial abundance* –the number of juvenile Chinook salmon entering the model based on the target number of reproducing parent fish; (2) *initial timing and size* –the number of fish on each day that exit the spawning grounds and the average size of the fish exiting the spawning grounds; (3) *migration speed* –the daily downstream movement of juvenile salmon in each reach; (4) *survival* –the number of fish that avoid death each day in each reach; (5) *growth* –the daily growth and resulting size of juvenile salmon in each reach; (6) *territory size* –territory size requirements of juvenile salmon in each reach based on their size; and (7) *required SH* – the required suitable habitat needed to support the juvenile salmon present in each reach.

For the number of reproducing Chinook salmon, this analysis includes a fish population scenario for a growth population target of 30,000 adult and spring-run and 10,000 adult fall-run Chinook salmon (SJRRP, 2010) and a fish population scenario for the long-term target of 45,000 adult spring-run Chinook salmon and 15,000 adult fall-run Chinook salmon (Hanson, 2007; Hanson, 2008). The long-term target allows for variability in the fish population to meet the growth population target (an annual average).

Juvenile entry timing, fish speed, survival, and growth cannot be determined experimentally for the San Joaquin River as no naturally reproducing population of salmon currently exists. Data from the Stanislaus River informs fall-run Chinook salmon timing and all fish speeds, and Feather River data informs spring-run Chinook salmon timing, both of which are representative rivers with existing (extant) populations. Multiple scenarios bracketed the range of fish numbers (abundance).

Fish entry timing created a distribution of fish entering the system, which was used to group fish by the date of entry and then apply the same parameters to this group (cohort) as they moved downstream. Fish timing scenarios used included an Early scenario, to model fish moving out in large numbers at the beginning of the season and smaller numbers throughout the season, Late to represent fish moving out in consistent amounts for most of the season with a small increase in fish movement at the end of the season, and Pulse, to represent fish moving out rapidly early in the season as if triggered to move from a February pulse flow release. Fish timing and speed scenarios were applied together. Fish speed scenarios used included Early (12.62 or 18.55 kilometers per day) to represent fish moving medium speed downstream, Late (4.14 or 7.11 kilometers per day to represent fish moving slowly downstream, and Pulse (24.91 or 35.13 kilometers per day) to represent rapid fish movement.

Survivals used include a low value of 0.03% to represent a low bookend from nearby rivers, a medium value of 5% to represent the SJRRP target (SJRRP 2010), and a high value of 28.25% to represent a high bookend from nearby rivers. Other parameters were applied consistently throughout based on scientific literature (Table ES-1). A total of 36 model scenarios included all combinations of 2 abundance targets, 3 emigration strategy types, 3 survival assumptions, and 2 habitat quality assumptions.

Table ES-1: Input Data

	Spring-run Sub-yearlings	Fall-run Sub-yearlings
Number of Reproducing Fish (spawners)	30,000 or 45,000	10,000 or 15,000
Female Fish Percentage	50%	50%
Number of eggs per fish (fecundity)	4,900	5,500
Egg Survival to Emergence	0.485	0.485
Yearlings Percentage	10%	--
Entry Timing and Size	Feather River, 3 scenarios	Stanislaus River, 3 scenarios
Migration Speed - Pre Smolts	4.14, 12.62, or 24.91 km/day (2.57, 7.84 or 15.48 mi/day)	
Migration Speed - Smolts	7.11, 18.55, or 35.13 km/day (4.42, 11.53 or 21.83 mi/day)	
Downstream Survivals	0.03%, 5%, or 28.25% through all SJRRP reaches	
Growth Curve	Fisher, 1992	
Territory Size to Fish Size Relationship	Grant and Kramer, 1990	
Habitat Quality	7% to 27% by reach, or 21% - 30% by reach	
Depth & Velocity Method	HSI Curve, Stanislaus River	
Cover	HSI Value by vegetation type plus edge features as 1	
Flow	Dry (1000-1500cfs), Normal (2180-2500cfs), Wet (3600-4500cfs)	

1.2 Available Suitable Habitat

The available suitable habitat already existing in the system depends on the flow level at which available suitable habitat is determined. Three scenarios were run to determine available suitable habitat in dry (1,000 – 1,500 cfs), normal (2,180 – 2,500 cfs) and wet years (3,600 – 4,500 cfs). For simplification, a weighted combination of the three flow scenarios was used for determining the amount of available suitable habitat.

Suitable habitat quantity and quality is related to water depth, water velocity, and amount of protection (also known as cover, and defined mostly as vegetation). To determine the quantity of available suitable habitat, the concept of a habitat suitability index (HSI) was used. HSI provides a quantitative value for habitat quality. Habitat suitability index scores between zero and one were assigned to the modeled depth, velocity, and cover for each model cell. The minimum depth, velocity, or cover score became the total HSI score for that cell (see Figure ES-2). These scores were combined to determine the total quantity of available suitable habitat.

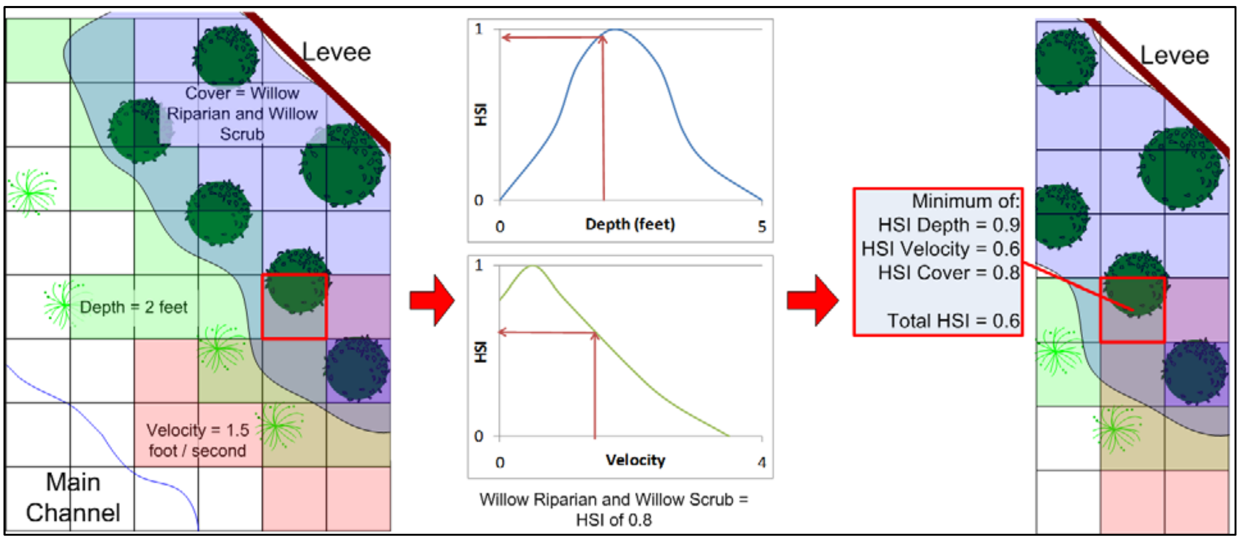

Figure ES-2: Example showing Total Habitat Suitability Index is the minimum of the component HSI scores

1.3 Scenarios

Table ES-2 shows the different values for each factor that were combined to make scenarios. Fish entry timing and speed were applied together, and so this results in a total of 36 required suitable habitat scenarios and 3 available suitable habitat scenarios.

Table ES-2: Scenarios

Model Component	Model Assumptions	Description/Value
Abundance Target	Growth	30,000 spring-run, 10,000 fall-run
	Long-Term	45,000 spring-run, 15,000 fall-run
Emigration Strategy	Early	fast-moving, abbreviated emigration
	Late	slow-moving, extended emigration
	Pulse	fast-moving, pulse flow response

Model Component	Model Assumptions	Description/Value
Survival	Lower	0.03%
	Middle	5%
	Upper	28.25%
Habitat Quality	Mean	present quality of habitat
	Upper	one standard deviation above
Flow	Dry	1,000 – 1,500 cfs
	Normal	2,180 – 2,500 cfs
	Wet	3,600 – 4,500 cfs

1.4 Results

Available suitable habitat ranged between 59 and 374 acres depending on the reach. Suitable habitat deficits (i.e. required suitable habitat minus available suitable habitat) were calculated for each reach for each scenario (see Section 4.4). Total suitable habitat deficits ranged from approximately 6 to 975 acres when summed across all reaches for the 36 required suitable habitat scenarios, resulting in total inundated areas from 10 to 9,760 acres depending on the fraction of the total inundated area that is suitable.

Total inundated area equals the suitable habitat deficit divided by the fraction (or percentage) of the inundated area that is suitable. The average fraction of inundated area that is suitable in Reaches 1B-3 currently is around 0.10 (or 10 percent), and the average fraction of inundated area that is suitable in Reaches 4-5 currently is around 0.25 (or 25 percent). However, managers can choose to add additional habitat features such as vegetation or large woody debris (cover is the limiting factor, see Appendix A), or adjust the grading on the floodplain to target depths and velocities to likely floodplain inundation flows. These projects could increase the fraction of suitable habitat, and thus require less inundated area confined between levees.

Assuming that all reach 1-3 habitat deficits are incorporated into the Reach 2B project and all reach 4-5 habitat deficits are incorporated into the Reach 4B project, results in terms of total inundated area for the model scenarios are shown in Table ES-32 below with a range of percent suitable habitat assumptions.

Table ES-3: Total Inundated Area required by scenario and percent suitable habitat assumptions.

Scenario				Total Inundated Area (acres) for habitat quality from 10-25 percent suitable			
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Reach 2B - 10% Suitable**	**Reach 2B - 25% Suitable**	**Reach 4B1 - 10% Suitable**	**Reach 4B1 - 25% Suitable**
Growth	Early	0.03%	Mean	60	20	0	0
Growth	Early	0.03%	Upper	30	10	0	0
Growth	Early	5.00%	Mean	180	70	70	30
Growth	Early	5.00%	Upper	100	40	40	20
Growth	Early	28.25%	Mean	260	100	220	90
Growth	Early	28.25%	Upper	140	60	140	50
Growth	Late	0.03%	Mean	400	160	10	10

Scenario				Total Inundated Area (acres) for habitat quality from 10-25 percent suitable			
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Reach 2B - 10% Suitable**	**Reach 2B - 25% Suitable**	**Reach 4B1 - 10% Suitable**	**Reach 4B1 - 25% Suitable**
Growth	Late	0.03%	Upper	190	80	10	0
Growth	Late	5.00%	Mean	2,030	810	360	140
Growth	Late	5.00%	Upper	650	260	220	90
Growth	Late	28.25%	Mean	3,800	1,520	1,770	710
Growth	Late	28.25%	Upper	1,470	590	870	350
Growth	Pulse	0.03%	Mean	140	60	10	0
Growth	Pulse	0.03%	Upper	80	30	0	0
Growth	Pulse	5.00%	Mean	470	190	210	80
Growth	Pulse	5.00%	Upper	220	90	130	50
Growth	Pulse	28.25%	Mean	1,170	470	720	290
Growth	Pulse	28.25%	Upper	350	140	400	160
Long-Term	Early	0.03%	Mean	90	40	0	0
Long-Term	Early	0.03%	Upper	50	20	0	0
Long-Term	Early	5.00%	Mean	270	110	100	40
Long-Term	Early	5.00%	Upper	150	60	60	30
Long-Term	Early	28.25%	Mean	510	210	330	130
Long-Term	Early	28.25%	Upper	220	90	200	80
Long-Term	Late	0.03%	Mean	990	400	20	10
Long-Term	Late	0.03%	Upper	280	110	10	0
Long-Term	Late	5.00%	Mean	4,160	1,660	730	290
Long-Term	Late	5.00%	Upper	1,410	560	330	130
Long-Term	Late	28.25%	Mean	6,820	2,730	2,940	1,170
Long-Term	Late	28.25%	Upper	2,850	1,140	1,590	640
Long-Term	Pulse	0.03%	Mean	210	80	10	0
Long-Term	Pulse	0.03%	Upper	120	50	10	0
Long-Term	Pulse	5.00%	Mean	1,000	400	310	120
Long-Term	Pulse	5.00%	Upper	320	130	190	80
Long-Term	Pulse	28.25%	Mean	2,060	820	1,370	550
Long-Term	Pulse	28.25%	Upper	830	330	620	250

1.5 Discussion

Study findings should be viewed as a lower bookend for rearing and emigration habitat area and do not define total habitat needs for self-sustaining, naturally reproducing populations of spring- and fall-run Chinook salmon within the SJRRP. Instead, this analysis estimates habitat needs for adult growth and long-term abundance targets from the Technical Advisory Committee recommendations (Hanson 2007, Hanson 2008) and the Fisheries Management Plan (SJRRP 2010).

The main limitation of this analysis is the uncertain behavior of reintroduced fish in the San Joaquin River. Their timing, speed, growth, survival, required habitat per fish, and habitat preferences (i.e. HSI) will remain unknown until a population exists. However, the primary concepts used to model fish behavior and habitat requirements are taken from general salmonid ecology and model inputs were taken from watersheds that are either tributaries to the San Joaquin River or relevant analog streams. Also, a range of assumptions were modeled for multiple model components, thereby incorporating uncertainty in model results and presenting a range of habitat estimates.

Meeting average population goals includes accounting for variability in populations. Many factors affect population that are not within control of the San Joaquin River Restoration Program. Thus, it is necessary to set a minimum that allows for some of this variability. Setting minimum floodplain habitat values at acreages that only meet the average population goals will result in years with floodplain habitat as the limiting factor, limiting the population in 'boom' population years. These 'boom' years are necessary to account for the low population years and average out to meet the population target.

Scenarios allow for lower and upper bounds to constrain the realm of possibility for uncertain parameters. Any selected scenario will include a high degree of uncertainty. Data from the nearest rivers (other San Joaquin basin or Sacramento basin rivers, generally) was used as the best available information.

Juvenile entry timing affects the concentration of fish entering the river at a single time. Timing scenarios (late) with a more elongated migration period would result in lower habitat areas, and scenarios (early, pulse) with concentrated numbers of fish leaving the spawning reaches at a given time would result in higher habitat areas. However, fish speeds were applied with entry timing in an overall emigration strategy, and speed was the controlling factor rather than entry timing. For example, the late emigration strategy results in the largest habitat areas due to the slow speed of fish movement, even though entry timing was distributed. Emigration strategy scenarios are based on the Feather River for spring-run entry timing, and the Stanislaus River for fall-run entry timing and both spring-run and fall-run speeds. Speeds are likely to be similar between fall-run and spring-run so this assumption was made to enable the use of the nearest fish speed data.

The speed of fish moving in floodplains will determine the selected emigration strategy scenario due to the sensitivity to speed discussed above. The greatest area of floodplain inundation will occur in wet or normal-wet years with high volumes of Restoration flows. In these wet years, most fish may slow down when they encounter floodplains, adapt to their surroundings and grow and rear, requiring more floodplain habitat. This is represented by the late emigration strategy scenario. Another possibility is that most fish would be swept through the system by the higher flows present in wet years, move quickly and thus require smaller areas of floodplain habitat (represented by the "early" emigration strategy scenario). This hypothesis is supported by fish monitoring data from other rivers that do not have a lot of floodplain habitat. Thus, if floodplain habitat is built, fish may slow down, but the precise reaction of fish remains to be seen. Regardless, the pulse emigration strategy scenario can be eliminated from consideration. The pulse scenario results in fish moving through some entire reaches in less than a day, and thus results in zero habitat required since the model has a one-day timestep. This unrealistic consequence of modeling means this scenario is not recommended for setting a minimum floodplain habitat.

Fish growth was modeled using an exponential relationship between fish age in days and fork length (Fisher 1992). This relationship came from Sacramento fall-run Chinook salmon data, but is assumed to be the best available information as it is the nearest. No other growth relationships were considered.

Survival scenarios include the 50th percentile from nearby rivers (0.03 percent), the Fisheries Management Plan target (5 percent) and the 95th percentile from nearby rivers (28.25 percent). The 0.03 percent survival scenario results in the lowest number of floodplain habitat acres of the three scenarios with the 28.25 percent survival scenario resulting in the largest number of floodplain habitat acres as it results in the largest numbers of fish.

The required habitat per fish is set with a relationship between fish needs (territory size) and fish size (fork length, in millimeters). This relationship uses data gathered from a variety of salmon family (salmonid) published literature. A literature review found additional sources, which did not indicate a different trend, but did highlight the uncertainty in the relationship, especially at large fork lengths. Luckily, the high fork lengths are generally not reached in this modeling exercise.

Habitat preferences, or the habitat suitability curves used to define already available suitable habitat, were based on fish observations from the Stanislaus River for depth and velocity, and literature from the pacific northwest such as the state of Washington for cover. Stanislaus River suitability curves are from within the San Joaquin Basin, they are based on data collected from actual fish observations over multiple years, and the data generally fit in the center/ mean area of the range of curves from the multiple river systems considered. Despite these benefits, Stanislaus River fish observations are based on habitat preferences within the channel, as there was no available data on juvenile habitat preferences on floodplains within the San Joaquin Basin. This parameterization likely narrows the range of suitable habitat, decreasing the available suitable habitat already existing and increasing the total floodplain habitat areas required from what could be expected if data was available from a river with floodplains.

1.6 Conclusions

This report recommends one scenario, with a range of habitat quality, to set the minimum floodplain area for the Reach 2B and Reach 4B projects. The long-term fish population scenario is recommended (45,000 spring-run; 15,000 fall-run) as it follows Technical Advisory Committee recommendations for determining floodplain habitat and allows for the population variability necessary to meet average population targets. The late (slow fish movement) emigration strategy represents expected movement of fish on floodplains, although some fish will move faster as they are swept downstream in the river channel. This report recommends the late emigration strategy scenario. This scenario provides the high end of the range of timing scenarios that addresses the high uncertainty in emigration strategy. The recommended survival scenario is the middle survival of 5 percent based on the recommendations in the Fisheries Management Plan. This provides a target that is attainable and does not overly constrain the population. Finally, the mean habitat quality is recommended. For this scenario, the suitable habitat area deficit in Reach 2B was 416 acres and the suitable habitat area deficit was 73 acres in Reach 4B1 corresponding to the total inundated areas from 1,660 to 4,160 acres for Reach 2B and inundated areas from 290 to 730 acres for Reach 4B (see Figure ES-3 and Table ES-4).

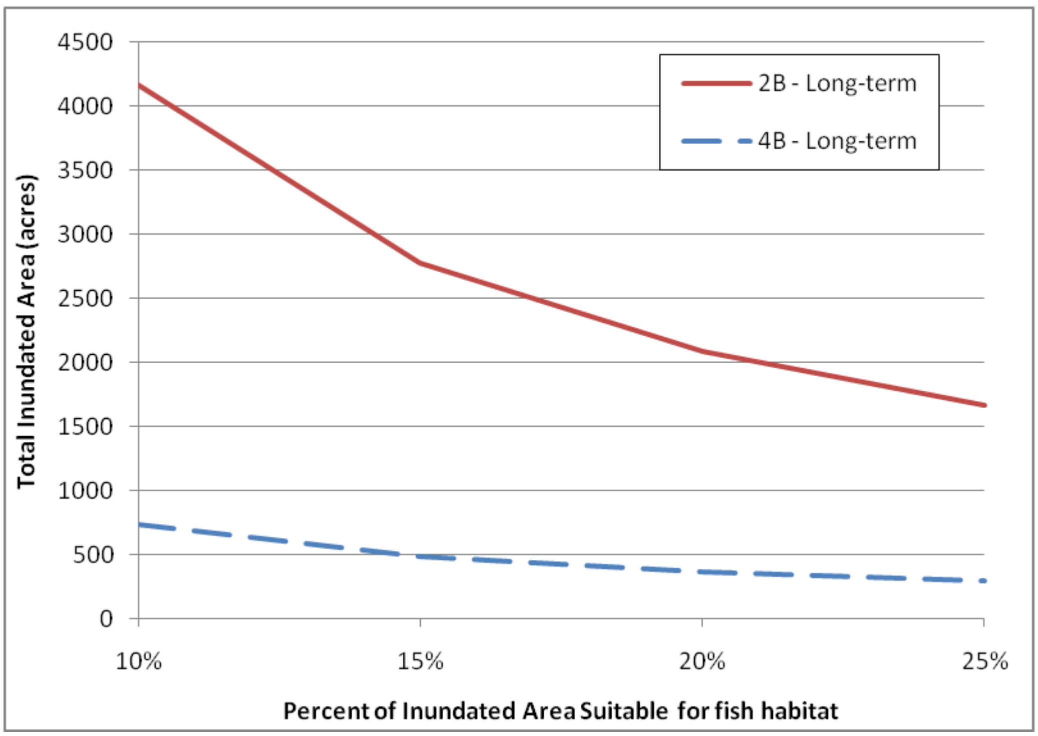

Figure ES-3: Total Inundated Area by project reach

Table ES-4: Total Inundated Area for Reach 2B and Reach 4B by percent suitable

Scenario					Total Inundated Area (acres)			
Population	Emigration Strategy	Survival	Habitat Quality	Reach	10% Suitable	15% Suitable	20% Suitable	25% Suitable
Long-Term	Late	5%	Mean	2B	4160	2770	2080	1660
Long-Term	Late	5%	Mean	4B	730	480	360	290

This document provides a minimum for total enclosed area. The Reach 2B and Reach 4B projects have several floodplain alternatives under consideration at this juncture. This report may inform the selected alternative by removing floodplain alternatives that cannot meet the minimum inundated area requirements, even after improving the percent suitable habitat to the highest reasonable level. This report may also assist the project teams in selection of a preferred alternative. While the selected floodplain alternative will likely be larger than this minimum area, this report helps to delineate some of the tradeoffs (habitat quality vs. quantity, for example) that are necessary to decide on a preferred alternative. The selected or preferred alternative will be selected after considering tradeoffs, risk, impacts and benefits between alternatives. This document is expected to be used by stakeholders and project teams to help select the preferred alternatives for the Reach 2B and 4B projects.

This study calculates the minimum required land to provide rearing habitat for the offspring of the adult growth and long-term population targets for both spring- and fall-run Chinook salmon. This present endeavor is not intended for the purposes of defining the total rearing habitat needs of a sustainable population, but just the minimum required.

2 INTRODUCTION

The purpose of this report is to determine the minimum rearing habitat area necessary to meet the fall-run and spring-run Chinook salmon (*Oncorhynchus tshawytscha*) adult growth population targets identified in the San Joaquin River Restoration Program (SJRRP) Fisheries Management Plan and Technical Advisory Committee Recommendations. The results from this report will inform tradeoffs between impacts and benefits on floodplain alternatives for ongoing projects and long-term restoration efforts.

To meet the Restoration Goal in the Settlement, the SJRRP will develop channel and structural improvements, release flows, and reintroduce Chinook salmon. Two of the identified channel and structural improvements in the Settlement include floodplain habitat. Fish need floodplain habitat in order to grow and develop (rear) as they move downstream (emigrate) from the Restoration area. Floodplains provide food and protection from predators. In order to optimally use floodplain, fish require certain characteristics that make it "suitable". For the purposes of this analysis, these include depth, velocity, and cover. This report estimates the current suitable habitat deficit in each reach of the SJRRP and recommends a minimum floodplain habitat area to inform project floodplain alternatives.

2.1 Background

In 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and the Central Valley Project Friant Division Long-Term Contractors. After more than 18 years of litigation of this lawsuit, known as *NRDC, et al. v Kirk Rodgers, et al.*, a Settlement was reached. On September 13, 2006, the Settling Parties, including NRDC, Friant Water Users Authority, and U.S. Departments of the Interior and Commerce, agreed on the terms and conditions of the Settlement, which was subsequently approved by the U.S. Eastern District Court of California on October 23, 2006. The Settlement establishes two co-equal goals: (1) Restoration Goal – To restore and maintain fish populations in "good condition" in the main stem San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish, and (2) Water Management Goal – To reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the Interim Flows and Restoration Flows provided for in the Settlement.

To achieve the Restoration Goal, the SJRRP will implement a combination of channel and structural projects along the San Joaquin River, restoration of an annual flow regime through water releases from Friant Dam, and fish reintroduction. Projects include modifications to channel capacity, incorporating floodplain habitat. The SJRRP Fisheries Management Plan (2010), which provides an adaptive framework to meet the Restoration Goal, identified an objective for the SJRRP to provide suitable habitat for all freshwater Chinook salmon life stages during a variety of water year types, and restore habitat for spawning, rearing, and migration of native species, including salmon, during winter and spring.

Two site-specific projects currently evaluate the potential for levee setbacks and the incorporation of new floodplain and related riparian habitat in Reaches 2B, 4B, and the Eastside and Mariposa Bypasses (Figure 4). The San Joaquin River Restoration Area includes 150 miles (240 kilometers or km) of the main stem San Joaquin River and its associated tributaries, sloughs, canals, and bypass channels between Friant Dam and the confluence of the Merced River. For the purposes of restoration planning, the Restoration Area has been divided into nine reaches (1A, 1B, 2A, 2B, 3, 4A, 4B1, 4B2, 5) based on physical and flow characteristics of the river and key infrastructure (Figure 1).

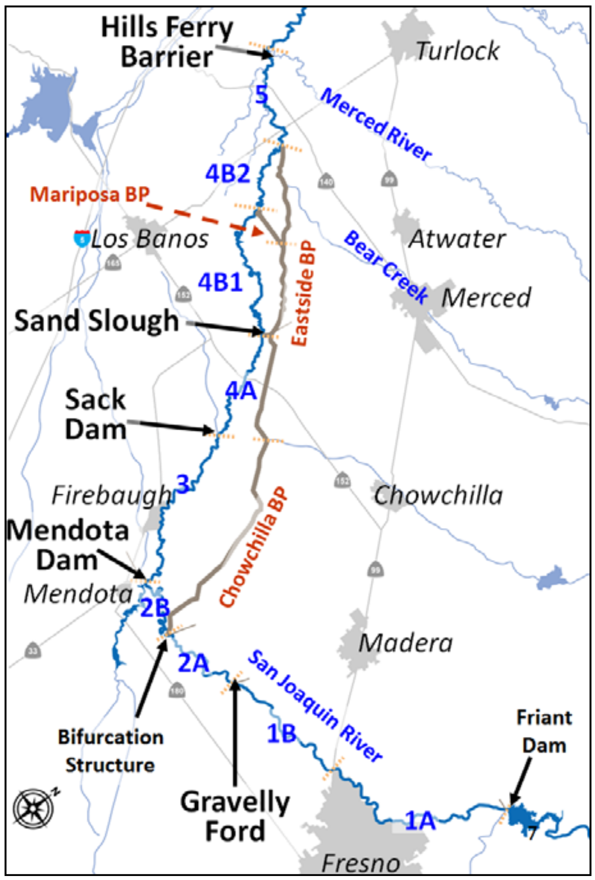

Figure 1: SJRRP Map

Table 1. Reach lengths and upstream and downstream extents in river miles (RM)

Reach	Length mi (km)	RM (RKM) bottom	RM (RKM) top	Location
Lower 1B	5 (8)	229 (369)	234 (377)	Skaggs Bridge to Gravelly Ford
2A	13 (21)	216 (348)	229 (369)	Gravelly Ford to Chowchilla Bifurcation Structure
2B	11 (18)	205 (330)	216 (348)	Chowchilla Bifurcation Structure to Mendota Dam
3	23 (37)	182 (293)	205 (330)	Mendota Dam to Sack Dam
4A	14 (22)	168 (271)	182 (293)	Sack Dam to the Sand Slough Control Structure
4B1	21 (34)	147 (237)	168 (271)	Sand Slough Control Structure to the confluence with the Mariposa Bypass
4B2	11 (18)	136 (219)	147 (237)	Confluence of the Mariposa Bypass, where flood flows in the bypass system rejoins the main stem of the San Joaquin River, to the confluence of Eastside Bypass

Reach	Length mi (km)	RM (RKM) bottom	RM (RKM) top	Location
5	18 (29)	118 (190)	136 (219)	Confluence of the Eastside Bypass downstream to the Merced River Confluence

This study includes the suggestions of a multi-disciplinary team with members from multiple state and federal agencies as well as the Technical Advisory Committee.

2.2 Chinook Salmon Life History

The salmon family displays remarkable within-species (intraspecific) diversity in the timing and location of key life events (life-history). The expression of alternative life-histories is the result of a complex interaction between genetic variation, including local adaptation, and environmental conditions (Satterthwaite *et al*. 2010). Within the ocean-type life-history displayed by Central Valley fall-run Chinook salmon, there is considerable variation in size of fish leaving the river (emigrants). The juveniles can emigrate as fry (<55 mm fork length or FL), parr (<75 mm FL), or smolts (>75 mm FL) (Brandes and McLain 2001; Williams 2006). Each of these life stages has demonstrated it survives to contribute to the adult population, known as recruitment (Miller *et al.* 2010). Spring-run Chinook salmon demonstrate the stream-type life-history with juveniles residing in streams from 3-15 months before emigration (Yoshiyama 1998; Moyle 2002). Although there is relatively little information on the proportion of spring-run that remain over a year before emigration, the few surveys that have been performed suggest it is a relatively small proportion of California populations (McReynolds *et al.* 2007), and in this report is assumed to be 10 percent (Fisheries Management Plan 2010). In the Central Valley, fry and parr generally emigrate from river systems during February–March, whereas smolt emigration occurs during April–May, with a general tapering-off through June (Brandes and McLain 2001; Williams 2006). In some systems, the proportion of juveniles emigrating as fry, parr, or smolts may shift from year-to-year (Watry *et al.* 2007, 2008, 2009; Workman 2003, 2004, 2005, 2006).

For some fish, leaving the tributary stream (emigration) takes place relatively quickly (*i.e.,* over a few days or weeks). For other fish, emigration is drawn out, with individuals presumably stopping and establishing territories along the way (*i.e.,* over months). Regardless of life-history strategy, territories such as holding, resting, and feeding areas are likely the most useful predictors of space required by an individual member of the salmon family (salmonid) and are therefore the most useful way to determine required habitat during emigration (Grant *et al.* 1998; Keeley 2000).

2.3 Habitat

An organism's habitat is the place where it lives (Odum 1971; Baltz 1990; Peters and Cross 1992; Hayes *et al.* 1996). Ecologists attempt to describe the habitat of a species based on physical and biological characteristics that are ecologically meaningful to that particular species, and make it "suitable" (Minello 1999). For fish species, these characteristics may include: (1) a geographical range; (2) features (e.g., woody debris, undercut banks; plants); (3) substrate (e.g., sediment grain size, organic content); (4) hydrodynamics (e.g., currents, tidal and flood patterns); and (5) general hydrology (e.g., depth, velocity, temperature, salinity, turbidity). Cover includes the features or substrate that provide refuge for organisms, and is an important factor in predicting distributions of habitat richness.

For juvenile Chinook salmon, suitable habitat area consists of floodplain for rearing and main river channel for rearing and emigration. A functional floodplain must be connected to the adjacent river channel allow the exchange of flow, water quality, sediment, nutrients, and organisms, including access and egress by juvenile salmon. As flow moves from the river onto the floodplain, water velocity decreases which in turn allows sediments to drop out of suspension in the water column. As a result, water in the floodplain is often less turbid than river water. This process enables a greater rate of photosynthesis of algae and phytoplankton (Ahearn *et al.* 1989 in Opperman *et al.* 2010) that helps increase productivity as food supply for rearing juvenile Chinook salmon. Fish yields and production are strongly related to the extent of accessible floodplain, whereas the main river is used as a migration route by most of the fishes (Junk *et al.* 1989). For this reason, both the floodplain and main river will be quantified as elements that define suitable habitat for rearing and emigrating juvenile Chinook salmon.

3 METHODS

The purpose of this study is to determine the minimum land area required to support rearing and emigration habitat for juvenile production from adult population targets set for spring- and fall-run Chinook salmon as defined in the Technical Advisory Committee recommendations for restoring spring-run and fall-run Chinook salmon to the upper San Joaquin River (Hanson, 2007; Hanson, 2008). Steps included calculating the:

1) Number of fish (abundance)
2) Required suitable habitat for the fish number and fish size in each reach
3) Available suitable habitat in each reach
4) Deficits in suitable habitat in each reach
5) Fraction of total inundated area that is suitable
6) Total inundated area needed in each reach
7) Total inundated area needed for 2B and 4B

Figure 2 below shows the process undertaken to calculate the minimum rearing and emigration habitat required for juvenile salmon, and calculate the location and amount of additional floodplain habitat that needs to be created to meet habitat requirements.

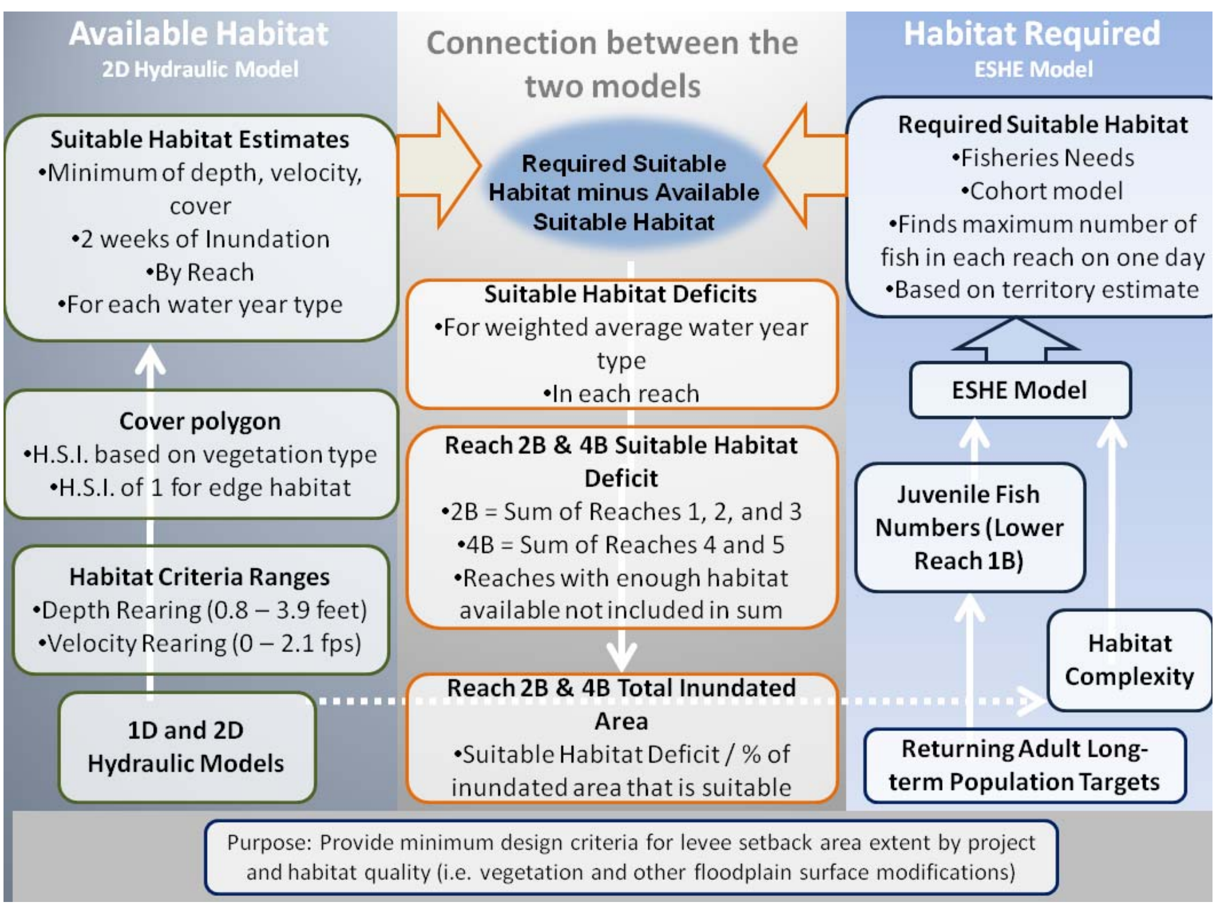

Figure 2. Minimum Habitat Calculation Methodology

The Fisheries Management Plan specifies the target annual average number of reproducing fish for the SJRRP, from 2025 on, as "A Growth Population Target of 30,000 naturally produced adult spring-run Chinook salmon and 10,000 naturally produced fall-run Chinook salmon" (SJRRP, 2010). This number is based on recommendations from the Technical Advisory Committee in 2007 and 2008. These spring-run and fall-run target recommendations from the Technical Advisory Committee specify the creation of "in-river holding, spawning, and rearing habitat necessary to support the upper range of returns for the Long-term Period" (Hanson, 2007). The upper range of returns for the Long-term Period is 45,000 spring-run adult Chinook salmon and 15,000 fall-run adult Chinook salmon (Hanson, 2007; Hanson, 2008). Therefore, this analysis includes two fish population scenarios, for both the adult growth population target and the long-term target of 45,000 adult spring-run Chinook salmon and 15,000 adult fall-run Chinook salmon.

