RECLAMATION

Managing Water in the West

Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids

U.S. Department of the Interior
Bureau of Reclamation
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REVIEW REQUIREMENT

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Peer review the entire technical memorandum to insure it meets professional standards of the US Bureau of Reclamation and the fisheries profession.

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

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Preparer - I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Signature Mark D. Bowen Date: 3/27/12

Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids

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MISSION STATEMENTS

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photograph: Stanislaus River near Valley Oak, August 14, 2009.

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ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
ASH	area of suitable habitat
ASPRS	American Society for Photogrammetry and Remote Sensing
CCAO	Central California Area Office
cfs	cubic feet per second
CSI	composite suitability index
EDS	Environmental Data Solutions
F	Froude number
ft	feet
GIS	Geographic Information System
GPS	global positioning satellite
HSC	habitat suitability criteria
IDW	inverse distance weighted
JM	Jacob Meyers
KF	Knights Ferry
LiDAR	Light Detection And Ranging
LSR	Lower Stanislaus River
LWD	Large woody debris
mi	mile
NMFS	National Marine Fisheries Service
NMRPO	New Melones Revised Plan of Operations
O. mykiss	*Onchorhynchus mykiss* (steelhead trout)
OB	Orange Blossom
PHABSIM	Physical Habitat Simulation System
Q	discharge

Reclamation	Bureau of Reclamation
RK	river kilometer
RM	river mile
RP	Ripon
RTK	Real Time Kinematic
Service	Fish and Wildlife Service
SI	Suitability Index
SONAR	Sound Navigation And Ranging
SZF	Stage of Zero Flow
TIN	Triangulated Irregular Network
TL	total length
TSC	Technical Service Center (Bureau of Reclamation)
U.S.	United States
USGS	U.S. Geological Survey
WSEL	water surface elevation
WUA	weighted usable area
YOY	young of the year
1-D	one-dimensional
2-D	two-dimensional

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FOREWARD

Please see Appendix J for reviewer comments regarding questions, suggestions, and changes that were made to the draft of this report.

SUMMARY

The Department of the Interior, Bureau of Reclamation (Reclamation), Denver Technical Service Center, in cooperation with the Central California Area Office and the Mid-Pacific Regional Office developed a "Discharge to Habitat Relationships for Anadromous Salmonid Juveniles in the Stanislaus River" (Stanislaus River Study) study in 2007 which was first called the Scale-up Study. It was building on the Stanislaus Habitat Use Pilot Investigation done in 2006-2007 on smaller (1/4 mile) reaches of the river. The Stanislaus River Study was conducted to describe the discharge-to-habitat relationships for fry and juvenile fall run Chinook salmon (*Onchorynchus tschawytscha*) and steelhead (*Onchorynchus mykiss*) in the lower Stanislaus River (LSR). In February 2008, Reclamation provided a presentation to stakeholders of its instream flow study plan for the Stanislaus River. The U.S. Fish and Wildlife Service (Service) provided Reclamation with a list of concerns and recommendations regarding Reclamation's Stanislaus River Study. Reclamation halted further Stanislaus River Study progress to consider Service's recommendations. In January 2009, Service, with the support of National Marine Fisheries Service (NMFS) and the California Department of Fish and Game, contacted Reclamation to recommend a different approach for quantifying flow-habitat relationships that had been peer reviewed over many years.

Reclamation and Service agreed to collaborate on the "Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids". The purpose of this study was to provide managers, stakeholders, regulatory agencies, and the public with tools to evaluate discharge requirements for rearing salmonids. Two principal modeling methodologies were employed to aid in the development of a flow prescription for the Stanislaus River: a two-dimensional (2D) hydrodynamic model, River2D (Steffler and Blackburn, 2002), and a spatially explicit geographic information system (GIS) tool (Bowen et al., 2003). Habitat was simulated from 250 cfs to 1,500 cfs which falls within the typical range of New Melones operations. Flow releases from Goodwin Dam on the Stanislaus River ranged from 198 to 1,504 cfs) during the period of field surveying (2007-2011), indicating a relatively dry period.

The goals of the collaboration were 1) utilize River 2D to compare to the GIS study; 2) utilize the GIS tool to determine if the River 2D studies were representative of the entire river and to evaluate coarse–scale measures such as floodplain inundation as a function of flow; and 3) provide a basis for a new flow prescription in the Stanislaus River.

To meet the River2D objectives, habitat mapping was conducted to allow extrapolation from the study site scale to the segment scale. First, mesohabitats were mapped for 10 miles of the entire 58 miles of the LSR between Goodwin Dam and its mouth. Second, from the maps, the proportion of each mesohabitat in each study segment was determined. Third, the mesohabitat proportions were used to weight each mesohabitat type within each study segment for the River2D model.

The River2D study focused in detail on four study sites totaling 2 miles; one study site in each stream study segment. Intensive two-dimensional hydraulic modeling was done in each mesohabitat in each study site. Habitat suitability criteria (HSC) curves were used to estimate the amount of fish habitat from the hydraulic modeling results. The results from these intensively modeled study sites were extrapolated up to the entire study segment using mesohabitat proportions obtained in the habitat mapping. Study segment results were summed to estimate the total weighted usable area (WUA) in the LSR at each modeled flow.

The GIS spatially explicit study utilized a combination of remote sensing, two-dimensional hydraulic modeling, GIS analysis, field surveys, and the same HSCs used by the River2D model, to estimate the area of suitable habitat (ASH) at each of three discharges in 100 percent of the LSR downstream from Knights Ferry Recreation Area. Methods used in the River2D habitat study are compared to the spatially explicit GIS tool in table 1.

Table 1 Comparison of methods used with the River2D and GIS spatially explicit models on the Stanislaus River

Parameter	Methods/study	
	River2D	**GIS spatially explicit**
Two-dimensional Hydraulic model	River2D	SRH-2D
Mesh dimensions	Equilateral triangulation (variable mesh size)	1 m *x* 1 m fixed rectangular mesh
Segments/study sites modeled	1) Two-mile Bar representing 4 mi of river below Goodwin Dam (Segment A) 2) Knights Ferry (Segment 1) to Orange Blossom Bridge 3) Orange Blossom Bridge to Riverbank, CA (Segment 2) 4) Jacob Meyers to confluence with San Joaquin River (Segment 3) Total length modeled – 2.0 mi	1) Knights Ferry to Orange Blossom Bridge (Segment 1) 2) Orange Blossom Bridge to Riverbank (Segment 2) 3) Riverbank to Ripon (Segment 3) 4) Ripon to confluence with San Joaquin River (Segment 4) Total length modeled – 56 mi Note: It is not possible to get a continuous survey of the river above Knights Ferry because of the unsafe conditions in the river and poor GPS reception through the canyon. Therefore, it was decided not to model upstream of Knights Ferry.
Discharge range modeled	Discharges ranging from 250 cfs to 1,500 cfs	Same
Habitat mapping	Approximately 10 miles	Mapped habitat for the entire river using the model
Bed topography	Total station (x, y ,z coordinates) Light Detection And Ranging (LiDAR) Sound Navigation And Ranging (SONAR) River2D R2D_BED utility program	Arc GIS LiDAR and photogrammetry SONAR- inverse distance weighted (IDW) interpolation Surface-water Modeling System (SMS)
Water surface elevations (WSELs)	Total station – PHABSIM, 1d model	RTK-GPS survey equipment
Velocity validation	None	ADCP RTK-GPS – Arc GIS
Species/life stages	Fall run Chinook salmon fry Fall run Chinook salmon juvenile *O.mykiss* fry *O.mykiss* juvenile	Same
Microhabitat modeled	Mean column velocity (m/sec) Depth (m) Cover Adjacent velocity (m/sec)	Mean column velocity (m/sec) Depth (m) Distance to edge (m) Velocity shear (s^{-1})
Composite suitability index (CSI) equation	$CSI = SI_{vel} \times SI_{dep} \times SI_{cov} \times SI_{adj\ vel}$, where *SI* = suitability index, *vel* = velocity, *dep* = depth, *cov* = cover, and	$CSI = SI_{vel} \times SI_{dep} \times SI_{d2e} \times SI_{she}$, where *SI* = suitability index, *vel* = velocity, *dep* = depth, *d2e* = distance to edge,

	adj vel = adjacent velocity.	and *she* = velocity shear.
Habitat suitability criteria (HSC)	Yuba River depth, velocity, cover, and adjacent velocity	Yuba River depth and velocity Site-specific distance to wetted edge Theoretical velocity shear
Habitat unit equation	Weighted usable area (WUA) sq m = CSI x variable area represented by each node. Results are reported in sq m and sq ft.	Area of suitable habitat (ASH) sq m = CSI x 1 sq m (fixed rectangular mesh area) represented by each mesh cell. Results are reported in sq m and sq ft.

Tables 2 and 3 report the final results for River2D and GIS spatially explicit modeling, respectively. Values in the tables represent flows with the highest predicted habitat values: WUA for River2D and ASH for GIS.

Table 2 Summary of flow-habitat relationships for River2D study on Stanislaus River: flows with the highest WUA for each species/life stage combination. These results are based on flows ranging from 250 to 1,500 cfs.

Species	Life stage	Segment A-Two-mile Bar	Segment 1-Knights Ferry	Segment 2-Orange Blossom	Segment 3-Jacob Meyers	Combined Segments 1-3
Chinook salmon	Fry	1,500	250	250	250	250
Chinook salmon	Juvenile	1,500	800	800	800	800
O. mykiss	Fry	1,500	250	250	250	250
O. mykiss	Juvenile	1,500	800	800	800	800

Table 3 Summary of flow-habitat relationships for GIS spatially explicit model on the Stanislaus River: flows with the highest ASH. These results are based on modeled flows: 250, 800, and 1,500 cfs.

Species	Life stage	Segment 1-Knights Ferry	Segment 2-Orange Blossom	Segment 3-Jacob Meyers	Combined Segments 1-3
Chinook salmon	Fry	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
Chinook salmon	Juvenile	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
O. mykiss	Fry	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
O. mykiss	Juvenile	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs

For the River2D results, with the exception of the Two-mile Bar segment, useable habitat occurred between 250 and 800 cfs, depending on life stage and river segment. Useable habitat in the Two-mile Bar segment was 1,500 cfs for all life stages of both species. The likely explanation for this difference in modeling results is that, compared to the other three stream segments, the Two-mile Bar segment differs dramatically in terms of river morphology and resulting hydraulics. Suitable habitat for the GIS modeling occurred at 1,500 cfs for all life stages and all river segments and ASH increased as simulated flows increased. An interesting comparison between the two studies was the general trend of decreasing habitat with flow for the River2D model and increasing habitat with flow for the GIS study, leading to a convergence of predicted habitat at 1,500 cfs (see Figures 21 and 22).

The River2D-predicted LSR discharge-habitat relationship was determined by channel morphology, the range of discharges studied, and HSUs. The channel morphology in the Stanislaus River is such that increased discharges did not greatly increase wetted area when comparing the range of discharges evaluated for this within-the-banks study. Additionally, the increase in available space was counteracted by a decrease in habitat quality due to increasing velocity and depth. Therefore, increasing discharge produced more wetted area, but the habitat quality declined over the same range of discharges. Therefore, as discharge increases River2D predicts that WUA will decrease.

Habitat suitability criteria used for this study for depth and velocity were taken from the Yuba River and indicate that the optimum velocity for Chinook salmon and *O. mykiss* fry and juveniles is at low velocities. The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek). As discharge increases in a narrowly confined channel such as the Stanislaus River, increases in velocity are more pronounced, and thus quickly move away from the optimal velocities indicated by the HSCs. A similar scenario exists for the depth criterion. Optimum depths for Chinook salmon and *O. mykiss*, both fry and juvenile, as indicated by the Yuba HSCs, are 3.3 ft or less. As discharge increases without significantly increasing wetted width, available habitat decreases.

As opposed to River2D, the GIS model predicted an increase in ASH over the range of discharges studied, 250 to 1,500 cfs. This increase in ASH occurred because the increase in wetted area, as discharge increased, was enhanced by GIS-predicted habitat quality improvement. It appears that the habitat quality improvement arises from how the GIS utilized the distance to edge parameter compared to how River2D used the cover parameter.

These two modeling methodologies, River2D and GIS, were compared to each other within the flow range studied: 250 to 1,500 cfs. Both models predicted differences in habitat within this flow range. The River2D model predicts decreasing habitat area with discharge increase. The GIS model predicts increasing habitat area with discharge increase. Further study is needed to explain why these different approaches predict different trends in habitat suitability as a function of flow, and for which purposes each modeling approach may be most appropriate.