These adult target scenarios were first used to calculate the number of fish, or abundance, in each reach on each day of the year and the size of the fish. This was done through the use of cohorts, or groups of fish. The Emigrating Salmonid Habitat Estimation (ESHE) model was used to perform these calculations. It took an initial number of reproducing fish, termed spawners, and calculated the number of immature fish, or juveniles, resulting under various assumptions (Table 4). It then routed these juveniles through the system given a distribution for the number of fish that begin to move downstream on each day, also known as entry timing. The group of fish that entered the river on the same day became a cohort. Each cohort then traveled at the same speed, arrived in each reach at the same time, grew at the same rate, and a fraction of them died every kilometer of distance.

Following the fish population calculations, which gave the number of fish of a given size in each reach on each day, the habitat requirements were determined. In order to support the overall population goal, enough habitat for the maximum daily population must exist. The amount of habitat required for each day was calculated. The size of the fish was measured by the fork length, or distance from the fish nose to the split of its tail. The amount of habitat required for each fish was determined through use of a territory size to fork-length relationship published by Grant and Kramer in 1990. The maximum daily habitat results in the required suitable habitat. This gave a required area of suitable habitat (required *ASH)* in each reach.

Then, a two-dimensional hydraulic model (SRH-2D) was used to calculate the amount of existing San Joaquin River inundated area that was suitable for fish to use. SRH-2D created a 5 by 5 foot grid along the entire SJR except for Reach 5 (which was modeled in 1D). A depth and velocity and cover type was determined for each of these grid cells. Habitat suitability was determined through the use of depth, velocity, and cover criteria. These criteria were in the form of non-binary Habitat Suitability Indices (HSI). Thus, all depths and velocities were sorted into a series of bins. For each of these bins, a HSI value between 0 and 1 was assigned, based on data from other existing systems. Cover was delineated based on previous vegetation mapping, as well as digitizing of edge habitat for subportions of each reach. A HSI value was assigned for each vegetation type. The minimum HSI value for each model grid cell was then used to determine the amount of total inundated area meeting suitable habitat criteria. This area became the available area of suitable habitat (available *ASH)*.

The last step was to subtract the available *ASH* from the required *ASH* in each reach, to define the habitat deficit in each reach, and then convert this to a total inundated area need for each of the Reach 2B and Reach 4B projects. Throughout the report, most results are presented in terms of suitable habitat. This area is not the total amount of land required. Not all inundated area provides the necessary depth, velocity, and cover for fish. Thus, suitable habitat is a small portion of the total inundated area.

The following sections describe the methodology for the required suitable habitat simulation using ESHE in Section 3.1, the methodology for the available suitable habitat modeling using SRH-2D in Section 3.2, and a summary of all inputs in Section 3.3. Subparts of each section describe the individual steps.

3.1 Required Suitable Habitat Methodology

The Emigrating Salmonid Habitat Estimation (ESHE) model helps to estimate the minimum suitable rearing and emigration habitat required to support the future population abundance targets of Central Valley Chinook salmon (Cramer Fish Sciences 2011). The model incorporates best available observational data (San Joaquin Basin data when available) to inform juvenile salmon behavior during rearing and emigration. The model simulates the rearing and downstream movement of juvenile salmon cohorts and tracks survival, movement, growth, ultimately calculating the amount of suitable habitat required to sustain the number of juvenile salmon present within a model reach on a given day.

The following sections describe the conceptual framework for the model, the model structure, the scenarios run for this analysis, and finally a section on each model function: initial juvenile fish abundance, entry timing and size, migration speed, survival, growth, territory size, and finally the calculations for the resulting required suitable habitat.

4.1.1 Conceptual Framework

The fundamental concept underlying the ESHE model is that salmonids either defend or rely on food from an area of territory (Cramer and Ackerman 2009). Observations of the combination of salmonid feeding and territorial behavior have been of interest to fisheries biologists for some time because territory size is thought to limit the density and production of stream-dwelling salmonids (Chapman 1966; Allen 1969; Grant and Kramer 1990). Territory size requirements of individual fish of a given size are generally constant regardless of the local numbers of fish (abundance) (Cramer and Ackerman 2009; Grant and Kramer 1990). In open (*i.e.,* natural) systems, territory requirements result in competition for space and displacement of smaller/weaker individuals (Titus 1990; Keeley 2001; Keeley 2003; Cramer and Ackerman 2009). Smaller/weaker individuals in turn occupy sub-optimal territories (see Titus 1990 and Keeley 2001) and are likely to experience increased stress, which reduces growth and fitness, causing increased mortality. Therefore, providing an adequate quantity and quality of rearing territory during emigration can reduce the negative effects associated with competition for space on a population level.

An important component of territory size is the relationship between territory size and fish body size, also known as the "allometry of territory size" (Grant and Kramer 1990). Because salmonids in streams defend territories, from small (post-emergent) juveniles until they either become ocean-ready fish (smolts) or become sexually mature, they must increase the area they defend to meet increasing food and energy (energetic) requirements as they grow (Keeley and Slaney 1996). This results in a decreasing population density as average body size within a cohort increases (Grant and Kramer 1990). Several studies have provided allometric territory size relationships for salmonids, including a general multi-species (interspecific) regression model (Grant and Kramer 1990), and single species (intraspecific) relationships for brook trout (*Salvelinus fontinalis*; Grant *et al*. 1989), brown trout (*Salmo trutta*; Elliott 1990), and Atlantic salmon (*S. salar*; Keeley and Grant 1995). Variability in the intraspecific relationships described above suggests that relationships provided for individual species or populations may offer poor estimates of salmonid carrying capacity when applied to other species or populations. However, when tested with experimental laboratory and field data from multiple species and populations, the interspecific relationship provided by Grant and Kramer (1990) was surprisingly robust. Therefore, allometric territory size relationships developed using data from multiple species or populations may be good predictors of space requirements and maximum densities of salmonids in streams.

In addition to fish body size, territory size may also be dependent on environmental factors such as food abundance and habitat complexity. Higher levels of food abundance mean that fish require a relatively small area to meet bioenergetic demands in comparison to areas of low food abundance (Slaney and Northcote 1974; Dill *et al.* 1981; Keeley and Grant 1995). In general, increased food abundance leads to reduced territory size, whereas reduced food abundance leads to increased territory size (Symons 1968; Slaney and Northcote 1974; Dill *et al*. 1981; Grant *et al.* 1998; Keeley 2000; Cramer and Ackerman 2009). Changes in territory size related to food abundance are likely driven by increased or reduced levels of aggression related to hunger (Symons 1968; Slaney and Northcote 1974; Dill *et al.* 1981). Similar to food abundance, increased habitat complexity generally leads to reduced territory size, whereas reduced habitat complexity generally leads to increased territory size (Imre *et al.* 2002; Kalleberg 1958). Habitat complexity has been described in terms of structural components such as trees and large woody debris (McMahon and Hartman 1989), hydraulic variation (Lamberti *et al.* 1989; Pearsons *et al.* 1992), and the diversity of depth, velocity, and substrate (Gorman and Karr 1978; Angermeier and Schlosser 1989).

Similar to the salmonid studies described above (see Grant and Kramer 1990 and Grant *et al.* 1998), ESHE relies on the conclusion that the maximum number of individuals a habitat area can support, without the need for smaller/weaker individuals to occupy sub-optimal territories and the resulting increased mortality (i.e. density dependent effects), is limited by territory size. Therefore, the juvenile salmon carrying capacity, or the number of fish that can be supported in a given area (*capacity*), of a given stream reach is a function of the available Area of Suitable Habitat (*ASH*) and average fish *territory size*:

$$capacity = ASH \, / \, territory\ size \qquad (1)$$

Salmon require specific habitat conditions for rearing, including suitable water depths, velocities (Raleigh *et al.* 1986; Keeley and Slaney 1996), and temperatures (Marine and Cech 2004). Therefore, juvenile salmon will only rear (and set-up territories) in habitat that meets their preferred range of habitat conditions. This defines the area of suitable habitat *(ASH)* as the total area of habitat meeting rearing requirements. In most natural systems, *ASH* is only a small fraction of total inundated area (*TIA*). Therefore, *ASH* can also be defined as the proportion of *TIA* which has suitable components, such as depths (Ds) and velocities (Vs). Within *ASH*, habitat complexity (*e.g.,* woody debris) and food abundance influence habitat quality, which in turn increases or decreases fish territory size.

Figure 3 depicts two alternative conservation measures for increasing the juvenile salmon carrying capacity of a stream reach. First, habitat quality (indexed in this example by habitat complexity) can be increased (B). Carrying capacity can be increased by decreasing fish territory size. Decreasing fish territory size can be accomplished by increasing habitat complexity. Increasing food abundance would have a similar effect on territory size and the resulting carrying capacity. In this situation, increased habitat quality allows a greater number of fish to occupy the same suitable rearing and emigration habitat area. Second, *ASH* can be increased (C). Increasing *ASH* for juvenile salmon (while keeping territory size constant) increases the potential number of fish that can be supported in a habitat (carrying capacity) and hence potential fish numbers (abundance) (Equation 1). In this situation, habitat quality (and the resulting territory size) is held constant while more suitable rearing habitat area is added. The transitions from (A) to (B) and (A) to (C) depict the primary drivers of changes in carrying capacity; (1) the quality of *ASH* and (2) the quantity of *ASH*.

In all situations depicted in Figure 3 (A, B, and C), *TIA* is greater than *ASH*. While not all inundated area supports juvenile salmon directly, it provides the inputs that create and maintain *ASH* (*e.g.,* water quality, sediment and organic inputs, and migration corridors). When working with juvenile salmon and floodplain systems, inundated area typically includes floodplain and all main-channel habitat while *ASH* typically includes floodplain and main-channel edge habitat.

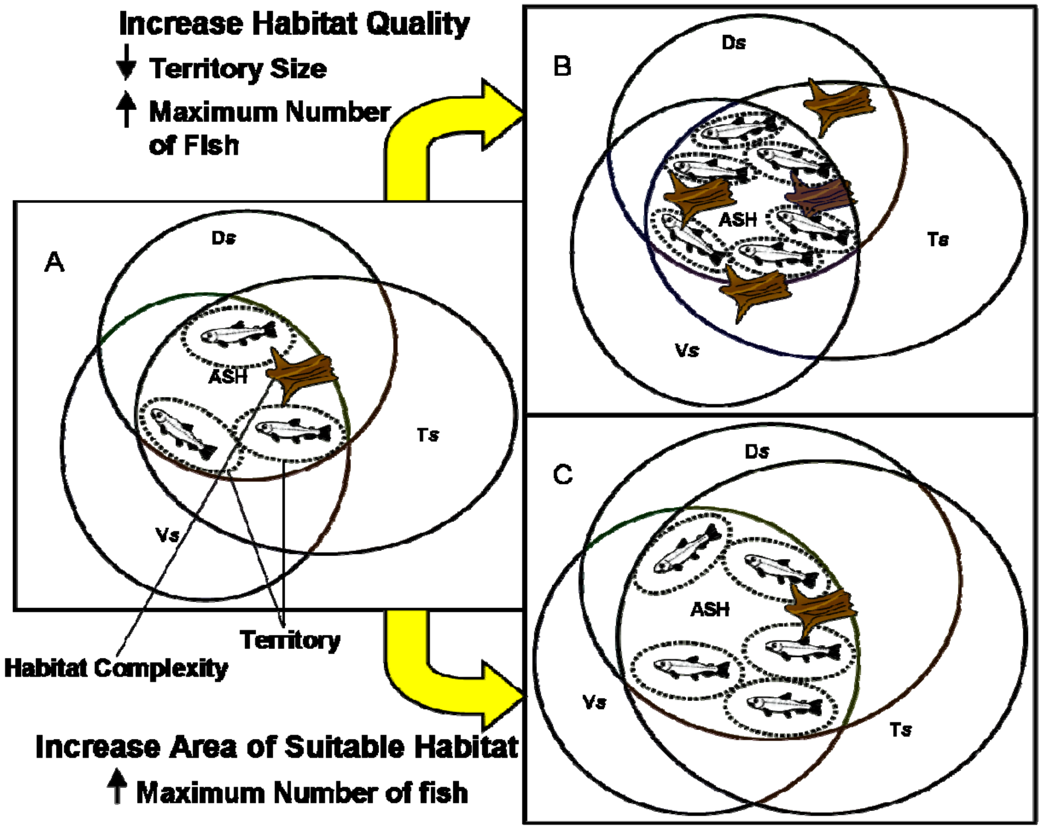

Figure 3. Conceptual model of primary physical drivers of juvenile salmon carrying capacity for three hypothetical stream reaches (A–C). Large squares are total inundated area within a reach. Broken circles indicate relative territory size for individual fish. Solid circles indicate relative area of possible suitable habitat parameters (Suitable Depths = D*s*; Suitable Temperatures = T*s*; Suitable Velocities = V*s*). Intersect of all solid circles indicates Available Suitable Habitat (*ASH*). Habitat quality is measured by available habitat complexity (*e.g.,* woody debris). In this example, habitat quality B > habitat quality A. Therefore, carrying capacity B > carrying capacity A. Similarly, *ASH* C > *ASH* A. Therefore, carrying capacity C > carrying capacity A.

In order for the EHSE model to enumerate the amount of suitable rearing and emigration habitat required to support future population abundance targets, Equation 1 was re-organized to calculate *ASH* as a function of fish *abundance* and *territory size*:

$$ASH = abundance \cdot territory\ size. \qquad (2)$$

When applied in the ESHE model, Equation 2 estimates the date-specific and reach-specific *ASH* required to support the cumulative territory size requirements of the total number (abundance) of juvenile salmon present within the SJRRP reaches throughout the juvenile rearing and emigration period.

4.1.2 Model Structure

The ESHE model is a Microsoft Excel-based model that simulates rearing and emigration of individual daily groups (cohorts) of juvenile spring-run and fall-run Chinook salmon. The model tracks their abundance, average migration speed, size, territory size, and ultimately the amount of suitable rearing and emigration habitat required to sustain the number of juvenile salmon present within a model reach. The model assumes a 274 day model year that ranges from November 1st through July 31st of the following year. These dates are the combined rearing and emigration period for Central Valley fall-run and spring-run Chinook salmon. Model outputs provide daily estimates of the number of juvenile spring-run and fall-run Chinook salmon present in each model reach and the required *ASH* needed to support them throughout the rearing and emigration period.

The ESHE model simulates several functions to track fish abundance and habitat needs of daily cohorts, based on accepted parameters taken from appropriate literature and regional studies (Table 2). These functions include: (1) *initial abundance* – models the abundance of juvenile salmon entering the model; (2) *initial timing and size* – models the timing and average size of juvenile salmon entering the model; (3) *migration speed* – models the daily downstream movement of juvenile salmon in each reach; (4) *survival* – models daily survival and abundance of juvenile salmon in each reach; (5) *growth* – models the daily growth and resulting size of juvenile salmon in each reach; (6) *territory size* – models the territory size requirements of juvenile salmon in each reach; and (7) *required ASH* – estimates the required amount of *ASH* needed to support the number of juvenile salmon present in each reach. Model functions are described in detail in the following sections.

Table 2. ESHE model functions applied as fish enter the model and as fish emigrate through model reaches, data sources, and factors that influence model functions.

	Function	Data Source	Influences
Model Entry	**Initial Abundance**	SJRRP RMT Spawner Targets	
	Initial Timing and Size	Rotary Screw Trap	Time of Year, Emigration Strategy Type
Reaches	**Migration Speed**	Tagging Studies	Fish Length, Emigration Strategy Type
	Survival	Tagging Studies, SJRRP RMT	
	Growth	Laboratory Studies	Fish Age
	Territory Size	Field and Lab Studies	Fish Length, Habitat Quality
	Required ASH	N/A	N/A

To help illustrate the series of operations performed by the ESHE Model, Table 3 depicts the "migration" of a single daily cohort of juveniles entering at the bottom of the spawning grounds at RM 234 (RKM 377) (Figure 4) and emigrating through each successive SJRRP reach. It is important to remember that cohorts of differing numbers of juveniles are entering the model each day during the rearing and emigration period of each salmon run (see section 4.1.5). This particular example is depicting the migration of a cohort of 100,000 subyearling spring-run Chinook salmon entering the model on day 25 at an average size of 34 mm fork length (FL), exhibiting an "early" emigration strategy, 5 percent overall survival, and medium habitat quality (see section 4.1.3 for details on model scenarios). For simplification, reach-specific values for fish processes are for the last model day fish were present in each reach (since these values change daily). As juveniles migrate through the reaches, their abundance decreases, average migration speed, size, and territory size increase, and their required *ASH* changes as a product of fish territory size and abundance (Table 3). For this example, the cohort moves through the reaches rapidly (7.84 miles / day or 12.62 km/day) assuming an "early" emigration strategy (see sections 4.1.5 and 4.1.6 for details) and remain fry-sized throughout their entire emigration.

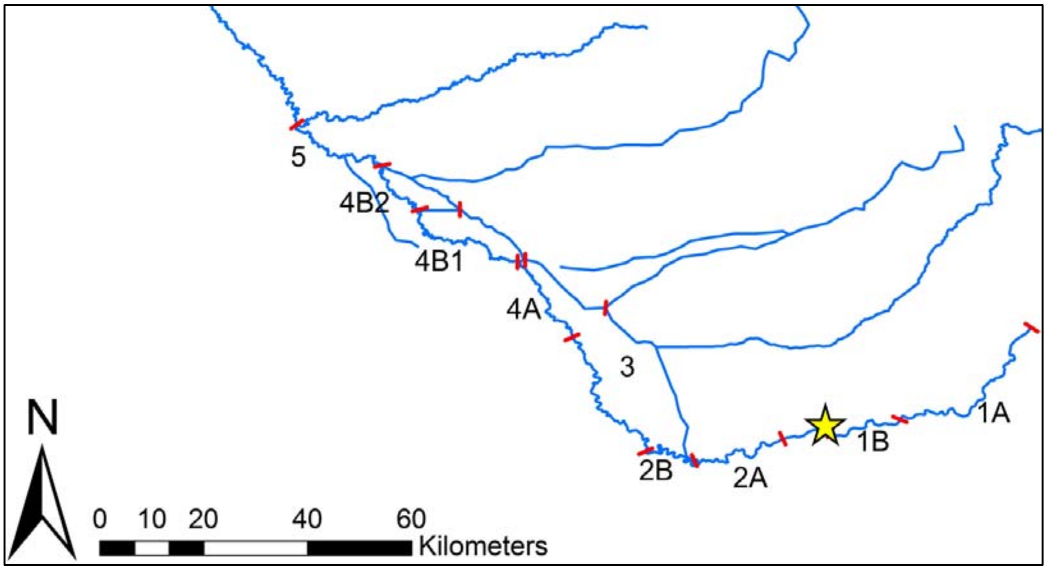

Figure 4. San Joaquin River Restoration Program reaches. Yellow star indicates location of the end of the spawning grounds and point where juvenile spring-run and fall-run Chinook salmon enter the Emigrating Salmonid Habitat Estimation model. The ESHE model tracks juvenile salmon abundance and habitat needs from the lower 5 miles (8 km) of reach 1B through reach 5 at the confluence with the Merced River.

Table 3. Example migration of 100,000 subyearling spring-run Chinook salmon through each successive SJRRP reach. Fish enter the model on day 25 at the bottom of the spawning grounds (RM 234 or RKM 377) at an average size of 34 mm in fork length. Reach-specific values for fish processes are for the last model day fish were present in each reach.

Location (RKM)	Model Day(s)	Survival per km	Abundance	Migration Speed (km/day)	Fish Size (mm)	Territory Size (m2)	Required ASH (m2)
Model Entry (377)	25	0.98412	21,968	12.62	34	N/A	N/A
Lower 1B (377-369)	27	0.98412	19,721	12.62	34	0.06	1,238
2A (369-348)	28	0.98412	16,113	12.62	35	0.05	800
2B (348-330)	29-30	0.98412	10,756	12.62	35	0.06	666
3 (330-293)	31-33	0.98412	5,867	12.62	36	0.08	441
4A (293-271)	34	0.98412	4,794	12.62	36	0.06	296
4B1 (271-237)	35-37	0.98412	2,615	12.62	37	0.05	126
4B2 (237-219)	38-39	0.98412	1,745	12.62	37	0.05	83
5 (219-190)	40-41	0.98412	1,098	12.62	38	0.05	54

3.1.3 Model Scenarios for SJRRP

The ESHE model was used to estimate the required suitable habitat needs for juvenile offspring of future San Joaquin River spawner abundance targets for spring-run and fall-run Chinook salmon. The growth adult population targets of 30,000 spring-run and 10,000 fall-run, along with the long-term spawner abundance targets defined in the Technical Advisory Committee recommendations (Hanson, 2007; Hanson, 2008) of 45,000 spring-run and 15,000 fall-run fish were modeled.

Although it is generally assumed that all Central Valley fall-run Chinook salmon populations emigrate to the ocean during the first spring following emergence from the gravel, a portion of Central Valley spring-run Chinook salmon populations reside in their natal rivers during the summer and fall months and leave as larger yearlings during their second winter and spring (Moyle 2002). Therefore, required suitable habitat needs were estimated for subyearling and yearling spring-run and subyearling fall-run fish. The ESHE model assumed 10 percent of spring-run juveniles emigrated as yearlings, which is the maximum percentage of yearlings expected for the future San Joaquin River spring-run population as defined in the SJRRP Fisheries Management Plan (2010). Yearling behavior (entry timing and size, migration speed, and survival) was modeled differently than subyearling behavior (see sections 4.15–4.17 for details). However, both yearling and subyearling behaviors were informed by Central Valley tagging and trapping data.

To incorporate uncertainty in model outputs and provide a range of estimates of required suitable habitat, key model components, including emigration strategy type, survival, and reach-specific habitat quality were modeled under a range of conditions. A total of 36 model scenarios were run for the SJRRP, including all combinations of 2 population scenarios, 3 emigration strategy types, 3 survival assumptions, and 2 habitat quality assumptions.

To incorporate uncertainty in emigration timing and initial size of juvenile spring-run and fall-run Chinook salmon, the ESHE model was run under three different emigration strategies, including early, late, and pulse types (see sections 4.1.5 and 4.1.6 for details). The first two emigration strategy types, early (fast-moving, abbreviated emigration) and late (slow-moving, extended emigration), reflect the range of emigration behaviors observed in surrogate Central Valley Chinook salmon populations. Additionally, a third emigration strategy (pulse-type) was modeled to simulate the effect of applying a managed early spring pulse flow in the future restored San Joaquin River. High water temperatures predicted by recent modeling efforts conducted for reach 4B of the SJRRP and temperature sensitivity analyses conducted for the San Joaquin River reach immediately upstream of the Merced River confluence (SJRRP 2008) indicated that juvenile Chinook salmon may experience temperature-related stress or direct mortality during emigration through the SJRRP reaches when emigration continues past April and into May and June. Therefore, a pulse flow occurring in early spring (February–March) has been proposed as a management strategy to speed up juvenile Chinook salmon emigration (particularly for later migrating fall-run fish) to avoid extreme temperatures expected during May–June (see section 4.1.5 for details).

Three survival assumptions were modeled to incorporate uncertainty in juvenile abundance through the reaches (see section 4.1.7 for details). The lower and upper survival assumptions were informed by trapping data from surrogate San Joaquin River tributary Chinook salmon populations. The middle survival assumption was informed by the SJRRP Fisheries Management Plan survival target for juvenile Chinook salmon.

Two habitat quality assumptions (mean and upper) were modeled to incorporate uncertainty in reach-specific measures of habitat quality (see section 4.1.9 for details). Two dimensional habitat modeling of reaches (Reclamation 2012, Section 4.2) was conducted to estimate the present quality of fish habitat in each reach. Uncertainty in mean habitat quality (mean + 1 standard deviation) was used as an estimate of the upper habitat quality in each reach. Upper habitat quality was assumed to represent the maximum habitat quality possible for a given reach.

3.1.4 Initial Juvenile Abundance

To estimate the suitable habitat requirements of the juvenile offspring of spring-run and fall-run Chinook salmon spawners, spawner abundance needed to be converted to juvenile salmon entering the model (Table 4). First, the total number of spawners was converted to female spawners by assuming a sex ratio of 50 percent, which for the growth spawner population target resulted in 15,000 spring-run and 5,000 fall-run females. Second, the number of eggs produced by each female was set at 4,900 for spring-run and 5,500 for fall-run females, as described by Moyle (2002) as the average observed fecundities for each run. The product of the number of female spawners and fecundity resulted in 73.5 million spring-run and 27.5 million fall-run eggs for the growth spawner population target. Third, the average survival to emergence (48.5 percent) predicted using the model of Tappel and Bjorn (1983) of samples collected at random riffles in the San Joaquin River (Workman and Mesick 2012), was applied to spring-run and fall-run eggs, which resulted in 35.6 million spring-run and 13.3 million fall-run fry for the growth spawner population target. For spring-run, 10 percent of fry were assumed to migrate as yearlings, with the remaining 90 percent migrating as subyearlings. For fall-run, all fry were assumed to migrate as subyearlings. Therefore, the resulting numbers of juveniles entering the model were 3.6 million spring-run yearlings, 32.1 million spring-run subyearlings, and 13.3 million fall-run subyearlings for the growth spawner population target. The same assumptions were made for the long-term spawner population target, resulting in 5.3 million spring-run yearlings, 48.1 million spring-run subyearlings, and 20 million fall-run subyearlings entering the model.

Table 4. Resulting numbers of yearling and subyearling spring-run and subyearling fall-run juveniles entering the ESHE model under the growth and long-term spawner abundance targets with intermediate life stages and calculations applied to convert spawner abundance targets to juveniles.

	Spring-run		Fall-run	
	Growth	Long-Term	Growth	Long-Term
Number of Spawners	**30,000**	**45,000**	**10,000**	**15,000**
Sex Ratio	0.5	0.5	0.5	0.5
Number of Female Spawners	**15,000**	**22,500**	**5,000**	**7,500**
Fecundity	4,900	4,900	5,500	5,500
Number of Eggs	**73,500,000**	**110,250,000**	**27,500,000**	**41,250,000**
Survival to Emergence	0.485	0.485	0.485	0.485

Number of Fry	**35,647,500**	**53,471,250**	**13,337,500**	**20,006,250**
Proportion Yearlings	0.1	0.1	N/A	N/A
Number of Yearlings	**3,564,750**	**5,347,125**	N/A	N/A
Number of Subyearlings	**32,082,750**	**48,124,125**	**13,337,500**	**20,006,250**

3.1.5 Initial Timing and Size

Initial timing and size distributions were created for yearling and subyearling spring-run and subyearling fall-run juveniles to inform the date of emigration and average size at emigration for each daily cohort entering the model. Rotary screw trap (RST) catch data from surrogate Central Valley Chinook salmon populations were used to inform initial timing and size distributions for spring-run and fall-run subyearlings under each of 3 emigration strategy types (early, late, and pulse). Limited RST catch data for spring-run yearling Central Valley Chinook salmon populations were available to inform separate distributions for each emigration strategy type. Therefore, single spring-run yearling initial timing and size distributions were applied to all 3 emigration strategy types.

Fall-Run Subyearlings

The expanded daily proportional catches of subyearling fall-run Chinook salmon from the RST located at Caswell State Park on the Stanislaus River, 1995–2009 (Cramer Fish Sciences 2011), were used to create the fall-run initial timing and size distributions. To adjust timing and size data from the Stanislaus River RST to a comparable location on the San Joaquin River, all data were applied to a location on the San Joaquin River (RM 217; RKM 350) the same distance downstream of the uppermost barrier to adult salmonid migration (50 miles or ~80 km downstream). Since the ESHE model begins tracking individual daily cohorts at the bottom of the adult spawning grounds (RM 234; RKM 377), timing and size distributions were "backed-up" 17 miles (27 km) from RM 217 (RKM 350) using appropriate migration speeds and growth rates, with migration speeds dependent on fish size and emigration strategy type and growth rates dependent on fish size the following model day (see section 4.1.6 for migration speeds and section 4.1.8 for growth).

Because variability in annual flow regime has been observed to be a major influence of juvenile Chinook salmon emigration behavior (Cavallo *et al.* 2012; Lister *et al.* 1966), flow data from the Orange Blossom Bridge gauge (available online from the Department of Water Resources) was used to identify the range of emigration strategies of Stanislaus River fall-run Chinook salmon. The average of the average daily flows during the emigration period across all years was calculated. Individual flow years were considered above average if flows exceeded the multiyear average and below average if flows did not exceed the multiyear average. During above average flow years, juveniles exhibited a fast and abbreviated emigration, categorized as an "early" emigration strategy. During below average flow years, juveniles exhibited a slow and extended emigration, categorized as a "late" emigration strategy.

Yearly estimates of initial emigration timing and size were smoothed using a locally-weighted least squares (LOWESS) method. Smoothed yearly estimates of initial emigration timing and size were then averaged by emigration strategy type to obtain daily estimates for early and late emigration strategy types. Daily estimates for early and late types were then smoothed again using a LOWESS method in the statistical software SYSTAT to obtain final daily estimates of initial emigration timing and size by emigration strategy type (Figure 5 and Figure 6).

Both initial emigration timing and average size distributions were smoothed in order to capture general population level trends and remove outlier data points related to trap efficiency or the capture of a few abnormally-sized fish. In general, Stanislaus River RST data exhibited many days with relatively large catches followed by days of relatively small catches because gear efficiency was low and varied tremendously from day-to-day. Similarly, relatively small catches paired with the capture of abnormally-sized fish created additional outlier data points. Therefore, without applying a smoothing procedure, the shape of resulting distributions would be highly erratic thereby highlighting large swings in capture efficiency and size instead of general population level trends.

To define a pulse emigration strategy type, Stanislaus River flow and RST catch data were paired and used to determine what flow and timing characteristics drove early subyearling emigration during 1995–2009. The relationships between the proportion of total annual flow (acre-ft) released in individual winter and spring months (January–April) and the proportion of fall-run subyearlings captured in the Caswell Memorial State Park RST by both April 1st and May 1st were examined to determine the month and magnitude of pulse flow release that provided the greatest acceleration in juvenile emigration. The proportion of total annual flow released in February was the best predictor of the proportion of juveniles captured by both April 1st and May 1st (N = 14, F = 2.963, and P = 0.11 for April 1st; N = 14, F = 3.767, and P = 0.08 for May 1st). The two relationships explained ~20 percent and 24 percent of variation in the proportion of juveniles captured by the 1st of each month, respectively. The two years (1997–1998 and 1998–1999) with the greatest proportion of total annual flow released in February (>15 percent total annual acre-ft) were used to inform initial timing and size distributions and migration speeds (see section 4.1.6) for both fall-run and spring-run subyearlings during the pulse emigration strategy type.

Average initial timing and size distributions for a pulse emigration strategy type for fall-run subyearlings were created by averaging the Stanislaus River fall-run distributions during the 2 years with February flows greater than 15 percent total annual acre-ft. Similar to the early and late emigration strategy types, the resulting distributions were smoothed using a LOWESS method to capture the general population level trends in initial timing and size (Figure 5 and Figure 6).

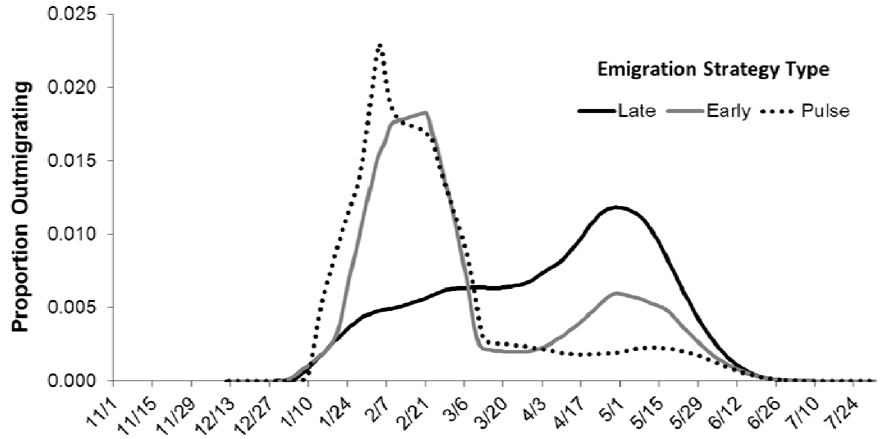

Figure 5. Fall-run subyearling initial timing of model entry for late, early, and pulse emigration strategy types.

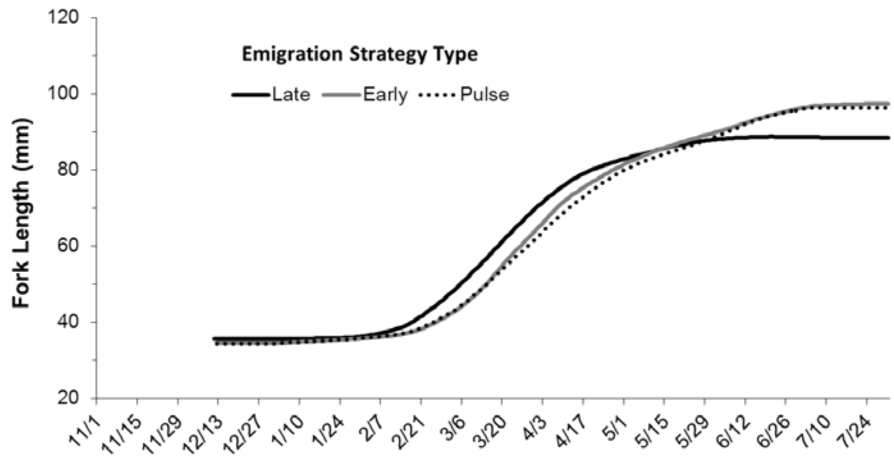

Figure 6. Fall-run subyearling initial size at model entry for late, early, and pulse emigration strategy types.

Spring-Run Subyearlings

Daily catch data from the RST located at Live Oak on the Feather River, 1999–2010 (available online from the Department of Water Resources) were used to create the initial timing and size distributions for spring-run subyearlings. Unlike Stanislaus River fall-run RST data, efficiency tests were not performed to expand the raw Feather River catch data. Therefore, the raw catch data were converted to daily passage estimates before calculating daily proportional catches. Since trap efficiency estimates are essential for producing accurate estimates of the number of natural migrants passing RSTs, efficiency relationships from the Caswell Memorial State Park RST on the Stanislaus River were used as a surrogate for Feather River trap efficiency.

Mark-recapture experiments using juvenile Chinook salmon to estimate catch rate (trap efficiency) on the Stanislaus River were previously performed (Watry *et al.* 2009). Data from these experiments were used to develop predictive logistic regression models to determine daily trap efficiencies and estimate total juvenile salmonid passage. While water temperature and turbidity were originally considered as predictors of trap efficiency, only fork length and the logarithm of flow were significant in the final model (Watry *et al.* 2009). Therefore, these were the only two variables included when applying the Stanislaus River efficiency model to raw Feather River catch data.

Before applying the Stanislaus River efficiency model to raw Feather River catch data, the approach of applying an efficiency model from one Central Valley river to another was validated by applying the Stanislaus River efficiency model to raw fall-run catch data from the Mokelumne River, a tributary of the San Joaquin River, with a known, river-specific efficiency model (Workman 2000-2007). Raw daily catches and average fork lengths from 2001, 2005, and 2006 RST captures, along with average daily log-transformed Mokelumne River flow, were applied in both the Mokelumne River and Stanislaus River logistic regression models to predict daily estimates of capture efficiency. Daily passage estimates (*n*) of migrating juvenile Chinook salmon were then calculated as follows:

$$\hat{n} = \frac{c}{\hat{q}} , \qquad (3)$$

where *c* was the raw daily catch and *q* was the estimated daily trap efficiency based on each model. To obtain the proportion of Mokelumne River fall-run juveniles emigrating on a given day in a given year, daily passage estimates were then divided by the estimated total yearly juvenile passage. Proportional daily passage estimates from each model were linearly regressed against one another to test for a significant relationship (Figure 7).

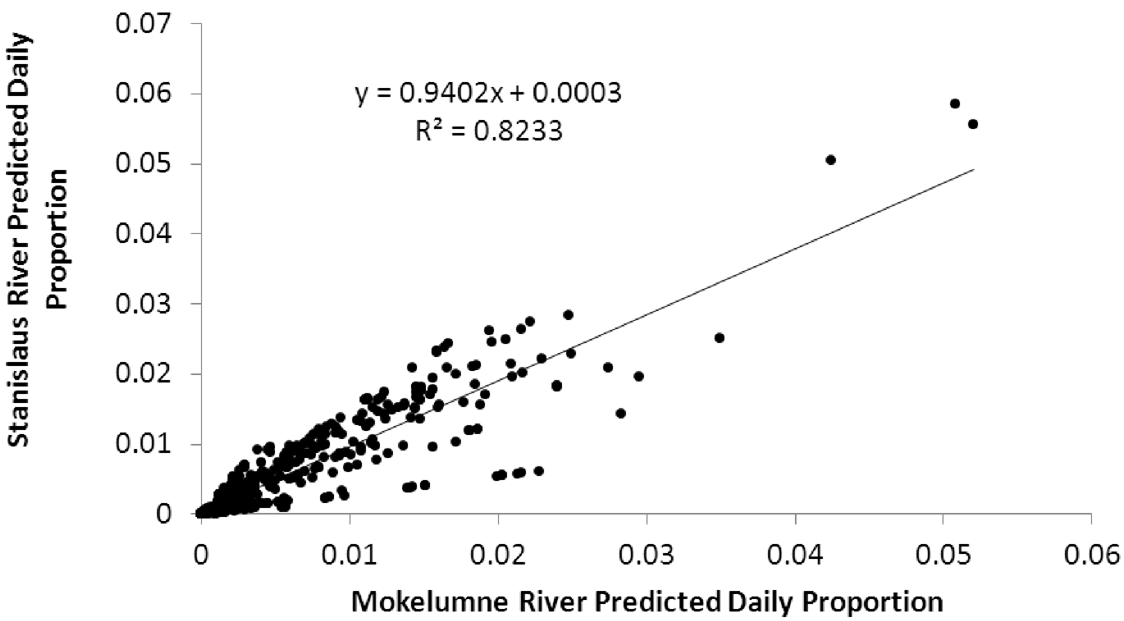

Figure 7. Proportional daily passage estimates for subyearling fall-run Chinook salmon in the Mokelumne River estimated by applying a Stanislaus River efficiency model (y-axis) and a Mokelumne River efficiency model (x-axis).

Proportional daily passage estimates for subyearling fall-run Chinook salmon in the Mokelumne River estimated using the Stanislaus River efficiency model were significantly related to estimates made using the Mokelumne River efficiency model (N = 525, $F = 2{,}310$, $P < 0.001$), with 82 percent of the variability in Mokelumne River model proportions explained by Stanislaus River model proportions. This analysis suggests that the relationships between RST trap efficiency, flow, and fish size are consistent for San Joaquin River Basin Chinook salmon and can be applied to other rivers within close geographic proximity as long as efficiency models are used to estimate daily proportions and not absolute abundances. Therefore, the same procedure and efficiency model (Stanislaus River) were applied to raw Feather River catch data to generate proportional daily passage estimates for subyearling spring-run Chinook salmon.

In order to expand catch data for spring-run subyearlings, the statistical relationships derived from the Stanislaus River efficiency model were applied to raw Feather River daily catch data. First, raw daily catch and fork length data for spring-run subyearlings captured at Live Oak on the Feather River were acquired from the Department of Water Resources (Jason Kindopp, personal communication). Second, the logarithm of daily average Feather River flow was calculated from historical flow data acquired from the monitoring station at Gridley (Department of Water Resources). Third, the Stanislaus River efficiency model was applied to fork length and log-transformed daily flow data to acquire daily efficiency estimates for Feather River spring-run subyearlings. Similar to the Mokelumne River example (see above), daily passage estimates (n) were calculated from raw daily catches and daily efficiency estimates. Finally, daily passage estimates were divided by the estimated total yearly juvenile passage to obtain proportional daily passage estimates for Feather River spring-run subyearlings.

Similar to fall-run subyearlings, spring-run subyearling timing and size data from the Feather River RST were adjusted to a location on the San Joaquin River (RM 246; RKM 396) the same distance downstream of the uppermost barrier to adult salmonid migration (~21 miles or ~34 km downstream). Since the ESHE model begins tracking individual daily cohorts at the bottom of the adult spawning grounds (RM 234; RKM 377), timing and size distributions were “moved forward” 12 miles (19 km) from RM 246 (RKM 396) using appropriate migration speeds and growth rates, with migration speeds dependent on fish size and emigration strategy type and growth rates dependent on fish size the previous model day (see section 4.1.6 for migration speeds and section 4.1.8 for growth).

Feather River flow data were used to categorize years into early and late emigration strategy types using methods identical to those used for fall-run subyearlings (see above). Similarly, yearly estimates of initial emigration timing and size were smoothed, averaged by emigration strategy type, and smoothed again using methods identical to those used for fall-run subyearlings to obtain final daily estimates of initial emigration timing and size by emigration strategy type (see above; Figure 5 and Figure 6). Both initial emigration timing and average size distributions were smoothed in order to capture general population-level trends and remove outlier data points related to trap efficiency or the capture of a few abnormally-sized fish (see above).

Limited RST and flow data were available to inform the relationship between February pulse flows and initial timing and size of emigration for Feather River fish. Therefore, the general relationship between February pulse flows and initial timing and size developed for fall-run subyearlings was applied to spring-run subyearlings. The pulse-initiated emigration timing for spring-run was created by modifying the late emigration strategy distribution. This management tool assumes that a February pulse flow could trigger juvenile salmon movement downstream and out of reaches during years when juvenile emigration is slow and spread-out, reducing potential temperature impacts that may occur by April–May (SJRRP 2008). Therefore, the goal was to provide an initial timing distribution that maintained the overall shape and duration of the late emigration strategy type distribution for spring-run while allowing for daily proportional changes in emigration based on the observed response of fall-run subyearlings to February pulse flows. The pulse initial timing distribution developed for fall-run subyearlings was used to establish “cut-offs” for applying the late-type spring-run and pulse-type fall-run initial timing distributions. The late-type spring-run distribution was applied before the earliest (January 11) and after the latest (April 25) intersection point of the two curves, whereas the pulse-type fall-run distribution was applied between the intersection points (January 11 – April 25). Each section of the resulting distribution (before January 11, January 11 – April 25, and after April 25) was appropriately scaled to maintain the correct proportions of fish emigrating before, between, and after each cut-off. The resulting distribution was smoothed using methods identical to those used for early and late emigration strategy types (see above; Figure 8). The late-type initial emigration size distribution previously developed for spring-run subyearlings was assumed to accurately represent the size distribution expected during February pulse flow years (see above; Figure 9).

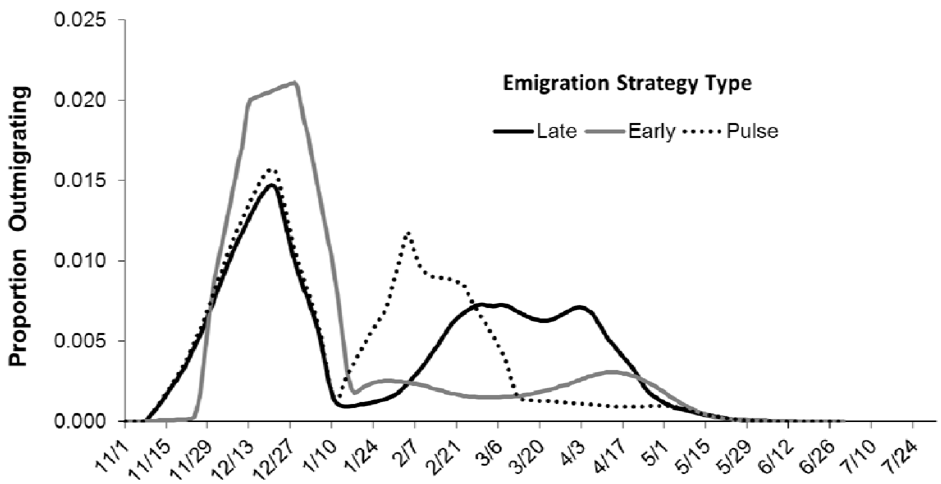

Figure 8. Spring-run subyearling initial timing of model entry for late, early, and pulse emigration strategy types.

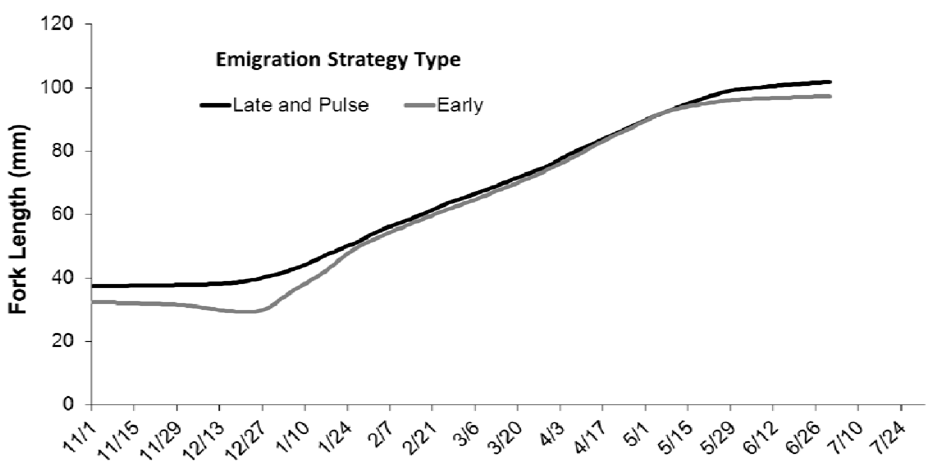

Figure 9. Spring-run subyearling initial size at model entry for late, early, and pulse emigration strategy types.

Spring-Run Yearlings

Limited data for spring-run yearling Central Valley Chinook salmon populations were available to inform initial timing and size distributions required by the ESHE model. Unlike subyearling RST data, limited spring-run yearling catches resulted in more qualitative than quantitative data for most Central Valley rivers. Therefore, catch data from screen traps and RSTs located at Parrott-Phelan Diversion Dam (39^{o} 42’ 33” N, 121^{o} 41’ 59” W) and RSTs located in the Sutter Bypass (39^{o} 02’ 06” N, 121^{o} 44’ 33” W) on Butte Creek, 1998–2000 (Ward and McReynolds 2001), were used to create single initial timing and size distributions for a pulse emigration strategy type. These single initial timing and size distributions created for spring-run yearlings were then applied to all three emigration strategy types.

Spring-run yearling catch data available for Butte Creek included dates of first and last yearling capture, average yearling fork lengths reported on a bi-weekly basis, and general descriptions of the magnitude of yearling emigration for both the 1998–1999 and 1999–2000 trapping seasons (Ward and McReynolds 2001). Dates of first and last yearling capture indicated a relatively consistent emigration period extending from mid-October through mid-May. However, general descriptions of the magnitude of yearling emigration suggested two distinct strategies: (1) a longer, late emigration strategy extending from mid-October through January (1998–1999), and (2) a shorter, early emigration strategy extending from mid-October to November (1999-2000). Because November spawner attraction flows are planned in the future restored San Joaquin River (Exhibit B of Settlement), spring-run yearling emigration timing would likely coincide with these pulse flows. Therefore, dates of first and last yearling capture and the general description of the magnitude of yearling emigration for the 1999–2000 trapping season were used to manually create the initial timing distribution for spring-run yearlings. This initial timing distribution was then scaled and smoothed using methods identical to those used for subyearlings to obtain proportional daily emigration estimates (see above). The resulting distribution was then “shifted” by 32 days to better coincide with planned November spawner attraction flows, with the original emigration peak at October 19 shifted to November 19 (Figure 10). Average spring-run yearling fork lengths reported for Butte Creek fish increased throughout the 1999–2000 trapping season, but were highly variable. Therefore, the date (October 1 – June 30) and fork length (80–150 mm) ranges provided for Central Valley spring-run yearlings in Moyle (2002) were used to develop a linear initial size distribution (Figure 11). To check for consistency between data sources, Butte Creek fork length data from the 1999–2000 trapping season were compared to the linear initial size distribution developed from the ranges provided by Moyle (2002).

Unlike subyearling modeling, yearling timing and initial size distributions were not adjusted to account for the differences in distance to the uppermost barrier to adult salmonid migration between Butte Creek and San Joaquin River. Trap location adjustments were nearly impossible because the general descriptions of the magnitude of yearling emigration were based on combined data from all 3 Butte Creek trapping locations. Similarly, adjusting the spring-run yearling initial emigration size distribution was unnecessary because the accelerated migration speed applied to spring-run yearlings in the ESHE model (see section 4.1.6) would make any modest difference in starting location have a negligible impact on juvenile emigration timing through each reach.

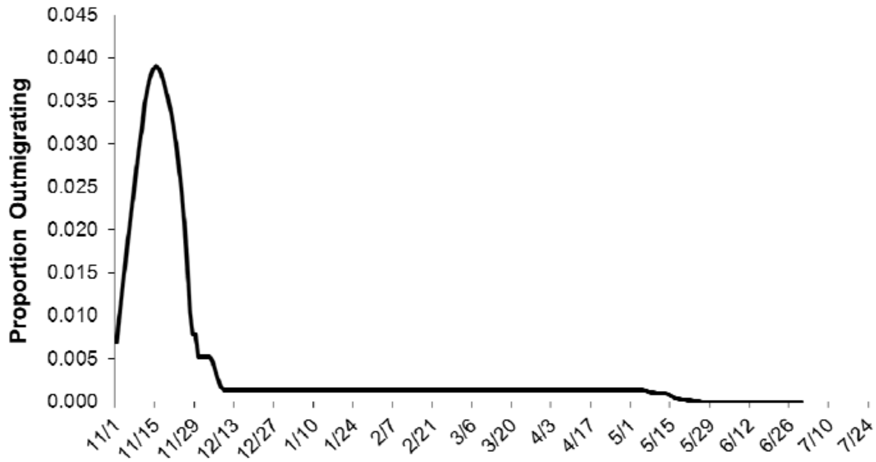

Figure 10. Spring-run yearling initial timing of model entry.

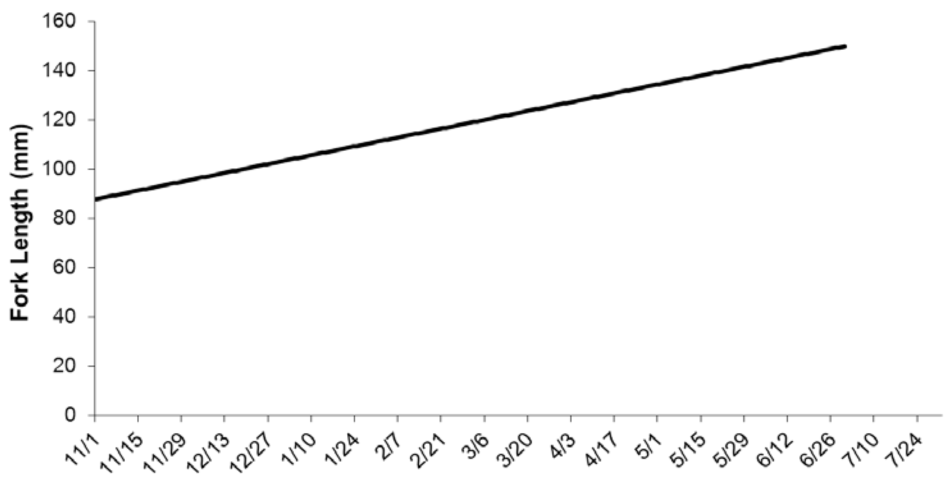

Figure 11. Spring-run yearling initial size at model entry.

3.1.6 Migration Speed

Stanislaus River juvenile fall-run Chinook salmon tagging data were used to examine how flow and fish size influence migration speed during emigration. A combination of Stanislaus River coded-wire tag, acoustic tag, and mark-recapture data were used to derive migration speed estimates (Demko and Cramer 1996; Demko *et al.* 1998a; Demko *et al.* 1998b; Demko *et al.* 1999a; Demko *et al.* 1999b; Demko *et al.* 1999c; Demko and Cramer 1999; Watry *et al.* 2007). Available data generally included individual fish or release group average FL (mm), average daily flow (cfs) at the time of release indexed at Orange Blossom Bridge (Department of Water Resources), days at large, total distance traveled, and corresponding migration speed per day. To determine whether or not flow influenced migration speeds, all available migration speed estimates were plotted against average daily flow (cfs) at the time of release. A commonly accepted FL size cutoff of 70 mm (Brandes and McLain 2001) defined the boundary between two stages (pre-smolt and smolt). An analysis of covariance using the statistical software SYSTAT was used to test for a significant relationship between migration speed and flow and significant differences between pre-smolt (<70 mm) and smolt (>70 mm) sized fish (Figure 12).

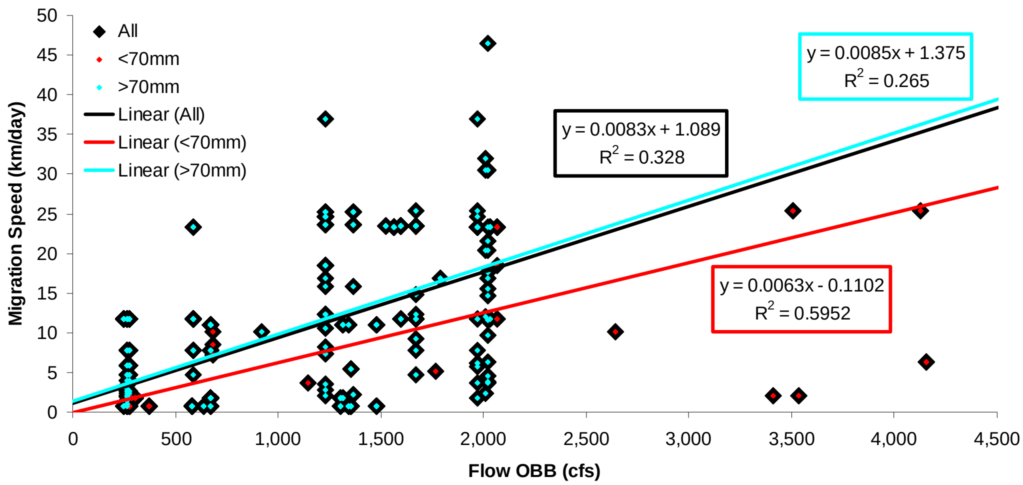

Figure 12. Juvenile Chinook salmon migration speed (km/day) vs. flow (cfs) relationships based on a combination of coded-wire tag, acoustic tag, and mark-recapture data from the Stanislaus River. Black represents all data combined. Red represents pre-smolt (<70 mm) data. Blue represents smolt (>70 mm) data.

The results of the analysis of covariance indicated that migration speeds of Stanislaus River juvenile fall-run Chinook salmon were significantly related to flow (N = 1,616; F = 666.942; P < 0.0001), with smolts migrating significantly faster than pre-smolts (N = 1,616; F = 37.792; P < 0.0001). Therefore, flow data were used to inform migration speeds under each emigration strategy type, with different migration speeds applied to pre-smolt (<70 mm) and smolt (>70mm) sized fish.

Similar to initial timing and size distributions, Stanislaus River flows during above-average flow years were used to predict subyearling juvenile Chinook salmon migration speed under an early emigration strategy type, when juveniles exhibited a fast and abbreviated emigration. Likewise, Stanislaus River flows during below-average flow years were used to predict subyearling juvenile Chinook salmon migration speed under a late emigration strategy type, when juveniles exhibited a slow and extended emigration. Average flows during above (2,021 cfs) and below (675 cfs) average flow years were applied to the linear relationships between flow and migration speed for pre-smolt and smolt-sized fish (Figure 12) to predict migration speeds for both spring-run and fall-run subyearlings (Table 5). Average Stanislaus River flows (3,972 cfs) during the two years (1997–1998 and 1998–1999) identified as exhibiting pulse flows in February (see section 4.1.5 for details) were also applied to the linear relationships between flow and migration speed to predict migration speeds for both spring-run and fall-run pre-smolt and smolt sized subyearlings for the pulse emigration strategy type. The fastest predicted migration speed (smolts under a pulse emigration strategy) was used due to limited data available to inform spring-run yearling migration speed, under the assumption that the much larger yearlings would migrate as fast as the fastest subyearling smolt sized fish.

Table 5. Migration speeds (km/day) applied to spring-run and fall-run pre-smolt (<70 mm) and smolt (>70 mm) sized subyearlings and spring-run yearlings under each emigration strategy type.

Emigration Strategy Type	Pre-smolts	Smolts	Yearlings
Late	4.14	7.11	35.13
Early	12.62	18.55	35.13
Pulse	24.91	35.13	35.13

3.1.7 Survival

To incorporate survival uncertainty, three survival assumptions were modeled. The SJRRP Fisheries Management Plan overall juvenile survival target of 5 percent (98.4 percent per km) was used as the middle survival assumption. To inform the lower and upper survival assumptions, annual survival estimates for emigrating juvenile fall-run Chinook salmon captured in RSTs located on three San Joaquin River tributaries were used: (1) the Mokelumne River (Bilski *et al.* 2011); (2) the Tuolumne River (Sonke *et al.* 2012); and (3) and the Stanislaus River (Cramer Fish Sciences 2011; Table 6). First, annual survival (*S*) estimates were converted to survival per km (*survival / km*) using the following equation:

$$survival / km = S^{\frac{1}{L}}, \qquad (3)$$

where *L* = length of river reach (RKM) between paired RSTs. Second, the per-km survival rates were extrapolated to the 187 km length of the SJRRP rearing reaches ($survival / km^{187}$). The 50th percentile of the pooled extrapolated survivals, 0.03 percent (95.7 percent per km), was used for the lower survival assumption. The 95th percentile of the pooled extrapolated survivals, 28.25 percent (99.3 percent per km), was used for the upper survival assumption.

Table 6. Annual survival estimates for emigrating juvenile fall-run Chinook salmon captured in RSTs located on the Mokelumne, Tuolumne, and Stanislaus rivers. Extrapolated survival through the SJRRP rearing reaches was calculated by applying the per km survival rate to the 187 km of rearing habitat below the bottom of the spawning grounds (RKM 377).

Population	Survival	Survival/km	Year (Spring)	Reach Length (km)	Source	Extrapolated Survival Through SJRRP reaches
Stanislaus	0.275	0.975	1996	51.4	Cramer Fish Sciences 2011	0.009
	1.091	1.002	1998	51.4		1.374
	0.365	0.981	1999	51.4		0.026
	0.707	0.993	2000	51.4		0.283
	0.146	0.963	2001	51.4		0.001
	0.087	0.954	2002	51.4		0.000
	0.077	0.951	2003	51.4		0.000
	0.156	0.964	2004	51.4		0.001
	0.186	0.968	2005	51.4		0.002
	0.067	0.949	2007	51.4		0.000
	0.107	0.957	2008	51.4		0.000
	0.038	0.938	2009	51.4		0.000
Tuolumne	0.104	0.938	2006	35.6	Sonke et al. 2012	0.000
	0.236	0.960	2008	35.6		0.001
	0.132	0.945	2009	35.6		0.000
	0.119	0.942	2010	35.6		0.000
	0.207	0.957	2011	35.6		0.000
Mokelumne	0.018	0.851	2007	24.9	Bilski et al 2011	0.000
	0.180	0.934	2008	24.9		0.000
	0.548	0.976	2009	24.9		0.011
	0.341	0.958	2010	24.9		0.000

As subyearling juveniles migrate through the river reaches, survival is applied daily on a per-km basis dependent on the distance traveled the previous day. For example, a cohort of subyearlings migrating through the river reaches under the upper survival assumption, 98.4 percent per km (5 percent overall), which migrated 10 km the previous day, will experience a daily survival of 0.852 (0.984^{10}).

Unlike subyearlings, which alternate between stationary rearing and migration as they progressively move downstream, yearlings emigrate downstream relatively quickly and rarely stop to rear (Healey 1991). Larger sizes and faster migration speeds likely leave yearlings much less vulnerable to predation, as has been observed in reservoirs in the Columbia River (Poe et al. 1991). Therefore, yearling mortality is applied all at once prior to emigration through the rearing reaches, under the assumption that nearly all mortality would have occurred during the year-long rearing stage in the upstream spawning reaches.

3.1.8 Growth

The formula used to track average growth of individual cohorts of subyearlings through time is based on an age-length curve developed for juvenile Sacramento River fall-run Chinook salmon by Fisher (1992):

$$FL = e^{3.516+0.007(Age)}, \qquad (4)$$

where FL = fork length (mm) and Age = age (days) . The model uses this equation to determine the initial age of average subyearlings in an individual cohort, and then increases FL by adding age on a daily basis. Although developed using Sacramento River data, this age-length curve represents the nearest data for the San Joaquin River and can be modified as additional growth data from the San Joaquin River becomes available. The initial size distribution developed for yearlings (see section 4.1.5; Figure 11) is used to inform yearling daily growth. The model uses this relationship to determine the initial size of average yearlings in an individual cohort, and then increases FL on a daily basis.

3.1.9 Territory Size

The formula used to track individual cohort territory size through time is based on a length-territory size relationship for salmonids from Grant and Kramer (1990):

$$TS = \frac{(FL/10)^{2.61}}{10^{2.83}}, \quad (6)$$

where TS = territory size (m^2) and FL = fork length (mm). The model uses this equation to determine the initial territory size of average fish in an individual cohort, and then increases territory size as fish grow on a daily basis. Grant and Kramer indicate that depending on food availability, intruder pressure, water depth, and current velocity, the territory-size fork-length curve may be different. Thus, ESHE has developed a range of curves depending on the habitat quality, with the average or 0.50 habitat quality curve defined as the original Grant and Kramer relationship. The residual variation around the mean relationship is used to calculate a minimum, mid-point, and maximum territory size for individual fish of a given length based on 95 percent prediction intervals (Zar 1999):

$$TS_{\min} = 10^{\log_{10}(TS) - 2.08 \times \sqrt{0.07 \times (1 + (1/23) + ((\log_{10}(FL/10) - 6.74)^2 / 1{,}518.07)}}; \; TS_{mid} = TS;$$

$$\text{and } TS_{\max} = 10^{\log_{10}(TS) + 2.08 \times \sqrt{0.07 \times (1 + (1/23) + ((\log_{10}(FL/10) - 6.74)^2 / 1{,}518.07)}}, \quad (7)$$

where TS and FL are as above, TS_{min}= the minimum territory size for fish of a given length (m^2), TS_{mid}= the mean relationship from Grant and Kramer (1990), and TS_{max} = the maximum territory size for fish of a given length (m^2).

Increased habitat quality reduces territory size, whereas reduced habitat quality increases territory size (Imre *et al.* 2002; Kalleberg 1958). However, both reductions and increases in territory size are constrained within the overall minimum and maximum territory size limits for individual fish of a given length (see above – based on modeled residual variation around the mean relationship). The model incorporates reach-specific estimates of habitat quality (Habitat Suitability Index values; HSI) ranging from 0.00–1.00. These values (HSI) are then used to calculate reach-specific territory size multipliers (TS_{mult}) using a series of conditional IF-THEN statements:

$$
\begin{aligned}
&IF: HSI \geq 0.95\\
&THEN: TS_{mult.} = -2.08\\
&ELSE\_IF: HSI \leq 0.05\\
&THEN: TS_{mult.} = 2.08\\
&ELSE\_IF: HSI > 0.50\\
&THEN: TS_{mult.} = -1 \times TINV(1-((HSI-0.50)\times 2),21)\\
&ELSE\_IF: HSI < 0.50\\
&THEN: TS_{mult.} = TINV(1-((0.50-HSI)\times 2),21)\\
&ELSE\_IF: HSI = 0.50\\
&THEN: TS_{mult.} = 100
\end{aligned}
$$

where *TINV*(1-((*HSI*-0.50) x 2),21) and *TINV*(1-((0.50-*HSI*) x 2),21) return t-values of the Student's t-distribution as a function of the probability (1-[[HSI – 0.5] x 2] and 1-[[0.50 – HSI] x 2]) and the degrees of freedom. The resulting reach-specific territory size multipliers (TS_{mult}) are applied to the length-territory size relationship for salmonids from Grant and Kramer (1990) using a series of conditional IF-THEN statements and a modified version of the 95 percent prediction interval relationships (see above):

$$
\begin{aligned}
&IF: TS_{mult.} = 100\\
&THEN: TS_{final} = TS\\
&ELSE\_IF: TS_{mult.} \neq 100\\
&THEN: TS_{final} = 10^{\log_{10}(TS) + TS_{mult.} \times \sqrt{0.07 \times (1 + (1/23) + ((\log_{10}(FL/10) - 6.74)^2 / 1{,}518.07)}}
\end{aligned}
$$

where *TS* is as above and TS_{final}= the final territory size for fish of a given length (m^2). Therefore, the mean relationship from Grant and Kramer (1990) is used for user inputs equal to medium habitat quality (HSI = 0.50) and a modified prediction interval relationship is used for all other habitat quality user inputs (0.00≤HSI<0.50<HSI≤1.00). The model effectively allows territory size to vary based on FL and habitat quality (Figure 13). However, estimates of territory size are constrained to what would be expected in natural systems (*i.e.*, constrained to the 95 percent prediction intervals based on residual variation around the mean length-territory size relationship for salmonids).

For the SJRRP, the mean reach-specific estimates of habitat quality and associated upper 1 standard deviation above estimates predicted from 2D habitat modeling (See Section 39) were used to inform the territory size versus fork length curve applied. The mean and upper habitat quality estimates applied for each reach are described in Table 21 of the results section (Section 4.3).

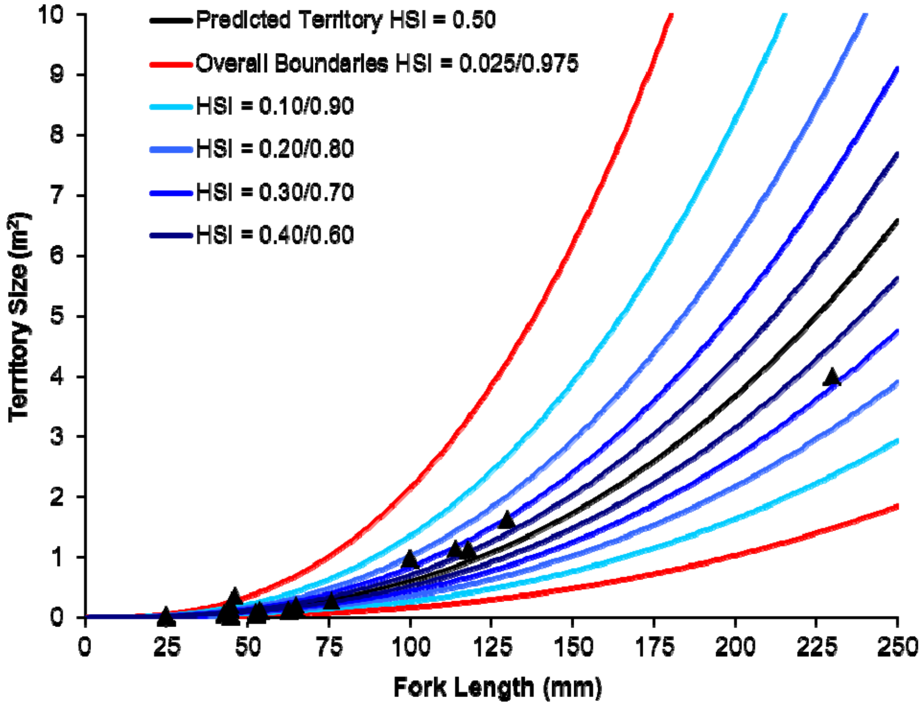

Figure 13. Example fork length-territory size relationships used in the ESHE model. Black line indicates mean relationship and black triangles are raw data from Grant and Kramer (1990). Red lines indicate 95 percent prediction interval limits. Blue lines are example modified prediction interval relationships based on user-defined habitat quality inputs ranging from HSI = 0.10 to HSI = 0.90. For blue lines, like colors represent paired “Low” and “High” quality habitats (*i.e.,* HSI = 0.10/0.90 and HSI = 0.40/0.60).

3.1.10 Calculating Required Area of Suitable Habitat

The ESHE model calculates the amount of suitable habitat area required (required *ASH*) to sustain the number of juvenile salmon present within a model reach on a given day. Daily required *ASH* is calculated in each reach by multiplying the predicted territory size by the abundance of each cohort present in a given reach, and summing across all cohorts.

Overall required *ASH* for a given run in a particular reach is estimated as the maximum daily required *ASH* during the emigration period. Overall required *ASH* for both populations (runs) combined is estimated as the maximum of the summed daily required *ASH* values for each run.

The analysis includes these values for each of the 36 scenarios (2 population targets, 3 emigration strategies, 3 survival values, 2 habitat quality values).

3.2 Available Suitable Habitat Methodology

The hydraulics in Reaches 1B through 4B2 were modeled using the Sedimentation and River Hydraulics Two Dimensional (SRH-2D) software package (Lai 2008), while Reach 5 was modeled using the one-dimensional Hydrologic Engineering Center’s one-dimensional River Anaysis System (HEC-RAS) model (Mussetter 2008, USACE 2010). Results from hydraulic simulations of prescribed river restoration flows through Reaches 1B, 2A, 3, 4A, 4B2, and 5 were used to inform a habitat estimation model. Predictions and comparisons of available suitable salmon rearing habitat are described herein.

The following sections describe the basis for the hydraulic model, the method used to determine suitable depths and velocities, the method used to determine suitable cover, and finally the methodology for combining individual Hydraulic Suitability Indexes to arrive at an area of available suitable habitat.

3.2.1 Hydraulic Modeling

There are three basic informational components needed to construct a hydraulic model using SRH-2D: river geometry, hydraulic roughness, and boundary conditions. Terrestrial geometry is comprised of the above water and below water ground elevations in the vicinity of the river, floodplain and levees. Aerial optical remote imaging (LiDAR) acquired in 2008 by the California Department of Water Resources was used to define the topography over the study reach. The development of the 2D numerical model begins with construction of the computational mesh, and is dependent on a model surface built from geographically-referenced ground elevations. The design extent and resolution of the mesh was based on the objective of capturing an appropriate level of detail in the computed hydraulics while considering the practical limits imposed by the computational time to run the simulations. The computational mesh is a hybrid unstructured grid, which means that the resolution varies with element shape and size throughout the domain. Figure 14 shows a representative portion of a computational mesh and a color scale representing the surface elevation.