INTRODUCTION

Reclamation is currently developing a New Melones Revised Plan of Operations (NMRPO) http://www.usbr.gov/mp/ccao/nmrpo/index.html), to "…reduce the reliance on New Melones Reservoir for meeting water quality and fishery flow objectives, and to ensure that actions to enhance fisheries in the Stanislaus River are based on the best available science (CALFED Bay-Delta Authorization Act [Public Law 108-361])." New Melones Reservoir is located in the upper Stanislaus River drainage and its flow releases are controlled by Goodwin Dam. One component of the NMRPO is to develop an instream fishery flow schedule for the lower Stanislaus River (LSR). Presently, Goodwin Dam release requirements and ramping rates ensure compliance with the National Marine Fisheries Service (NMFS) Biological Opinion (2009).

To support this effort, Reclamation developed a "Discharge to Habitat Relationships for Anadromous Salmonid Juveniles in the Stanislaus River" (Stanislaus River Study) study in 2007. In February 2008, Reclamation provided a presentation of its instream flow study plan for the Stanislaus River. Service provided Reclamation with a list of concerns and recommendations regarding Reclamation's Stanislaus River Study. Reclamation halted further Stanislaus River Study work to consider Service's recommendations. In January 2009, Service contacted Reclamation to recommend a different approach for quantifying flow-habitat relationships that had been peer reviewed over many years.

Reclamation and Service agreed to collaborate on the "Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids" to determine the relationship between discharge (Q) and salmonid juvenile habitat. With understanding of the salmonid discharge-habitat relationship, Reclamation can work with stakeholders and state and federal agencies to manage releases to meet the intent of Congress. The goals of the study were 1) utilize River 2D to compare to the GIS study; 2) utilize the GIS tool to determine if the River 2D studies were representative of the entire river and to evaluate coarse –scale measures such as floodplain inundation areas a function of flow; 3) provide a strong basis for a new flow prescription in the Stanislaus River.

Numerical habitat models have been used to predict the distribution of juvenile and spawning salmonids within rivers (Bowen, 1996; Allen, 2000; Guay et al., 2000; Gard, 2006). In addition, many studies conducted to provide an understanding of the relationship between fish habitat and discharge are based on the assumption that the amount and quality of habitat limits salmonid production. The relationship between fish population levels and habitat area may be specific to each river (Conder and Annear, 1987) (i.e., habitat vs. population levels should be utilized only when the relationship is well understood). In this study, we assumed that habitat was limiting production of Chinook salmon (*Onchorynchus tschawytscha*) and steelhead trout (*O. mykiss*) fry and juveniles. For this report, steelhead are referred to as *O. mykiss* because of the difficulty distinguishing rearing anadromous (steelhead) from resident (rainbow trout) fish. Also, when the relationship between available habitat and fish habitat use is known, then habitat models can predict usage, such as redd location for Chinook salmon (Gallagher and Gard, 1999).

In the recent past, there has been a significant increase in the application of multidimensional hydraulic models to evaluate aquatic habitat in rivers (e.g., Leclerc et al., 1995; Allen, 2000; Guay et al., 2000; Tiffan et al., 2002; Hardy et al., 2006; Gard, 2006; Parasiewicz, 2007; Hilldale, 2007; Papanicolaou, 2010; Service, 2010a; Sutton et al., 2010). For this project, multidimensional hydraulic models were linked to habitat suitability modules to predict salmonid rearing habitat. The two modeling methods employed were River2D (Steffler and

Blackburn, 2002) and a 2D hydraulic model SRH-2D (Lai, 2008) linked to a spatially explicit geographic information system (GIS) tool (Bowen et al., 2003; Deason et al., 2007), to assist in the development of a flow prescription for the Stanislaus River.

The primary difference between the two studies is that River2D focused in detail on short river reaches and extrapolated the results to represent the entire river while the GIS tool analyzed 56 mi of the LSR, but with less detail than River2D. The GIS tool was especially valuable to supplement ground surveys for the bed topography needs of River2D and evaluate coarse-scale measures, such as floodplain inundation area as a function of flow. The goals of the study were 1) utilize River 2D to compare to the GIS study; 2) utilize the GIS tool to determine if the River 2D studies were representative of the entire river and to evaluate coarse –scale measures such as floodplain inundation areas a function of flow; 3) provide a strong basis for a new flow prescription in the Stanislaus River.

An early review suggested problems with the use of habitat suitability criteria (HSC) from the Yuba River in the Stanislaus River (Greg Pasternack, University of California at Davis, personal communication). However, they use of the Yuba River HSCs were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek).

River2D

River2D Version 0.93 is a two-dimensional (2-D) depth averaged finite element hydrodynamic model developed by the University of Alberta that has been customized for fish habitat evaluation studies (Steffler and Blackburn, 2002). Hydraulic models, such as River2D, can be very useful for evaluating hydraulic properties as they relate to habitat (Hardy and Addley, 2003; Goodwin et al., 2006). River2D avoids problems of transect placement inherent with one-dimensional (1-D) models like the Physical Habitat Simulation System (PHABSIM) (Bovee et al., 1998) since data are collected uniformly across the entire site (Gard, 2009). However, River2D is typically limited to the site scale due to intense computing requirements. The process of computing habitat in River2D starts with developing a spatially-explicit index, based on hydrodynamic and habitat variables (Service, 2010a). The index is multiplied by area to compute a habitat index called weighted usable area (WUA).

Field surveys in 2009 and 2010 led to a River2D habitat modeling effort in 2010 and 2011 to describe the discharge-to-habitat relationships for fall-run Chinook salmon and *O. mykiss* rearing in the LSR. The study was coordinated with Reclamation's CCAO and Mid-Pacific Regional Office.

GIS – Spatially Explicit Model

The primary objective of the Stanislaus River GIS modeling work was the expansion of the spatial scale over which salmonid habitat was evaluated on the LSR, addressing the need to consider river and watershed scales in habitat assessments (Roni et al., 2001; Hardy and Addley, 2003; Wheaton et al., 2004). Evaluating habitat over the entire LSR avoided characterizing the river as a discontinuous system (Marcus and Fonstad, 2008), as is done in studies where local results are extrapolated over large spatial scales. The GIS spatially explicit study utilized a combination of remote sensing, 2-D hydraulic modeling using the SRH-2D model developed by Reclamation (Lai, 2008), GIS analysis, field surveys, and the same HSCs used by River2D (except as noted below) to predict the amount of salmonid rearing habitat.

The results from the River2D habitat study were compared to the spatially explicit GIS tool. The modeling methods are comparative and results differ in their predictions of amount of habitat.

STUDY AREA

The first decisions related to geographic boundaries regard the number and aggregate length of the river incorporated in the habitat analysis (Bovee et al., 1998). The following definitions apply to this discussion:

> *Study area* – The study area of a river is bounded by the point at which the impact of flow alteration occurs to where it is no longer significant. Typically, only a portion of a single river makes up the study area.
>
> *Segment* – The portion of the study area that has a homogeneous flow regime (+/- 10% of the mean monthly flow) and similar channel morphology, slope, and land use. A study area may have one or more segments.
>
> *Study site* – One or more mesohabitat units within a segment.

The study area for this project on the Stanislaus River extended from Goodwin Dam downstream to its confluence with the San Joaquin River–58 river miles (RM). A general map of the study area is shown in figure 1.

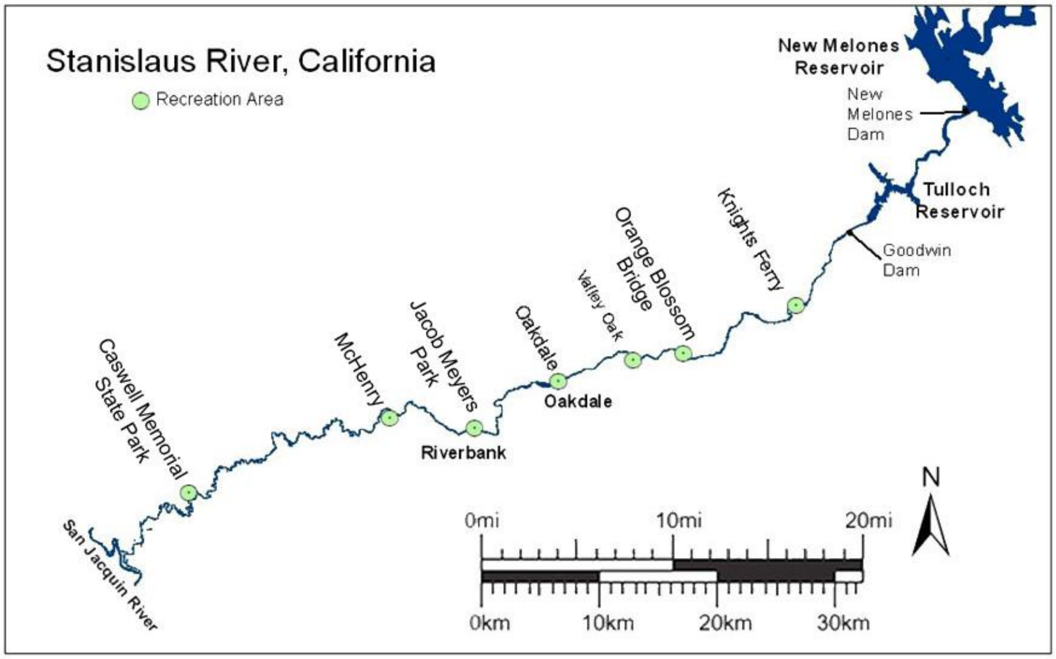

Figure 1 Stanislaus River. Study area includes all the river available to Chinook salmon and anadromous *O. mykiss*: Goodwin Dam to confluence with the San Joaquin River.

River2D

In figure 2, four study segments used for the River2D study are indicated for the lower 56 mi of the Stanislaus River:

A) Two-mile Bar representing 4 mi of river below Goodwin Dam

1) *Knights Ferry* (KF) begins at Knights Ferry Recreation Area, RM 56, and ends near the Orange Blossom Bridge, RM 48.2

2) *Orange Blossom* (OB) begins near the Orange Blossom Bridge, RM 48.2, and ends near Jacob Meyers Park, RM 34.5, in Riverbank (CA).

3) *Jacob Meyers* (JM) begins near Jacob Meyers Park in Riverbank, RM 34.5, and ends at the confluence with the San Joaquin River, RM 0.

Four study sites were initially selected (one per segment, plus one site in the uppermost 4 mi of river below Goodwin Dam in the Two-mile Bar Recreation Area) to represent mesohabitat types in the entire lower Stanislaus River (figures 3 to 6). Boundary coordinates for the River2D study sites representing these segments are summarized in table 4. These segments lie along a continuum from highest (Segment 1) to lowest gradient (Segment 3) (see figure 2 in Aceituno (1990).

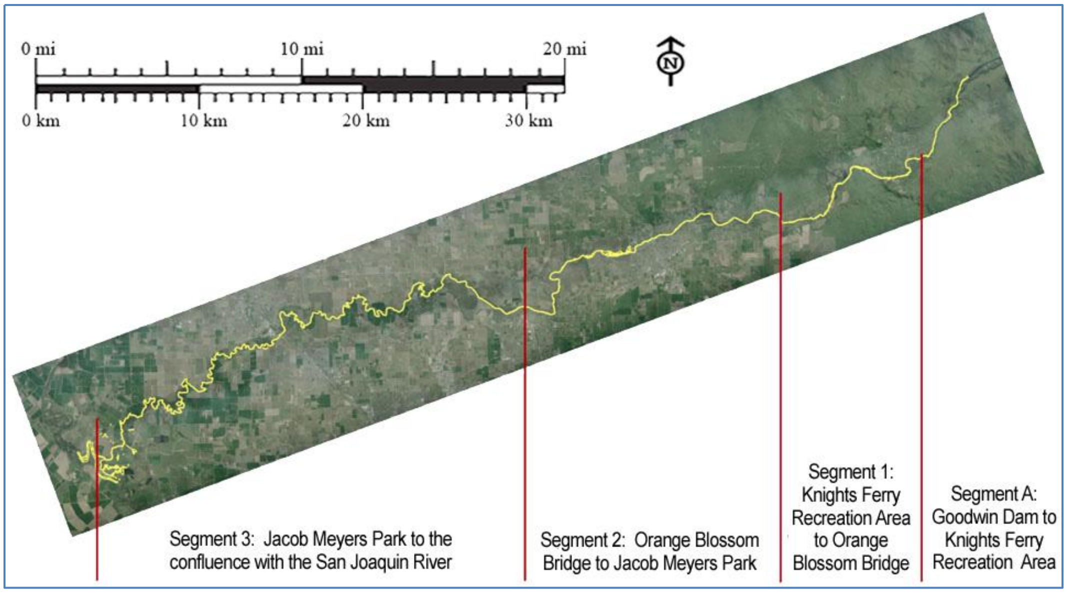

Figure 2 Map of the Stanislaus River with three identified study segments used for the River2D study. Water flows from right to left.

We used the River2D methodology described in Service (2010a) to estimate the amount of habitat available at discharges ranging from 250 cfs to 1,500 cfs for 58 miles of river from Goodwin Dam to the confluence with the San Joaquin River. We selected the study sites to meet the following criteria:

- The presence of at least one established control point tied to a vertical and horizontal datum
- Accessibility
- All segment mesohabitat types likely to be present in the site
- If possible, have the study sites overlap with habitat mapping in the GIS spatially explicit study

These criteria, including logistical difficulties, did not allow for a simple random selection of all mesohabitat units. Also, with random sampling, the luck of the draw may result in a non-representative sample. Due to safety concerns, limited accessibility, and limited satellite coverage, the study site below Goodwin Dam was located at one bar complex riffle, run, and pool that represented 70-80 percent of the reach upstream from Knights Ferry Recreation Area. Each study site included at least one mesohabitat type of those mapped, as defined by the 12 mesohabitat types listed in table 5. General definitions of these

Figure 3 Study site A on Stanislaus River for River2D study. The length of the study site is 0.2 mile.

Figure 4 Study site 1 on Stanislaus River for River2D study. The length of the study site is 0.6 mile.

Figure 5 Study site 2 on Stanislaus River for River2D study. The length of the study site is 0.6 mile.

Figure 6 Study site 3 on Stanislaus River for River2D study. The length of the study site is 0.6 mile.

Table 4 Universal Transverse Mercator (UTM) coordinates for River2D study site boundaries on the Stanislaus River

Study site	Northing (m)	Easting (m)
Site A-Two-mile Bar Recreation Area		
Upstream	4,190,933	707,524
Downstream	4,190,770	707,418
Site 1-Horseshoe Recreation Area		
Upstream	4,187,489	701,287
Downstream	4,186,707	700,575
Site 2-Valley Oak Recreation Area		
Upstream	4,184,602	694,395
Downstream	4,184,238	693,504
Site 3-McHenry Recreation Area		
Upstream	4,180,461	674,993
Downstream	4,180,562	675,154

Note: UTM North Zone 10, NAD83, meters, Geoid model g2003u05.

mesohabitat types are described in table 6. Two additional mesohabitat types were identified (appendix A) for the Stanislaus River that were not identified in Service (2010a). These mesohabitat types are:

> *Off channel* – A habitat unit that is not part of the main channel (e.g., small backwaters).
>
> *Gravel pit* – Any gravel pit that is filled with water. Usually there is no velocity in the habitat unit, and it can be connected to the main stream by a channel. This connecting channel would be considered “off channel,” as is the gravel pit. An example of this occurs at the downstream end of McHenry Recreation Area opposite from the Recreation Area beach. Another example is Willms Pond. Willms Pond is a gravel pit but is not “off-channel,” so gravel pits can fall into either category.

Study site 1 (Horseshoe Recreation Area), within Segment 1, included known spawning habitat for *O.mykiss* and Chinook salmon (John Hannon, Reclamation, personal communication). Total length of all study sites combined was about 2 miles. Ground photos of each study site are presented in appendix B.

Table 5 Mesohabitat types used for River2D study in the Stanislaus River.
Source: Snider et al. (1992) as cited in Service (2010a)

Mesohabitat type
Bar complex riffle (BCR)
Bar complex run (BCRu)
Bar complex glide (BCG)
Bar complex pool (BCP)
Flat water riffle (FWRi)
Flat water run (FWRu)
Flat water glide (FWG)
Flat water pool (FWP)
Side channel riffle (SCRi)
Side channel run (SCRu)
Side channel glide (SCG)
Side channel pool (SCP)

Table 6 Mesohabitat type definitions used for River2D study in the Stanislaus River.
Source: Snider et al. (1992) as cited in Service (2010a)

Mesohabitat type	Definition
Bar complex	Submerged and emergent bars are the primary feature, sloping cross-sectional channel profile.
Flatwater	Primary channel is uniform, simple and without gravel bars or channel controls, with fairly uniform depth across channel.
Side channel	A secondary channel with less than 20% of total flow.
Pool	Primary determinant is downstream control – thalweg gets deeper going upstream from bottom of pool; fine and uniform substrate; below average water velocity, above average depth; tranquil water surface.
Glide	Primary determinants are no turbulence (surface smooth, slow and laminar) and no downstream control; low gradient, substrate uniform across channel width and composed of small gravel and/or sand/silt; depth below average and similar across channel width (but depth not similar across channel width for Bar Complex Glide), below average water velocities, generally associated with tails of pools or heads of riffles, width of channel tends to spread out, thalweg has relatively uniform slope going downstream.
Run	Primary determinants are moderately turbulent and average depth; moderate gradient, substrate a mix of particle sizes and composed of small cobble and gravel, with some large cobble and boulders, above average water velocities, usually slight gradient change from top to bottom, generally associated with downstream extent of riffles; thalweg has relatively uniform slope going downstream.
Riffle	Primary determinants are high gradient and turbulence; below average depth, above average velocity; thalweg has relatively uniform slope going downstream, substrate of uniform size and composed of large gravel and/or cobble; change in gradient noticeable.

GIS

For the GIS spatially explicit study, the entire LSR was modeled with a discretized mesh with 3 ft resolution from Knights Ferry Recreation Area to the confluence with the San Joaquin at Two Rivers Park (CA), a total of 56 RM (figure 7). SRH-2D uses a hybrid mesh, consisting of both quadrilateral and triangular mesh elements. Hydraulic parameters (e.g. flow depth, velocity, applied shear stress, Froude number, etc.) are calculated for each cell in the mesh. Polygons provide the ability to specify any number of roughness conditions to the mesh cells (e.g. main channel, side channel, dense vegetation, sparse vegetation, ag. Land, etc.). Details on hydraulic and habitat modeling for the GIS spatially explicit study can be found in Appendix E.

The study area was divided into the following four smaller segments to maintain manageable mesh sizes and run times:

1) *Knights Ferry* (KF) - begins near the covered bridge in Knights Ferry, RM 56.0, and ends near the Orange Blossom Bridge, RM 48.2 (Segment 1)

2) *Orange Blossom* (OB) - begins near the Orange Blossom Bridge, RM 48.2 , and ends near Jacob Meyers park, RM 34.5 in Riverbank (Segment 2)

3) *Jacob Meyers* (JM), begins near Jacob Meyers Park in Riverbank, RM 34.5, and ends near the Highway 99 Bridge in Ripon, RM 17.1 (Segment 3)

4) *Ripon* – (RP), begins near the Highway 99 Bridge in Ripon, RM 17.1 , and ends at the confluence with the San Joaquin River, RM 0 (Segment 4)

Results from segments 3 (JM) and 4 (RP) were combined in the final model output to allow direct comparison with the River2D results for JM segment.

METHODS

Examination of table 7 shows that there were differences between the River2D and GIS spatially explicit modeling methodologies. But many parameters were similarly modeled, such as the range of discharges and the life stages and species modeled. To some degree, the differences reflect how each study approached habitat modeling for the river. River2D focused on short river reaches and expanded the results to represent the entire river, whereas the GIS study analyzed the entire river but with less detail than River2D. The following sections provide more details on methods.

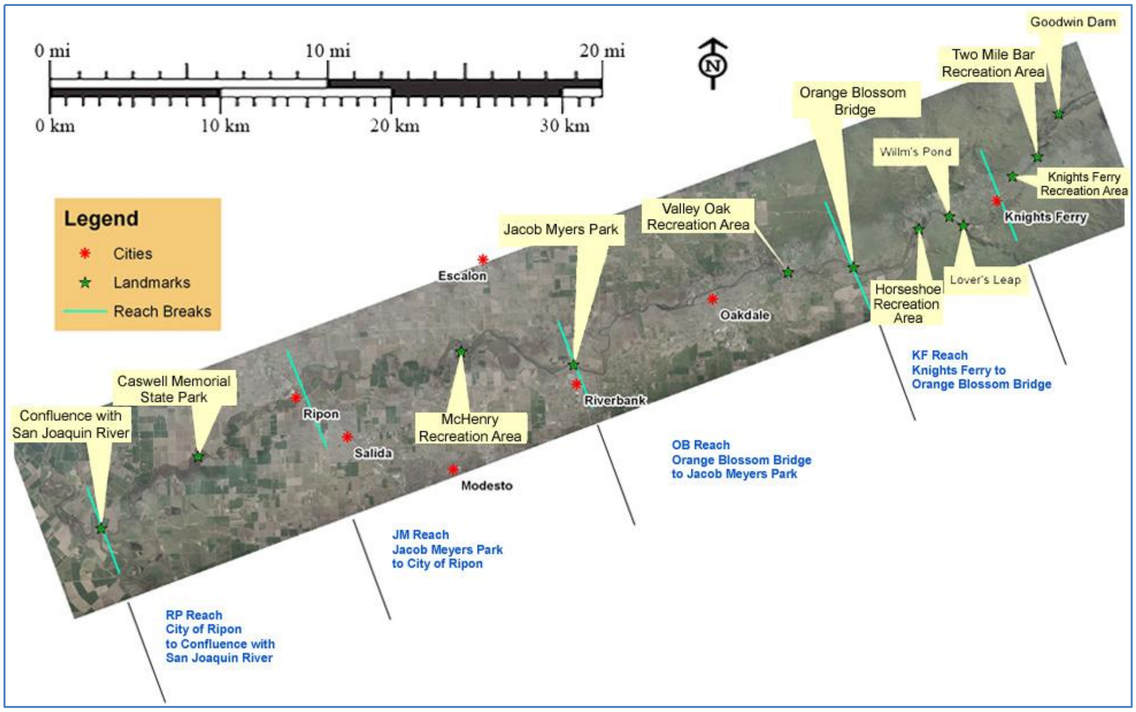

Figure 7 Map of the Stanislaus River with four identified study segments used for the GIS spatially explicit study. Water flows from right to left.

Table 7 **Comparison of methods used with the River2D and GIS spatially explicit models on the Stanislaus River**

Parameter	Methods/study	
	River2D	**GIS spatially explicit**
Two-dimensional Hydraulic model	River2D	SRH-2D
Mesh dimensions	Equilateral triangulation (variable mesh size)	1 m *x* 1 m fixed rectangular mesh
Segments/study sites modeled	1) Two-mile Bar representing 4 mi of river below Goodwin Dam 2) Horseshoe Recreation Area representing Knights Ferry to Orange Blossom Bridge 3) Valley Oak Recreation Area representing Orange Blossom Bridge to Riverbank, CA 4) McHenry Recreation Area representing Riverbank, CA to confluence with San Joaquin River Total length modeled –2.0 mi	1) Knights Ferry to Orange Blossom Bridge 2) Orange Blossom Bridge to Riverbank 3) Riverbank to Ripon 4) Ripon to confluence with San Joaquin River Total length modeled –56 mi
Discharge range modeled	Discharges ranging from 250 cfs to 1,500 cfs	Same
Habitat mapping	Approximately 10 miles	Mapped habitat for the entire river using the model
Bed topography	Total station (x, y ,z coordinates) LiDAR SONAR River2D R2D_BED utility program	Arc GIS LiDAR and Photogrammetry SONAR- inverse distance weighted (IDW) interpolation Surface-water Modeling System (SMS)
Water surface elevations (WSELs)	Total station – PHABSIM, 1d model	LiDAR - SRH-2D, 2D model
Velocity validation	None	ADCP – Arc GIS
Species/life stages	Fall run Chinook salmon fry Fall run Chinook salmon juvenile *O.mykiss* fry *O.mykiss* juvenile	Same
Microhabitat modeled	Mean column velocity (m/sec) Depth (m) Cover Adjacent velocity (m/sec)	Mean column velocity (m/sec) Depth (m) Distance to edge (m) Velocity shear (s^{-1})
Composite suitability index (CSI) equation	$CSI = SI_{vel} \times SI_{dep} \times SI_{cov} \times SI_{adj\ vel}$, where *SI* = suitability index, *vel* = velocity, *dep* = depth, *cov* = cover, and *adj vel* = adjacent velocity.	$CSI = SI_{vel} \times SI_{dep} \times SI_{d2e} \times SI_{she}$, where *SI* = suitability index, *vel* = velocity, *dep* = depth, *d2e* = distance to edge, and *she* = velocity shear.
Habitat suitability criteria (HSC)	Yuba River depth, velocity, cover, and adjacent velocity	Yuba River depth and velocity Site-specific distance to wetted edge Theoretical velocity shear
Habitat unit equation	Weighted usable area (WUA) sq m = CSI x variable area represented by each node. Results are reported in sq m and sq ft.	Area of suitable habitat (ASH) sq m = CSI x 1 sq m (fixed rectangular mesh area) represented by each mesh cell. Results are reported in sq m and sq ft.