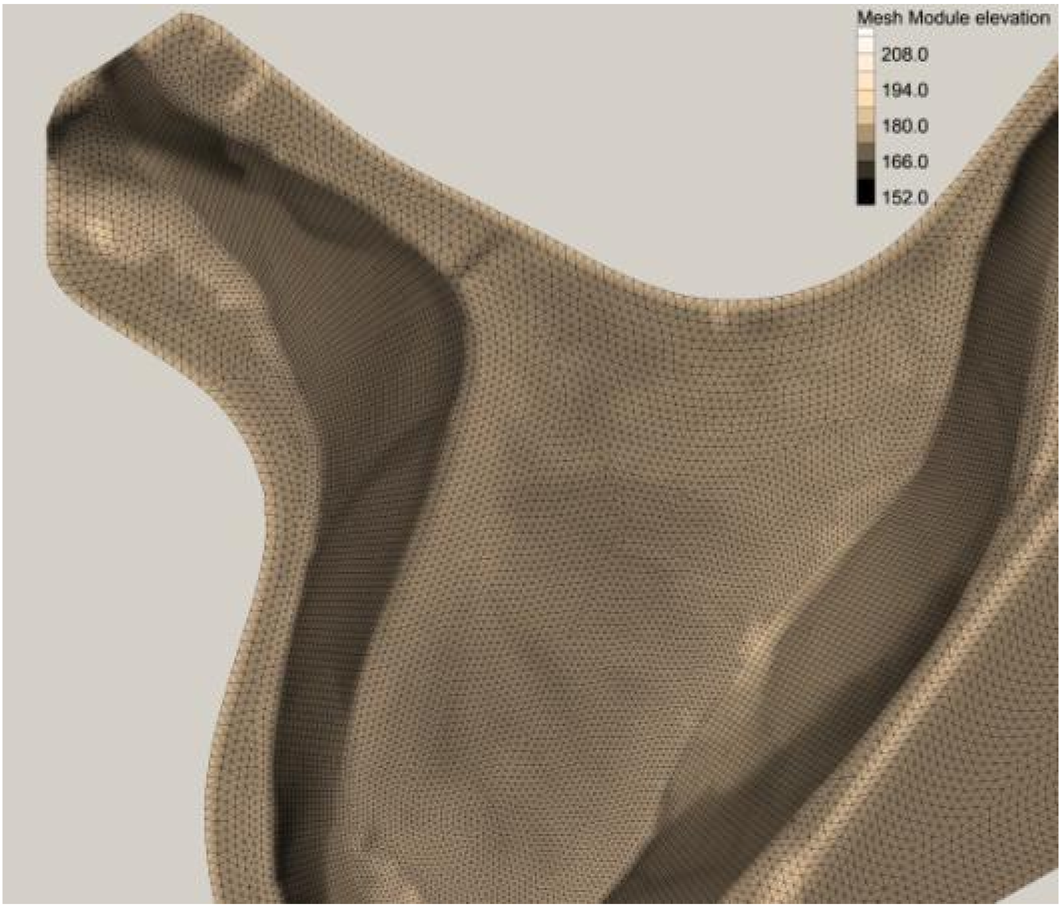

Figure 14. Example of the computational mesh in the vicinity of the Chowchilla Bifurcation Structure in Reach 2A. The color scale is mapped to the assigned elevation (NAVD88, ft) at each nodal point.

Hydraulic roughness represents the resistance to flow provided by the channel and floodplain boundary. The hydraulic roughness accounts for flow resistance provided by the channel and floodplain ground (bed) material, hills and valleys (bed forms), vegetation, and channel alignment (planform). It is often used as a calibration parameter to match modeled and observed hydraulic conditions. This study uses Manning's *n* to quantify hydraulic roughness.

Boundary conditions for the hydraulic models are specified at the upstream and downstream extent of each model reach. Additional boundary conditions are defined for each input or output to a model reach (e.g., tributaries, inlets, outlets, diversions, etc). The downstream boundary condition of each reach was specified with a water surface elevation for each modeled flow. These elevations were developed from measured water surfaces when possible, or from simulated conditions (HEC-RAS model) when sufficient measurements were not available. The upstream boundary condition of each reach was specified as an input volumetric flow rate. The Settlement specifies maximum two-week periods of flow for various year types. These benchmarks define the flow available for various water year types (i.e., "dry", "normal", and "wet"), and the corresponding flows simulated in the hydraulic models. Due to variation in inputs and outputs from reach to reach, the flow rate corresponding to water year type is reach-dependent. Table 7 gives the simulated flows for each reach and water year type used in the analysis.

Table 7. Maximum two-week Restoration flows in Settlement for various year types used in the analysis.

	Maximum 2-week flow (cfs)		
Water Year Classification	**Reach 1B**	**Reach 2A**	**Reach 2B to 5**
Dry	1500	1375	1225
Normal	2500	2355	2180
Wet	4000	3855	3655

Two-dimensional SRH-2D hydraulic models were developed for each of the Reaches 1B-4B2. A one-dimensional HEC-RAS hydraulic model was developed for Reach 5. For each two-dimensional hydraulic simulation performed, the model computes depth and velocity of flow at every grid point within the computational mesh. The one-dimensional model for Reach 5 produced an estimate of the area of inundation for each flow. Figure 15 and Figure 16 show representative distributions of computed depth and velocity, respectively, for simulation of a “normal” water year flow in Reach 2A. A complete description of hydraulic simulation results and further details concerning development, calibration, and validation of the hydraulic models is documented in Reclamation (2012).

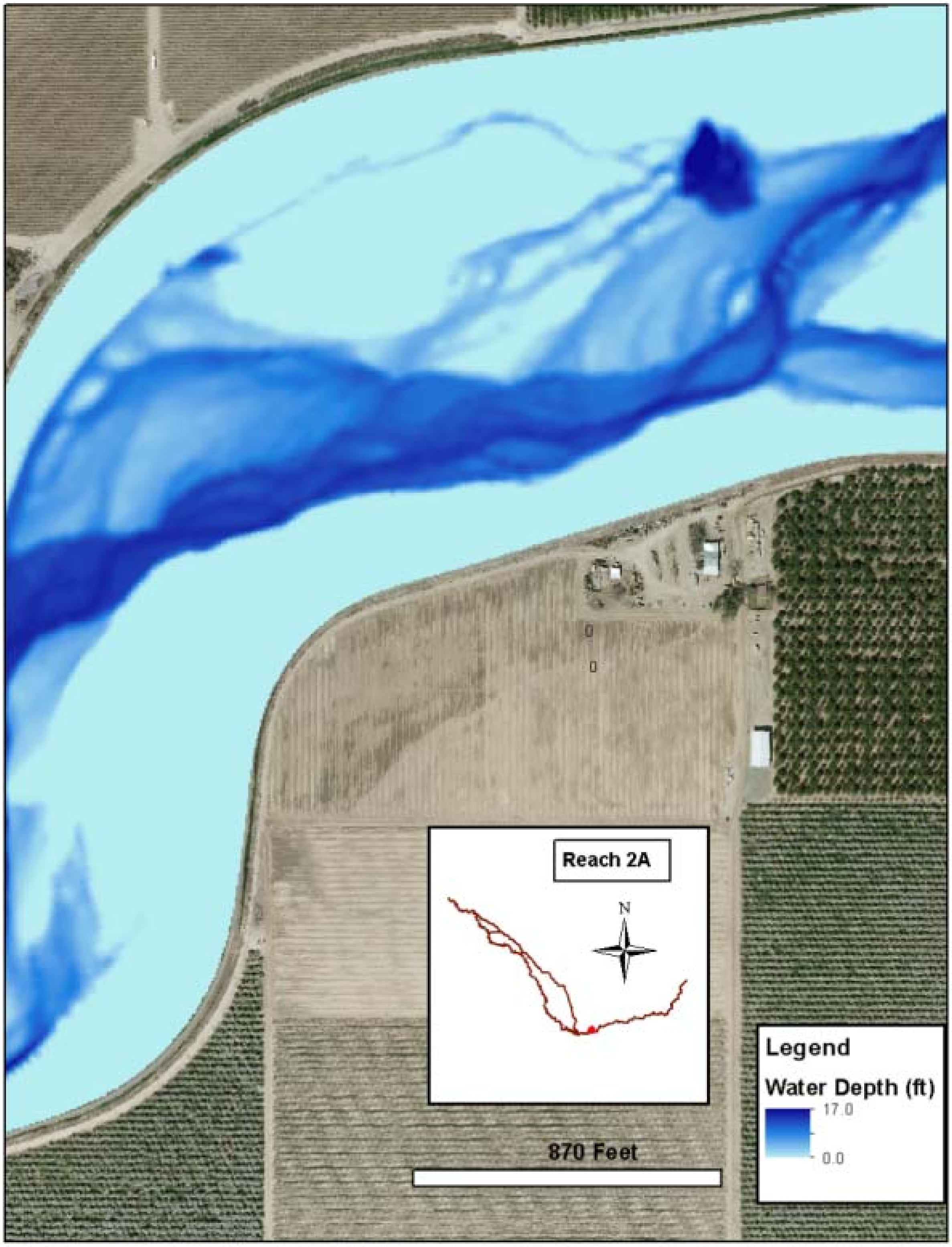

Figure 15. Representative distribution of computed water depth from simulation of a “normal” water year flow in Reach 2A.

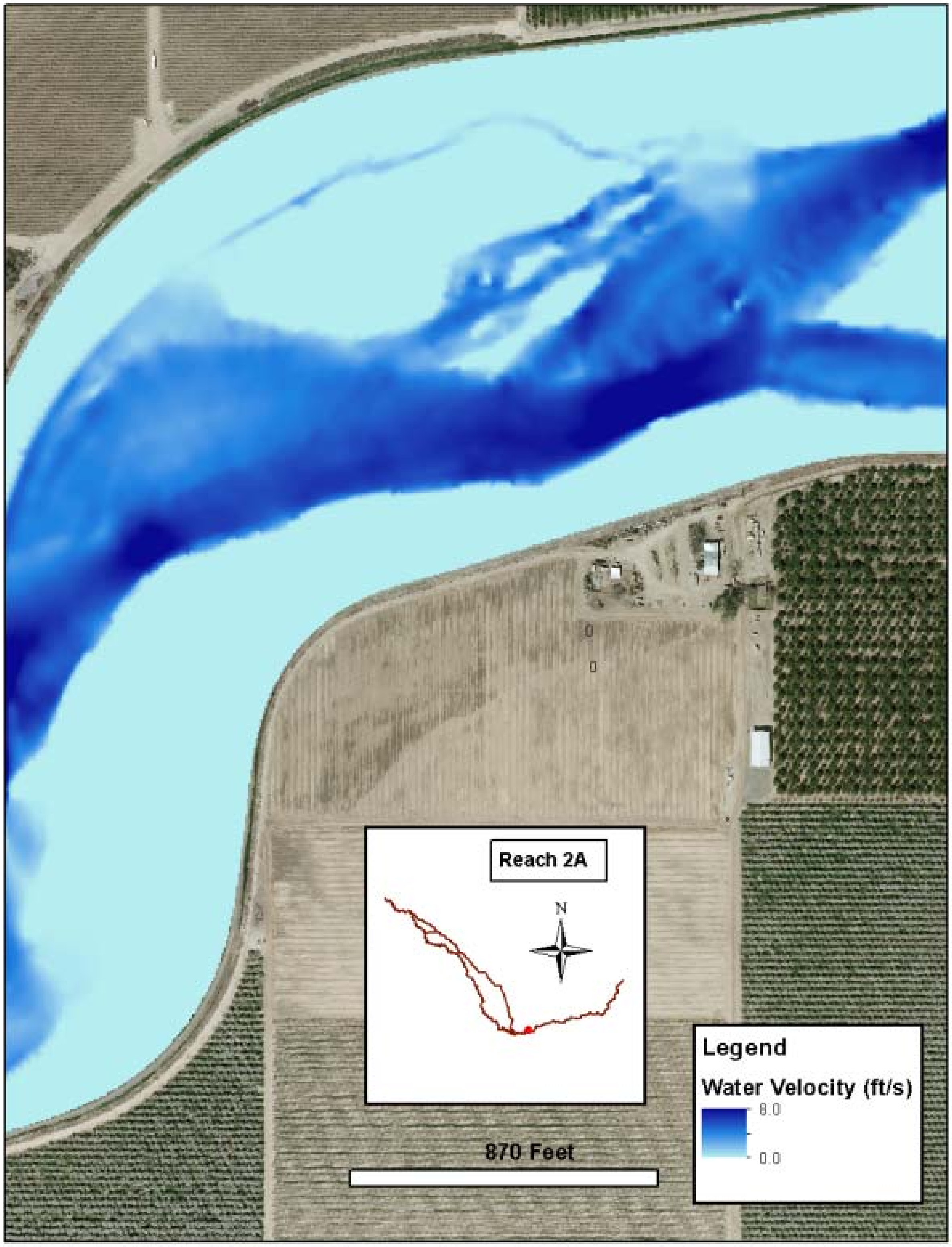

Figure 16. Representative distribution of computed water velocity from simulation of a “normal” water year flow in Reach 2A.

Distributions of simulated water depth were used to compute the *total inundated area* (*TIA*) for each reach and flow. Results from the hydraulic modeling of Reaches 1B, 2A, 3, 4A, and 4B2 were used to inform a habitat estimation model based on suitability criteria. To compute the *suitable habitat area* (available *ASH*), habitat suitability relationships were applied to depth, velocity, and cover variables on 5 ft by 5 ft grid cells distributed over a subportion of each reach. Habitat suitability indices (HSI) are correlative relationships developed from field observations of species numbers and habitat conditions. The indices provide a simple and efficient way of mapping habitat quality over large expanses of a river system. Subportions of each reach were selected for the purpose of further reducing the computational overhead of habitat calculations. The subportion habitat results were extrapolated to the entirety of each reach using *TIA* as a scaling factor.

4.2.1 Hydraulic Suitability

Fish observations from the Stanislaus River, a tributary of the San Joaquin River, were used as the basis for depth and velocity hydraulic habitat suitability (Figure 17; Aceituno 1990). Hydraulic suitability relationships exist from other river systems such as the Trinity River (Hampton 1997), however, the Stanislaus River data had several benefits over the other data sets. Stanislaus River habitat suitability curves are from within the San Joaquin Basin, they are based on data collected from actual fish observations over multiple years, and the data generally fit in the center/ mean area of the range of curves from multiple river systems considered. It should be noted that Stanislaus River fish observations are based on habitat preferences within the channel, as there was no available data on fry or juvenile habitat preferences on floodplains within the San Joaquin Basin.

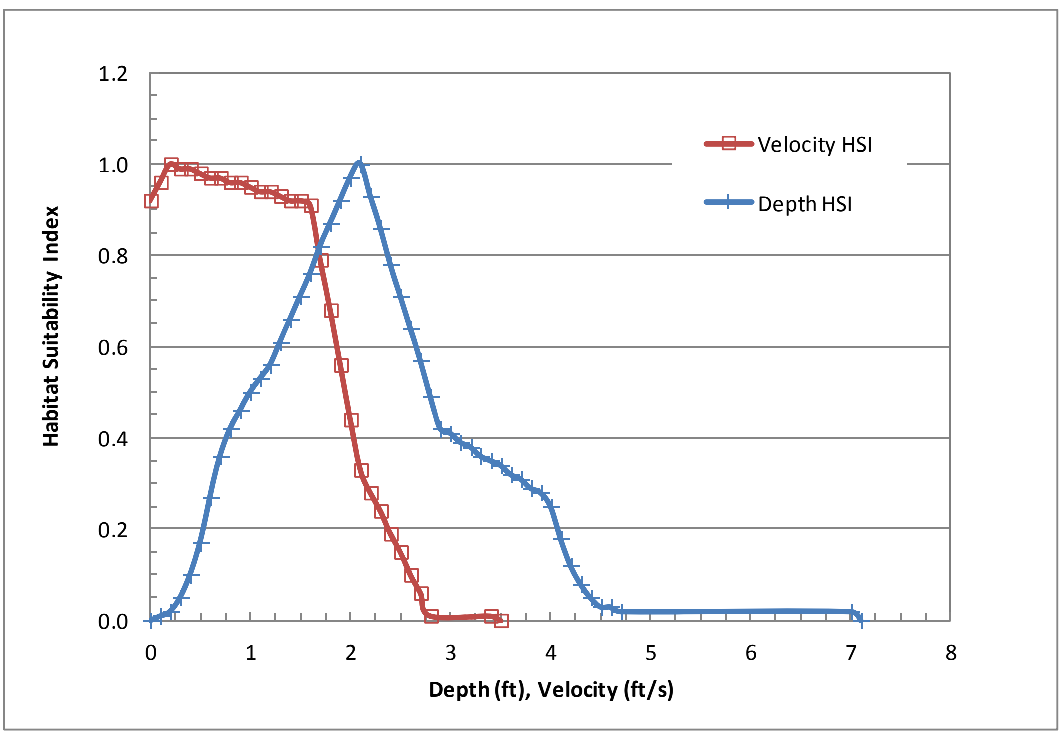

Figure 17. Habitat Suitability Index values as a function of depth and velocity from Stanislaus River (Aceituno, 1990).

4.2.2 Cover Suitability

Cover is an important component of overall habitat quality, and has a direct effect on the density of juvenile salmonids observed (McMahon and Hartman, 1989), therefore it was applied along with depth and velocity to determine suitable habitat.

To compute cover suitability under existing conditions in each reach, a review of the literature values for cover types was first conducted. Table 8 contains the categories and values from four different studies of cover: Raleigh (1986), Sutton (2006), Washington Department of Fish and Wildlife (WDFW 2004), and Hampton (1988). The average cover suitability value is also given in the table. This data was then correlated to the two datasets primarily used to determine cover types: 1) the vegetation mapping data documented in Moise and Hendrickson (2002) and 2) 2007 aerial photography that has a pixel density of 0.5 ft to delineate edge habitat.

The vegetation mapping data did not contain the same cover categories as Table 8 and therefore some adjustment of the categories was necessary. Eleven basic vegetation communities were found along the San Joaquin in Moise and Hendrickson (2002). The percentage area within each category and within each reach is given in Figure 18 to Figure 23. This vegetation mapping did not identify overhanging vegetation, aquatic vegetation, root wads, or woody debris. Conversely, the cover categories for which literature values are available (Table 8) did not contain values for cottonwood and many other riparian tree species.

Therefore, a modified set of categories was used in this study as specified in

Table 9. In this study, average literature values were applied for No Cover, River Wash, Gravel, Grasses, Wetland, and Willow categories. Gravel and Cobble/Boulder categories were not used because there are not significant areas of these features in Reaches 1B through 5. To provide a value for tree species missing from the literature, a new category called “Edge Habitat” was defined as high value ($HSI_C = 1$) habitat adjacent to features that provide cover for juvenile salmon.

Table 8. Cover habitat categories considered in development of cover methodology.

	HSI_C score for each cover type				Average HSI Value
Cover Type	**Raleigh 1986**	**Sutton 2006**	**WDFW 2004**	**Hampton 1988**	
No Cover	0.01	N/A	0.1	0.1	0.07
Woody Debris	0.9	0.6	N/A	0.7	0.73
Cobble/Boulder	0.2	0.5	N/A	0.18	0.29
Grass	N/A	0.5	0.48	N/A	0.49
Gravel	0.25	0.3	N/A	N/A	0.28
Willow	N/A	0.8	N/A	N/A	0.80
Undercut Bank	1	1	1	1	1.00
Aquatic Vegetation	0.3	0.6	1	0.5	0.60
Overhanging Vegetation	0.38	0.8	1	0.1	0.57
Root Wad	N/A	0.7	1	0.7	0.80

Table 9. Cover HSI scores from literature and those assumed for this study.

	HSI_C score for each cover type				
Cover Type	**Raleigh 1986**	**Sutton 2006**	**WDFW 2004**	**Hampton 1988**	**Assumed HSI Value**
No Cover, River Wash	0.01	N/A	0.1	0.1	**0.07**
Gravel Bars	0.25	0.3	N/A	N/A	**0.28**
Grass, Herbaceous	N/A	0.5	0.48	N/A	**0.49**
Willow Riparian and Willow Scrub	N/A	0.8	N/A	N/A	**0.80**
Wetland/Marsh	0.3	0.6	1	0.5	**0.60**
Edge Habitat	N/A	N/A	N/A	N/A	**1.00**

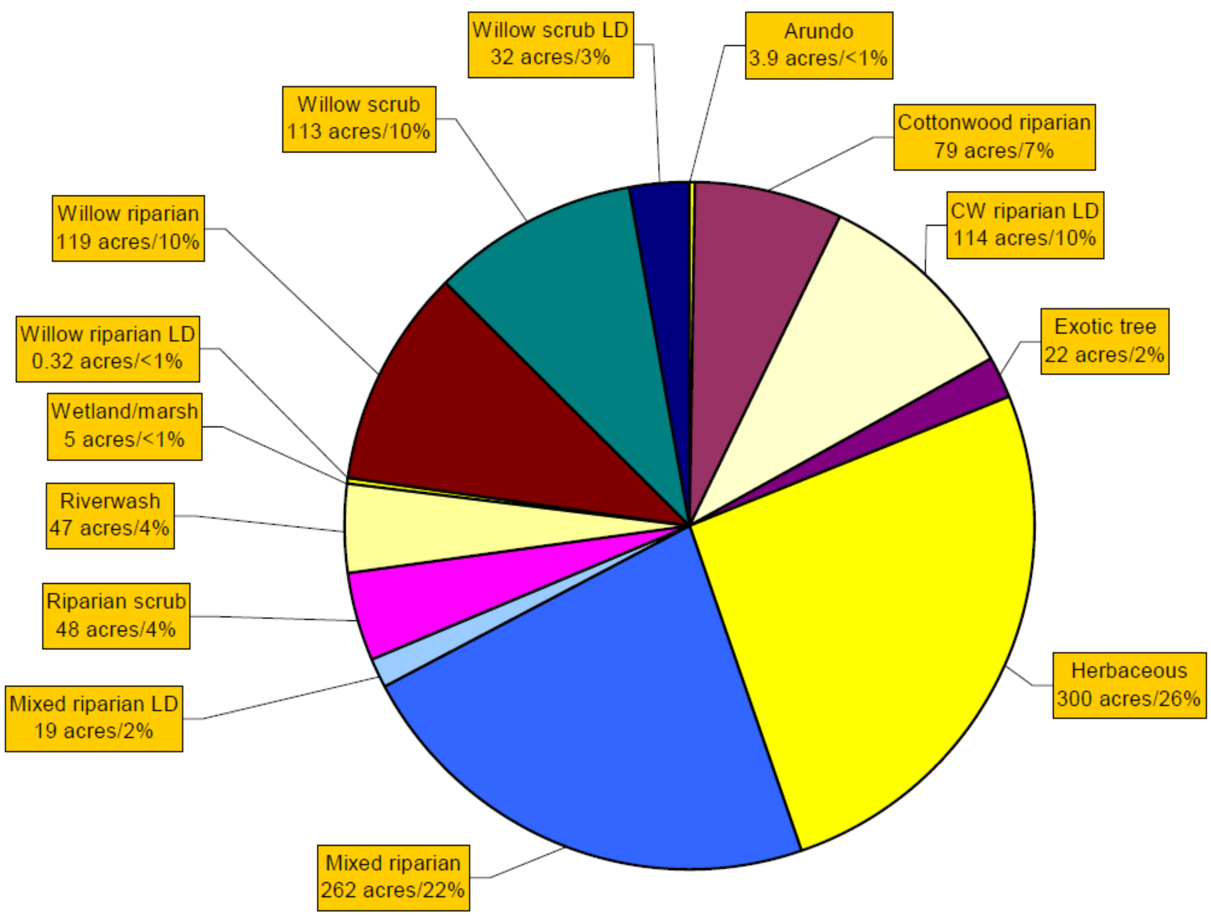

Figure 18. Percentage within each vegetation category for Reach 1b from Moise and Hendrickson (2002).

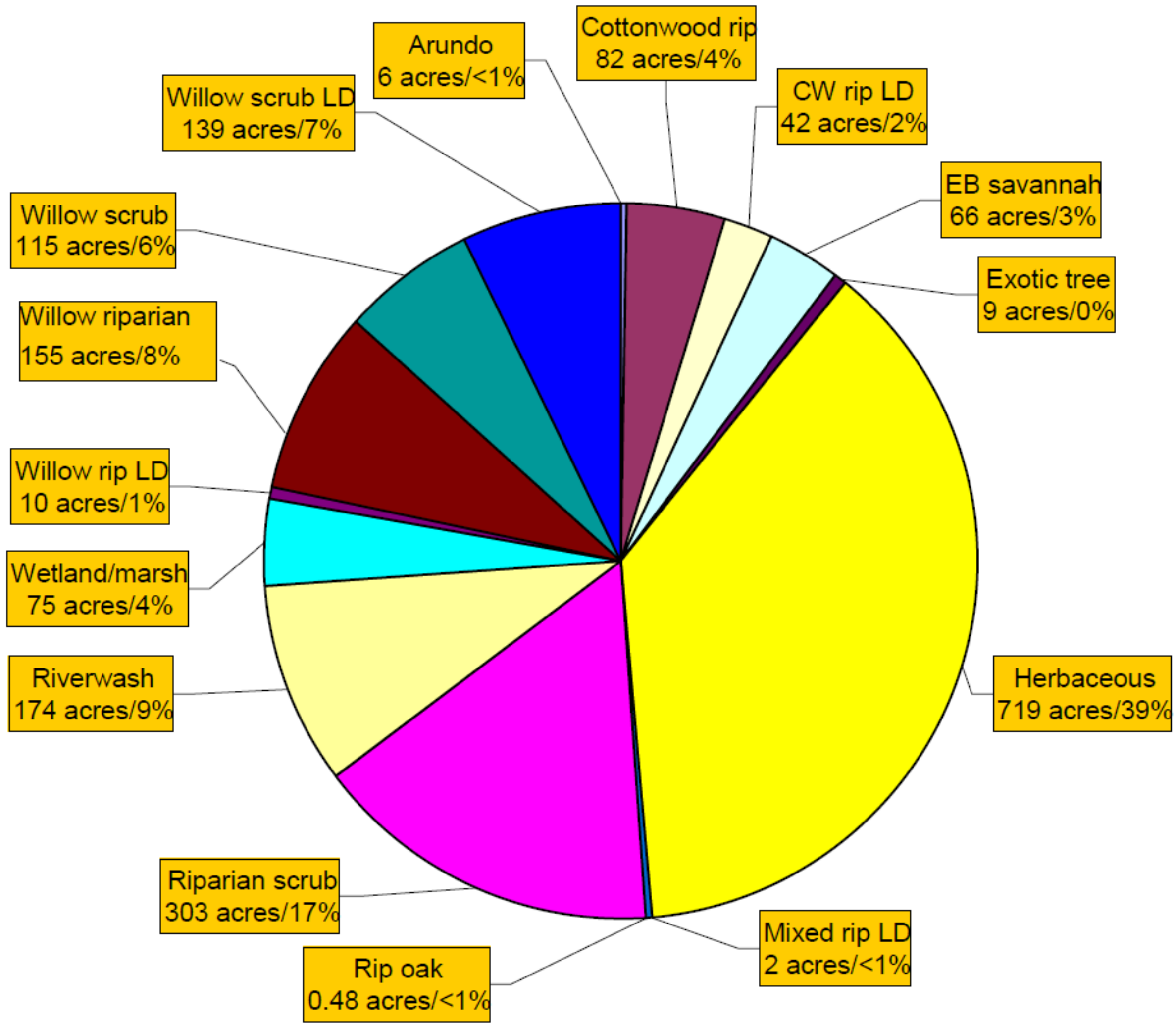

Figure 19. Percentage within each vegetation category for Reach 2 from Moise and Hendrickson (2002).

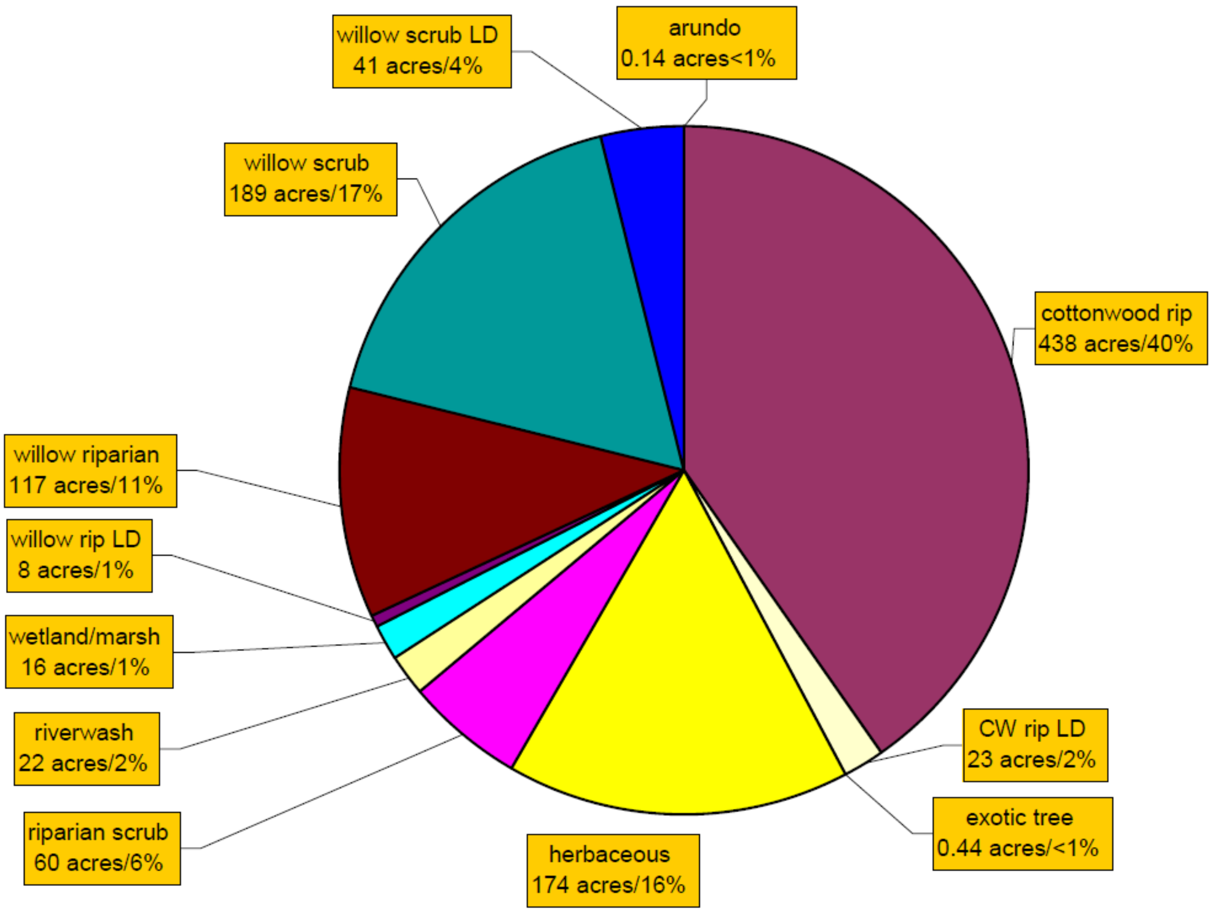

Figure 20. Percentage within each vegetation category for Reach 3 from Moise and Hendrickson (2002).

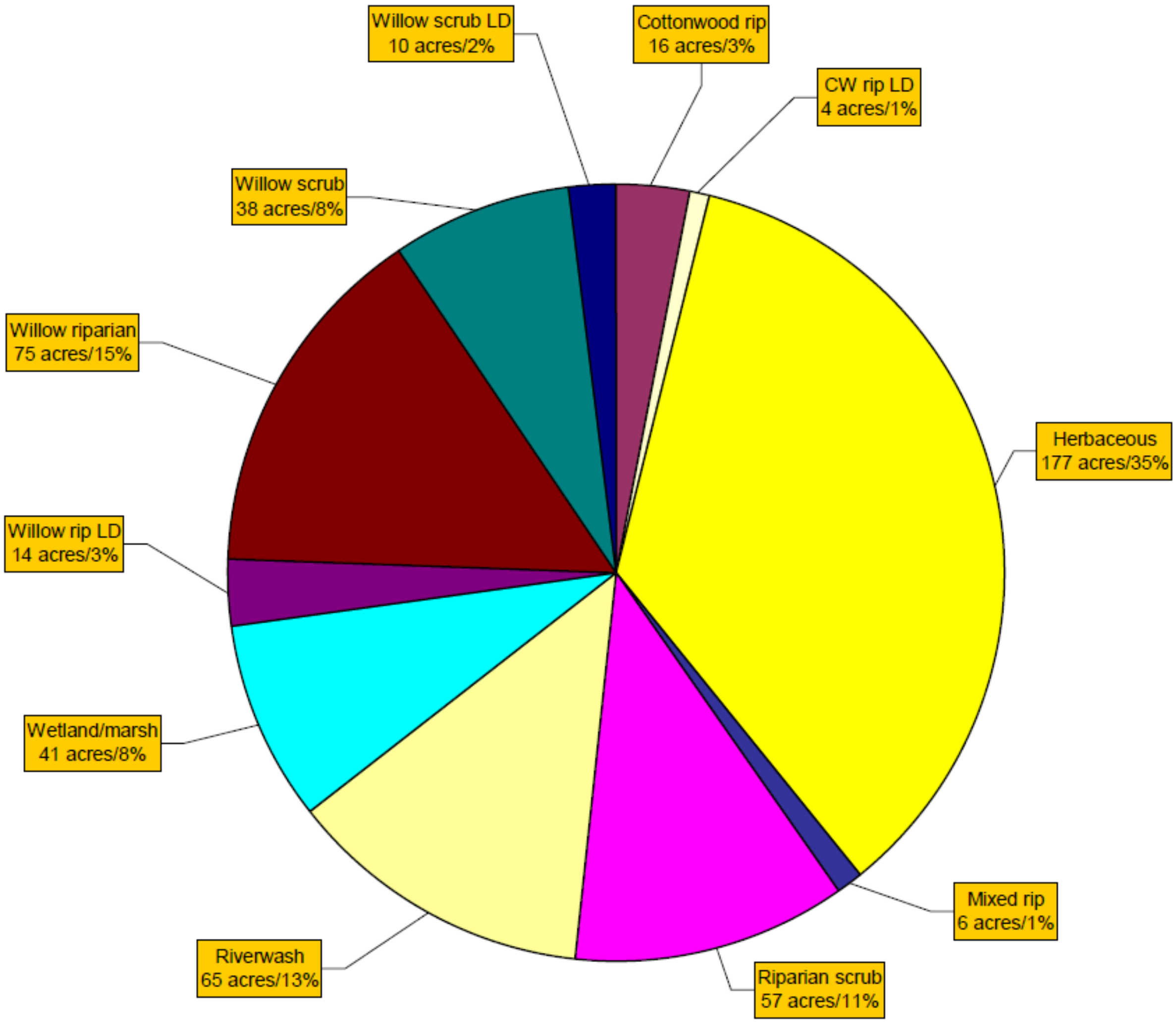

Figure 21. Percentage within each vegetation category for Reach 4A from Moise and Hendrickson (2002).