River 2D

Survey Data

Habitat Mapping

Habitat mapping was required to allow extrapolation from the study site scale to the segment scale. First, using the classification in table 5, mesohabitats were mapped for 10 miles of the entire 58 miles of the LSR between Goodwin Dam and its mouth The mapping was accomplished at a discharge of approximately 350 cfs. Second, from the maps, proportion of each mesohabitat in each study segment was determined. Third, the mesohabitat proportions were used to weight each mesohabitat type within each study segment for the River2D model.

The 10 miles of LSR subsampled through mapping, included approximately equal lengths in each of the three segments. For the mapping, the anterior and posterior boundary of each mesohabitat polygon was pinpointed with a Global Positioning System (GPS) unit following the methods of the Service (2010a).

Bed Topography

Bed topography surveys were conducted at each study site by field crews using total stations. Dominant substrate sizes and cover type were visually assessed for each bed topography point according to the coding systems provided in tables 5 and 6.

Three Sokkia Set 3100 total stations with Recon data collectors were used to collect bed topography. Survey points were geo-referenced by backsighting to known control points (UTM Zone 10 – meters; NAVD 88) on the Stanislaus River. Additional control points were established at each site for total station placement to serve as the reference location from which all horizontal locations (northings and eastings) were tied when collecting bed topography data (appendix C). Bed topography points were collected along each stream bank in shallow areas less than (<) 3.9 feet deep, as conditions allowed, and out of the water above the expected water's edge at approximately 5,000 cfs, if possible. Sound Navigation and Ranging (SONAR) data from the GIS study (see below) was used to complete the topography in the deeper channel areas at each study site. All efforts were made to take bed topography points at a density of approximately 40 points/100 m^2 (40 points/ 1,076 ft^2) to an accuracy within 0.3 ft. Since substrate and cover data were not collected during the SONAR survey, polygons of substrate and cover for the deeper areas were delineated using an Aquascope (Dynamic Aqua Supply Limited, Surrey, BC, Canada) and marked with a total station.

Topography was measured in all areas of the selected study sites representing about 2 miles of river between 2009 and 2011. Survey points were spaced approximately 3.3 ft apart laterally and 4.9–6.6 ft apart

Table 8 Substrate codes, descriptors, and particle sizes used for River2D study on the Stanislaus River

Code	Type	Particle size (inches)
0.1	Sand/silt	<0.1
1	Small gravel	0.1–1
1.2	Medium gravel	1–2
1.3	Medium/large gravel	1–3
2.3	Large gravel	2–3
2.4	Gravel/cobble	2–4
3.4	Small cobble	3–4
3.5	Small cobble	3–5
4.6	Medium cobble	4–6
6.8	Large cobble	6–8
8	Large cobble	8–10
9	Large cobble	10–12
10	Boulder/bedrock	>12

Table 9 Cover coding system used for River2D study on the Stanislaus River

Type	Code
No cover	0
Cobble	1
Boulder	2
Fine woody vegetation (<1 in diameter)	3
Fine woody vegetation + overhead	3.7
Branches	4
Branches + overhead	4.7
Log (> 1 ft diameter)	5
Log + overhead	5.7
Overhead (> 2 ft above substrate)	7
Undercut bank	8
Aquatic vegetation	9
Aquatic vegetation + overhead	9.7
Rip-rap	10

longitudinally in and out of the wetted channel. Higher densities were used in areas with more complex or quickly varying bed topography, substrate and cover, and lower densities were used in areas with uniformly varying bed topography and uniform substrate and cover.

For each study site, transects oriented perpendicular to the flow were placed at the downstream and upstream ends of the site. Whenever possible, the study site boundaries (upstream and downstream transects) were selected to coincide with the upstream and downstream ends of a mesohabitat unit. The downstream transect was located at a hydraulic control (e.g., head of riffle or channel constriction) which was modeled using PHABSIM to simulate water surface elevations (WSEL) at unmeasured flows as an input to the River2D model. The data collected at the inflow and outflow transects included:

1. WSEL measured to the nearest 0.01 m (0.03 ft) at three significantly different stream discharges using standard surveying techniques (differential leveling). Since WSELs are used to calibrate the River2D model at measured flows, they needed to be precisely measured

2. Wetted streambed coordinates determined by total station

3. Dry ground elevations to points above the approximately 5,000 cfs water's edge, if possible, surveyed to the nearest 0.1 m (0.3 ft)

4. Mean water column velocities measured at the three flows (265 cfs, 782 cfs, and 1,042 cfs) at the points where bed elevations were taken

5. Substrate and cover classification measured at these same locations (tables 8 and 9) and also where dry ground elevations were surveyed

A subjective determination of the approximately 5,000 cfs water level was made in the field. Then, we surveyed along each stream bank between approximately 5,000 cfs) water level and the water's edge. The upper limit of the model simulation was restricted by how far up the bank we could reasonably survey. In 2009 and 2010, discharge/WSELs were measured at a minimum of three different flows. A fourth "higher" flow was not available to be measured in 2010 because it was not a wet year.

Hydraulic Model Construction and Calibration

Water surface elevations were measured to calibrate the River 2D model so that the WSELs were within 0.1 ft of measured elevations at defined locations.

The topographic data used for the four sites included the total station data as well as previously collected LiDAR and SONAR data obtained through GIS data collection (see GIS-Methods section below). The LiDAR and SONAR data were also used to develop the topography for a two- to four-channel-width upstream extension for the Horseshoe Recreation Area, Valley Oak Recreation Area and McHenry Recreation Area sites (appendix E) to allow simulated velocities to stabilize before reaching the modeled site. Since SONAR data were not available for the Two-mile Bar site, an artificial one-channel-width upstream extension was used, based on the cross-sectional profile at the upstream end of the site. The topographic data for the 2-D model was first processed using the R2D_BED utility program, where breaklines were added to produce a smooth bed topography. The resulting data set was then converted into a computational mesh composed of variable-sized equilateral triangles using an additional utility program, R2D_MESH (Waddle and Steffler 2002). This utility program was also used to define the inflow and outflow boundaries, to improve the fit between the mesh and the final bed file, and to improve the quality of the mesh, as measured by the Quality Index (QI) value. The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002). The final step with the R2D_MESH software was to generate the computational (cdg) file, with mesh elements sized to reduce the error in bed elevations resulting from the mesh-generating process to 0.03 m where possible, given the computational constraints on the number of nodes. The resulting mesh was used in River2D to simulate depths and velocities at the simulation flows.

The PHABSIM transect at the outflow end of each site was calibrated to provide the WSEL at the outflow end of the site used by River2D. The PHABSIM transect at the inflow end of the site was calibrated to provide the WSELs used to calibrate the River2D model. The Stage of Zero Flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered into the PHABSIM file. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. The initial bed roughnesses used by River2D were based on the observed substrate sizes and cover types. A multiplier was applied to the resulting bed roughnesses, with the value of the multiplier adjusted so that the WSEL generated by River2D at the inflow end of the site matched the WSEL predicted by the PHABSIM transect at the inflow end of the site. River2D calibration was considered achieved when the WSELs predicted by River2D at the upstream transect were within 0.031 m (0.1 ft) of the WSEL predicted by PHABSIM. The computational file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each computational file was run in River2D to steady state. A stable solution will generally have a Solution $\Delta < 0.00001$ and a net $Q < 1$ percent. In addition, solutions should usually have a Maximum Froude number (F) of less than one. The River2D model was run at the flows at which the validation data set was collected with the output used to determine the difference between simulated and measured velocities, depths, bed elevations, substrate, and cover. The River2D model was also run at the simulation flows to use in computing habitat.

Habitat Suitability Criteria

Species-specific HSC are required for River2D analyses. Habitat suitability criteria, or suitability curves, are interpreted using a suitability index (SI) on a scale of 0 to 1, with 0 being unsuitable and 1 being most utilized, or preferred. Habitat suitability criteria that accurately reflect the habitat requirements of the species and life stages of interest are essential to developing meaningful and defensible instream flow recommendations. However, the habitat requirements of a number of species and life stages are not known; therefore, application can be limited unless emphasis is placed on developing HSCs specifically for the species of interest. The recommended approach in unregulated streams is to develop site-specific criteria for each species and life stage of interest. An alternative approach is to use existing curves and literature to develop suitability criteria for the life stages of interest with input from local independent experts.

Originally, a comparison was planned to contrast juvenile HSCs developed using logistic regression on the Yuba River (Service 2010a) to depth and velocity fish use data collected in the Stanislaus River. The planned comparison with new fish observations and data from Aceituno (1990) would use a goodness-of-fit test to determine whether the Yuba dataset was transferrable to the Stanislaus River. However, limited site-specific fish data could be collected and the original data of Aceituno (1990) could not be located; this restricted any meaningful statistical comparison. Therefore, the Yuba datasets for Chinook salmon and *O. mykiss* were used in the River2D model. The Yuba dataset consisted of two sets of *O. mykiss* HSC – one for fry and one for juveniles. Fry were defined as < 60 mm total length (TL) and juveniles were defined as greater than (>) 60 mm TL. In general, the juvenile criteria were based on fish < 120 mm (4.7 in) TL. We did not have HSC for 1+ *O. mykiss* > 120 mm TL. The Yuba HSCs for juvenile *O. mykiss* and Chinook salmon are shown in appendix E. The velocity, depth, and adjacent velocity criteria are curves, not categories so the values between each entry needed to be interpolated. Cover is a categorical variable, so interpolation between values did not apply.

Biological Verification Data Collection

Biovalidation data were collected during 2010 at the microhabitat scale (0.1 m^2 grid) to determine if the combined suitability of fish occupied locations was greater than the combined suitability of unoccupied locations. The objective of this work was to collect data to verify the accuracy of the River2D model's predictions regarding habitat availability and use (Gard 2006) of the four River2D sites established by Reclamation.

From April 5 to April 8, 2010 (flows at the Ripon gage were 1,266, 1,249, 1234, and 1230 cfs), snorkel surveys were conducted at each study site for young-of-year (YOY) fall-run Chinook salmon and *O. mykiss*. The length of banks surveyed at each site was: 0.12 mile at Two-mile Bar Recreation Area, 0.28 mile at Horseshoe Recreation Area, 0.31 mile at Valley Oak Recreation Area and 0.06 mile at McHenry Recreation Area. Depth, velocity, adjacent velocity and cover data were collected both at locations with YOY salmonids and at locations which were not occupied by YOY fall-run Chinook salmon and *O. mykiss* (unoccupied locations). One person snorkeled upstream along the bank and placed a weighted, numbered tag at each location where YOY fall-run Chinook salmon or *O. mykiss* were observed. The snorkeler recorded the tag number, the species, the cover code and the number of individuals observed in each 10-20 mm size class on a polyvinyl chloride wrist cuff. The average and maximum distance from the water's edge that was sampled, and the length of bank was sampled with a tape 298 ft long) and recorded.

A tape 298 ft long was put out with one end at the location where the snorkeler finished and the other end where the snorkeler began. At every 39.4-ft interval along the tape, a stadia rod was used to measure out the distance from the bank given in the data book. If there was a tag within 3 ft of the location, that tag was recorded on that line in the data book and the field crew proceeded to the next 1.5-ft mark on the tape, using the distance from the bank on the next line. If there was no tag within 3 ft of that location, the depth, velocity and adjacent velocity at that location were measured with a wading rod and velocity meter, and the cover at that location was noted. Depth was recorded to the nearest 0.1 ft and average water column velocity and adjacent velocity were recorded to the nearest 0.1 ft/sec. For occupied locations, the tags were retrieved, the depth and mean water column velocity at the tag location were measured, the adjacent velocity for the location was measured, and the data was recorded for each tag number. Data taken by the snorkeler and the measurer were correlated at each tag location. The location of both occupied and unoccupied points was recorded with a survey-grade Real Time Kinematic (RTK) GPS unit.

The adjacent velocity was measured within 2 ft on either side of the location where the velocity was the highest, consistent with the definition of adjacent velocity. The distance, 2 ft, was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon and *O. mykiss* reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of the Stanislaus River is around 3.9 ft. This measurement was taken to provide the option of using an alternative habitat model which considers adjacent velocities in assessing habitat quality. Adjacent velocity can be an important habitat variable for fish, particularly fry and juveniles, which frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed (Fausch and White, 1981). Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. If there were no cover elements (as defined in table 9) within 1 ft horizontally of the fish location, the cover code was 0.1 (no cover).

Habitat Modeling

River2D was used to simulate habitat for fall-run Chinook salmon and *O. mykiss* fry and juvenile rearing. The WUAs were calculated as an aggregate of the product of a composite suitability index (CSI, range 0.0–1.0) evaluated at every point in the domain and the "tributary area" associated with that point. In River2D, the “points” are the computational nodes of the finite element mesh and the tributary areas are the “Thiessen polygons,” including the area closer to a particular node than all other nodes (Steffler and Blackburn, 2002). The CSI at each node was calculated as a combination of the separate SIs for depth, velocity, cover, and channel index (i.e., adjacent velocity) by exporting each set of SIs into a comma-delimited file for each flow, species, life stage, and each mesohabitat type present in each site. These files were then run through a GIS post-processing software to incorporate the adjacent velocity criteria into the habitat suitability. The software calculated the adjacent velocity for each node and then used the adjacent velocity criteria to calculate the adjacent velocity SI for that node.

To calculate the CSI value, the software multiplied together the velocity SI, the depth SI, the cover SI, and the adjacent velocity SI:

$$CSI = SI_{vel} \text{ x } SI_{dep} \text{ x } SI_{cov} \text{ x } SI_{adj\ vel}$$

where *vel* = velocity, *dep* = depth, *cov* = cover, and *adj vel* = adjacent velocity. This product was then multiplied by the area represented by each node to calculate the WUA for each node with the WUA for all nodes summed, using the post-processing software described above, to determine the total WUA for each mesohabitat type, flow, life stage and species. WUA values were computed for each flow using the fry HSC file and then the process was repeated using the juvenile HSC file. Habitat was simulated for 30 flows ranging from 250 cfs to 1,500 cfs at roughly equal increments.

The WUA in each mesohabitat unit was weighted by the percent of that habitat type found in the site. The total WUA for each segment was calculated using the following equation:

$$\text{Segment WUA} = \Sigma\ (\text{Ratio}_i * \Sigma\ \text{Mesohabitat Unit}_{i,j}\ \text{WUA})$$

where Ratio_i was the ratio of the total area of mesohabitat type_i present in a given segment to the area of mesohabitat type_i that was modeled in that segment and Mesohabitat $\text{Unit}_{i,j}$. WUA was the WUA for mesohabitat unit_j of habitat type_i that was modeled in that segment.

GIS

Survey Data

The field survey for the GIS spatially explicit study was conducted from 2007 to 2010. This effort involved fish surveys, a bare earth LiDAR survey, aerial photography, bathymetry using SONAR and RTK GPS survey gear,and velocity and water surface elevation data collected for the purpose of calibration and verification of the hydraulic model. Each of these tasks is described below.

Fish Surveys

The Fishery Foundation (2010) conducted fish surveys in five 0.5-mile reaches at 300 and 1,500 cfs. Snorkelers collected microhabitat data at precise positions that fish were occupying. Five microhabitat parameters, depth, velocity, shear, distance to cover from predation, and distance to edge were measured at fish focal positions. When a fish was observed, the snorkeler recorded species (Chinook salmon or *O.mykiss*), total body length (in millimeters), and distance from substrate (in centimeters) on a dive slate and placed a numbered marker directly below the observed focal position. The unique number on the marker was recorded on a dive slate to allow multiple positions to be marked before collecting the associated data.

LiDAR and Photogrammetry

To obtain the above water topography, a bare earth LiDAR survey was performed by Aerometric, Inc. (Seattle, WA) on March 10, 2008, from Goodwin Dam to the mouth of the Stanislaus River at the San Joaquin River. The spot density achieved was 0.5 m (1.6 feet). A sidelap of 50 percent improved the penetration of the vegetation canopy to obtain bare earth elevations. The stated accuracy was less than 0.15 m (0.5 ft). Two sets of orthorectified aerial photography were collected on the same date resulting in a 0.3 m (1 ft) pixel size in riparian areas and a 1 m (3.3 ft) pixel size capturing much of the valley width. The smaller scale photography was used for the GIS spatially explicit modeling. Average daily discharge in the Stanislaus River on March 10th, 2008 was 417 and 339 cfs at Goodwin (Reclamation, GDW) and Ripon (USGS #11303000) gages, respectively.

Bathymetry

The primary bathymetric survey data collection was performed by Environmental Data Solutions (EDS) using SONAR. Bathymetry was obtained from Knights Ferry to the mouth of the Stanislaus River at Two Rivers Park (the 90-RK [56-mile] reach) in February and March 2008, with additional ‘mop-up’ surveys conducted in June and July 2008. The Stanislaus River upstream of Knights Ferry is severely confined, with drops greater than 1 m and a ubiquitous presence of very large boulders, preventing a proper survey using boat-mounted SONAR. The survey in the other reaches used a series of four boat-mounted transducers spaced less than 6.6 ft apart in a swath system. RTK GPS positioning was provided by a Leica System 1200. The survey utilized a Crescent VS100 DGPS heading and roll sensor to provide accurate, reliable heading and position information at high update rates. The Crescent VS100 used moving base station RTK technology to achieve very precise heading and position accuracies. The relative positions of the RTK antenna and fathometers were measured twice daily and entered into the Hypack configuration files. Stated accuracy of the survey was 0.3 ft. The point density for the surveyed portion of the channel ranged from 0.028 to 0.037 points per square foot. When the entire wetted portion of the river (as defined by aerial photography and bare earth LiDAR flown March 10, 2008) was used to evaluate point densities, the average was approximately 0.02 point per square foot. The decrease in resolution was due to the inability to survey very near the shoreline throughout much of the river, although every effort was made to do so where feasible. Downed trees line a significant portion of the banks of the LSR and prevent safe survey access, either by boat or while wading.

Bed Topography

Topographic representation of the river channel is the most important input to a hydraulic model. The topography was accomplished in Arc GIS (ESRI, Redlands, CA) using a combination of raster and terrain surfaces. The mapping began by defining the wetted edge of the right and left banks. This task proved difficult using only aerial photography due to the significant amount of overhanging vegetation on the LSR. To assist with the delineation of the wetted edge, a terrain was constructed using the bare earth LiDAR. The wetted edge was determined to be the junction of the down-sloping bank and the flat surface created by returns from the water surface. Lines were drawn delineating the wetted edge using the terrain and then verified with the aerial photography. These lines were then used to delete the bare earth LiDAR from the wetted portions of the channel. For all reaches, the wetted portion of the channel was mapped using inverse distance weighted (IDW) interpolation of the SONAR data. Over 40 tests were performed at three sites to determine an appropriate interpolation scheme using isotropic interpolation methods, included kriging, ordinary and universal; spline, with and without tension, inverse distance weighting, and nearest neighbor. Various parameters available in each of the interpolation schemes were adjusted and optimized. Within a few tests it became apparent that kriging and nearest neighbor interpolations would not provide the appropriate interpolation, limiting the remaining tests to IDW and a tensioned spline.

The three sites chosen for the raster interpolation tests were in the upstream, middle, and downstream portions of the LSR and each tested area included a bank-to-bank bathymetric survey. Points along the channel margin were selected for removal and a raster was made of each data set, one complete and one with points removed. Removing points along the channel margin replicated those areas near the banks that were not surveyed due to a lack of access by the boat, primarily because of vegetation and/or shallow water. A misrepresentation of the channel edges can result in a loss of conveyance, altering the hydraulic properties, and potentially affecting the habitat evaluation in these areas. After a 1 m raster was made of each test data set (complete set of points and with channel margin points removed), a statistical comparison was made using the Geostatistical Analyst function in Arc GIS and the mean absolute error was minimized. A comparison was also made with a cross section cut through each raster and compared to survey data. Upon completion of the analysis, bathymetry rasters were then constructed for all four reaches using IDW interpolation with optimized variables.

For the Knights Ferry reach, a raster was made of the above water topography resulting from the bare earth LiDAR data. This raster and the bathymetry raster were then merged to provide a seamless raster surface. For the remaining reaches (OB, JM, and RP) the rasters representing the bathymetry were converted to points, spaced at 1 m, and combined with the LiDAR point data. A terrain was then built in Arc GIS. The terrain, as opposed to a raster, was used because of the size, and therefore the number of survey points, of the lower three reaches. The linear interpolation of the terrain provided a quality surface provided there was a sufficient point density, which was obtained from the LiDAR survey. Recall that the LiDAR point spacing was approximately 0.5 meter. An example of the resulting terrain is shown on figure 8.

Hydraulic Model Construction and Calibration

Sedimentation and River Hydraulics – Two Dimensional (SRH-2D) Model

Surface-water Modeling System (SMS, ver. 10.0.11 [Aquaveo Water Modeling Solutions, Provo, UT]) software was used to generate the modeling mesh, which was input into the hydraulic model, SRH-2D. SRH-2D utilized a flexible, hybrid mesh system whereby a combination of triangular and quadrilateral cells were used. This flexible mesh allowed for varying resolutions throughout the model and improved efficiencies (Lai, 2010). The hybrid, flexible mesh provided the ability to create a finer resolution in the channel and a coarser resolution in the floodplain, if desired. This decreased the number of cells in the model, decreasing computation time.

The wetted and near-bank portions of the mesh for all reaches used a 1 m x 2 m rectangular computational mesh (when entered into GIS a 1 m x 1 m mesh was used for habitat modeling), with the long dimension in the longitudinal (downstream) direction and the short dimension in the lateral (cross stream) direction. Construction of the mesh began with the water lines created to delineate the wetted perimeter of the channel. These lines were imported from Arc GIS and were the same lines used to form the channel boundary when creating the seamless surface terrain. The meshing began with the channel and continued to the floodplain. Elevations were added to the mesh using a routine written in Visual Basic. This program applied elevations to each mesh node from the terrain created in Arc GIS. SMS possesses this capability; however, memory errors occur (using the 32-bit version of SMS) when working with over 3 million points, which was the case in three of the four reaches in this study.

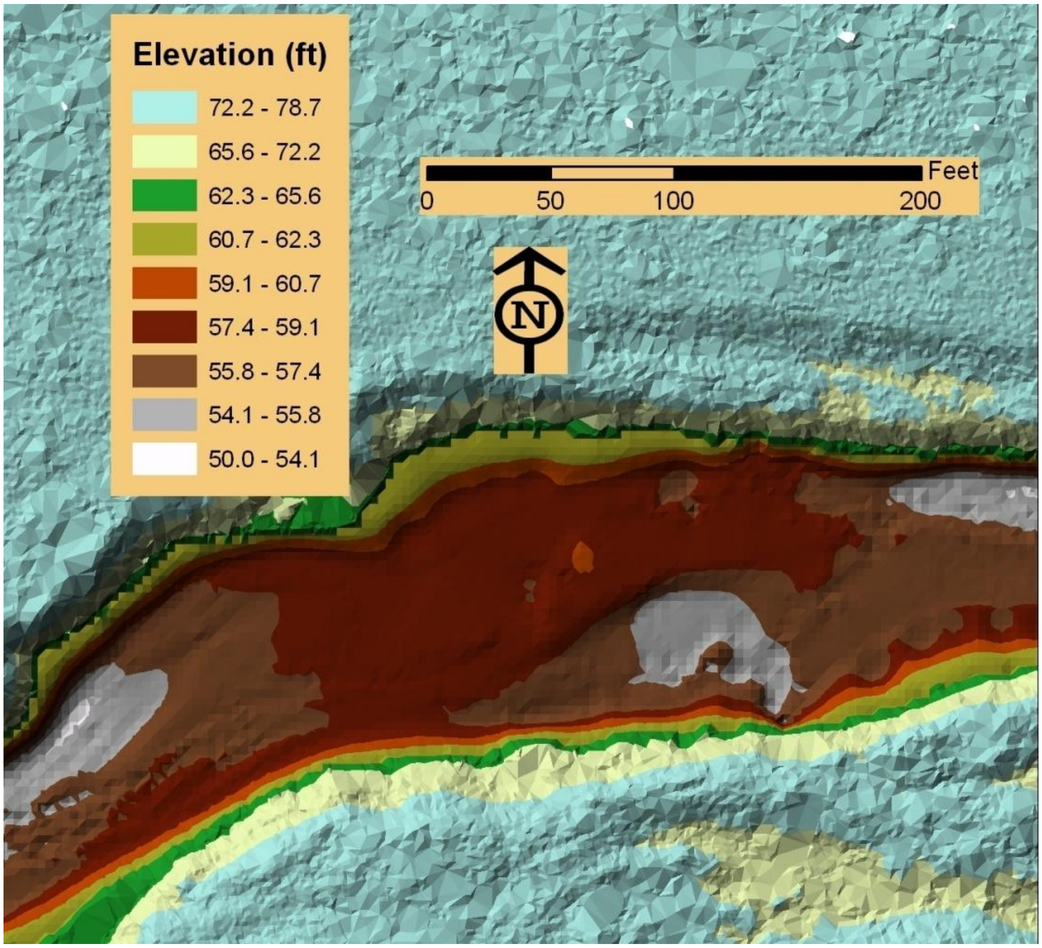

Figure 8 Example of the terrain resulting from point data.