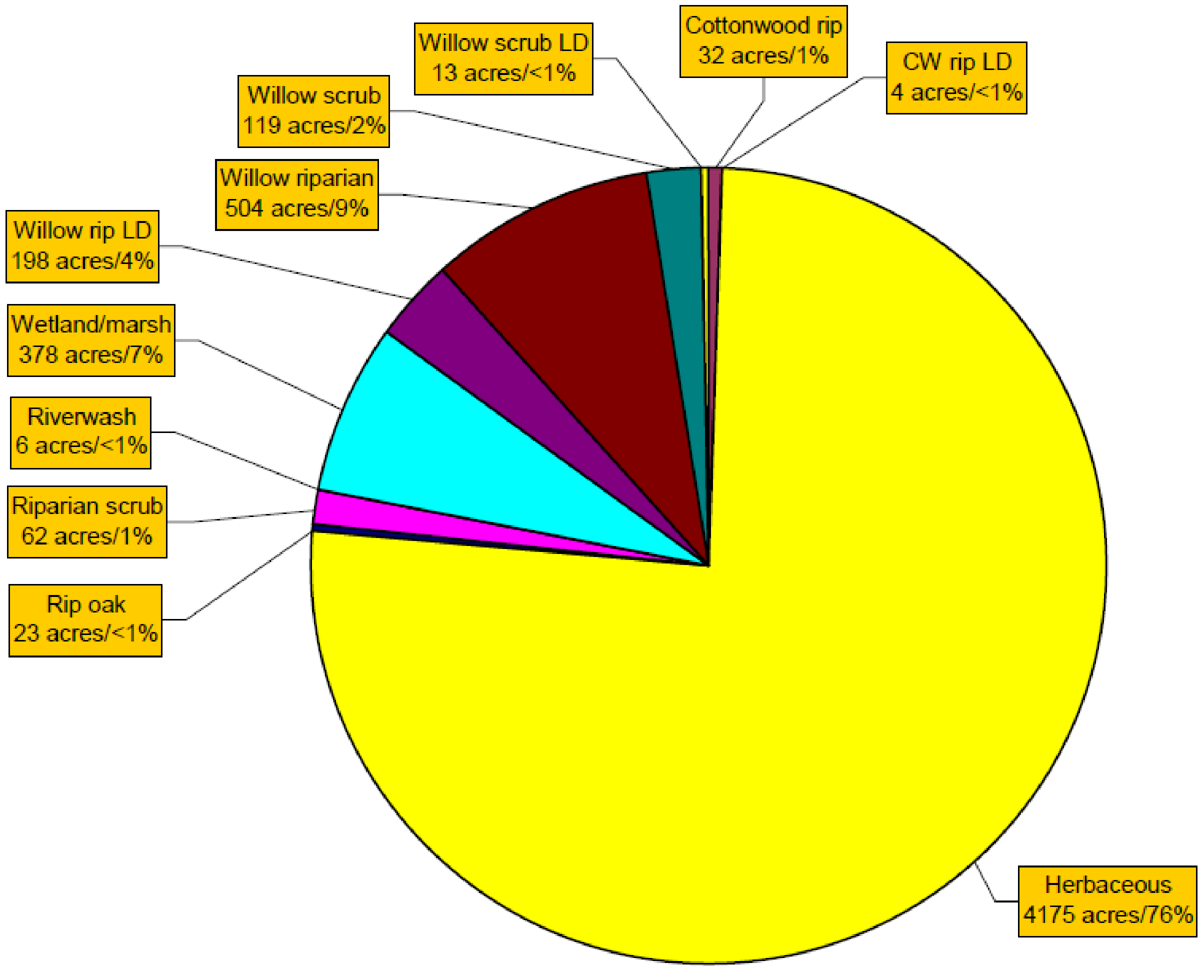

Figure 22. Percentage within each vegetation category for Reach 4B from Moise and Hendrickson (2002).

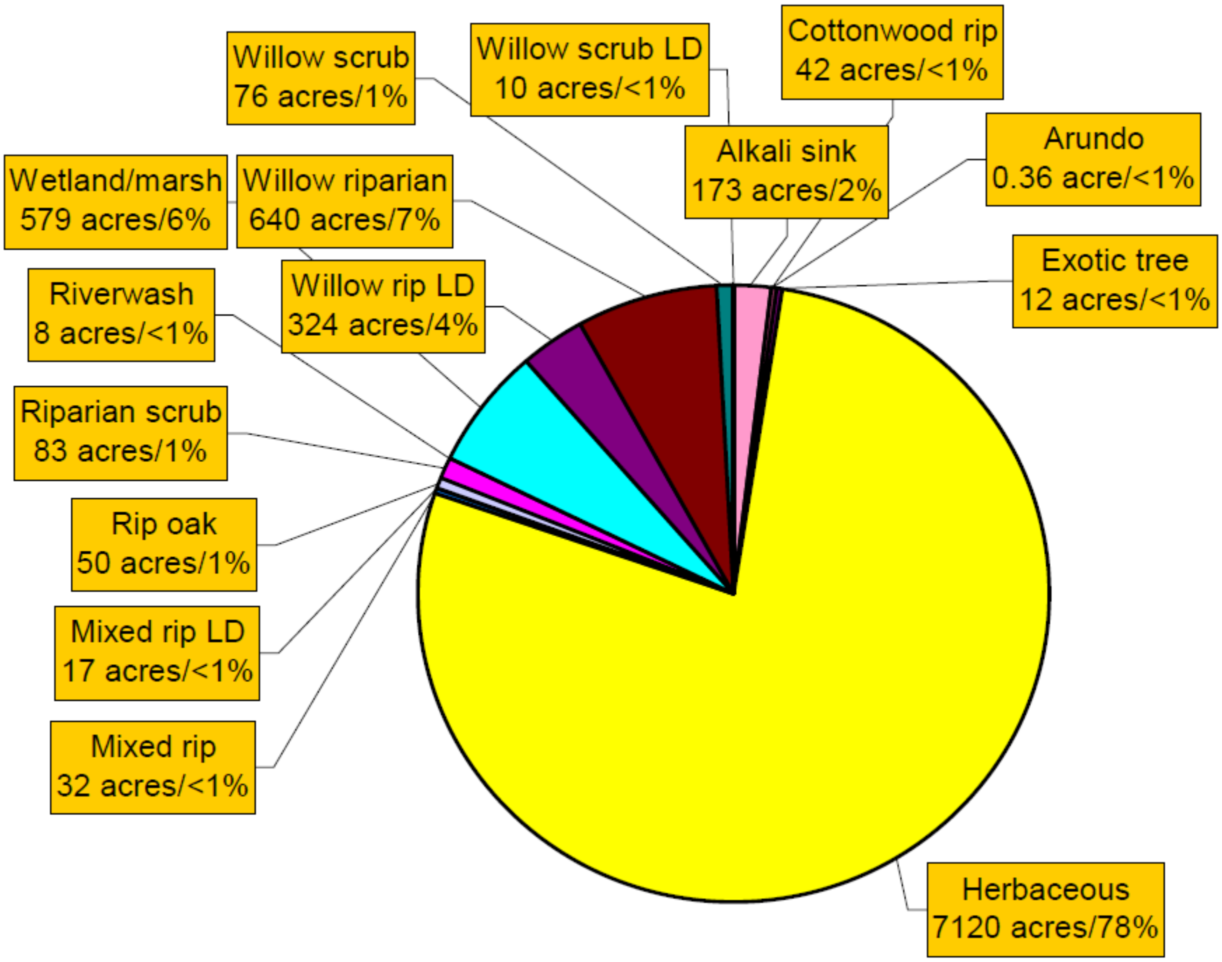

Figure 23. Percentage within each vegetation category for Reach 5 from Moise and Hendrickson (2002).

Edge Habitat Classification

The basic concept of edge habitat is that juvenile salmonids set up territories around cover features. The cover features act as current breaks and provide safety from potential predators and competitors, but they also serve as feeding stations. Therefore, cover features must be within close proximity to a food source to be used by juvenile salmonids. In most stream systems, optimal cover features are close to open water, which acts as a transport mechanism bringing food to juvenile salmonids stationed near the features. The distance juveniles are willing to move from cover to open water to feed and the distance of the cover feature to open water determines its overall utility. A cover feature with an HSI value of 1.0 (e.g., undercut bank above) may have a high cover value, but if it is not located within close proximity to open water, juvenile salmonids will abandon the feature in favor of other, more bioenergetically favorable features. This represents a trade-off between “safety” and optimal foraging strategy, and inherently means that habitats with high heterogeneity and edge features are more useful to juvenile salmonids than habitats with low heterogeneity and no edge features (Figure 24).

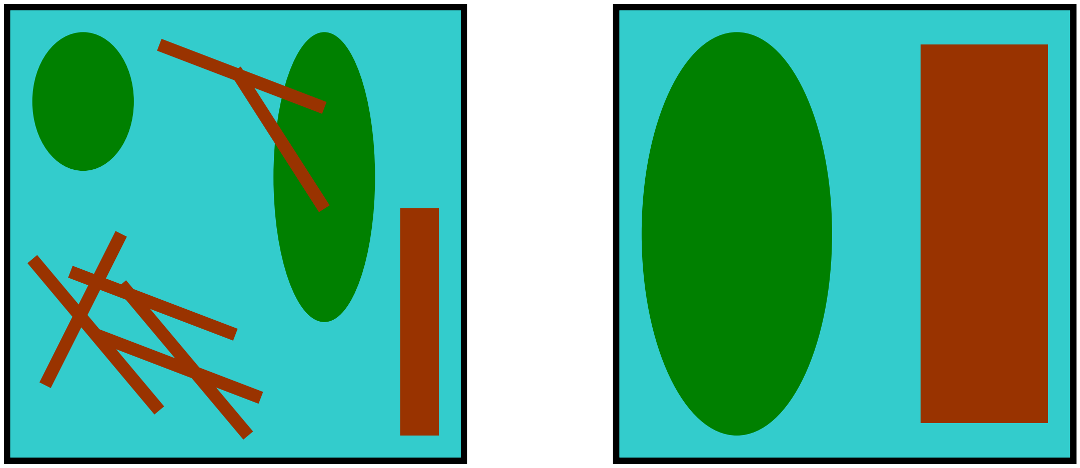

Figure 24. Example high (left) and low (right) heterogeneity habitats. Green and brown areas represent cover. Blue areas represent open water. Juvenile salmonids generally station themselves on the edges of cover features, so a greater number of smaller cover features generally provides more suitable "edge" habitat than a limited number of larger cover features even though the larger cover features may provide more overall cover area.

Juvenile salmonid burst speeds are one useful way to define areas surrounding cover features that are suitable for occupation. Burst speeds typically determine how far into open water juvenile salmonids will move from cover to forage (i.e., maximum range of taking prey if a prey item is detected). This tradeoff represents a combination of "safety" and optimal foraging strategy, and can be used to quantify habitat based on fish size and corresponding burst speed. A position that allows juveniles to remain near cover and dart into open water to forage is considered optimal and can be defined in terms of darting time. Bell (1991) suggested that a maximum darting time of 7.5 sec should be used for fish, because after this period fish are unable to pass water over their gills at a rate necessary to obtain the increased oxygen levels required for additional energy expenditure. The distance from optimal holding positions that juveniles can travel in 7.5 sec (out and back to holding position) becomes the optimal foraging distance (3.75 sec). Therefore, suitable habitat can be considered open water habitat that meets depth and velocity criteria within 3.75 sec of cover. Based on NMFS fish passage criteria, this distance is 0.90 m (3.75 sec * 0.24 m/sec) for juvenile size fish (>50 mm). Therefore, a rough approximation of usable rearing habitat area is the area which meets depth and velocity suitability criteria within ~1.0 m of cover. These values are similar to those reported by Hardin et al. (2005) in an observational study of juvenile Chinook salmon in the Klamath River, California (~0–3 ft).

This approach assumes cover features themselves are not important habitat; however, cover features influence the quality of open water habitat near their perimeter. For GIS-based modeling, this concept is relatively easy to apply by (1) buffering edge features by 1.0 m), (2) cropping the original cover feature out of the resulting buffered polygon, and (3) overlaying vegetation-based cover polygons on the resulting edge habitat polygons. The cover suitability (HSIc) distribution used in this study was ultimately produced through a union of the buffered edge habitat and the mapping classifications (Figure 26).

To compute the amount of edge habitat available, features within the 2007 aerial photographs were digitized by hand. Because of the time required for the digitization, cover features were digitized only within subportions of each reach; locations are given in Figure 25. A feature was digitized as edge habitat if it was a tree, large woody debris, steep bank line, irregular bank line, large bush, or other flow obstruction visible in the aerial photographs. If there was a dense stand of woody vegetation, only the outer edge of the dense stand was digitized. There was no digitization of edge habitat features in Reaches 2B and 4B1, because these will be subject to significant re-vegetation efforts and the current vegetation status will not be necessarily representative of future conditions. An example of the edge habitat features overlaying the vegetation classification of Moise and Hendrickson (2002) is shown in Figure 26.

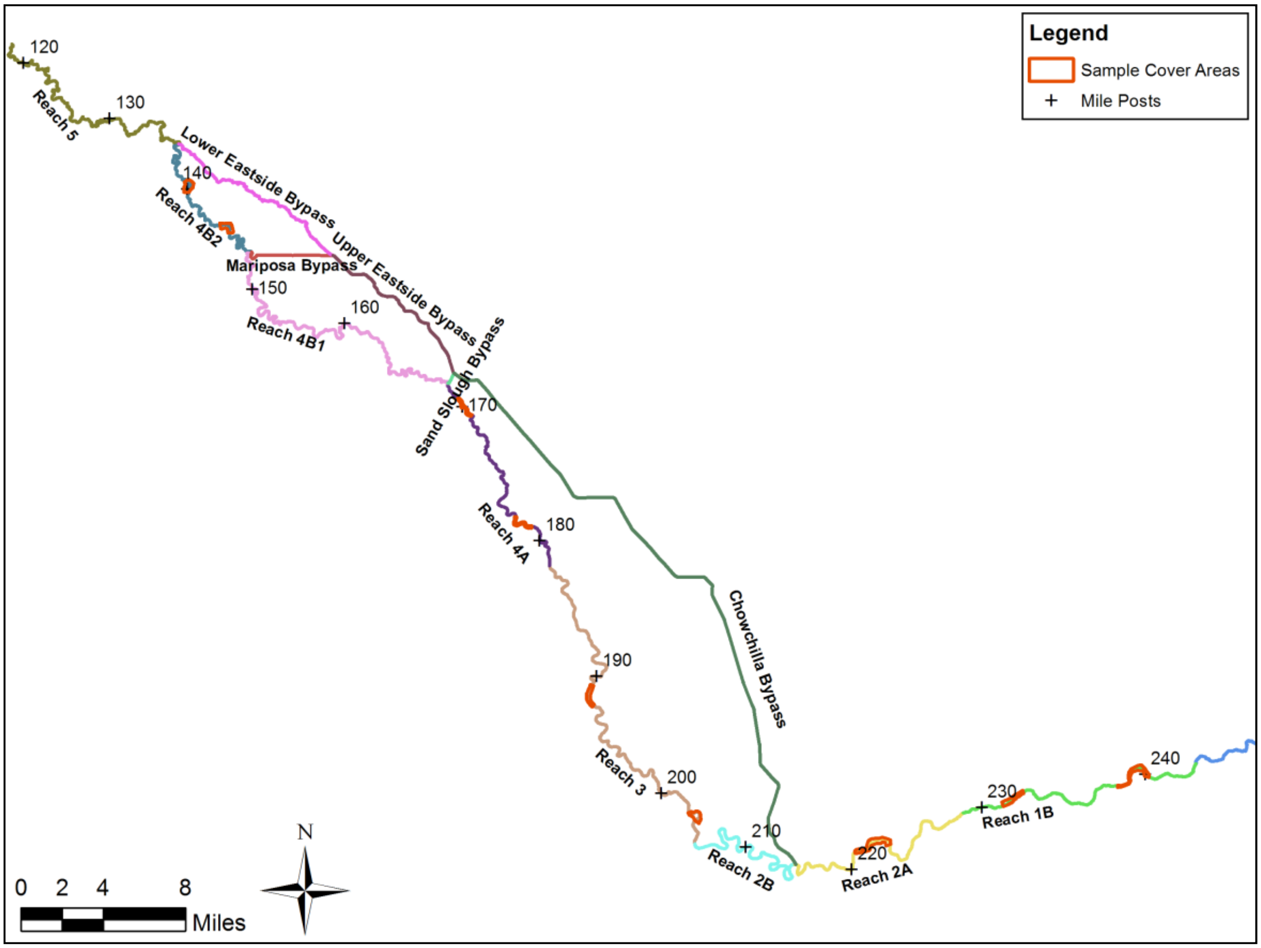

Figure 25. Representative cover habitat areas used to determine cover habitat available in each reach.

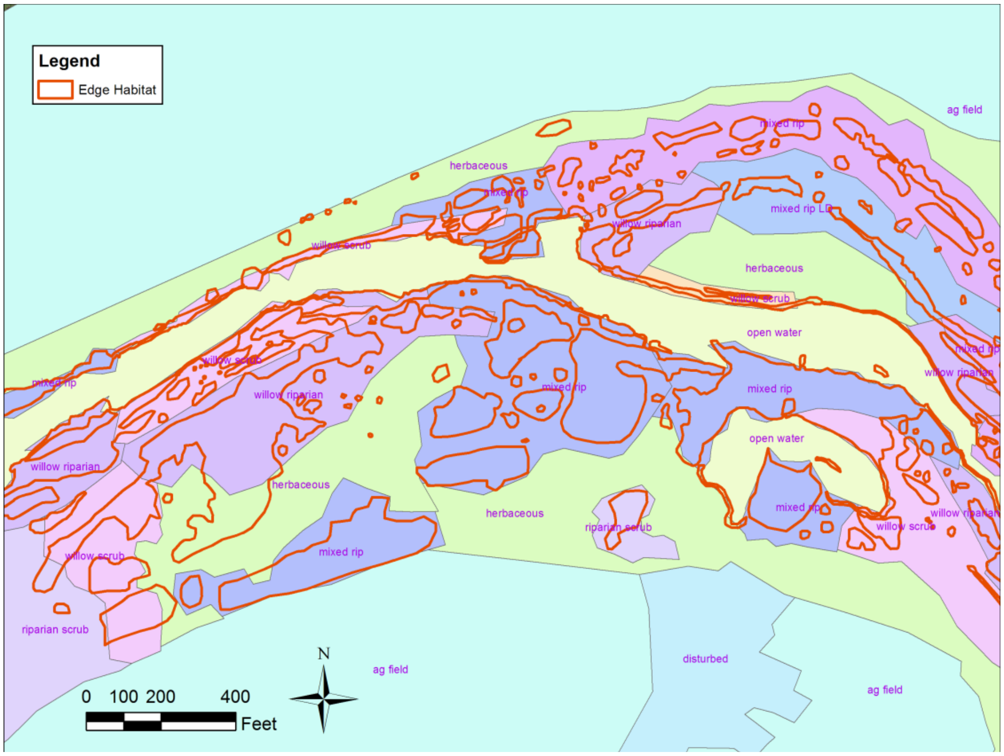

Figure 26. Example of the vegetation types overlaid with the Edge Habitat in Reach 1B.

3.2.2 Habitat Modeling

The model for predicting available *ASH* relies on distributions of both hydraulic suitability and cover suitability. At each grid cell within the selected subportions of each reach and for each flow, an HSI ranging from 0 to 1 was assigned to each variable (depth, velocity, and cover), from which a total HSI was computed at each grid cell. The total habitat suitability index (HSI_T) of each grid cell was computed as the minimum of the individual HSI values using the following equation:

$$\mathbf{HSI_T = \min(HSI_D, HSI_V, HSI_C)} \qquad (13)$$

where HSI_T = total habitat suitability of the grid cell
HSI_D = depth habitat suitability of the grid cell
HSI_V = velocity habitat suitability of the grid cell
HSI_C = cover habitat suitability of the grid cell

The above equation assumes that each variable can be a limiting factor to the habitat suitability. Total HSI can also be computed as the geometric mean or simply as the product of the three individual HSI values. However, using the geometric mean or the product does not consider that certain habitat factors may limit the suitability of particular area. For example, if $HSI_C = 0.1$ and the $HSI_D = HSI_V = 0.6$, the minimum method gives $HSI_T = 0.1$, whereas the product method would give $HSI_T = 0.036$, and the geometric mean would give $HSI_T = 0.47$. For this analysis, it is assumed that the product method could underestimate habitat quality by not limiting the HSI_T

score by the lowest individual HSI score, and the geometric mean could overestimate habitat quality when an individual factor is limiting.

Available *ASH* was calculated as the sum over all the grid cells of the inundated area multiplied by HSI_T for that grid cell:

$$\mathrm{ASH} = \sum_{i=1}^{N} \mathrm{TIA}_i \cdot \mathrm{HSI}_{\mathrm{T},i} \qquad (14)$$

where *ASH* = area of suitable habitat
TIA_i = inundated area within the grid cell *i*
$HSI_{T,i}$ = total habitat suitability of the grid cell *i*
N = number of grid cells within simulation domain

In practice, the available area of suitable habitat was computed for the selected subportions of each reach and then scaled by the reach *TIA* in order to estimate available *ASH* for the entire reach. The procedure to do this was to first calculate the depth, velocity, and cover HSI at every 5 ft by 5 ft grid cell within the subportion areas. Then the total HSI was computed at every grid cell within the subportion area by taking the minimum of the three HSI components (see Figure 27). The fraction of the total inundated area that was available *ASH* (fractional available ASH) for the subportion areas was then computed by multiplying the total HSI by the area of each cell that is inundated and dividing by the total inundated area. The fractional available *ASH* of the subportion areas was then extrapolated to the entire reach to determine the total suitable area for that reach. For Reach 5, the fractional available *ASH* values from Reach 4B2 were used to extrapolate to the available *ASH* for the entire reach.

The averaged total HSI for each reach is used by the ESHE model to compute the territory size needed by an individual fish (Section 3.1.9, Figure 13). Average total HSI is mathematically equivalent to fractional available *ASH,* as shown below.

$HSI_{T,a}$ = Sum of ($HSI_{T,i}$ x TIA_i) / TIA_T (15)

Fraction of TIA that is available Suitable Habitat = ASH_t / TIA_T (16)

Given equation 14 above, plug equation 14 into equation 16, and you obtain:

Fraction of TIA that is ASH = Sum of (TIA_i x $HSI_{T,i}$) / TIA_T (17)

Equation 17 is the same as equation 15.

Thus, average total HSI is computed as the ratio *ASH*/*TIA* for each reach. A representative distribution of calculated total HSI is presented with aerial imagery in Figure 28.

The computational procedure to compute the area of suitable habitat is similar to that used in PHABSIM (Milhous 2012) and RIVER2D (Steffler and Blackburn 2002) computer programs.

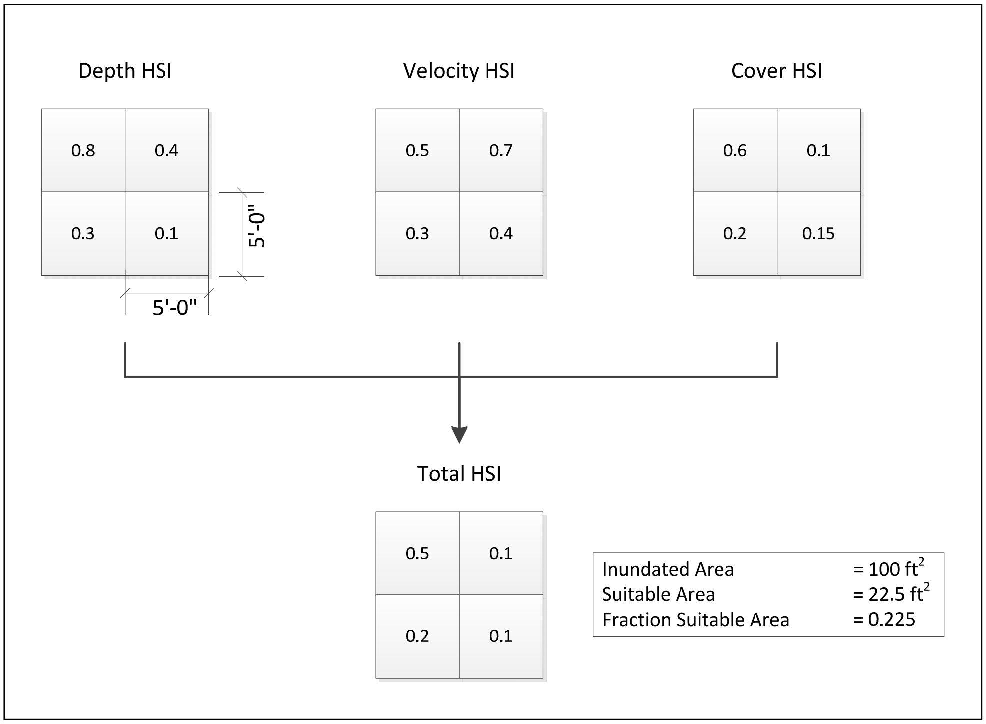

Figure 27. Graphical representation of an example HSI and suitable area calculation.

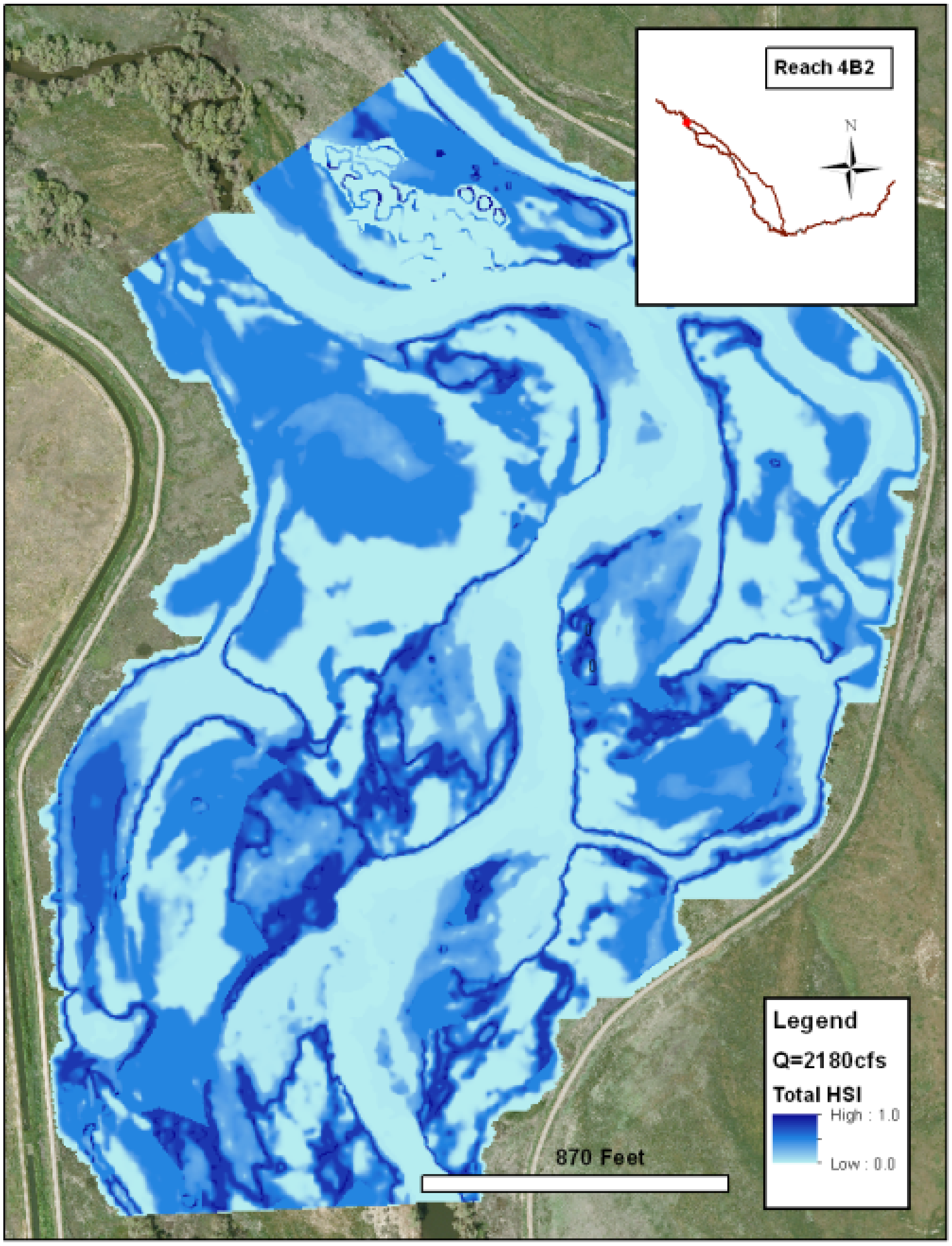

Figure 28. Distribution of calculated total HSI in Reach 4B2 for simulation "normal" water year type.

The analysis calculates a weighted usable average of available suitable habitat by multiplying the area of each cell (25 square feet) by the total HSI value for that cell (between 0 and 1) and summing these values for each cell in the reach. This was completed for three different flow levels, representing dry, normal and wet years (Table 7), which make up the three scenarios for available suitable habitat. The detailed results from calculations of available *ASH* for each reach and flow are presented in the results section.

3.3 Summary of Model Inputs

A summary of the input data for the computation of the required *ASH* and the available *ASH* is given in Table 10. Modeling exercises require assumptions and interpretation of the available data for inputs and calibration. Input data used for the ESHE portion of this exercise was tied to existing SJRRP targets (e.g., Technical Advisory Committee habitat creation population targets), or based on information from some of the nearest rivers with extant Chinook salmon populations. Not shown in Table 10 are spring-run yearlings (10 percent of spring-run), for which entry timing and speed were based on limited Butte Creek data resulting in one entry timing, size and speed. For details of the hydraulic modeling input and calibration discussion, please see the draft report Reclamation (2012). Vegetation and edge information, used to determine cover features, were based on California Department of Water Resources (DWR) mapping and aerial photos, respectively.

Table 10. Model Assumptions and Sources Summary for the calculation of the Required ASH and Available ASH.

	Spring-run Sub-yearlings	Fall-run Sub-yearlings
Number of Spawners	30,000	10,000
Number of Female Spawners	15,000	5,000
Fecundity	4,900	5,500
Number of Eggs	73,500,000	27,500,000
Survival to Emergence	0.485	0.485
Number of Fry	35,647,500	13,337,500
Number of Subyearlings	32,082,750	13,337,500
Downstream Survivals	0.03, 5 or 28.25% Stanislaus, Tuolumne, Mokelumne	
Entry Timing and Size	Feather River RST, 3 scenarios	Stanislaus RST, 3 scenarios
Migration Speed - Pre Smolts	4.14, 12.62, or 24.91 km/day (2.57, 7.84 or 15.48 mi/day) Stanislaus tagging studies	
Migration Speed - Smolts	7.11, 18.55, or 35.13 km/day (4.42, 11.53 or 21.83 mi/day) Stanislaus tagging studies	
Growth	Fisher, 1992	
Territory Size	Grant and Kramer 1990	
Habitat Quality	7% to 27% by reach, 1 std (.21 - .3) above Grant and Kramer 1990	
Depth & Velocity Method	HSI Curve, Stanislaus	
Cover	H.S.I. Value by vegetation type plus edge features as 1 DWR Vegetation classifications + Average HSI values	
Flow	Dry (1000-1500cfs), Normal (2180-2500cfs), Wet (3600-4500cfs)	
Number of Fish Emigration Strategies	3	
Number of Survival Scenarios	3	
Habitat Quality Scenarios	2	
Total Number of ESHE Scenarios	18	
Existing Habitat Scenarios	3	

Many key factors and input data described above include uncertainty. To address this, a variety of scenarios have been developed. Table 11 below shows the different numbers used for each of the key factors. Fish entry timing and speed were applied together, so these values result in a total of 36 required suitable habitat scenarios (2 population scenarios, 3 survival scenarios, 3 fish timing and speed scenarios, 2 habitat quality scenarios) and 3 available suitable habitat scenarios (3 flows).

Table 11: Values used for Scenarios

Survival	Fish Entry Timing	Fish Speed Pre-smolt / smolt (miles/day)	Habitat Quality (0-1 score)	Flow (cfs)
0.03%	Early	7.84 / 11.53	7% to 27% by reach	Dry: 1000-1500
5%	Late	2.57 / 4.42	21% to 30% by reach	Normal: 2180-2500
28.25%	Pulse	15.48 / 21.83		Wet: 3600-4500

4 MODEL RESULTS

Model results include results for each step in the methodology process, starting with daily fish numbers (abundance), then the required suitable habitat for the numbers of fish, then available suitable habitat already existing in the system, the deficit still needed (i.e. required minus available), and finally the total inundated area needed.

4.1 Daily Abundance

Across all scenarios and races, the maximum number of Chinook salmon present in each reach on a given day varied as a function of their initial abundance, cumulative survival/km, initial timing, and migration speed (Table 12 through Table 15). The number of subyearlings present in each reach generally decreased as they moved downstream through each successive reach, as mortality was applied on a per-km basis. Yearling abundance generally stayed constant as they moved through each successive reach because rearing mortality was applied prior to emigration (see section 4.1.7 for details).

Fall-run Chinook salmon maximum daily abundance was generally highest during the late emigration strategy type across all reaches (Table 13). The extended emigration period and slower speeds (see sections 4.1.5 and 4.1.6 for details) of Chinook salmon during the late emigration strategy type lead to more fish residing in each reach for a longer period of time, thereby leading to a higher maximum number of fish present in each reach on a single day. Conversely, spring-run Chinook salmon abundance was similar between the late and pulse emigration strategy types due to similar emigration period lengths for each type (see section 4.1.5 for details).

The maximum daily number of fish was not calculated for spring-run yearlings in 3 reaches (lower 1B, 2B, and 5, see Table 15) and fall-run subyearlings during the pulse emigration strategy in reach 2B, indicating that these fish spent less than one day traversing the reach. These results indicate that as large yearlings and pulse-type fall-run subyearlings are actively emigrating downstream at high speeds, some smaller reaches are only occupied for less than 1 day.

Abundance was generally higher across all reaches for spring-run versus fall-run Chinook salmon (Table 13 through Table 15 and Figure 30). Larger initial abundance for spring-run (35.6 million) versus fall-run (13.3 million) resulted in higher spring-run abundances throughout the emigration period (Table 14)

Because spring-run yearlings are actively emigrating out of the system at a fast migration speed (21 miles per day or 35 km/day) and their mortality is applied prior to emigration (during their rearing stage upstream of the restoration area), the numbers of yearlings present throughout the emigration period is miniscule compared to subyearling fall- and spring-run Chinook salmon (Table 15 and Figure 29).

The first three columns describe the model scenario for which results are presented. The next columns, for Reaches lower 1B through 5, show the maximum number of fish present in each reach on a single day (maximum daily abundance). The day on which daily abundance is the largest may be different for each reach. Also, please note that the Reach 5 numbers are a daily maximum abundance, and do not represent total juvenile production. Total juvenile production is much larger, as Table 12 only presents juvenile production on one day.

Table 12. Maximum daily number of total Chinook salmon predicted in each reach under each scenario.

Scenario				Maximum Daily Number of Chinook salmon in each reach							
Population	**Strategy**	**Survival**	**Habitat**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	496,370	286,550	260,740	105,230	10,610	11,680	1,860	590
Growth	Early	0.03%	Upper	496,370	286,550	260,740	105,230	10,610	11,680	1,860	590
Growth	Early	5.00%	Mean	597,560	488,540	724,590	661,500	145,530	294,910	117,850	76,490
Growth	Early	5.00%	Upper	597,560	488,540	724,590	661,500	145,530	294,910	117,850	76,490
Growth	Early	28.25%	Mean	636,010	585,490	1,028,440	1,249,350	351,600	888,600	478,920	397,930
Growth	Early	28.25%	Upper	636,010	585,490	1,028,440	1,249,350	351,600	888,600	478,920	397,930
Growth	Late	0.03%	Mean	745,850	1,014,560	357,190	267,320	43,870	17,110	2,750	1,830
Growth	Late	0.03%	Upper	745,850	1,014,560	357,190	267,320	43,870	17,110	2,750	1,830
Growth	Late	5.00%	Mean	835,950	1,652,790	982,590	1,429,520	581,830	487,010	164,340	197,830
Growth	Late	5.00%	Upper	835,950	1,652,790	982,590	1,429,520	581,830	487,010	164,340	197,830
Growth	Late	28.25%	Mean	869,250	1,959,900	1,385,670	2,560,400	1,399,410	1,524,960	652,500	966,320
Growth	Late	28.25%	Upper	869,250	1,959,900	1,385,670	2,560,400	1,399,410	1,524,960	652,500	966,320
Growth	Pulse	0.03%	Mean	796,290	1,083,030	381,240	285,620	47,310	20,060	3,320	2,070
Growth	Pulse	0.03%	Upper	796,290	1,083,030	381,240	285,620	47,310	20,060	3,320	2,070
Growth	Pulse	5.00%	Mean	892,480	1,764,460	1,048,800	1,528,120	629,150	567,600	202,310	231,450
Growth	Pulse	5.00%	Upper	892,480	1,764,460	1,048,800	1,528,120	629,150	567,600	202,310	231,450
Growth	Pulse	28.25%	Mean	928,030	2,091,980	1,479,070	2,737,090	1,514,650	1,773,920	808,650	1,147,620
Growth	Pulse	28.25%	Upper	928,030	2,091,980	1,479,070	2,737,090	1,514,650	1,773,920	808,650	1,147,620
Long-Term	Early	0.03%	Mean	744,550	429,830	391,100	157,840	15,910	17,530	2,790	880
Long-Term	Early	0.03%	Upper	744,550	429,830	391,100	157,840	15,910	17,530	2,790	880
Long-Term	Early	5.00%	Mean	896,340	732,820	1,086,880	992,250	218,300	442,360	176,770	114,730
Long-Term	Early	5.00%	Upper	896,340	732,820	1,086,880	992,250	218,300	442,360	176,770	114,730
Long-Term	Early	28.25%	Mean	954,020	878,240	1,542,660	1,874,030	527,400	1,332,900	718,380	596,900
Long-Term	Early	28.25%	Upper	954,020	878,240	1,542,660	1,874,030	527,400	1,332,900	718,380	596,900
Long-Term	Late	0.03%	Mean	1,118,770	1,521,840	535,780	400,980	65,800	25,660	4,120	2,750
Long-Term	Late	0.03%	Upper	1,118,770	1,521,840	535,780	400,980	65,800	25,660	4,120	2,750
Long-Term	Late	5.00%	Mean	1,253,920	2,479,180	1,473,880	2,144,270	872,740	730,520	246,510	296,740
Long-Term	Late	5.00%	Upper	1,253,920	2,479,180	1,473,880	2,144,270	872,740	730,520	246,510	296,740
Long-Term	Late	28.25%	Mean	1,303,870	2,939,860	2,078,510	3,840,600	2,099,110	2,287,440	978,750	1,449,480
Long-Term	Late	28.25%	Upper	1,303,870	2,939,860	2,078,510	3,840,600	2,099,110	2,287,440	978,750	1,449,480
Long-Term	Pulse	0.03%	Mean	1,194,430	1,624,540	571,860	428,430	70,960	30,090	4,980	3,100
Long-Term	Pulse	0.03%	Upper	1,194,430	1,624,540	571,860	428,430	70,960	30,090	4,980	3,100
Long-Term	Pulse	5.00%	Mean	1,338,710	2,646,680	1,573,200	2,292,180	943,730	851,390	303,460	347,170
Long-Term	Pulse	5.00%	Upper	1,338,710	2,646,680	1,573,200	2,292,180	943,730	851,390	303,460	347,170
Long-Term	Pulse	28.25%	Mean	1,392,040	3,137,970	2,218,610	4,105,630	2,271,980	2,660,870	1,212,980	1,721,430
Long-Term	Pulse	28.25%	Upper	1,392,040	3,137,970	2,218,610	4,105,630	2,271,980	2,660,870	1,212,980	1,721,430

Table 13. Maximum daily number of fall-run subyearlings predicted in each reach under each scenario.