Channel and floodplain roughnesses were applied to the mesh using a series of polygons, which were generated in Arc GIS or SMS. Roughness values remained constant over all discharges. Six roughness values were used to represent flow resistance. Floodplain vegetation was described as dense and sparse to represent different floodplain conditions. The purpose of increasing the roughness along the channel margins was to replicate the low growing vegetation protruding into the water, which was ubiquitous throughout the LSR. Additional modeling details can be found in Hilldale (appendix E).

Model Validation

The only significant parameter for calibration in the SRH-2D model is Manning's *n*. During construction of the model input, Manning's *n* values were assigned based on experience related to modeling channel hydraulics and familiarity with channel roughness. The previous section demonstrated the lack of sensitivity to the roughness coefficient, both for WSEL and depth, assuming reasonable values are chosen. Upon completion of a model run, predicted WSELs were then compared to measured values from the Reclamation and EDS surveys. The comparison was carried out by spatially joining the model results to the surveyed elevations for a given discharge.

When the modeling was complete and WSEL comparisons had been made, the model results were validated using depth average velocity. Velocity measurements were collected during the Reclamation surveys in all reaches at discharges approximately equal to 250 and 800 cfs. Velocity measurements were made using an Acoustic Doppler Current Profiler (ADCP) and were post-processed using AdMap to obtain depth average velocity and horizontal position. These data were imported to Arc GIS for comparison to model results.

A comparison of measured and modeled point velocities does not necessarily provide an appropriate comparison for 2-D model validation. This is because the modeled velocity represents a spatially (within a cell) and temporally averaged quantity while a field measurement from the ADCP is an instantaneous velocity at a single point. Due to the turbulent fluctuations, mismatched velocities may be more representative of a natural phenomenon than incorrect modeling. This problem was addressed in this study by spatially averaging velocity measurements, which also represented a time averaged value because neighboring data points were not taken at the same time. A spatial join was performed in a GIS whereby all measured velocity points within 1 m (3.3 ft) of a model point were joined to a modeled value. The average of the measured data was then compared to the modeled value. This process typically provided a minimum of three measured points to average and sometimes returned ten or more. If the search returned only one measured point velocity, that value was not used in the comparison.

Habitat Suitability Criteria

The GIS study used the same fry and juvenile rearing HSCs that were used for the River2D study with two exceptions:

1. Distance to wetted edge was a surrogate for cover because it can be remotely sensed

2. Velocity shear was used instead of adjacent velocity (appendix D)

Wetted edge was defined as any point where the water surface intersected with an object in the wetted portion of the channel. For this study an edge was a feature at any position in or adjacent to the wetted channel (e.g., gravel bar, bank, boulder, large woody debris [LWD], or vegetated island). Because proximity to edge is important, we chose to demarcate edge habitats throughout the LSR. We chose 2 m (6.6 ft) as the primary zone of influence around edge habitat. This distance was chosen based on observations by Allen (2000) that found < 1 percent of Chinook fry observations were of individuals > 6.6 ft from a bank. We used the SHUPI fish distance to edge (Fishery Foundation, 2010) observation data to develop an HSC for distance to edge (figure 9). A total of 88 fry and juvenile *O. mykiss* observations were used to construct the HSC. The SI was estimated for

0, 3.3, and 6.6 ft distances to edge by dividing the number of observations greater than these distances by the total number of observations (88). We assumed a constant SI (0.6) for distances greater than 6.6 ft based on figure 9.

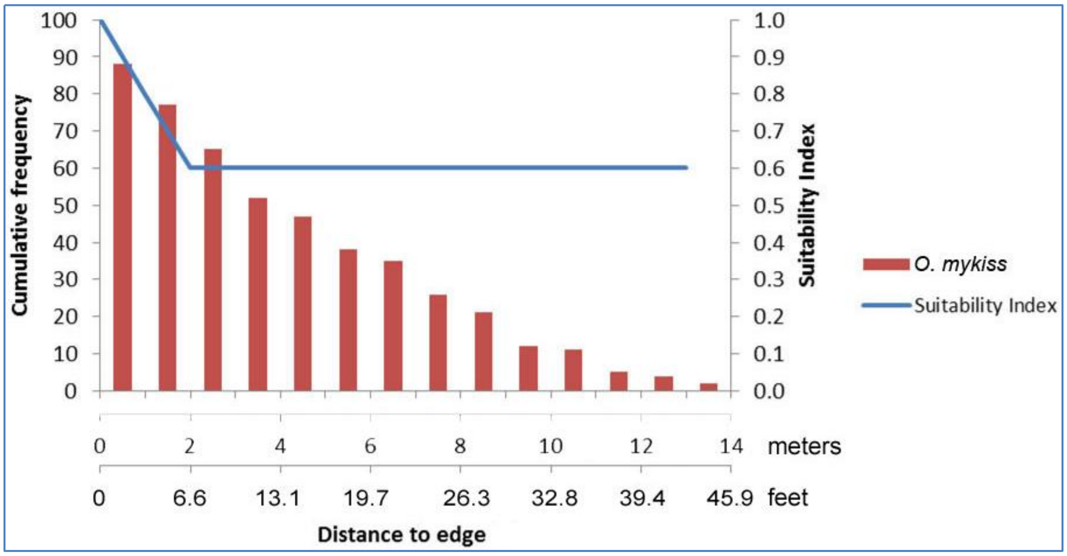

Figure 9 Distance to edge habitat suitability criteria based on cumulative frequency of fish observations (Fishery Foundation, 2010) in the Stanislaus River.

Some investigators have begun to investigate hydraulic properties in adjacent cells as they pertain to aquatic habitat. Of particular interest is the velocity gradient, because drift feeding salmonids minimize energy expenditure by often swimming in low velocity regions and feeding in nearby higher velocity regions (Hayes and Jowett, 1994; Bowen, 1996). Crowder and Diplas (2000) evaluated energy gradients related to energy expenditure of a fish moving from a region of lower to higher velocity. Adjacent velocity has also been evaluated for habitat value by Gard (2006), where the fastest velocity is within a lateral distance of (2 ft (orthogonal to the flow direction).

In this project, the velocity shear was defined as follows:

$$V_s = (V_{max} - V_i)/d$$

where V_{max} is the maximum velocity in a 3 x 3 cell matrix surrounding the cell of interest, V_i (both in units of distance/time), and d is the distance between V_{max} and V_i (in units of length). In our case, that was always 1 m. The evaluation results in units of sec^{-1} (The units of inverse seconds results from dividing the difference in velocity in units of length/time by distance across the measurement (cell size) in units of length. That produces a unit of 1/sec, or inverse seconds.). During the search for V_{max} all nine cells are included, such that the center cell could be V_{max}, which would result in a V_s equal to 0, also eliminating the possibility that V_s is negative. This methodology is used because it provides for the ability of a young salmonid to swim in a low-velocity area and feed in a higher-velocity area (Bowen, 1996), and we wished to incorporate this behavior into our habitat estimates. We requested a review of this velocity shear methodology from published researchers in the field of salmonid habitat estimation (Ken Tiffan, USGS Western Fisheries Research Center, Cook, WA; and John Williams, Independent Consultant and Former Executive Director of the Bay-Delta Modeling Forum, Davis, CA.). They confirmed that no known velocity shear habitat suitability curve exists and that this method was a reasonable theoretical approach.

Our theoretical curve (figure 10) suggests that when the maximum adjacent velocity is less or equal to the focal velocity, the SI is 0. Then, as the maximum velocity in nearby cells (a surrogate for feeding velocity) increases above the focal velocity, the SI improves until it reaches 1. The SI remains at 1 for a range of velocity shears. Eventually, the shear becomes so high that when a fish leaves its velocity refuge to feed, it loses distance and must swim at a high speed to attain the previous position.

Habitat Modeling

The SRH-2D model provided the following output at the cell center of each mesh element: point ID, horizontal position, bed elevation, water surface elevation, depth, velocity – X direction, velocity – Y direction, magnitude velocity, Froude number (F), and bed shear stress. A point shapefile was created in Arc GIS from the output of each model run. Rasters were constructed for depth, velocity, distance to edge, and velocity shear. The interpolation scheme used was IDW; however, the parameters were set such that very minimal interpolation was performed, resulting in a nearly linear interpolation. The limited interpolation insured that the output data were not changed significantly. Details on construction of depth, velocity, distance to edge, and velocity shear rasters are summarized in appendix E.

After the four rasters were remapped to contain SI values, a CSI raster was created, from which area of suitable habitat (ASH) was calculated. The CSI was computed as follows:

$$CSI = SI_{vel} \text{ x } SI_{dep} \text{ x } SI_{d2e} \text{ x } SI_{she}$$

where the subscripts were: *vel* = velocity, *dep* = depth, *d2e* = distance to edge, and *she* = velocity shear. In this study, CSI (and ASH) was evaluated using equal weighting. This product was then multiplied by the area represented by each cell (1 m^2) (10.76 ft^2) to calculate the ASH. ASH was analogous to WUA in the River2D model and was used to distinguish between the two models because of the differences in the way ASH and WUA are estimated. For example, WUA is based on variable cell areas determined from equilateral triangulation and ASH is based on fixed cell areas determined from a fixed rectangular mesh area (1 m^2) (10.76 ft^2). Habitat was simulated at 250, 800, and 1,500 cfs.

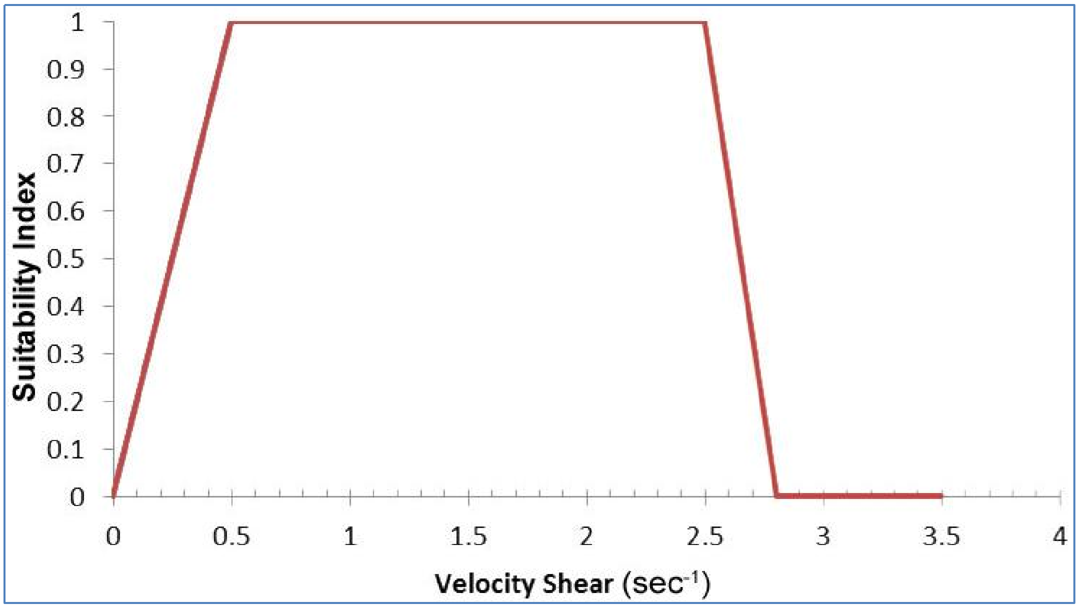

Figure 10 Theoretical shear velocity curve.

RESULTS

River2D

Reclamation's tasks were completed according to the schedule outlined in table 10, which includes measured flows. Survey dates, discharges, and mean boundary WSEL for River2D study segments in the Stanislaus River are shown in table 11. The highest flow measured by Reclamation was 1,327 cfs in Segment 2 on April 2, 2010. An additional set of WSELs was collected at 1,500 cfs at Horseshoe Recreation Area, Valley Oak Recreation Area, and McHenry Recreation Area on October 22, 2010 (table 11).

Table 10 Discharges and completion dates of tasks for Stanislaus River2D field work

Task	Segment A- Two-mile Bar	Segment 1- Horseshoe	Segment 2- Valley Oak	Segment 3- McHenry
Habitat mapping	Jun-09	Jun-09	Jun-09	Feb-11
Topography	8-Aug-09	7-Nov-09	1-Apr-10	28-Jan-10
Velocity calibration-1st flow	8-Aug-09 (287 cfs)	7-Nov-09 (265 cfs)	23-Apr-10 (1,035 cfs)	28-Jan-10 (268 cfs)
Velocity calibration-2nd flow	22-Apr-10 (991 cfs)	21-Apr-10 (1,042 cfs)	20-May-10 (863 cfs)	21-May-10 (782 cfs)
Boundary water surface elevations/ Q-low flow	4-Aug-09 (287 cfs)	7-Nov-09 (265 cfs)	14-Aug-09 (278 cfs)	25-Jan-10 (268 cfs)
Boundary water surface elevations/ Q-mid flow	19-May-10 (837 cfs)	20-May-10 (843 cfs)	21-Apr-10 (1,046 cfs)	21-May-10 (782 cfs)
Boundary water surface elevations/ Q-high flow	22-Apr-10 (1,000 cfs)	21-Apr-10 (1,042 cfs)	2-Apr-10 (1,327 cfs)	20-Apr-10 (990 cfs)

Table 11 Survey dates, discharges, and mean boundary water surface elevations for River2D study segments in the Stanislaus River

Stream segment	Survey date	Site discharge (instantaneous)		Nearest gage discharge (mean daily cfs)	Water surface elevation (mean values of left and right banks)			
					Lower boundary		Upper boundary	
		cfs		Goodwin Dam spill		ft		ft
Segment A-Two-mile Bar	4-Aug-09	287		303		249.51		249.77
	22-Apr-10	991		1,000		251.48		251.74
	19-May-10	837		824		250.95		251.15
				Orange Blossom				
Segment 1-Horseshoe	7-Nov-09	265		292		141.01		143.60
	21-Apr-10	1,042		–[1]		142.61		145.14
	20-May-10	843		863		142.12		144.71
	22-Oct-10[2]	1,500[2]		1,145		143.24		146.16
	1-Dec-10[2]	204		216		140.78		
				Orange Blossom				
Segment 2-Valley Oak	14-Aug-09	278		333		106.57		108.93
	2-Apr-10	1,327		1,332		110.34		111.82
	21-Apr-10	1,046		–[1]		108.14		111.06
	22-Oct-10[2]	1,500[2]		1,145				115.69
				Ripon				
Segment 3-McHenry	25-Jan-10	268		321		60.16		60.52
	20-Apr-10	990		1,010		63.53		63.70
	21-May-10	782		837		62.78		62.98
	22-Oct-10[2]	1,500[2]		1,110		64.71		65.11

[1] Missing data.

[2] Measured by field crew, not gage data.

Habitat Mapping

The ratios of the total area of each habitat type present in a given segment (table 12) to the area of each mesohabitat type that was modeled in that segment (table 13) are given in table 14. Lower values indicate more representation of that habitat unit in the study site relative to the segment. The ratios are used to expand WUA from the sites to the whole segment (see Methods).

Habitat Modeling

The ratios in table 14 serve as weighting factors for the mesohabitat units in each site, and also take into account mesohabitat types that were not present in a given site but were present in the segment. For example, the Bar Complex Pool at Two-mile Bar was used to represent Bar Complex Glides, Bar Complex Pools, Side Channel Glides and Side Channel Pools that were present in the Two-mile Bar segment. This enables the results from each site to be extrapolated to the entire segment based on that mesohabitat's share, plus non-modeled mesohabitat types, of the total segment area.

Flow-habitat relationships, by species, life stage, and segment are summarized in table 15. The River2D WUA values calculated for each site are contained in appendix G. Figures 11 through 14 show discharge-to-habitat relationships at each stream segment. With the exception of Two-mile Bar, useable habitat occurred between 250 and 800 cfs, depending on life stage and river segment (table 15). Useable habitat at Two-mile Bar was 1,500 cfs for all life stages of both species. The only explanation for this difference in results is that, compared to the other three stream segments, Two-mile Bar differs dramatically in terms of river morphology and hydraulics. Table S-17 summarizes WUA in the entire LSR (Two-mile Bar + Segments 1-3) from the River2D study. In general, habitat decreases slightly with discharge.

Biological Verification

The biological verification data collected by the Service resulted in too few observations to be useful for verifying the model. A total of nine YOY salmonid observations were made in the four sites. Two-thirds of the observations were at the Two-mile Bar segment.

Recreation Area site. One site (McHenry Recreation Area) did not have any YOY salmonids. Four of the observations were fall-run Chinook salmon, ranging in size from 35 to 50 mm (1.4 to 2 in) TL, and five were *O. mykiss*, ranging in size from 40 to 80 mm (1.6 to 3.1 in).

Hydraulic Model Calibration

River2D model run statistics are summarized in table S-18 for each site. All QI values were > 0.2, indicating acceptable meshes. All model runs had stable Solution Δ values (i.e., < 0.00001) but all Maximum F numbers were > 1 (table S-18). Calibration of WSELs was done at 1,000 cfs at Two-mile Bar and the highest measured discharge of 1,500 cfs at the other sites. Results showed that the maximum model predicted WSELs at the inflow end of each site were similar to measured WSELs (table S-19). The largest difference between measured and predicted WSEL was 0.2 ft on the right bank at Two-mile Bar.

Mesohabitat type	Segment A-Two-mile Bar			Segment 1-Knights Ferry			Segment 2-Orange Blossom			Segment 3-Jacob Meyers		
		Area (100 ft^2)	No. of units		Area (100 ft^2)	No. of units		Area (100 ft^2)	No. of units		Area (100 ft^2)	No. of units
Bar complex riffle (BCR)		1,459.1	17		3,843.5	18		1,752.8	6		355.1	4
Bar complex fun (BCRu)		3,346.4	23		5,043.2	25		3,009.6	13		106.5	1
Bar complex glide (BCG)		872.6	4		8,218.5	28		3,433.5	13		66,180.5	16
Bar complex pool (BCP)		5,883.6	17		9,690.5	32		1,940.0	8		6,765.9	12
Flat water riffle (FWRi)		93.6	1		2,734.1	13		2,928.9	10		1,829.2	9
Flat water run (FWRu)		81.8	1		2,907.4	14		2,727.7	9		348.6	2
Flat water glide (FWG)		0.0	0		5,207.8	15		3,088.1	9		7,387.8	16
Flat water pool (FWP)		0.0	0		4,313.7	9		13,514.6	10		4,826.9	11
Side channel riffle (SCRi)		206.6	5		239.9	5		510.0	1		0.0	0
Side channel Rrn (SCRu)		0.0	0		106.5	1		154.9	2		0.0	0
Side channel glide (SCG)		33.4	1		1,238.5	10		759.7	6		0.0	0
Side channel pool (SCP)		42.0	2		1,199.7	8		0.0	0		0.0	0
Cascade (C)		686.5	15		170.0	1		0.0	0		0.0	0
Off channel (OC)		73.2	1		529.4	5		402.4	2		8.6	1
Gravel pit (PIT)		0.0	0		3671.3	3		750.0	1		0.0	0
Total known mapped		12,777.5	87		49,114.0	187		34,972.2	90		27,472.4	72

Table 12 Lower Stanislaus River, sum of mesohabitat area for all habitat units measured in each study segment

Table 13 **Lower Stanislaus River, sum of mesohabitat area for all habitat units measured in each study site**

	Study site A-Two-mile Bar Recreation Area			Study site 1-Horseshoe Recreation Area			Segment 2-Valley Oak Recreation Area			Segment 3-McHenry Recreation Area		
Mesohabitat type		**Area (100 ft^2)**	**No. of units**		**Area (100 ft^2)**	**No. of units**		**Area (100 ft^2)**	**No. of units**		**Area (100 ft^2)**	**No. of units**
Bar complex riffle (BCR)		53.8	1		142.0	1						
Bar complex run (BCRu)		134.5	1		659.6	3		609.0	4			
Bar complex glide (BCG)					470.2	3		588.6	4		338.9	2
Bar complex pool (BCP)		320.6	1		1,151.3	2		49.5	2			
Flat water riffle (FWRi)					400.3	1		114.1	1			
Flat water run (FWRu)					361.5	1		297.0	1		173.2	1
Flat water glide (FWG)					846.8	2		800.5	2		625.2	2
Flat water pool (FWP)								346.5	2		212.0	1
Side channel riffle (SCRi)												
Side channel run (SCRu)												
Side channel glide (SCG)								165.7	2			
Side channel pool (SCP)												
Cascade (C)												
Off channel (OC)					107.6	1						
Gravel pit (PIT)												
Total known mapped		507.9	3		4,138.3	14		2,970.8	18		1,349.3	6

Mesohabitat type	Segment A-Two-mile Bar	Segment 1-Horseshoe	Segment 2-Valley Oak	Segment 3-McHenry
Bar complex riffle (BCR)	41.1	29.1	*	*
Bar complex run (BCRu)	36.4	7.7	11.9	*
Bar complex glide (BCG)	*	20.3	14.0	256.8
Bar complex pool (BCP)	25.1	16.5	111.6	*
Flat water riffle (FWRi)	*	6.9	*	99.0
Flat water run (FWRu)	*	8.1	22.1	69.7
Flat water glide (FWG)	*	6.2	9.3	54.1
Flat water pool (FWP)	*	*	96.2	250.7
Side channel riffle (SCRi)	*	*	*	*
Side channel run (SCRu)	*	*	*	*
Side channel glide (SCG)	*	*	20.6	*
Side channel pool (SCP)	*	*	*	*
Cascade (C)	*	*	*	*
Off channel (OC)	*	5.0	*	*
Gravel pit (PIT)	*	*	*	*

Table 14 Ratios of mesohabitat areas in segments to mesohabitat areas in each study site on the Stanislaus River. Entries with an asterisk indicate that the habitat type was not modeled in that segment because it represented less than 5 percent of segment length. Refer to text for description of mesohabitat type representation in the ratio

Chinook. fry				Chinook. juvenile			*O. mykiss*. fry			*O. mykiss*. juvenile		
Flow (cfs)		sq ft	% maximum		sq ft	% maximum		sq ft	% maximum		sq ft	% maximum
Segment A-Goodwin Dam to Two-mile Bar Recreation Area												
250		45,012	74.4		29,578	79.7		51,856	89.7		30,204	69.3
800		53,878	89.0		34,349	92.6		53,189	92.0		38,470	88.3
1,500		60,509	100.0		37,113	100.0		57,788	100.0		43,583	100.0
Segment 1-Knights Ferry Recreation Area to Orange Blossom Bridge												
250		195,095	100.0		86,335	71.1		166,554	100.0		96,057	82.2
800		144,327	74.0		121,510	100.0		133,842	80.4		116,817	100.0
1,500		139,210	71.4		118,466	97.5		116,197	69.8		107,219	91.8
Segment 2-Orange Blossom Bridge to Jacob Meyers Park												
250		535,376	100.0		295,532	72.2		414,417	100.0		337,523	85.5
800		378,407	70.7		409,133	100.0		375,933	90.7		394,966	100.0
1,500		291,861	54.5		358,312	87.6		284,860	68.7		313,957	79.5
Segment 3-Jacob Meyers Park to San Joaquin River												
250		666,629	100.0		455,738	84.1		671,097	100.0		610,116	100.0
800		516,114	77.4		542,044	100.0		468,044	69.7		473,012	77.5
1,500		500,261	75.0		443,823	81.9		406,112	60.5		352,851	57.8
Entire river (Segment A-Two-mile Bar + Segments 1-3)												
250		1,442,111	100.0		867,183	78.3		1,303,923	100.0		1,073,900	100.0
800		1,092,725	75.8		1,107,037	100.0		1,031,008	79.1		1,023,265	95.3
1,500		991,841	68.8		957,713	86.5		864,957	66.3		817,609	76.1

Table 15 Weighted usable area (WUA) for all life stages in the Stanislaus River using River2D modeling