Scenario	Maximum Daily Number of fall-run subyearlings in each reach

Population	Emigration Strategy	Survival	Habitat	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Growth	Early	0.03%	Mean	217,740	198,140	41,880	46,140	7,330	2,440	810	240
Growth	Early	0.03%	Upper	217,740	198,140	41,880	46,140	7,330	2,440	810	240
Growth	Early	5.00%	Mean	231,410	343,360	126,210	256,030	102,160	68,200	45,520	28,700
Growth	Early	5.00%	Upper	231,410	343,360	126,210	256,030	102,160	68,200	45,520	28,700
Growth	Early	28.25%	Mean	236,190	415,820	182,880	463,390	249,320	210,230	177,250	145,600
Growth	Early	28.25%	Upper	236,190	415,820	182,880	463,390	249,320	210,230	177,250	145,600
Growth	Late	0.03%	Mean	141,280	199,480	67,960	55,150	10,590	4,830	800	520
Growth	Late	0.03%	Upper	141,280	199,480	67,960	55,150	10,590	4,830	800	520
Growth	Late	5.00%	Mean	160,130	339,800	189,650	293,970	137,560	133,120	47,930	57,060
Growth	Late	5.00%	Upper	160,130	339,800	189,650	293,970	137,560	133,120	47,930	57,060
Growth	Late	28.25%	Mean	167,130	408,730	268,750	532,290	329,110	412,760	190,340	280,620
Growth	Late	28.25%	Upper	167,130	408,730	268,750	532,290	329,110	412,760	190,340	280,620
Growth	Pulse	0.03%	Mean	238,550	80,630	-	36,430	3,120	1,050	360	80
Growth	Pulse	0.03%	Upper	238,550	80,630	-	36,430	3,120	1,050	360	80
Growth	Pulse	5.00%	Mean	255,830	171,690	-	192,250	51,900	34,830	23,370	13,320
Growth	Pulse	5.00%	Upper	255,830	171,690	-	192,250	51,900	34,830	23,370	13,320
Growth	Pulse	28.25%	Mean	261,910	221,340	-	344,550	133,600	112,910	95,410	75,270
Growth	Pulse	28.25%	Upper	261,910	221,340	-	344,550	133,600	112,910	95,410	75,270
Long-Term	Early	0.03%	Mean	326,620	297,210	62,810	69,220	11,000	3,660	1,220	360
Long-Term	Early	0.03%	Upper	326,620	297,210	62,810	69,220	11,000	3,660	1,220	360
Long-Term	Early	5.00%	Mean	347,110	515,030	189,320	384,040	153,240	102,300	68,280	43,060
Long-Term	Early	5.00%	Upper	347,110	515,030	189,320	384,040	153,240	102,300	68,280	43,060
Long-Term	Early	28.25%	Mean	354,280	623,730	274,320	695,080	373,970	315,340	265,880	218,400
Long-Term	Early	28.25%	Upper	354,280	623,730	274,320	695,080	373,970	315,340	265,880	218,400
Long-Term	Late	0.03%	Mean	211,920	299,210	101,940	82,720	15,890	7,240	1,200	780
Long-Term	Late	0.03%	Upper	211,920	299,210	101,940	82,720	15,890	7,240	1,200	780
Long-Term	Late	5.00%	Mean	240,190	509,700	284,480	440,950	206,330	199,680	71,890	85,590
Long-Term	Late	5.00%	Upper	240,190	509,700	284,480	440,950	206,330	199,680	71,890	85,590
Long-Term	Late	28.25%	Mean	250,690	613,100	403,120	798,430	493,670	619,130	285,500	420,930
Long-Term	Late	28.25%	Upper	250,690	613,100	403,120	798,430	493,670	619,130	285,500	420,930
Long-Term	Pulse	0.03%	Mean	357,820	120,950	-	54,650	4,670	1,580	530	120
Long-Term	Pulse	0.03%	Upper	357,820	120,950	-	54,650	4,670	1,580	530	120
Long-Term	Pulse	5.00%	Mean	383,740	257,530	-	288,380	77,850	52,240	35,060	19,980
Long-Term	Pulse	5.00%	Upper	383,740	257,530	-	288,380	77,850	52,240	35,060	19,980
Long-Term	Pulse	28.25%	Mean	392,870	332,010	-	516,830	200,400	169,360	143,120	112,900
Long-Term	Pulse	28.25%	Upper	392,870	332,010	-	516,830	200,400	169,360	143,120	112,900

Note: No (-) fish indicates fish move through the reach in less than one day and are not captured in that reach by this cohort-based daily-step model.

Table 14. Maximum daily number of spring-run subyearlings predicted in each reach under each scenario.

Scenario	Maximum Daily Number of spring-run subyearlings in each reach

Population	Strategy	Survival	Habitat	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Growth	Early	0.03%	Mean	496,210	286,420	260,710	105,180	10,600	11,680	1,850	580
Growth	Early	0.03%	Upper	496,210	286,420	260,710	105,180	10,600	11,680	1,850	580
Growth	Early	5.00%	Mean	597,390	488,100	724,500	661,040	145,230	294,630	117,560	76,460
Growth	Early	5.00%	Upper	597,390	488,100	724,500	661,040	145,230	294,630	117,560	76,460
Growth	Early	28.25%	Mean	635,850	583,880	1,028,310	1,247,590	350,080	887,110	477,360	397,780
Growth	Early	28.25%	Upper	635,850	583,880	1,028,310	1,247,590	350,080	887,110	477,360	397,780
Growth	Late	0.03%	Mean	745,150	1,013,530	356,790	267,000	43,820	17,070	2,750	1,830
Growth	Late	0.03%	Upper	745,150	1,013,530	356,790	267,000	43,820	17,070	2,750	1,830
Growth	Late	5.00%	Mean	835,170	1,650,990	981,540	1,427,120	580,870	485,520	163,920	197,600
Growth	Late	5.00%	Upper	835,170	1,650,990	981,540	1,427,120	580,870	485,520	163,920	197,600
Growth	Late	28.25%	Mean	868,430	1,956,430	1,384,220	2,555,460	1,396,380	1,520,030	650,440	965,240
Growth	Late	28.25%	Upper	868,430	1,956,430	1,384,220	2,555,460	1,396,380	1,520,030	650,440	965,240
Growth	Pulse	0.03%	Mean	796,210	1,082,980	381,240	285,290	46,830	19,630	3,110	2,020
Growth	Pulse	0.03%	Upper	796,210	1,082,980	381,240	285,290	46,830	19,630	3,110	2,020
Growth	Pulse	5.00%	Mean	892,390	1,764,120	1,048,800	1,524,910	620,670	552,730	188,480	221,490
Growth	Pulse	5.00%	Upper	892,390	1,764,120	1,048,800	1,524,910	620,670	552,730	188,480	221,490
Growth	Pulse	28.25%	Mean	927,940	2,090,480	1,479,070	2,730,560	1,492,060	1,725,140	751,830	1,091,340
Growth	Pulse	28.25%	Upper	927,940	2,090,480	1,479,070	2,730,560	1,492,060	1,725,140	751,830	1,091,340
Long-Term	Early	0.03%	Mean	744,320	429,640	391,060	157,770	15,900	17,520	2,780	880
Long-Term	Early	0.03%	Upper	744,320	429,640	391,060	157,770	15,900	17,520	2,780	880
Long-Term	Early	5.00%	Mean	896,090	732,150	1,086,750	991,560	217,840	441,940	176,330	114,680
Long-Term	Early	5.00%	Upper	896,090	732,150	1,086,750	991,560	217,840	441,940	176,330	114,680
Long-Term	Early	28.25%	Mean	953,770	875,810	1,542,460	1,871,390	525,110	1,330,660	716,030	596,670
Long-Term	Early	28.25%	Upper	953,770	875,810	1,542,460	1,871,390	525,110	1,330,660	716,030	596,670
Long-Term	Late	0.03%	Mean	1,117,730	1,520,300	535,190	400,490	65,730	25,600	4,120	2,750
Long-Term	Late	0.03%	Upper	1,117,730	1,520,300	535,190	400,490	65,730	25,600	4,120	2,750
Long-Term	Late	5.00%	Mean	1,252,750	2,476,490	1,472,310	2,140,680	871,300	728,280	245,880	296,390
Long-Term	Late	5.00%	Upper	1,252,750	2,476,490	1,472,310	2,140,680	871,300	728,280	245,880	296,390
Long-Term	Late	28.25%	Mean	1,302,650	2,934,640	2,076,330	3,833,190	2,094,570	2,280,050	975,660	1,447,860
Long-Term	Late	28.25%	Upper	1,302,650	2,934,640	2,076,330	3,833,190	2,094,570	2,280,050	975,660	1,447,860
Long-Term	Pulse	0.03%	Mean	1,194,320	1,624,470	571,860	427,940	70,240	29,440	4,670	3,020
Long-Term	Pulse	0.03%	Upper	1,194,320	1,624,470	571,860	427,940	70,240	29,440	4,670	3,020
Long-Term	Pulse	5.00%	Mean	1,338,590	2,646,180	1,573,200	2,287,370	931,000	829,100	282,720	332,230
Long-Term	Pulse	5.00%	Upper	1,338,590	2,646,180	1,573,200	2,287,370	931,000	829,100	282,720	332,230
Long-Term	Pulse	28.25%	Mean	1,391,910	3,135,720	2,218,610	4,095,840	2,238,090	2,587,710	1,127,740	1,637,010
Long-Term	Pulse	28.25%	Upper	1,391,910	3,135,720	2,218,610	4,095,840	2,238,090	2,587,710	1,127,740	1,637,010

Note: No (-) fish indicates fish move through the reach in less than one day and are not captured in that reach by this cohort-based daily-step model.

Table 15. Maximum daily number of spring-run yearlings predicted in each reach under each scenario.

Scenario				Maximum Daily Number of spring-run yearlings in each reach							
Population	**Strategy**	**Survival**	**Habitat**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**

Scenario				Maximum Daily Number of spring-run yearlings in each reach							
Population	**Strategy**	**Survival**	**Habitat**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	-	40	-	40	40	40	40	-
Growth	Early	0.03%	Upper	-	40	-	40	40	40	40	-
Growth	Early	5.00%	Mean	-	6,380	-	6,390	6,390	6,410	6,420	-
Growth	Early	5.00%	Upper	-	6,390	-	6,390	6,390	6,410	6,420	-
Growth	Early	28.25%	Mean	-	36,070	-	36,080	36,130	36,190	36,260	-
Growth	Early	28.25%	Upper	-	36,070	-	36,080	36,130	36,190	36,260	-
Growth	Late	0.03%	Mean	-	40	-	40	40	40	40	-
Growth	Late	0.03%	Upper	-	40	-	40	40	40	40	-
Growth	Late	5.00%	Mean	-	6,380	-	6,390	6,390	6,410	6,420	-
Growth	Late	5.00%	Upper	-	6,390	-	6,390	6,390	6,410	6,420	-
Growth	Late	28.25%	Mean	-	36,070	-	36,080	36,130	36,190	36,260	-
Growth	Late	28.25%	Upper	-	36,070	-	36,080	36,130	36,190	36,260	-
Growth	Pulse	0.03%	Mean	-	40	-	40	40	40	40	-
Growth	Pulse	0.03%	Upper	-	40	-	40	40	40	40	-
Growth	Pulse	5.00%	Mean	-	6,380	-	6,390	6,390	6,410	6,420	-
Growth	Pulse	5.00%	Upper	-	6,390	-	6,390	6,390	6,410	6,420	-
Growth	Pulse	28.25%	Mean	-	36,070	-	36,080	36,130	36,190	36,260	-
Growth	Pulse	28.25%	Upper	-	36,070	-	36,080	36,130	36,190	36,260	-
Long-Term	Early	0.03%	Mean	-	60	-	60	60	60	60	-
Long-Term	Early	0.03%	Upper	-	60	-	60	60	60	60	-
Long-Term	Early	5.00%	Mean	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Early	5.00%	Upper	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Early	28.25%	Mean	-	54,110	-	54,120	54,190	54,290	54,390	-
Long-Term	Early	28.25%	Upper	-	54,110	-	54,120	54,190	54,290	54,390	-
Long-Term	Late	0.03%	Mean	-	60	-	60	60	60	60	-
Long-Term	Late	0.03%	Upper	-	60	-	60	60	60	60	-
Long-Term	Late	5.00%	Mean	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Late	5.00%	Upper	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Late	28.25%	Mean	-	54,110	-	54,120	54,190	54,290	54,390	-
Long-Term	Late	28.25%	Upper	-	54,110	-	54,120	54,190	54,290	54,390	-
Long-Term	Pulse	0.03%	Mean	-	60	-	60	60	60	60	-
Long-Term	Pulse	0.03%	Upper	-	60	-	60	60	60	60	-
Long-Term	Pulse	5.00%	Mean	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Pulse	5.00%	Upper	-	9,580	-	9,580	9,590	9,610	9,630	-
Long-Term	Pulse	28.25%	Mean	-	54,110	-	54,120	54,190	54,290	54,390	-
Long-Term	Pulse	28.25%	Upper	-	54,110	-	54,120	54,190	54,290	54,390	-

Note: No (-) fish indicates fish move through the reach in less than one day and are not captured in that reach by this cohort-based daily-step model.

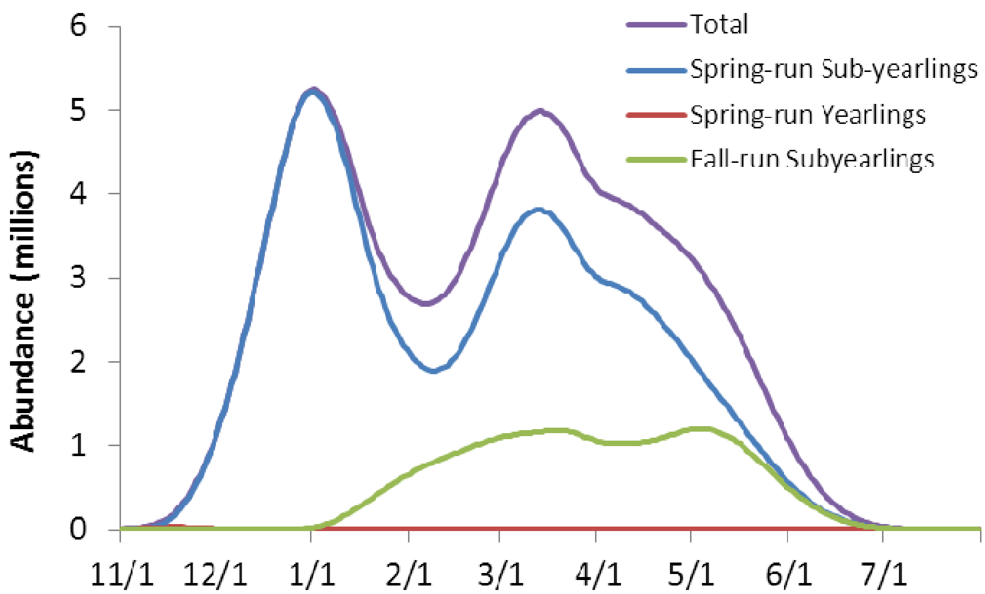

Figure 29. Daily abundance of salmon present across all restoration reaches predicted for spring-run subyearlings, spring-run yearlings, fall-run subyearlings, and all populations combined. Model scenario shown: emigration strategy = late, survival = middle, habitat quality = mean.

4.2 Required Suitable Habitat Results

Estimates of reach-specific required *ASH* across all scenarios and races varied as a trade-off of fish abundance and average territory size (Table 16 through Table 19 and Figure 30 through Figure 32). Therefore, estimates of required suitable habitat did not consistently decrease downstream (as observed for abundance) because juveniles were also growing and leaving the spawning grounds at larger sizes as the season progressed, thereby increasing their territory size requirements.

Similar to abundance, fall-run Chinook salmon required *ASH* across all reaches was generally highest during the late emigration strategy type (Table 13 and Figure 34). The extended emigration period and slower speeds (see sections 4.1.5 and 4.1.6 for details) of Chinook salmon during the late emigration strategy type lead to more fish residing in each reach for a longer period of time, thereby leading to a higher maximum number of fish present in each reach and greater required *ASH* overall.

Spring-run Chinook salmon required *ASH* across all reaches was generally highest during the late emigration strategy type (Table 18 and Table 19). Later timing of model entry for late emigration strategy type fish lead to fish entering the model at much larger sizes than pulse or early emigration strategy type fish, thereby resulting in higher estimates of required *ASH* (Figure 34).

Required *ASH* was zero for some reaches in some scenarios, indicating that in these reaches few fish spent a day or more to traverse the reach. These findings do not indicate that no habitat is needed in these reaches. Instead, the results demonstrate that as fish are actively emigrating downstream, habitat is only required for a brief time (less than 1 day) in some smaller reaches. These scenarios are not recommended for developing a minimum floodplain habitat area.

Similar to abundance, required *ASH* was generally higher across all reaches for spring-run versus fall-run Chinook salmon. Larger initial abundance for spring-run (35.6 million) versus fall-run (13.3 million) resulted in higher spring-run abundances and required *ASH* throughout the emigration period.

Because spring-run yearlings are actively emigrating out of the system at a fast migration speed (21 miles per day or 35 km/day) and their mortality is applied prior to emigration (during their rearing stage upstream of the restoration area), their estimates of required *ASH* are miniscule compared to subyearlings (Table 19).

See Appendix B for required suitable habitat in meters squared.

Table 16. Required suitable habitat estimated for the daily maximum number of total Chinook salmon in each reach under each scenario

Total Chinook Salmon											
Scenario				Maximum Daily Required Suitable Habitat (acres)							
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	23	20	6	4	0	0	0	0
Growth	Early	0.03%	Upper	11	13	3	2	0	0	0	0
Growth	Early	5.00%	Mean	23	31	18	25	7	7	2	2
Growth	Early	5.00%	Upper	11	20	10	14	4	4	1	1
Growth	Early	28.25%	Mean	23	38	26	48	18	22	9	12
Growth	Early	28.25%	Upper	11	24	14	26	11	14	6	7
Growth	Late	0.03%	Mean	65	76	34	24	4	1	0	0
Growth	Late	0.03%	Upper	32	49	19	13	2	1	0	0
Growth	Late	5.00%	Mean	73	122	96	135	51	36	13	15
Growth	Late	5.00%	Upper	36	78	53	72	31	22	8	9
Growth	Late	28.25%	Mean	76	144	136	247	122	112	50	74
Growth	Late	28.25%	Upper	37	93	76	131	75	69	31	45
Growth	Pulse	0.03%	Mean	29	32	14	12	2	1	0	0
Growth	Pulse	0.03%	Upper	14	20	8	7	1	0	0	0
Growth	Pulse	5.00%	Mean	34	52	39	68	27	21	8	10
Growth	Pulse	5.00%	Upper	16	33	22	36	16	13	5	6
Growth	Pulse	28.25%	Mean	35	62	55	122	64	65	31	48
Growth	Pulse	28.25%	Upper	17	40	30	65	40	40	19	30
Long-Term	Early	0.03%	Mean	34	30	9	6	1	0	0	0
Long-Term	Early	0.03%	Upper	17	19	5	3	0	0	0	0
Long-Term	Early	5.00%	Mean	34	47	27	38	11	10	3	3
Long-Term	Early	5.00%	Upper	17	30	15	20	6	6	2	2
Long-Term	Early	28.25%	Mean	34	57	39	72	26	33	14	18
Long-Term	Early	28.25%	Upper	17	36	22	38	16	20	9	11
Long-Term	Late	0.03%	Mean	98	114	51	36	6	2	0	0
Long-Term	Late	0.03%	Upper	48	73	28	19	4	1	0	0
Long-Term	Late	5.00%	Mean	109	183	144	203	76	54	19	23
Long-Term	Late	5.00%	Upper	53	118	80	108	47	33	12	14
Long-Term	Late	28.25%	Mean	114	216	204	370	183	168	75	111
Long-Term	Late	28.25%	Upper	56	139	114	196	112	104	46	68
Long-Term	Pulse	0.03%	Mean	43	48	21	19	3	1	0	0
Long-Term	Pulse	0.03%	Upper	21	31	12	10	2	1	0	0
Long-Term	Pulse	5.00%	Mean	51	78	58	102	40	31	12	15
Long-Term	Pulse	5.00%	Upper	25	50	32	54	25	19	7	9
Long-Term	Pulse	28.25%	Mean	53	93	82	184	97	97	46	73
Long-Term	Pulse	28.25%	Upper	26	60	46	97	59	60	28	44

Note: 0 acres indicates that less than 0.5 acres were required or that fish move through the reach in less than one day.

Table 17. Required suitable habitat estimated for fall-run subyearlings in each reach under each scenario

Fall-Run Subyearling Chinook Salmon											
Scenario				Maximum Daily Required Suitable Habitat (acres)							
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	6	13	2	2	0	0	0	0
Growth	Early	0.03%	Upper	3	9	1	1	0	0	0	0
Growth	Early	5.00%	Mean	7	21	8	11	3	3	1	1
Growth	Early	5.00%	Upper	3	13	4	6	2	2	1	0
Growth	Early	28.25%	Mean	7	24	12	22	8	10	4	3
Growth	Early	28.25%	Upper	3	16	7	12	5	6	2	2
Growth	Late	0.03%	Mean	27	36	13	14	2	1	0	0
Growth	Late	0.03%	Upper	13	23	7	7	1	0	0	0
Growth	Late	5.00%	Mean	32	61	37	71	31	16	8	8
Growth	Late	5.00%	Upper	16	39	21	38	19	10	5	5
Growth	Late	28.25%	Mean	34	73	53	126	74	49	32	38
Growth	Late	28.25%	Upper	16	47	29	67	45	30	20	23
Growth	Pulse	0.03%	Mean	6	2	0	1	0	0	0	0
Growth	Pulse	0.03%	Upper	3	1	0	1	0	0	0	0
Growth	Pulse	5.00%	Mean	7	4	0	5	1	1	0	0
Growth	Pulse	5.00%	Upper	3	2	0	3	1	0	0	0
Growth	Pulse	28.25%	Mean	7	5	0	9	3	2	2	1
Growth	Pulse	28.25%	Upper	3	3	0	5	2	1	1	1
Long-Term	Early	0.03%	Mean	10	20	3	2	0	0	0	0
Long-Term	Early	0.03%	Upper	5	13	2	1	0	0	0	0
Long-Term	Early	5.00%	Mean	10	31	12	17	5	5	1	1
Long-Term	Early	5.00%	Upper	5	20	7	9	3	3	1	1
Long-Term	Early	28.25%	Mean	10	37	18	33	12	15	6	5
Long-Term	Early	28.25%	Upper	5	24	10	17	7	9	4	3
Long-Term	Late	0.03%	Mean	40	54	20	20	4	1	0	0
Long-Term	Late	0.03%	Upper	20	35	11	11	2	1	0	0
Long-Term	Late	5.00%	Mean	48	91	56	107	46	24	12	12
Long-Term	Late	5.00%	Upper	23	59	31	57	28	15	7	7
Long-Term	Late	28.25%	Mean	51	110	79	190	111	74	48	57
Long-Term	Late	28.25%	Upper	25	71	44	101	68	46	29	35
Long-Term	Pulse	0.03%	Mean	10	3	0	1	0	0	0	0
Long-Term	Pulse	0.03%	Upper	5	2	0	1	0	0	0	0
Long-Term	Pulse	5.00%	Mean	10	6	0	8	2	1	1	0
Long-Term	Pulse	5.00%	Upper	5	4	0	4	1	1	0	0
Long-Term	Pulse	28.25%	Mean	10	7	0	14	5	3	2	2
Long-Term	Pulse	28.25%	Upper	5	5	0	7	3	2	1	1

Note: 0 acres indicates that less than 0.5 acres were required or that fish move through the reach in less than one day.

Table 18. Required suitable habitat estimated for the daily maximum number of spring-run subyearlings in each reach under each scenario

Spring-Run Subyearling Chinook Salmon											
Scenario				Maximum Daily Required Suitable Habitat (acres)							
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	23	8	6	3	0	0	0	0
Growth	Early	0.03%	Upper	11	5	3	2	0	0	0	0
Growth	Early	5.00%	Mean	23	13	16	17	5	5	2	2
Growth	Early	5.00%	Upper	11	9	9	9	3	3	1	1
Growth	Early	28.25%	Mean	23	16	23	31	11	15	8	9
Growth	Early	28.25%	Upper	11	10	13	16	7	9	5	6
Growth	Late	0.03%	Mean	54	56	26	18	2	1	0	0
Growth	Late	0.03%	Upper	26	36	15	9	2	1	0	0
Growth	Late	5.00%	Mean	60	92	73	99	33	27	10	11
Growth	Late	5.00%	Upper	29	59	41	53	20	17	6	7
Growth	Late	28.25%	Mean	63	109	104	181	78	83	39	57
Growth	Late	28.25%	Upper	31	70	58	96	48	51	24	35
Growth	Pulse	0.03%	Mean	29	32	14	12	2	1	0	0
Growth	Pulse	0.03%	Upper	14	20	8	7	1	0	0	0
Growth	Pulse	5.00%	Mean	32	52	39	67	26	20	7	10
Growth	Pulse	5.00%	Upper	16	33	22	36	16	13	5	6
Growth	Pulse	28.25%	Mean	33	62	55	121	63	63	30	47
Growth	Pulse	28.25%	Upper	16	40	30	64	39	39	18	29
Long-Term	Early	0.03%	Mean	34	12	9	4	1	0	0	0
Long-Term	Early	0.03%	Upper	17	8	5	2	0	0	0	0
Long-Term	Early	5.00%	Mean	34	20	24	25	7	7	3	3
Long-Term	Early	5.00%	Upper	17	13	13	13	4	4	2	2
Long-Term	Early	28.25%	Mean	34	24	34	46	16	22	12	14
Long-Term	Early	28.25%	Upper	17	15	19	24	10	14	7	9
Long-Term	Late	0.03%	Mean	81	85	39	27	4	1	0	0
Long-Term	Late	0.03%	Upper	39	55	22	14	2	1	0	0
Long-Term	Late	5.00%	Mean	90	138	110	149	49	40	15	17
Long-Term	Late	5.00%	Upper	44	89	61	79	30	25	9	11
Long-Term	Late	28.25%	Mean	94	163	156	271	117	125	58	85
Long-Term	Late	28.25%	Upper	46	105	87	144	72	77	36	52
Long-Term	Pulse	0.03%	Mean	43	48	21	19	3	1	0	0
Long-Term	Pulse	0.03%	Upper	21	31	12	10	2	1	0	0
Long-Term	Pulse	5.00%	Mean	48	78	58	101	39	30	11	14
Long-Term	Pulse	5.00%	Upper	23	50	32	54	24	19	7	9
Long-Term	Pulse	28.25%	Mean	50	92	82	182	95	95	44	71
Long-Term	Pulse	28.25%	Upper	24	59	46	97	59	59	27	43

Note: 0 acres indicates that less than 0.5 acres were required or that fish move through the reach in less than one day.

Table 19. Required suitable habitat estimated for the daily maximum number of spring-run yearlings in each reach under each scenario

Spring-Run Yearling Chinook Salmon											
Scenario				Maximum Daily Required Suitable Habitat (acres)							
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Growth	Early	0.03%	Mean	0	0	0	0	0	0	0	0
Growth	Early	0.03%	Upper	0	0	0	0	0	0	0	0
Growth	Early	5.00%	Mean	0	2	0	2	2	1	1	0
Growth	Early	5.00%	Upper	0	1	0	1	1	1	1	0
Growth	Early	28.25%	Mean	0	9	0	11	9	7	7	0
Growth	Early	28.25%	Upper	0	6	0	6	5	4	4	0
Growth	Late	0.03%	Mean	0	0	0	0	0	0	0	0
Growth	Late	0.03%	Upper	0	0	0	0	0	0	0	0
Growth	Late	5.00%	Mean	0	2	0	2	2	1	1	0
Growth	Late	5.00%	Upper	0	1	0	1	1	1	1	0
Growth	Late	28.25%	Mean	0	9	0	11	9	7	7	0
Growth	Late	28.25%	Upper	0	6	0	6	5	4	4	0
Growth	Pulse	0.03%	Mean	0	0	0	0	0	0	0	0
Growth	Pulse	0.03%	Upper	0	0	0	0	0	0	0	0
Growth	Pulse	5.00%	Mean	0	2	0	2	2	1	1	0
Growth	Pulse	5.00%	Upper	0	1	0	1	1	1	1	0
Growth	Pulse	28.25%	Mean	0	9	0	11	9	7	7	0
Growth	Pulse	28.25%	Upper	0	6	0	6	5	4	4	0
Long-Term	Early	0.03%	Mean	0	0	0	0	0	0	0	0
Long-Term	Early	0.03%	Upper	0	0	0	0	0	0	0	0
Long-Term	Early	5.00%	Mean	0	2	0	3	2	2	2	0
Long-Term	Early	5.00%	Upper	0	1	0	1	1	1	1	0
Long-Term	Early	28.25%	Mean	0	13	0	16	13	10	10	0
Long-Term	Early	28.25%	Upper	0	8	0	8	8	6	6	0
Long-Term	Late	0.03%	Mean	0	0	0	0	0	0	0	0
Long-Term	Late	0.03%	Upper	0	0	0	0	0	0	0	0
Long-Term	Late	5.00%	Mean	0	2	0	3	2	2	2	0
Long-Term	Late	5.00%	Upper	0	1	0	1	1	1	1	0
Long-Term	Late	28.25%	Mean	0	13	0	16	13	10	10	0
Long-Term	Late	28.25%	Upper	0	8	0	8	8	6	6	0
Long-Term	Pulse	0.03%	Mean	0	0	0	0	0	0	0	0
Long-Term	Pulse	0.03%	Upper	0	0	0	0	0	0	0	0
Long-Term	Pulse	5.00%	Mean	0	2	0	3	2	2	2	0
Long-Term	Pulse	5.00%	Upper	0	1	0	1	1	1	1	0
Long-Term	Pulse	28.25%	Mean	0	13	0	16	13	10	10	0
Long-Term	Pulse	28.25%	Upper	0	8	0	8	8	6	6	0

Note: 0 acres indicates that less than 0.5 acres were required or that fish move through the reach in less than one day.

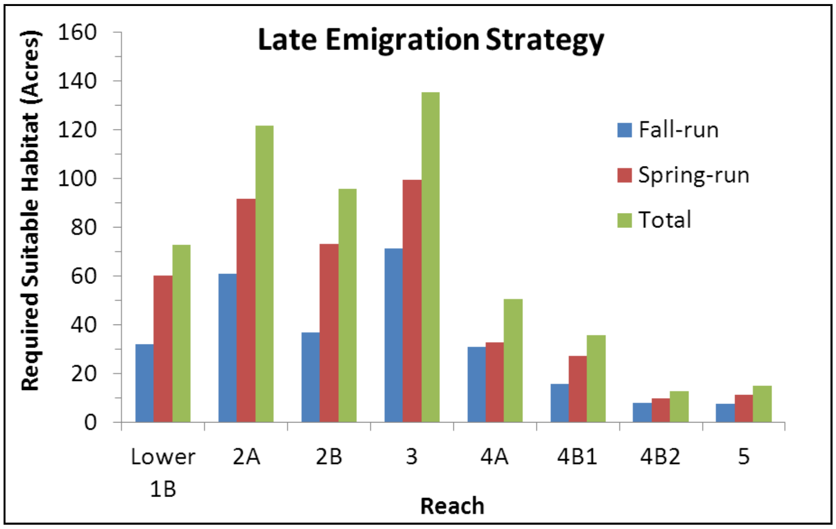

Figure 30. Required suitable habitat estimated for fall-run, spring-run, and total Chinook salmon for each reach under the late emigration strategy. Results depict scenario with middle survival (5 percent),mean habitat quality, and growth population target.

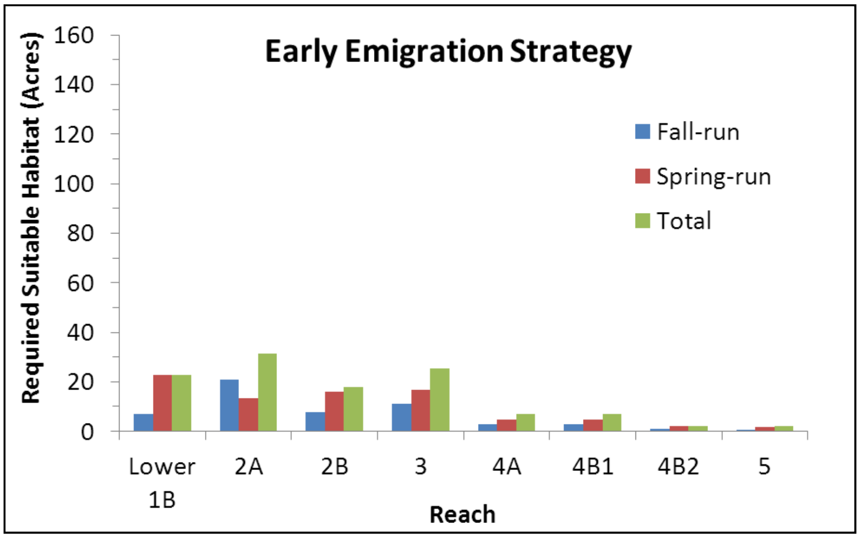

Figure 31. Required suitable habitat estimated for fall-run, spring-run, and total Chinook salmon for each reach under the early emigration strategy. Results depict scenario with middle survival (5 percent), mean habitat quality, and growth population target.

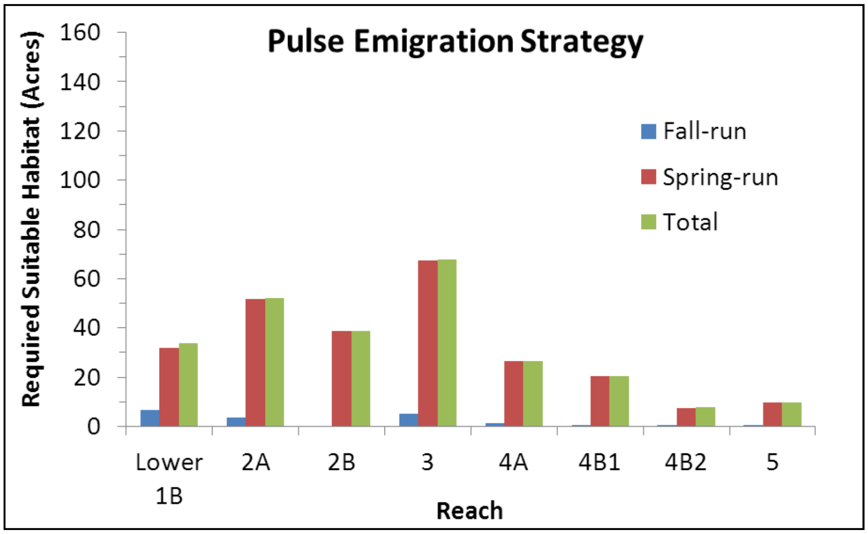

Figure 32. Required suitable habitat estimated for fall-run, spring-run, and total Chinook salmon for each reach under the pulse emigration strategy. Results depict scenario with middle survival (5 percent), mean habitat quality, and growth population target.

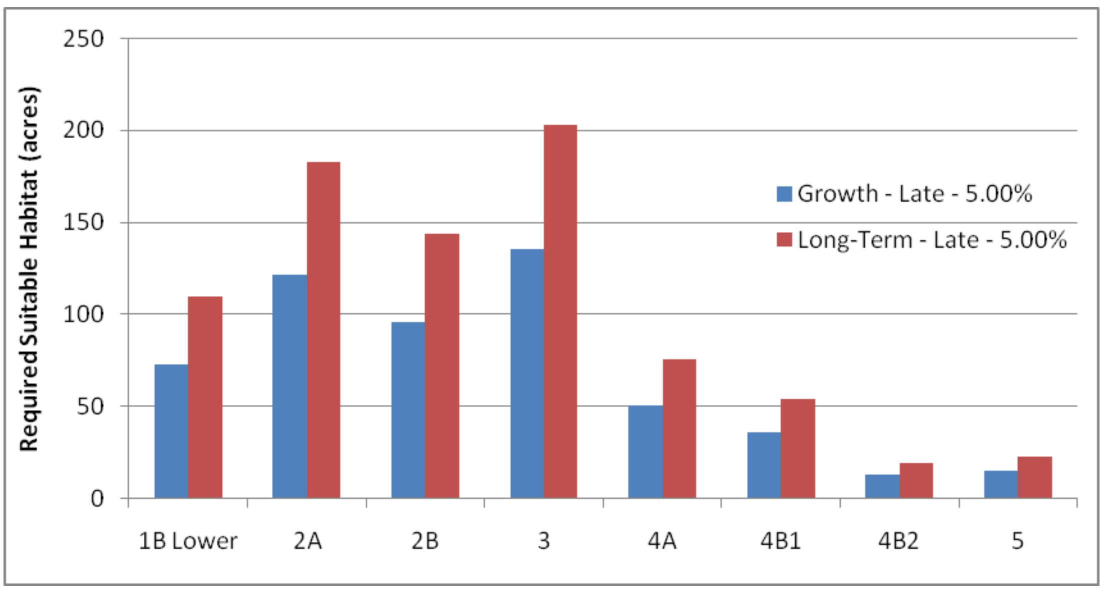

Figure 33. Sensitivity of required suitable habitat estimates to 2 different population targets for total Chinook salmon in each reach for the late emigration strategy, 5 percent survival, and mean habitat quality scenario.

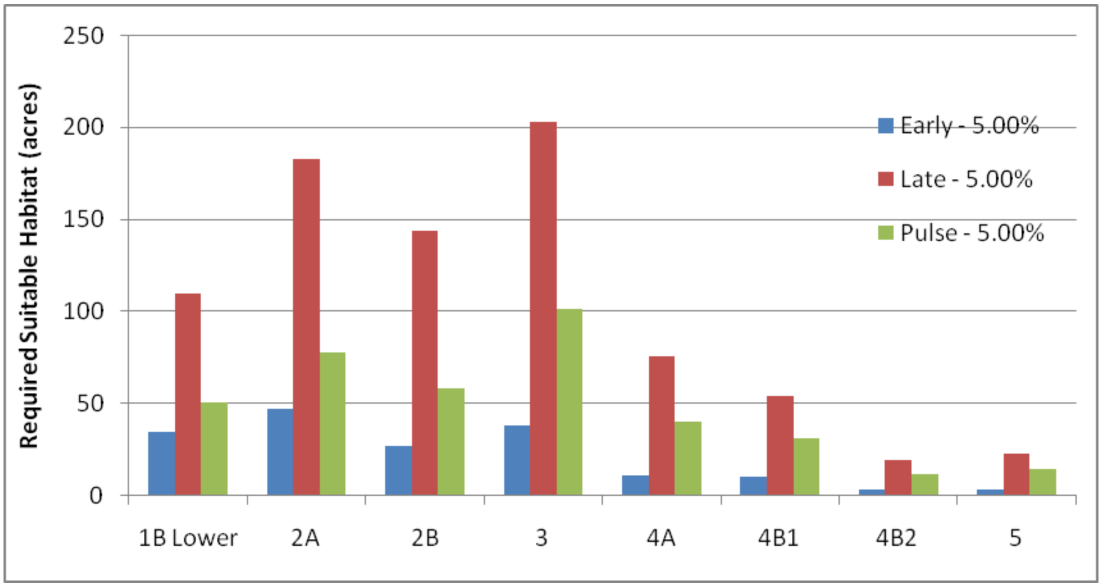

Figure 34. Sensitivity of required suitable habitat estimates to three different emigration strategy types for total Chinook salmon in each reach for the long-term population target, mean habitat quality, and 5 percent survival scenario.

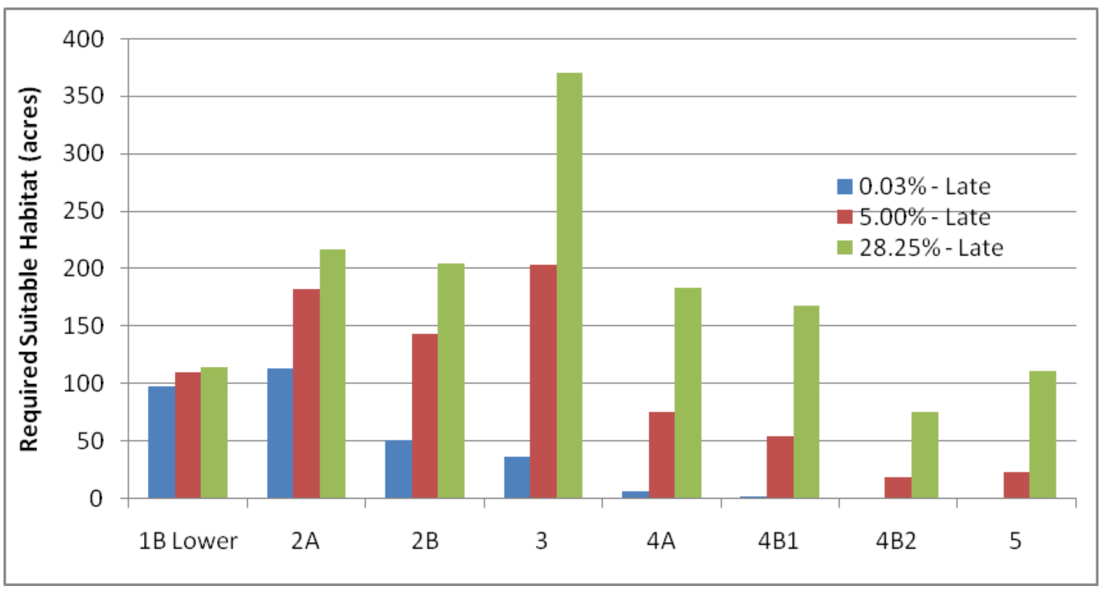

Figure 35. Sensitivity of required suitable habitat estimates to three different survival scenarios for total Chinook salmon for each reach under the long-term population target, late emigration strategy, and mean habitat quality scenario.

4.3 Available Suitable Habitat Results

For each simulated reach and flow scenario, the total inundated area (*TIA*) was computed. The available area of suitable habitat (*ASH*) was then computed for Reaches 1B, 2A, 3, 4A, and 4B2 as a fraction of *TIA* based on the habitat suitability framework presented in Section 4.2. Table 20, Table 21 and

Table 22 present the computed *TIA*, available *ASH*, and fractional *ASH* values for Reaches 1B, 2A, 3, 4A, and 4B2 for the dry, normal, and wet water year types, respectively. The standard deviation of the available *ASH* values was also calculated for each reach and presented in Table 20, Table 21, and Table 22. Habitat suitability estimates in Reach 5 were generated by assuming the same fractional available *ASH* as in Reach 4B2.

Available *ASH* was also calculated using each of the single-component HSI definitions (i.e., $HSI_T = HSI_D$, $HSI_T = HSI_V$, and $HSI_T = HSI_C$), and is presented in Appendix A.

Table 20. Summary of habitat analysis results for "dry" water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and available area of suitable habitat (*ASH*). Available *ASH* is given as fraction of *TIA* and as acres; the standard deviation of the available *ASH* calculation is also given. Habitat computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH*		
		Fraction	Acres	HSI_T Std. Dev.
1B	668	0.10	67	0.31
2A	625	0.15	94	0.21
3	495	0.09	45	0.20
4A	359	0.14	50	0.24
4B2	713	0.28	200	0.32
5*	823	0.28	230	0.32

*Reach 5 assumes Reach 4B2 fractional suitability

Table 21. Summary of habitat analysis results for "normal" water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and available area of suitable habitat (*ASH*). Available *ASH* is given as fraction of *TIA* and as acres; the standard deviation of the available *ASH* calculation is also given. Habitat computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH*		
		Fraction	Acres	HSI_T Std. Dev.
1B	798	0.07	56	0.29
2A	743	0.14	104	0.21
3	770	0.08	62	0.26
4A	427	0.13	56	0.23
4B2	1041	0.27	281	0.30
5*	1373	0.27	371	0.30

*Reach 5 assumes Reach 4B2 fractional suitability

Table 22. Summary of habitat analysis results for "wet" water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and available area of suitable habitat (*ASH*). Available *ASH* is given as fraction of *TIA* and as acres; the standard deviation of the available *ASH* calculation is also given. Habitat computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH*		
		Fraction	Acres	HSI_T Std. Dev.
1B	982	0.06	59	0.29
2A	876	0.13	114	0.21
3	1015	0.07	71	0.25
4A	525	0.13	68	0.24
4B2	1432	0.24	344	0.30
5*	2192	0.24	526	0.30

*Reach 5 assumes Reach 4B2 fractional suitability

Table 23 contains the *TIA* calculated for the levee options in Reaches 2B and 4B1. No results are shown for the wet year in Reach 2B for the existing levee because the existing levee alignment is currently not an option to convey 4500 cfs (SJRRP 2011a) and likewise no results are shown for the levee option A for Reach 4B1 because it is only designed to convey 1500 cfs (Reclamation, 2012). Cover and habitat suitability estimates have not yet been assessed in reaches 2B and 4B1 because these reaches are subject to proposed revegetation plans; further consultation is required to predict what the vegetative conditions will be.

Table 23. Summary of total inundated area (*TIA*) calculations for the levee options in Reaches 2B and 4B1 for each water year type. The columns from left to right indicate the river reach, levee option, and *TIA* in acres for each of the water year types.

Reach	Levee Option	*TIA* (acres)		
		Dry	Normal	Wet
2B	FP2	494	1176	1572
	FP4	549	1496	1983
	Existing	558	752	-
4B1	A	981	-	-
	B	2228	2756	2847
	C	3555	5306	5966
	D	5473	7309	9173

Table 24 presents the available *ASH* by reach, by water year type for the maximum flow that is sustained for at least 2 weeks during the Spring Pulse. The available ASH was calculated by a weighted average of the suitable habitat of the dry, normal, and wet water year, assuming that twenty percent of years are in the wet water year type, sixty percent of years are normal dry or normal wet, and twenty percent of years are dry. In defining the available suitable habitat, it is necessary to use the same flow assumptions as will be used in the design of the levee setbacks.

Table 24. Available area of suitable habitat (*ASH*) by reach, for each water year type (acres)

Reach	**Water Year Type**			**Weighted Average Available Suitable Habitat (acres)**
	Dry 1000-1500 cfs (20% of years)	**Normal** 2180-2500 cfs (60% of years)	**Wet** 3600-4500 cfs (20% of years)	
1B	67	56	59	**59**
2A	94	104	114	**104**
3	45	65	71	**60**
4A	50	56	68	**57**
4B2	200	281	344	**277**
5	230	371	526	**374**

4.4 Habitat Deficit Results

The purpose of this study was to define the minimum suitable rearing and emigration habitat necessary to sustain juvenile offspring of future San Joaquin River spawner abundance targets for spring-run and fall-run Chinook salmon. This section calculates the minimum habitat needed to meet suitable habitat requirements by calculating the difference between ESHE model estimates of required *ASH* and 2D modeling estimates of available *ASH*. It then calculates the total inundated area this represents at different levels of habitat quality.

Table 25 shows the current habitat deficit by reach for Early, Late, and Pulse Emigration Strategies for the growth population scenario and the various assumptions on habitat quality and survival (see also Table B.9 in Appendix B). This was calculated by taking the required habitat by reach from Table 16 minus available habitat per reach from Table 24. If there is no additional habitat necessary, a zero is shown for that reach. As Reach 2B and 4B1 are currently undergoing alternatives analysis and hydraulic and vegetation conditions may change significantly, no available habitat for 2B and 4B1 was calculated. Thus, the suitable habitat deficit for Reach 2B and Reach 4B1 in the below table comes directly from the ESHE model results.

Table 25. Current suitable habitat deficit by reach (*indicates that no suitable habitat is currently assumed to be present in that reach) for the growth population target, various emigration strategies, assumed habitat quality, and survival estimates.

Emigration Strategy	Reach	Current Suitable Habitat Deficit (acres)					
		HSI = Mean			HSI = Upper		
		0.03% Survival	5% Survival	28.25% Survival	0.03% Survival	5% Survival	28.25% Survival
Early	1B	0	0	0	0	0	0
	2A	0	0	0	0	0	0
	2B*	6	18	26	3	10	14
	3	0	0	0	0	0	0
	4A	0	0	0	0	0	0
	4B1*	0	7	22	0	4	14
	4B2	0	0	0	0	0	0
	5	0	0	0	0	0	0
Late	1B	6	14	17	0	0	0
	2A	0	18	40	0	0	0
	2B*	34	96	136	19	53	76
	3	0	75	187	0	12	71
	4A	0	0	65	0	0	18
	4B1*	1	36	112	1	22	69
	4B2	0	0	0	0	0	0
	5	0	0	0	0	0	0
Pulse	1B	0	0	0	0	0	0
	2A	0	0	0	0	0	0
	2B*	14	39	55	8	22	30
	3	0	8	62	0	0	5
	4A	0	0	7	0	0	0
	4B1*	1	21	65	0	13	40
	4B2	0	0	0	0	0	0
	5	0	0	0	0	0	0

The Settlement does not include Phase 1 or Phase 2 projects for habitat in Reaches 1, 2A, 3, 4A, or 5. Minimum needed suitable habitat by reach could be obtained in reaches that are not part of a Settlement project via improvements in habitat quality (e.g. an increase in vegetation, cover, complexity, or other changes to the San Joaquin River that do not involve levee setbacks). However, this could have channel conveyance implications and thus it is likely that habitat deficits in those reaches must be met in Reach 2B and Reach 4B1. If the SJRRP wishes to meet minimum rearing and emigration habitat requirements for Chinook salmon using only projects identified in the Settlement, it is assumed that the deficit of habitat in Reaches 1B, 2A, 2B and Reach 3 must be incorporated into Reach 2B, and all of the habitat deficit of Reaches 4A, 4B1, 4B2, and 5 must be incorporated into Reach 4B1 (or the Eastside Bypass).

Table 26 shows the minimum suitable habitat to be incorporated into Reach 2B and 4B for each scenario. The available habitat within Reaches 2B and 4B1 already will count towards attaining this amount of habitat, if it is kept intact.

Table 26. Deficit in Suitable Habitat for Reach 2B and Reach 4B1. Reach 2B deficits include Reaches 1-3, Reach 4B1 deficits include Reaches 4 and 5 and could also be incorporated into the Eastside Bypass.

Scenario				Suitable Habitat Deficit (acres)	
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**2B**	**4B1**
Growth	Early	0.03%	Mean	6	0
Growth	Early	0.03%	Upper	3	0
Growth	Early	5.00%	Mean	18	7
Growth	Early	5.00%	Upper	10	4
Growth	Early	28.25%	Mean	26	22
Growth	Early	28.25%	Upper	14	14
Growth	Late	0.03%	Mean	40	1
Growth	Late	0.03%	Upper	19	1
Growth	Late	5.00%	Mean	203	36
Growth	Late	5.00%	Upper	65	22
Growth	Late	28.25%	Mean	380	177
Growth	Late	28.25%	Upper	147	87
Growth	Pulse	0.03%	Mean	14	1
Growth	Pulse	0.03%	Upper	8	0
Growth	Pulse	5.00%	Mean	47	21
Growth	Pulse	5.00%	Upper	22	13
Growth	Pulse	28.25%	Mean	117	72
Growth	Pulse	28.25%	Upper	35	40
Long-Term	Early	0.03%	Mean	9	0
Long-Term	Early	0.03%	Upper	5	0
Long-Term	Early	5.00%	Mean	27	10
Long-Term	Early	5.00%	Upper	15	6
Long-Term	Early	28.25%	Mean	51	33
Long-Term	Early	28.25%	Upper	22	20
Long-Term	Late	0.03%	Mean	99	2
Long-Term	Late	0.03%	Upper	28	1
Long-Term	Late	5.00%	Mean	416	73
Long-Term	Late	5.00%	Upper	141	33
Long-Term	Late	28.25%	Mean	682	294
Long-Term	Late	28.25%	Upper	285	159

Scenario				Suitable Habitat Deficit (acres)	
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**2B**	**4B1**
Long-Term	Pulse	0.03%	Mean	21	1
Long-Term	Pulse	0.03%	Upper	12	1
Long-Term	Pulse	5.00%	Mean	100	31
Long-Term	Pulse	5.00%	Upper	32	19
Long-Term	Pulse	28.25%	Mean	206	137
Long-Term	Pulse	28.25%	Upper	83	62

Suitable habitat depends on depths, velocities, cover, and other criteria. Based on the available suitable habitat calculated in Reaches 1B to 5, between 7 percent and 27 percent of the total inundated area is suitable (Section 4.3). To compute the total inundated area necessary in 2B and 4B1 projects, various estimates of habitat suitability percent were assumed. If restoration activities result in the existing habitat quality of adjacent reaches, 10 percent suitable may be a reasonable estimate for Reach 2B requirements and 25 percent could be a reasonable estimate for Reach 4B.

Table 27 includes estimates of the minimum total inundated area required in the Reaches 2B and 4B1 projects. The actual fraction of suitable habitat in Reach 2B and 4B1 will be dependent upon the actual revegetation, floodplain grading, and channel restoration activities implemented in these reaches. This table provides tradeoffs for the project teams, as increases in the percent of habitat that is suitable can result in decreased inundated area. Suitable habitat is most sensitive to cover (i.e. vegetation) (see Appendix A). Therefore, this represents primarily a tradeoff between revegetation costs and levee setback costs.

Table 27. Minimum Floodplain Habitat Total Inundated Area for Reach 2B and 4B under all scenarios by percent suitable habitat assumptions (10 percent of inundated area is suitable, and 25 percent of inundated area is suitable)

Scenario				Total Inundated Area for 10-25 percent suitable (acres)			
Population	**Emigration Strategy**	**Survival**	**Habitat Quality**	**Reach 2B - 10% Suitable**	**Reach 2B - 25% Suitable**	**Reach 4B1 - 10% Suitable**	**Reach 4B1 - 25% Suitable**
Growth	Early	0.03%	Mean	60	20	0	0
Growth	Early	0.03%	Upper	30	10	0	0
Growth	Early	5.00%	Mean	180	70	70	30
Growth	Early	5.00%	Upper	100	40	40	20
Growth	Early	28.25%	Mean	260	100	220	90
Growth	Early	28.25%	Upper	140	60	140	50
Growth	Late	0.03%	Mean	400	160	10	10
Growth	Late	0.03%	Upper	190	80	10	0
Growth	Late	5.00%	Mean	2,030	810	360	140
Growth	Late	5.00%	Upper	650	260	220	90
Growth	Late	28.25%	Mean	3,800	1,520	1,770	710
Growth	Late	28.25%	Upper	1,470	590	870	350
Growth	Pulse	0.03%	Mean	140	60	10	0
Growth	Pulse	0.03%	Upper	80	30	0	0
Growth	Pulse	5.00%	Mean	470	190	210	80
Growth	Pulse	5.00%	Upper	220	90	130	50
Growth	Pulse	28.25%	Mean	1,170	470	720	290
Growth	Pulse	28.25%	Upper	350	140	400	160
Long-Term	Early	0.03%	Mean	90	40	0	0
Long-Term	Early	0.03%	Upper	50	20	0	0
Long-Term	Early	5.00%	Mean	270	110	100	40
Long-Term	Early	5.00%	Upper	150	60	60	30
Long-Term	Early	28.25%	Mean	510	210	330	130
Long-Term	Early	28.25%	Upper	220	90	200	80
Long-Term	Late	0.03%	Mean	990	400	20	10
Long-Term	Late	0.03%	Upper	280	110	10	0
Long-Term	Late	5.00%	Mean	4,160	1,660	730	290
Long-Term	Late	5.00%	Upper	1,410	560	330	130
Long-Term	Late	28.25%	Mean	6,820	2,730	2,940	1,170
Long-Term	Late	28.25%	Upper	2,850	1,140	1,590	640
Long-Term	Pulse	0.03%	Mean	210	80	10	0
Long-Term	Pulse	0.03%	Upper	120	50	10	0
Long-Term	Pulse	5.00%	Mean	1,000	400	310	120
Long-Term	Pulse	5.00%	Upper	320	130	190	80
Long-Term	Pulse	28.25%	Mean	2,060	820	1,370	550
Long-Term	Pulse	28.25%	Upper	830	330	620	250

5 DISCUSSION

These results should be viewed as a lower bookend for rearing and emigration habitat area and do not define total habitat needs for self-sustaining, naturally reproducing populations of spring- and fall-run Chinook salmon within the SJRRP. At present, there is limited empirical data on San Joaquin River salmon in the Restoration area. The primary concepts used to model fish behavior and habitat requirements are taken from general salmonid ecology and model inputs were taken from watersheds that are either tributaries to the San Joaquin River or relevant analog streams.

The discussion section includes subsections on limitations of the model, uncertainties in data inputs, parameters not included in the analysis, comparisons to other river systems for preliminary validation, other considerations for levee setbacks in addition to this analysis, and finally the next steps in the process – how this will be incorporated into the Phase 1 and Phase 2 projects.

5.1 Limitations

Limitations of the required suitable habitat modeling approach include the cohort based approach. This simplifies fish movement and thus may not capture the precise locations and variability of fish in time. Consequences include no habitat requirements in some reaches when fish speeds are high, thus underestimating the required suitable habitat.

Flow will have a large impact on when and how juveniles will utilize different reaches of the restoration project, as well as their survival rates (Perry et al. 2009; Cavallo et al 2012). Flow will also have a strong influence on how much habitat will be available at any given time including the quantity and quality of food (Ahearn et al. 2006; Jeffres et al. 2008). Flow may also alter how target species are exposed to other environmental stressors, including temperature and predation. Therefore, the magnitude, duration, and timing of flow will have strong implications on the quantity and quality of habitat available to rearing and emigrating juvenile Chinook salmon. Flow was not included in the estimates of required suitable habitat as there is no mechanism for doing so. ESHE models fish numbers, not flows. Fish timing scenarios used must be from other rivers, as there is no detailed empirical data on salmon populations on the San Joaquin River below Friant Dam. Therefore, the flow volumes observed at the same time as the early, late and pulse fish timing scenarios are different from those expected on the San Joaquin River.

Limitations of the available suitable habitat modeling approach include the use of a 1D model in Reach 5. Since Reach 5 has large quantities of available habitat and does not show a habitat deficit in any scenario, this has a minimal effect on the results. Additional limitations include that the hydraulic model assumes that the groundwater aquifer has been filled. The model does not account for significant losses that may occur if groundwater conditions are different than those assumed.

This report does not consider native fishes other than the spring-run and fall-run Chinook salmon. These other fish could potentially require additional habitat.

5.2 Data Input Uncertainties

As can be seen in the subsections below, large uncertainty arises in the model due to the lack of an existing population on the San Joaquin River. The ESHE model relies on empirical datasets, many with unknown uncertainty levels. Since there is no way to test whether an idealized SJRRP-specific case is realistic or not (yet), this study goes with the uncertain, but referenced, method of using other rivers with surrogate populations.

Yearlings: Yearling entry timing data is based on very limited data from Butte creek, and all mortality from predation is applied above the model. Yearlings are a small (10 percent) portion of the total spring-run fish numbers (abundance), and so this area of uncertainty has limited effects on this analysis, but yearling information used herein should not be used in other contexts.

Juvenile Chinook Salmon Emigration Strategy: Because Chinook salmon were extirpated from the lower San Joaquin River before restoration actions were implemented, no detailed empirical information is available to calculate specific habitat requirements for Chinook salmon in the San Joaquin River below Friant Dam. Therefore, juvenile Chinook salmon initial timing, size and migration speed were estimated from representative populations – both potential source populations within the Central Valley and extant populations occurring within the San Joaquin River Watershed. Unfortunately, these surrogate populations exist in river systems that do not have extensive floodplain habitat, or the same flow schedules. Therefore, the emigration strategy types identified in surrogate populations (late, early, and pulse) likely will not reflect the specific movement patterns of future restored San Joaquin River salmon. By modeling the range of emigration behaviors observed in the most representative populations, this study provides a range of potential emigration behavior. Speed, the controlling factor between emigration strategies, is likely the greatest uncertainty in the data inputs.

Restoration flow hydrographs include flow volumes during the expected migration periods of spring-run and fall-run Chinook salmon. Other rivers with existing populations may show migration in other months as well. For example, the late timing scenario may represent an unrealistic condition for the San Joaquin River as it includes fish emigrating during May and June, when temperature may be limiting. An earlier timing scenario is more realistic on the San Joaquin. This report uses entry timing based on rotary screw trap data from rivers with existing populations and thus may or may not represent when San Joaquin River juvenile Chinook salmon begin leaving the spawning grounds. However, it is the concentration of fish that actually affects the results, not the time of year of the migration.

In high water years with floodplain inundation, it is expected that some salmon will move quickly down the main river channel and that other salmon will move onto the floodplains, where they move slower and grow larger prior to emigration. Hydraulics shows that velocities are often lower on shallow floodplains than in the deeper main channel. Slower velocities, combined with increased food availability on floodplains, likely results in a longer duration of fish stay on the floodplain (i.e. slower speed). These fish would then emigrate at a larger size, requiring more suitable habitat per fish (Sommer, 2001). The proportion of fish using the floodplain versus fish moving faster through the main channel is not known. The late timing scenario includes slow speeds from the representative rivers, which is useful to bracket speeds on the San Joaquin and capture, to some extent, the hypothesized floodplain rearing speeds. It is important to remember that only relative timing is important (i.e. to establish, for each reach, the one day period with the maximum number of fish). The late timing scenario is useful as it includes a slow fish speed, even though the specific times of year may be unrealistic. If actual floodplain rearing speeds are slower than the late scenario speeds, than this analysis may underestimate the floodplain habitat area.

The pulse emigration strategy scenario should be used with care due to several assumptions. The timing for spring-run fish was developed with data from both spring-run and fall-run. Also, fish speeds are so fast in this scenario that cohorts travel through entire reaches in less than a day, resulting in no habitat required in that reach.

Additionally, this analysis models spring-run and fall-run timing based primarily on the Feather River and Stanislaus River (see Section 3.1.5). This timing does not correspond to the SJRRP flow hydrographs. San Joaquin River fish could all emigrate during Feburary through March spring-pulse flows before temperatures get warm. This highly concentrated fish emigration behavior is somewhat represented by the pulse emigration strategy scenario. Including a theoretical scenario with an even shorter emigration window would increase the number of fish in any given reach on a certain day, but decrease the amount of time fish spend in any one reach. If time is reduced to less than a day in a reach, this may have no effect on required habitat.

Growth: Similar to salmon timing, growth data from a surrogate population, Sacramento River fall-run, were applied to inform an average growth rate relationship for salmon. Although this relationship does utilize the best available data to inform an average growth rate, elevated growth rates expected for fish that utilize off-channel floodplain habitat (Sommer, 2001) in a future restored San Joaquin River are not modeled. Therefore, salmon growth rate and fish territory requirements are likely underestimated in the model.

Population Targets: The purpose of this analysis did not include population modeling or setting of population targets. The analysis uses adult growth or long-term population targets from the Technical Advisory Committee recommendations (Hanson 2007, Hanson 2008) and the Fisheries Management Plan (SJRRP 2010). There is a linear relationship between adult population targets and the resulting required suitable habitat.

Survivals: Survival values are an uncertain parameter. As mentioned above, there is no extant population of Chinook salmon on this portion of the San Joaquin River to provide empirical survivals. Because of this, the analysis ran 3 different survival scenarios to bracket the range of reasonable possible survivals. The 5 percent survival was chosen as the scenario to calculate habitat deficits, as it is the program goal, and falls within the range observed on other rivers in the San Joaquin basin.

Cover Suitability: Cover HSI values were not available for San Joaquin rivers. Therefore, Pacific Northwest data were used to determine the suitability index for each vegetation type in the cover delineation. This results in some uncertainty. Team members expressed specific concerns about the high suitability index for grass given the large areas of very low-density grass present along the San Joaquin River. A lower grass suitability index would result in a lower value for available Suitable Habitat, increasing the inundated area objectives. No other studies were found to justify a different HSI value for grass.

Cover HSI values are not appropriate for defining the exact types of revegetation. Fisheries requirements should be considered in the development of revegetation plans, but the habitat suitability index values used herein are too uncertain to be used as design criteria.

While the calculation method of taking the minimum of the depth, velocity, and cover HSI values minimizes the sensitivity of the results to this parameter in areas where depth or velocity is more limiting, in many reaches cover is the most limiting (see Appendix A). In fact, cover is the key parameter differentiating the fraction of inundated area that is suitable. This shows promise for the ability of the SJRRP to increase suitable floodplain habitat areas by planting vegetation or adding other forms of cover.

Territory Size: The territory size-fork length relationship was compared to other studies as well as those compiled in Grant and Kramer (1990). The data found did not suggest using a different curve. However, as most juvenile salmon are likely to be less than 50 mm in fork length, the effect of fish size on the model results is fairly small compared to the effect of fish numbers. This is a minor area of uncertainty.

The territory size curve was developed based on species within the salmonid family, not specifically Chinook salmon. In addition, the high data point on the curve, which is the one point defining the habitat needed at larger fish sizes, is based on brook trout. This is an area of uncertainty. If data is obtained relating fork length to territory size specifically for Chinook salmon, results could change in either direction.

Suitable Habitat: If restoration activities result in the existing habitat quality of adjacent reaches, 10 percent suitable may be a reasonable estimate for Reach 2B requirements and 25 percent could be a reasonable estimate for Reach 4B. The actual fraction of suitable habitat in Reach 2B and 4B1 will be dependent upon the actual revegetation, floodplain grading, and channel restoration activities implemented in these reaches. Habitat quality and quantity are tradeoffs for the project teams, as increases in habitat quality can result in decreased inundated area. Suitable habitat is most sensitive to cover (i.e. vegetation) (see Appendix A). Therefore, this represents primarily a tradeoff between revegetation costs and levee setback costs.

Flow: The available suitable habitat analysis models three different flow levels. These flow levels bracket the potential available suitable habitat depending on the flows released. However, the precise flow schedules are unknown at this time. This analysis uses a combined weighted average flow across all 3 flow levels to model available suitable habitat. Using the dry year alone would have resulted in larger total inundated area requirements (i.e. larger levee setbacks).

5.3 Other floodplain criteria

Several potential suitable habitat criteria were suggested as important, but not ultimately included in the analysis. These are described below.

Food Production: Juvenile Chinook salmon also need food as part of floodplain habitat in order to meet their energetic demands as they grow (Keeley and Slaney 1996). However, this study excludes food production because the SJRRP does not have detailed information about food abundance in all reaches as of the publish date. Therefore, food production was not included in this effort, either for limiting available suitable habitat or quantifying required suitable habitat.

Temperature: Water temperature is traditionally used to evaluate habitat quality along with depth and velocity. Above lethal levels, temperature reduces the amount of available suitable habitat and may preclude the ability of fish to make use of required suitable habitat. Below lethal levels, high temperature may increase the metabolism and growth rate of fish and therefore increase the territory size required to support fish. Uncertainty in the relationship between temperatures, floodplain habitat, and fisheries requirements precludes directly addressing temperature as a parameter for minimum floodplain areas.

The timing of the restoration flows will vary from year to year depending on physical and biological conditions. During the spring flows, a change of 1 or 2 weeks in the flow schedule results in a significant difference in stream temperature. In addition, it may be possible to adjust the flow timing so that temperature conditions are acceptable for salmon in the project reach. Temperature modeling (SJRRP 2008) shows release patterns and periods of time where flow releases meet temperature requirements, so incorporation of temperature is not required to determine when floodplain area would limit fisheries.

It is most likely that if temperature is a significant limiting factor, then levee setbacks in Reaches 2B and 4B1 will not make large differences to the survival of Chinook salmon as temperature effects will be overwhelming, and other measures to ensure adequate temperature will have to be undertaken.

Connectivity: Agency partners have also noted the importance of connectivity of the floodplain to the main channel as a habitat parameter. An isolated pool, clearly, either provides no habitat benefit or a stranding risk, depending on the flow regime. This analysis does not include verification that depths are great enough for fish to reach all areas of habitat.

However, a two-dimensional model accounts for lateral and longitudinal flow connectivity by maintaining a water surface of some depth between all inundated areas. Therefore, inundated areas have some connection to other inundated areas, although the hydraulic conditions of connectivity (velocity, depth) are variable. This analysis assumes that all areas inundated with the 2D model are accessible to fish. If this is not the case, physical projects can create connectivity.

Reach 1 Habitat (Spawning and Yearling Rearing): Habitat needs in Reach 1 include spawning habitat and habitat for yearlings that remain in the system. Temperature modeling (SJRRP 2008) shows that in the summer at low flows the upper reaches will remain cool enough while downstream reaches heat up, meaning yearlings may need to hold over in Reach 1 (or potentially Reach 2). Increasing the total inundated area is not an option in Reach 1 as the river is between hills, so spawning or yearling rearing habitat must be created via increases in suitable habitat. This report does not include those potential needs.

5.4 Comparisons

The following sections compare these results to other analyses.

Fisheries Management Plan: The SJRRP's first estimate of floodplain habitat requirements was calculated in the Fisheries Management Plan (SJRRP 2010), based on data from the Yolo Bypass suggesting habitat requirements of 0.47 fish per meter squared, or one fish for every 23 square feet (2.13 square meters) (Sommer et al 2005). The analysis in the Fisheries Management Plan used the juvenile outmigrant targets, a mean egg production of 4,200 eggs, 50 percent egg survival, and 50 percent survival to fry stage to result in 7,784 acres of floodplain rearing habitat for spring-run and 2,595 acres of floodplain rearing habitat for fall-run. This also assumed that a fry size fish required the 23 square feet (2.13 square meters) habitat area from the Yolo Bypass, and does not provide a reach-specific breakdown of habitat.

The most significant differences in methodology are in the method of calculating survival. The analysis presented in this study assumes 4,900 (or 5,500 for fall-run) eggs, 48.5 percent egg survival, both of which are similar to the Fisheries Management Plan calculations, and a 5% survival through the river, which is not similar. This study uses ESHE to model fish more closely as they move through the system, exiting the spawning reaches, growing, dying, and traveling in cohort groups. The fish size used cannot be compared, as the Yolo Bypass data presumably calculates total inundated area directly, whereas the ESHE model calculates suitable habitat first based on the territory size-fish length curve.

Overall, the available habitat calculations in this study resulted in a total inundated area already existing in the system of 5,230 acres when weighted by year-type and averaged. The total inundated area deficit for the recommended scenario (assuming 10 percent of inundated area is suitable) is 2,390 acres. This results in a total inundated area requirement of 7,620 acres which is similar to the Fisheries Management Plan spring-run floodplain rearing habitat requirement of 7,784 acres. This assumes the Fisheries Management Plan habitat number represents a level of habitat quality equal to that already existing in the San Joaquin River Reaches 1B and 2. However, with the inclusion of fall-run, this study recommends approximately 2,760 acres less floodplain habitat than the Fisheries Management Plan. While inclusion of a minimum buffer width (see Section 0 below) would add approximately 1,140 acres to the Reach 4B1 minimum floodplain habitat area, this is still approximately 1,620 fewer floodplain habitat acres than the Fisheries Management Plan. This suggests increasing the levee setbacks beyond this study's recommended minimum floodplain habitat numbers as part of the ongoing considerations of risks in the Reach 2B and 4B projects.

Historical Floodplain: Sources indicate approximately 200,000 to 500,000 spring-run salmon on the San Joaquin River prior to the construction of Friant Dam (DFG 1990). Estimates of historical riparian-zone floodplain habitat are approximately 93,800 acres as calculated from maps present in the Sierra to the Sea report (TBI, 1998). This results in approximately 3.7 spring-run salmon per riparian zone acre for 350,000 spring-run. If all floodplain habitat including the extensive historical wetlands are included, the historical San Joaquin River had approximately 611,000 acres or 0.57 spring-run salmon per acre.

This analysis suggests approximately 10,000 acres (including existing habitat) for 45,000 spring-run fish, or approximately 4.4 spring-run salmon per riparian zone acre. This is a slightly denser concentration of fish than the historical riparian-zone acreage, but generally within the same magnitude for the riparian zone only.

5.5 Other Considerations on Levee Setbacks

Another necessity for river restoration projects, not evaluated in the modeling, is a minimum riparian buffer width on either side of the main channel. The need for a riparian buffer to maintain an ecologically functional river system is well documented in the literature. Riparian buffers assist in regulating the stream temperature (Collier et al. 1995), increase bank stability and channel complexity (Abernethy and Rutherfurd 1999; Benda et al. 2003), promote biodiversity (Naiman et al. 2005; Pollack et al.1998), provide bird, mammal, and amphibian habitat (Hagar 1999; Hilty and Merenlander 2004; Cockle and Richardson 2003; Crawford and Semlitsch 2006), improve water quality (Micheli et al. 2004; Liquori and Benda 2008), and provide a food source for juvenile salmon (Ahearn et al. 2006). The revegetation approach in the Reach 4B1 project has the goal of maintaining a minimum riparian buffer of 150 ft on both sides of the main channel (ESA, 2012). A typical active channel width in Reach 2B and Reach 4A is approximately 150 ft (Reach 4A is considered an appropriate surrogate for the expected width of Reach 4B1 if flows are restored to this reach) and therefore the sum of the buffer widths and main channel width gives a minimum distance between levees of 450 ft. If the SJRRP values water quality, food sources, bank stability, channel complexity, and/or biodiversity as indirect benefits to the Chinook salmon, this minimum buffer width should be considered a minimum floodplain habitat value as well. If this approach is accepted, the greater of the fisheries territory size area minimum presented in Section 4.4 for each reach or a 150 foot width on both sides of the main channel for each reach would be the true minimum floodplain habitat area requirement.

5.6 Incorporation into Site-specific projects

This report is not intended to define the habitat needs of a sustainable population, but rather to define the minimum required land to provide habitat for the juvenile offspring expected from returning spring-run and fall-run Chinook salmon, based on the long-term adult spawner targets (Hanson, 2007; Hanson,2008). The site-specific projects may consider a broader range of factors including infrastructure, impacts, benefits, and risks. The scenarios and analyses help to describe the tradeoffs and assumptions that lead to a specific acreage estimate.

6 CONCLUSION

For reintroduction efforts to be successful, one of the important issues is the estimation of how much habitat must be conserved or restored to ensure persistence of populations (Fahrig 2001). This is typically addressed by determining the minimum habitat necessary to maintain a viable population (McCoy and Mushinsky 2007). This report estimated minimum land surface area required to support rearing habitat for the juvenile offspring of the adult long-term population targets for spring-run and fall-run Chinook salmon within the reaches of the San Joaquin River as defined in the Technical Advisory Committee recommendations (Hanson, 2007; Hanson, 2008). To meet these objectives, this study development followed a transparent process built on assumptions developed within the scientific community, clearly identified relevant uncertainties, and vetted peer review.

Available suitable habitat was quantified using relations between flow and juvenile rearing habitat quality characteristics in the San Joaquin River. Water depth and velocity for selected flows were determined using a two-dimensional model. Cover habitats were mapped and combined with simulated hydraulic characteristics to quantify habitat areas for 3 different flow scenarios. To obtain fisheries requirements for suitable habitat, estimated territory size relationships for salmonids from the literature were combined with simulated cohort Chinook populations parameterized with fish initial timing, size, speed, and survivals from nearby rivers. 36 required suitable habitat model scenarios (2 population targets, 3 emigration strategy types, 3 survival assumptions, and 2 habitat quality assumptions) were developed to bracket the possible ranges for uncertain parameters. Available suitable habitat was subtracted from required to obtain the deficit in suitable habitat. Several different suitable habitat percentages were applied to convert suitable habitat to total inundated area (i.e. levee setbacks) and to provide tradeoffs between habitat quantity and quality.

Key limitations and uncertainties of the model include the fish speed and entry timing, cover suitability, and the territory size relationship. Scenarios were developed for fish speed and entry timing to attempt to bracket the possibilities on the San Joaquin River. A lack of local data on cover suitability, and the assumptions necessary to convert literature values to different vegetation map categories, resulted in uncertainties in the suitability of cover applied. As other information available was limited, this is difficult to modify. Finally, the number of data points used to determine the territory size relationship is small, and when newer data is added, data does not demonstrate a strong trend due to large variability. This represents a large underlying uncertainty with the modeling approach. This was the best available relationship between fish and territory size at the time of this writing.

Key sensitivities of the model include the emigration strategy and the survival. The emigration strategy changes inundated area results by up to 15 times (i.e. 100 to 1500 acres). Survivals are sensitive largely due to the wide variability in survival (0.03 to 28.25). Sensitivity to survival increases as the fish move downstream, as more fish die. Survival scenarios can change results by up to 2 orders of magnitude (i.e. 10 to 1000 acres).

The total inundated area for floodplain habitat in the Reach 2B project ranged from 10 to 6,820 acres depending on the scenario selected and the habitat quality. The total inundated area for floodplain habitat in the Reach 4B project ranged from 0 to 2,940 acres depending on the scenario selected and the habitat quality.

Recommended Scenario: This report recommends one scenario, with a range of suitable habitat percentages, to set the minimum floodplain area for the Reach 2B and Reach 4B projects. The long-term fish population scenario is recommended (45,000 spring-run; 15,000 fall-run) as it follows Technical Advisory Committee recommendations for determining floodplain habitat and allows for the population variability necessary to meet average population targets. The late (slow and extended) emigration strategy is recommended because it best represents expected average movement of fish on floodplains, although some fish will move faster as they are swept downstream in the river channel. The pulse emigration strategy is unrealistic as it routes fish so quickly they do not spend a full day in several reaches, eliminating the need for any habitat in that reach. The recommended survival assumption is the middle survival of 5 percent based on the recommendations in the Fisheries Management Plan. This provides a target that is attainable and does not overly constrain the population. Finally, the mean habitat quality assumption is recommended because it represents the quality of habitat currently present in the restoration reaches, and because the upper habitat quality scenario provides a sensitivity estimate that may not be reasonably achievable. Habitat quality can instead be controlled by the SJRRP via the fraction or percentage of total inundated area that is suitable. For this scenario, the suitable habitat area deficit in Reach 2B was 416 acres and the suitable habitat area deficit was 73 acres in Reach 4B1 corresponding to the total inundated areas of 1,660 to 4,160 acres for Reach 2B and 290 to 730 acres for Reach 4B across the range of possible percent suitable habitat assumptions (Table 28 and Figure 36).

Table 28. Minimum inundated area in Reach 2B and 4B1 for the recommended scenario

Scenario					Total Inundated Area (acres)			
Population	Emigration Strategy	Survival	Habitat Quality	Reach	10% Suitable	15% Suitable	20% Suitable	25% Suitable
Long-Term	Late	5%	Mean	2B	4160	2770	2080	1660
Long-Term	Late	5%	Mean	4B	730	480	360	290

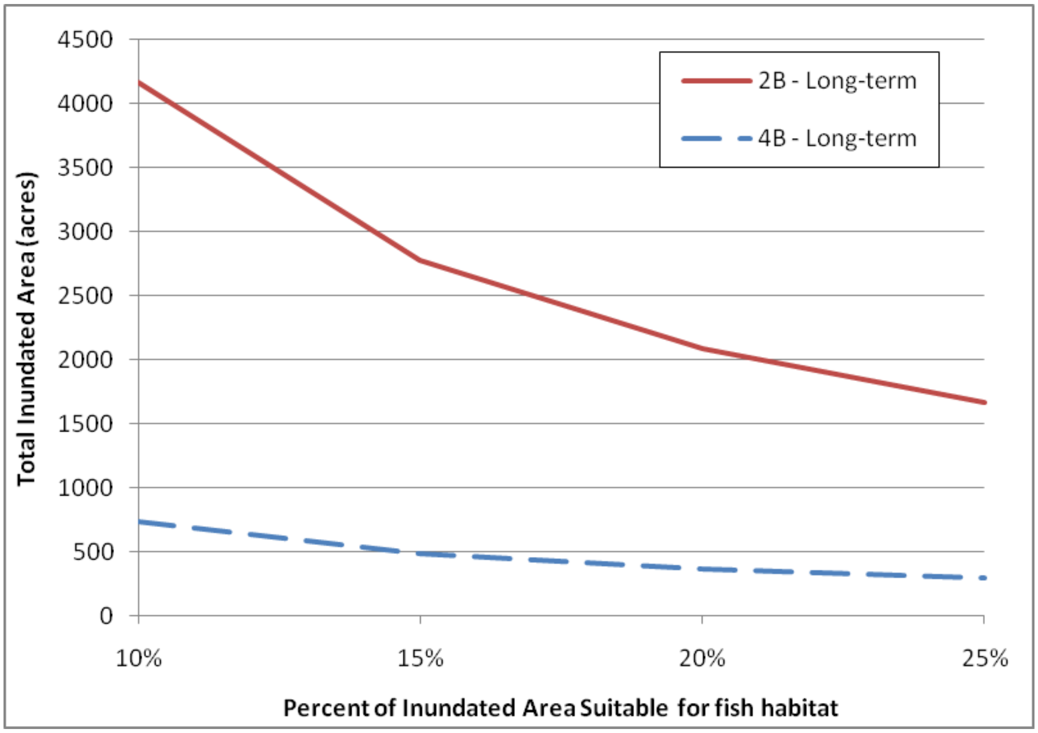

Figure 36. Total Inundated Area by project and population target

This document provides a minimum bookend for total enclosed floodplain area. The Reach 2B and Reach 4B projects have several floodplain alternatives under consideration at this juncture. This report may inform the selected alternative by removing floodplain alternatives that cannot meet the minimum inundated area requirements, even after improving the habitat quality to the highest reasonable level. This report may also assist the project teams in selection of a preferred alternative. While the selected floodplain alternative may be larger than this minimum area, this report helps to delineate some of the tradeoffs (habitat quality vs. quantity, for example) that are necessary to decide on a preferred alternative. Increased revegetation costs to increase the percent of suitable inundated area can be compared to increased land acquisition costs. The selected or preferred alternative will be selected after considering tradeoffs, risk, impacts and benefits between alternatives. This document is expected to be used by stakeholders and project teams to help select the preferred alternatives for the Reach 2B and 4B projects.

This study calculates the minimum required land to provide rearing habitat for the offspring of the adult growth and long-term population targets for both spring- and fall-run Chinook salmon. This present endeavor is not intended for the purposes of defining the total habitat needs of a sustainable population, but just the minimum required.

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8 APPENDIX A

Available *ASH* was calculated using each of the single-component HSI definitions (i.e., $HSI_T = HSI_D$, $HSI_T = HSI_V$, and $HSI_T = HSI_C$) for purposes of comparison with the results presented in Section 5.3. Single-component HSI definitions use a single HSI suitability map to define the overall suitability at each grid cell instead of using the minimum of multiple HSI suitability maps. For example, the depth-based single component HSI defines the HSI at each grid cell solely based on the depth suitability criteria without consideration of the velocity or cover suitability. While not used in the habitat analysis, the single-component HSI calculations may offer some insight into which of the suitability criteria are most limiting to predictions of available *ASH*. Tables A.1 to A.3 contain results from available *ASH* calculations using the single-component HSI definitions for each reach and flow.

Table A.1. Summary of single-component HSI analysis results for “dry” water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and fraction of available area of suitable habitat (*ASH*). Available *ASH* is calculated using three different definitions of HSI: $HSI_T = HSI_D$, $HSI_T = HSI_V$, and $HSI_T = HSI_C$. Computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH* (fraction)		
		HSI_D	HSI_V	HSI_C
1B	668	0.27	0.89	0.34
2A	625	0.34	0.85	0.29
3	495	0.18	0.68	0.26
4A	359	0.24	0.86	0.39
4B2	713	0.29	0.95	0.67
5*	823	0.29	0.95	0.67

*Reach 5 assumes Reach 4B2 values

Table A.2. Summary of single-component HSI analysis results for “normal” water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and fraction of available area of suitable habitat (*ASH*). Available *ASH* is calculated using three different definitions of HSI: $HSI_T = HSI_D$, $HSI_T = HSI_V$, and $HSI_T = HSI_C$. Computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH* (fraction)		
		HSI_D	HSI_V	HSI_C
1B	798	0.25	0.87	0.33
2A	743	0.30	0.76	0.31
3	770	0.23	0.69	0.27
4A	427	0.21	0.76	0.41
4B2	1041	0.30	0.95	0.64
5*	1373	0.30	0.95	0.64

*Reach 5 assumes Reach 4B2 values

Table A.3. Summary of single-component HSI analysis results for “wet” water year type. The columns from left to right indicate the river reach, total inundated area (*TIA*), and fraction of available area of suitable habitat (*ASH*). Available *ASH* is calculated using three different definitions of HSI: $HSI_T = HSI_D$, $HSI_T = HSI_V$, and $HSI_T = HSI_C$. Computations were not performed for Reaches 2B and 4B1 because future vegetative conditions are unknown.

Reach	*TIA* (acres)	Available *ASH* (fraction)		
		HSI_D	HSI_V	HSI_C
1B	982			
2A	876	0.26	0.67	0.33
3	1015	0.24	0.71	0.29
4A	525	0.18	0.70	0.43
4B2	1432	0.31	0.95	0.63
5*	2192	0.31	0.95	0.63

*Reach 5 assumes Reach 4B2 values

9 APPENDIX B

The tables below show required suitable habitat in meters squared for the growth and long-term population scenario. The long-term population scenario consists of a 50 percent increase in the returning adults from the growth population scenario. Required suitable habitat for the long-term scenario was calculated by multiplying the growth scenario required suitable habitat in meters squared by 1.5 and then converting back to acres.

Table B.1. Required Suitable Habitat for growth population target, spring-run subyearling (meters squared)

			Spring-Run Subyearling Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	155,841	92,491	32,389	23,063	12,009	1,419	774	124	62
Early	Mean	5.00%	308,476	92,619	54,052	64,189	67,244	18,263	19,601	7,870	7,505
Early	Mean	28.25%	498,134	92,661	64,205	91,154	123,565	43,106	59,101	31,974	38,257
Early	Upper	0.03%	83,134	45,215	20,877	12,822	6,365	873	478	76	38
Early	Upper	5.00%	171,251	45,277	34,840	35,686	35,639	11,237	12,104	4,818	4,597
Early	Upper	28.25%	282,530	45,298	41,385	50,678	65,430	26,523	36,495	19,574	23,436
Late	Mean	0.03%	611,523	217,732	228,275	105,684	71,986	10,003	4,028	663	419
Late	Mean	5.00%	1,443,932	243,580	371,077	296,503	402,186	132,211	109,241	39,550	46,326
Late	Upper	28.25%	2,462,658	253,129	439,727	421,781	730,636	316,954	336,733	157,070	228,770
Late	Upper	0.03%	344,452	106,415	147,118	58,804	38,146	6,154	2,489	406	257
Late	Upper	5.00%	822,817	119,049	239,152	164,978	213,123	81,339	67,496	24,226	28,378
Late	Upper	28.25%	1,422,899	123,715	283,396	234,684	387,173	194,999	208,053	96,212	140,137
Pulse	Mean	0.03%	338,707	115,372	128,267	56,940	50,364	7,991	2,889	492	348
Pulse	Mean	5.00%	831,621	129,379	209,817	157,032	273,096	106,556	81,908	29,942	38,696
Pulse	Mean	28.25%	1,426,970	134,558	249,098	221,641	491,643	256,651	256,272	119,597	191,528
Pulse	Upper	0.03%	191,457	56,353	82,635	31,663	26,675	4,915	1,785	301	213
Pulse	Upper	5.00%	473,267	63,195	135,173	87,321	144,644	65,532	50,590	18,335	23,696
Pulse	Upper	28.25%	820,032	65,724	160,480	123,248	260,398	157,840	158,286	73,234	117,285

Table B.2. Required Suitable Habitat for growth population target, fall-run subyearling (meters squared)

Fall-Run Subyearling Chinook (Max. Hab. Req. m^2)											
Emigration Strategy	**HSI Value**	**Survival**	**Total Hab.**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Early	Mean	0.03%	70,941	25,922	54,539	8,964	6,316	793	370	68	21
Early	Mean	5.00%	191,190	27,548	84,195	31,809	45,128	12,263	12,238	3,832	2,500
Early	Mean	28.25%	336,262	28,117	98,805	48,690	88,636	31,415	40,225	16,430	13,681
Early	Upper	0.03%	44,181	12,661	35,153	4,988	3,347	488	229	42	13
Early	Upper	5.00%	114,392	13,455	54,269	17,699	23,917	7,546	7,562	2,347	1,531
Early	Upper	28.25%	199,377	13,733	63,686	27,092	46,977	19,329	24,855	10,065	8,381
Late	Mean	0.03%	369,975	108,956	144,554	52,963	54,761	9,545	2,236	567	274
Late	Mean	5.00%	1,028,010	128,953	246,809	149,841	288,068	124,544	63,833	32,823	31,043
Late	Upper	28.25%	1,842,360	136,467	297,111	213,007	511,807	298,459	199,031	129,161	154,316
Late	Upper	0.03%	210,529	53,262	93,173	29,470	29,023	5,873	1,382	347	168
Late	Upper	5.00%	590,807	63,038	159,083	83,375	152,676	76,632	39,445	20,108	19,018
Late	Upper	28.25%	1,070,487	66,711	191,505	118,522	271,259	183,644	122,989	79,128	94,540
Pulse	Mean	0.03%	36,789	25,729	6,983	0	3,909	350	74	25	5
Pulse	Mean	5.00%	71,873	27,593	14,869	0	20,696	5,159	2,455	1,610	935
Pulse	Mean	28.25%	114,606	28,249	19,170	0	37,137	12,743	7,958	6,574	5,282
Pulse	Upper	0.03%	19,237	12,566	4,501	0	2,070	215	46	15	3
Pulse	Upper	5.00%	39,403	13,476	9,584	0	10,960	3,174	1,516	986	572
Pulse	Upper	28.25%	64,336	13,796	12,356	0	19,666	7,841	4,914	4,025	3,233

Table B.3. Required Suitable Habitat for growth population target, spring-run yearling (meters squared)

Spring-Run Yearling Chinook (Max. Hab. Req. m^2)											
Emigration Strategy	**HSI Value**	**Survival**	**Total Hab.**	**Lower 1B**	**2A**	**2B**	**3**	**4A**	**4B1**	**4B2**	**5**
Early	Mean	0.03%	176	0	37	0	46	38	29	28	0
Early	Mean	5.00%	29,375	0	6,116	0	7,622	6,401	4,850	4,696	0
Early	Mean	28.25%	165,967	0	34,553	0	43,062	36,166	27,403	26,535	0
Early	Upper	0.03%	106	0	24	0	24	24	18	17	0
Early	Upper	5.00%	17,603	0	3,942	0	4,040	3,939	2,997	2,877	0
Early	Upper	28.25%	99,459	0	22,273	0	22,824	22,254	16,933	16,256	0
Late	Mean	0.03%	176	0	37	0	46	38	29	28	0
Late	Mean	5.00%	29,375	0	6,116	0	7,622	6,401	4,850	4,696	0
Late	Upper	28.25%	165,967	0	34,553	0	43,062	36,166	27,403	26,535	0
Late	Upper	0.03%	106	0	24	0	24	24	18	17	0
Late	Upper	5.00%	17,603	0	3,942	0	4,040	3,939	2,997	2,877	0
Late	Upper	28.25%	99,459	0	22,273	0	22,824	22,254	16,933	16,256	0
Pulse	Mean	0.03%	176	0	37	0	46	38	29	28	0
Pulse	Mean	5.00%	29,375	0	6,116	0	7,622	6,401	4,850	4,696	0
Pulse	Mean	28.25%	165,967	0	34,553	0	43,062	36,166	27,403	26,535	0
Pulse	Upper	0.03%	106	0	24	0	24	24	18	17	0
Pulse	Upper	5.00%	17,603	0	3,942	0	4,040	3,939	2,997	2,877	0
Pulse	Upper	28.25%	99,459	0	22,273	0	22,824	22,254	16,933	16,256	0

Table B.4. Required Suitable Habitat for growth population target, total Chinook salmon (meters squared)

			Total Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	208,585	92,491	79,841	23,816	16,797	1,988	987	137	72
Early	Mean	5.00%	457,677	92,619	127,154	72,099	103,085	28,441	28,234	9,158	9,300
Early	Mean	28.25%	775,496	92,661	152,583	105,018	195,455	71,402	89,495	38,112	48,488
Early	Upper	0.03%	116,651	45,215	51,462	13,252	8,903	1,223	610	84	44
Early	Upper	5.00%	261,806	45,277	81,959	40,118	54,635	17,500	17,446	5,611	5,697
Early	Upper	28.25%	448,730	45,298	98,350	58,435	103,592	43,934	55,301	23,348	29,704
Late	Mean	0.03%	782,532	263,289	306,441	137,733	97,531	15,416	5,131	867	573
Late	Mean	5.00%	2,076,247	295,250	492,623	387,463	547,739	204,454	144,991	51,011	61,430
Late	Upper	28.25%	3,694,366	307,266	583,751	551,250	998,077	492,977	453,281	201,851	300,362
Late	Upper	0.03%	445,676	128,676	197,515	76,636	51,691	9,485	3,170	531	351
Late	Upper	5.00%	1,191,719	144,300	317,519	215,588	290,297	125,800	89,594	31,251	37,634
Late	Upper	28.25%	2,141,016	150,173	376,256	306,723	528,973	303,328	280,096	123,659	184,011
Pulse	Mean	0.03%	338,746	116,808	128,273	56,940	50,466	8,045	2,923	508	352
Pulse	Mean	5.00%	833,547	136,308	210,139	157,032	274,178	107,769	83,255	31,184	39,426
Pulse	Mean	28.25%	1,441,535	143,627	250,870	221,641	495,378	260,881	261,504	125,210	195,842
Pulse	Upper	0.03%	191,479	57,076	82,639	31,663	26,729	4,947	1,805	311	215
Pulse	Upper	5.00%	474,397	66,605	135,381	87,321	145,218	66,278	51,422	19,096	24,143
Pulse	Upper	28.25%	829,238	70,182	161,622	123,248	262,377	160,442	161,518	76,672	119,926

Table B.5. Required Suitable habitat for long-term population target, spring-run subyearling (meters squared)

			Spring-Run Subyearling Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	233,761	138,737	48,584	34,594	18,014	2,129	1,161	186	93
Early	Mean	5.00%	462,715	138,928	81,078	96,283	100,866	27,395	29,402	11,805	11,257
Early	Mean	28.25%	747,200	138,992	96,308	136,731	185,348	64,659	88,652	47,961	57,385
Early	Upper	0.03%	124,701	67,823	31,316	19,233	9,548	1,310	717	114	57
Early	Upper	5.00%	256,876	67,916	52,260	53,529	53,459	16,856	18,156	7,227	6,896
Early	Upper	28.25%	423,795	67,948	62,077	76,017	98,145	39,784	54,742	29,361	35,155
Late	Mean	0.03%	917,284	326,598	342,413	158,525	107,979	15,005	6,042	994	629
Late	Mean	5.00%	2,165,897	365,370	556,616	444,755	603,279	198,316	163,862	59,325	69,488
Late	Upper	28.25%	3,693,987	379,693	659,591	632,671	1,095,953	475,432	505,099	235,604	343,155
Late	Upper	0.03%	516,678	159,623	220,677	88,206	57,219	9,231	3,733	609	385
Late	Upper	5.00%	1,234,226	178,573	358,729	247,468	319,685	122,009	101,244	36,340	42,566
Late	Upper	28.25%	2,134,348	185,573	425,094	352,026	580,759	292,498	312,080	144,319	210,206
Pulse	Mean	0.03%	508,061	173,058	192,401	85,410	75,546	11,987	4,334	738	521
Pulse	Mean	5.00%	1,247,431	194,069	314,726	235,548	409,644	159,834	122,862	44,914	58,045
Pulse	Mean	28.25%	2,140,455	201,836	373,648	332,462	737,465	384,976	384,409	179,395	287,292
Pulse	Upper	0.03%	287,186	84,530	123,953	47,494	40,012	7,372	2,677	452	319
Pulse	Upper	5.00%	709,900	94,792	202,760	130,981	216,966	98,298	75,885	27,503	35,544
Pulse	Upper	28.25%	1,230,048	98,586	240,720	184,871	390,597	236,760	237,429	109,852	175,928

Table B.6. Required Suitable Habitat for long-term population target, fall-run subyearling (meters squared)

			Fall-Run Subyearling Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	106,412	38,883	81,808	13,446	9,474	1,190	555	102	31
Early	Mean	5.00%	286,784	41,322	126,293	47,714	67,692	18,395	18,356	5,748	3,750
Early	Mean	28.25%	504,392	42,176	148,208	73,035	132,955	47,122	60,337	24,645	20,522
Early	Upper	0.03%	66,271	18,991	52,730	7,482	5,021	732	343	63	19
Early	Upper	5.00%	171,588	20,182	81,403	26,549	35,876	11,318	11,343	3,521	2,296
Early	Upper	28.25%	299,065	20,599	95,529	40,638	70,465	28,994	37,283	15,097	12,572
Late	Mean	0.03%	554,962	163,434	216,831	79,445	82,141	14,317	3,354	850	410
Late	Mean	5.00%	1,542,014	193,429	370,214	224,761	432,102	186,815	95,750	49,235	46,564
Late	Upper	28.25%	2,763,540	204,701	445,666	319,510	767,711	447,689	298,546	193,742	231,474
Late	Upper	0.03%	315,793	79,893	139,760	44,205	43,535	8,809	2,072	521	251
Late	Upper	5.00%	886,211	94,556	238,624	125,063	229,014	114,948	59,168	30,163	28,527
Late	Upper	28.25%	1,605,731	100,067	287,257	177,783	406,888	275,465	184,483	118,692	141,810
Pulse	Mean	0.03%	55,183	38,594	10,475	0	5,864	525	111	37	8
Pulse	Mean	5.00%	107,809	41,389	22,303	0	31,045	7,739	3,682	2,415	1,402
Pulse	Mean	28.25%	171,909	42,374	28,754	0	55,706	19,115	11,936	9,861	7,923
Pulse	Upper	0.03%	28,855	18,848	6,752	0	3,105	323	69	23	5
Pulse	Upper	5.00%	59,105	20,214	14,376	0	16,439	4,762	2,274	1,479	859
Pulse	Upper	28.25%	96,504	20,695	18,534	0	29,498	11,761	7,371	6,037	4,850

Table B.7. Required Suitable Habitat for long-term population target, spring-run yearling (meters squared)

			Spring-Run Yearling Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	264	0	55	0	69	58	44	42	0
Early	Mean	5.00%	44,062	0	9,173	0	11,432	9,602	7,275	7,045	0
Early	Mean	28.25%	248,950	0	51,830	0	64,593	54,249	41,104	39,802	0
Early	Upper	0.03%	158	0	35	0	36	35	27	26	0
Early	Upper	5.00%	26,405	0	5,913	0	6,060	5,908	4,496	4,316	0
Early	Upper	28.25%	149,189	0	33,409	0	34,237	33,381	25,400	24,384	0
Late	Mean	0.03%	264	0	55	0	69	58	44	42	0
Late	Mean	5.00%	44,062	0	9,173	0	11,432	9,602	7,275	7,045	0
Late	Upper	28.25%	248,950	0	51,830	0	64,593	54,249	41,104	39,802	0
Late	Upper	0.03%	158	0	35	0	36	35	27	26	0
Late	Upper	5.00%	26,405	0	5,913	0	6,060	5,908	4,496	4,316	0
Late	Upper	28.25%	149,189	0	33,409	0	34,237	33,381	25,400	24,384	0
Pulse	Mean	0.03%	264	0	55	0	69	58	44	42	0
Pulse	Mean	5.00%	44,062	0	9,173	0	11,432	9,602	7,275	7,045	0
Pulse	Mean	28.25%	248,950	0	51,830	0	64,593	54,249	41,104	39,802	0
Pulse	Upper	0.03%	158	0	35	0	36	35	27	26	0
Pulse	Upper	5.00%	26,405	0	5,913	0	6,060	5,908	4,496	4,316	0
Pulse	Upper	28.25%	149,189	0	33,409	0	34,237	33,381	25,400	24,384	0

Table B.8. Required Suitable Habitat for long-term population target, total Chinook (meters squared)

			Total Chinook (Max. Hab. Req. m^2)								
Emigration Strategy	HSI Value	Survival	Total Hab.	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Early	Mean	0.03%	312,877	138,737	119,761	35,723	25,196	2,982	1,481	205	108
Early	Mean	5.00%	686,516	138,928	190,731	108,148	154,627	42,662	42,351	13,738	13,951
Early	Mean	28.25%	1,163,244	138,992	228,875	157,527	293,183	107,103	134,242	57,168	72,732
Early	Upper	0.03%	174,976	67,823	77,193	19,877	13,354	1,835	915	126	66
Early	Upper	5.00%	392,709	67,916	122,938	60,177	81,952	26,250	26,170	8,416	8,546
Early	Upper	28.25%	673,095	67,948	147,525	87,652	155,387	65,901	82,951	35,022	44,556
Late	Mean	0.03%	1,173,798	394,933	459,661	206,599	146,297	23,124	7,696	1,301	859
Late	Mean	5.00%	3,114,371	442,875	738,934	581,194	821,609	306,681	217,486	76,516	92,145
Late	Upper	28.25%	5,541,548	460,899	875,626	826,876	1,497,115	739,465	679,922	302,776	450,543
Late	Upper	0.03%	668,514	193,013	296,273	114,954	77,536	14,228	4,756	797	526
Late	Upper	5.00%	1,787,579	216,450	476,278	323,383	435,446	188,701	134,391	46,876	56,451
Late	Upper	28.25%	3,211,525	225,259	564,383	460,084	793,460	454,992	420,143	185,489	276,016
Pulse	Mean	0.03%	508,120	175,212	192,410	85,410	75,698	12,067	4,384	762	527
Pulse	Mean	5.00%	1,250,321	204,462	315,209	235,548	411,267	161,654	124,882	46,777	59,138
Pulse	Mean	28.25%	2,162,302	215,441	376,306	332,462	743,067	391,321	392,256	187,815	293,763
Pulse	Upper	0.03%	287,218	85,614	123,958	47,494	40,093	7,421	2,708	467	323
Pulse	Upper	5.00%	711,596	99,907	203,071	130,981	217,827	99,417	77,133	28,643	36,214
Pulse	Upper	28.25%	1,243,857	105,272	242,433	184,871	393,565	240,663	242,277	115,008	179,889

Table B.9. Habitat Deficit By Reach

Scenario				Suitable Habitat Deficit (acres)							
Population	Emigration Strategy	Survival	Habitat Quality	Lower 1B	2A	2B	3	4A	4B1	4B2	5
Growth	Early	0.03%	Mean	0	0	6	0	0	0	0	0
Growth	Early	0.03%	Upper	0	0	3	0	0	0	0	0
Growth	Early	5.00%	Mean	0	0	18	0	0	7	0	0
Growth	Early	5.00%	Upper	0	0	10	0	0	4	0	0
Growth	Early	28.25%	Mean	0	0	26	0	0	22	0	0
Growth	Early	28.25%	Upper	0	0	14	0	0	14	0	0
Growth	Late	0.03%	Mean	6	0	34	0	0	1	0	0
Growth	Late	0.03%	Upper	0	0	19	0	0	1	0	0
Growth	Late	5.00%	Mean	14	18	96	75	0	36	0	0
Growth	Late	5.00%	Upper	0	0	53	12	0	22	0	0
Growth	Late	28.25%	Mean	17	40	136	187	65	112	0	0
Growth	Late	28.25%	Upper	0	0	76	71	18	69	0	0
Growth	Pulse	0.03%	Mean	0	0	14	0	0	1	0	0
Growth	Pulse	0.03%	Upper	0	0	8	0	0	0	0	0
Growth	Pulse	5.00%	Mean	0	0	39	8	0	21	0	0
Growth	Pulse	5.00%	Upper	0	0	22	0	0	13	0	0
Growth	Pulse	28.25%	Mean	0	0	55	62	7	65	0	0
Growth	Pulse	28.25%	Upper	0	0	30	5	0	40	0	0
Long-Term	Early	0.03%	Mean	0	0	9	0	0	0	0	0
Long-Term	Early	0.03%	Upper	0	0	5	0	0	0	0	0
Long-Term	Early	5.00%	Mean	0	0	27	0	0	10	0	0
Long-Term	Early	5.00%	Upper	0	0	15	0	0	6	0	0
Long-Term	Early	28.25%	Mean	0	0	39	12	0	33	0	0
Long-Term	Early	28.25%	Upper	0	0	22	0	0	20	0	0
Long-Term	Late	0.03%	Mean	39	10	51	0	0	2	0	0
Long-Term	Late	0.03%	Upper	0	0	28	0	0	1	0	0
Long-Term	Late	5.00%	Mean	50	79	144	143	19	54	0	0
Long-Term	Late	5.00%	Upper	0	14	80	48	0	33	0	0
Long-Term	Late	28.25%	Mean	55	112	204	310	126	168	0	0
Long-Term	Late	28.25%	Upper	0	35	114	136	55	104	0	0
Long-Term	Pulse	0.03%	Mean	0	0	21	0	0	1	0	0
Long-Term	Pulse	0.03%	Upper	0	0	12	0	0	1	0	0
Long-Term	Pulse	5.00%	Mean	0	0	58	42	0	31	0	0
Long-Term	Pulse	5.00%	Upper	0	0	32	0	0	19	0	0
Long-Term	Pulse	28.25%	Mean	0	0	82	124	40	97	0	0
Long-Term	Pulse	28.25%	Upper	0	0	46	37	2	60	0	0