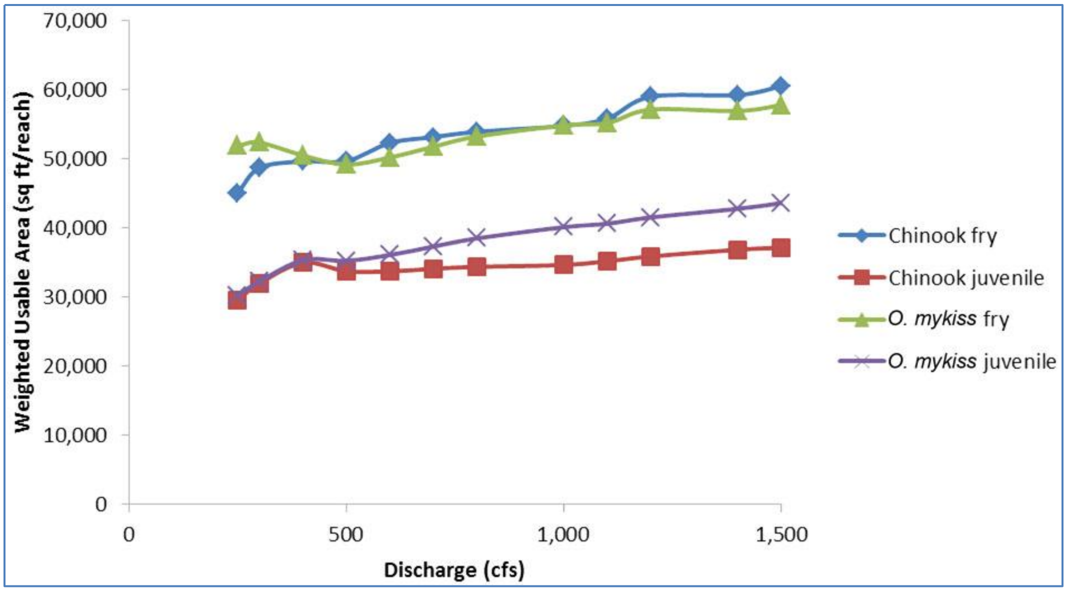

Figure 11 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment A (Goodwin Dam to Knights Ferry Recreation Area) in the Stanislaus River.

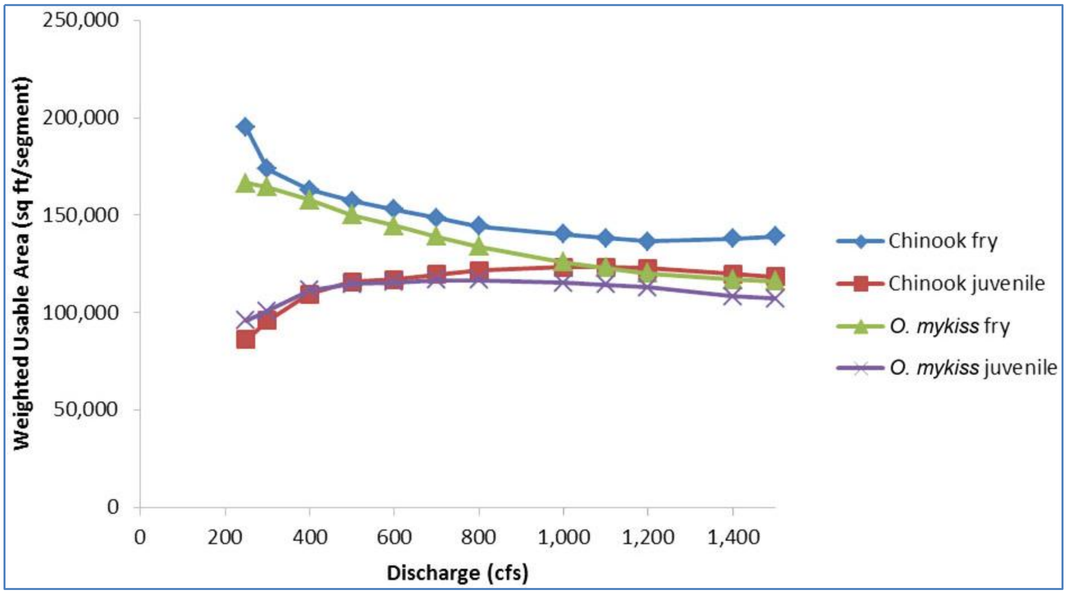

Figure 12 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 1 (Knights Ferry Recreation Area to Orange Blossom Bridge) of the Stanislaus River.

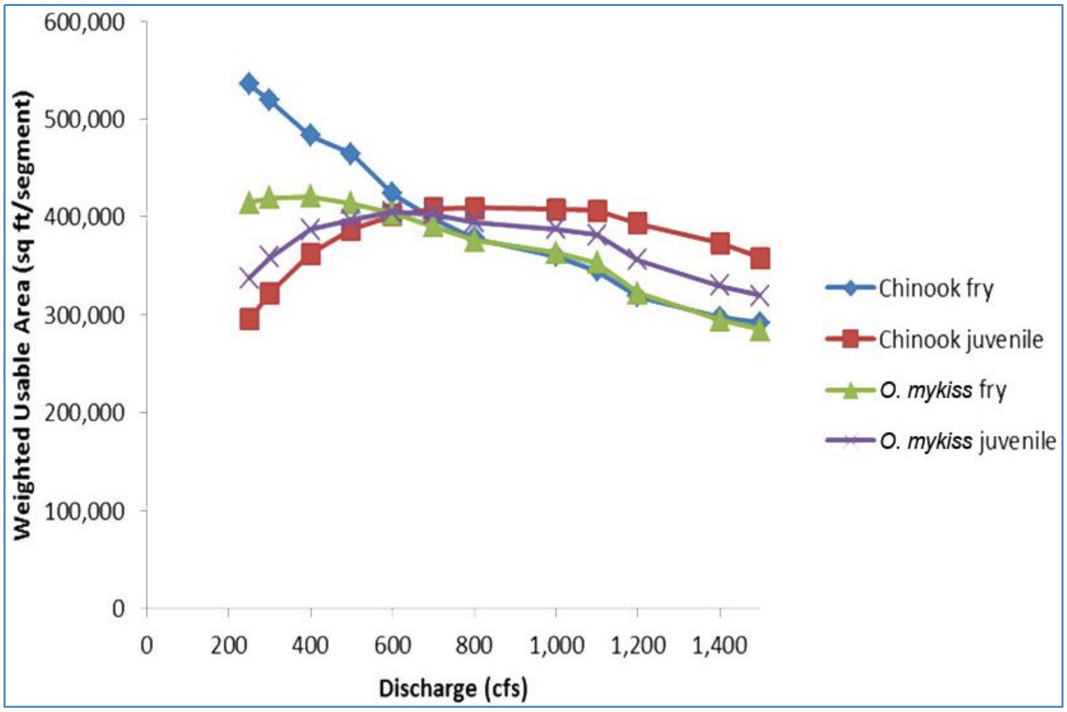

Figure 13 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 2 (Orange Blossom Bridge to Jacob Meyers Park) of the Stanislaus River.

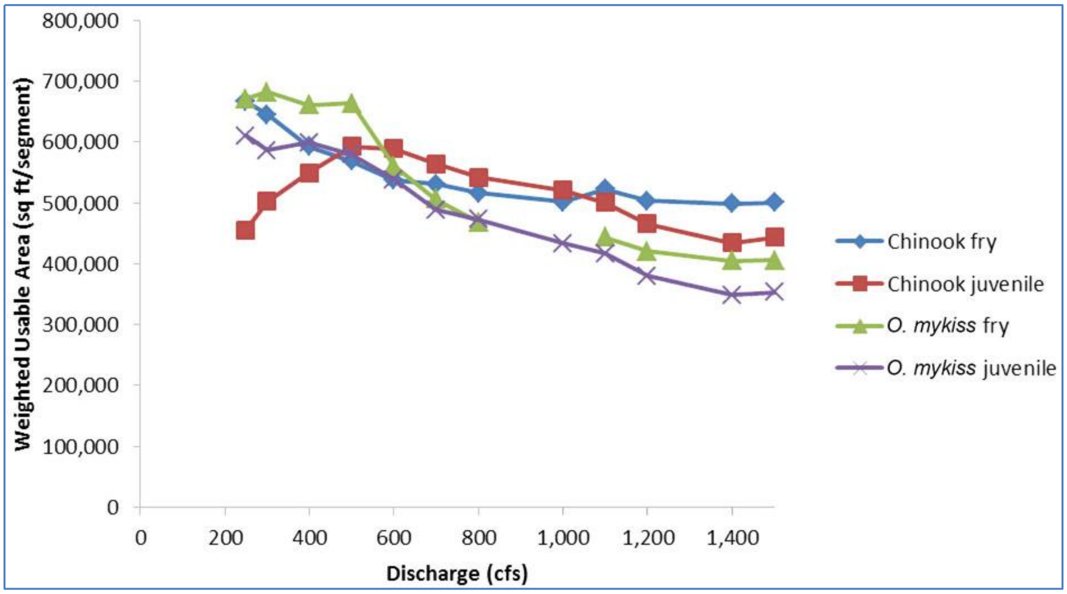

Figure 14 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 3 (Jacob Meyers Park to the San Joaquin River) of Stanislaus River.

Table 16 Summary of flow-habitat relationships for River2D study on Stanislaus River: flows (cfs) with the highest weighted usable area (WUA) for each species/life stage combination. These results are based on flows ranging form 250 to 1,500 cfs.

Species	Life stage	Segment A-Two-mile Bar	Segment 1-Knights Ferry	Segment 2-Orange Blossom	Segment 3-Jacob Meyers	Combined Segments 1-3
Chinook salmon	Fry	1,500	250	250	250	250
Chinook salmon	Juvenile	1,500	800 cfs	800 cfs	800 cfs	800 cfs
O. mykiss	Fry	1,500	250	250	250	250
O. mykiss	Juvenile	1,500	800 cfs	800 cfs	250	800 cfs

Table 17 Summary of weighted usable area (WUA) in sq ft for entire Stanislaus River (Segment A-Two-mile Bar + Segments 1-3) from River2D model

Flows (cfs)	Chinook fry	Chinook juvenile	*O. mykiss* fry	*O. mykiss* juvenile
250	1,442,111	867,183	1,303,923	1,073,900
800	1,092,725	1,107,037	1,031,008	1,023,265
1,500	991,841	957,713	864,957	817,609
% difference between high and low WUA	31	22	34	24

Table 18 River2D model run statistics for each Recreation Area study site

Site name	Cal Q in cfs	Nodes	Quality index (QI)	Solution Δ	Maximum Froude (F)
Two-mile Bar	1,000	16,045	0.3	2×10^{-11}	4.65
Horseshoe	1,500	131,161	0.3	3×10^{-6}	12.28
Valley Oak	1,500	139,809	0.3	3×10^{-6}	1.32
McHenry	1,500	53,699	0.3	7×10^{-6}	2.15

Table 19 River2D measured and predicted water surface elevation comparisons

Site name	Upstream cross section (boundary)	Bed roughness (BR) multiplier	Measured water surface	Maximum predicted water surface	Difference
			ft	ft	ft
Two-mile Bar	Left bank	0.3	251.9	251.8	0.07
	Right bank	0.3	251.6	251.8	0.20
Horseshoe	Entire	1.0	146.2	146.3	0.10
Valley Oak	Entire	1.4	115.7	115.7	0.03
McHenry	Entire	2.0	65.1	65.2	0.07

GIS

LiDAR, Photogrammetry, and Bathymetry

Lidar, photogrammetry, and bathymetry results from the GIS spatially explicit study on the LSR are described in appendix E. Methodologies are also covered in this appendix.

Hydraulic Model Validation

The results of the GIS predicted versus measured WSEL comparisons are summarized in appendix E. Water surface elevation comparisons were made at, or close to, discharges used to evaluate habitat (250, 800, and 1,500 cfs). One exception was the JM reach, where comparisons were only made at 250 and 800 cfs, which correlated with Reclamation field surveys. The project was dependent on the EDS survey for measurements above 989 cfs, and discharges greater than this did not occur during the EDS survey of the JM reach. Discharges of 989 cfs are infrequent on the LSR. Water surface elevation comparisons were made over several kilometers (miles) of the reach. It should not be assumed that a small number of samples indicates a short comparison reach.

The results of the velocity comparison are summarized in appendix E.
Good agreement between measured and modeled depth averaged velocity was achieved throughout the LSR. Velocity measurements were collected during the Reclamation surveys in all reaches at discharges approximately equal 247 and 741 cfs. Velocity measurements were made using an ADCP (see Bathymetry data collection) and were post-processed using AdMap to obtain depth average velocity and horizontal position. These data were imported to Arc GIS for comparison to model results.

Habitat Modeling

Flow-habitat relationships, by species, life stage and segment from the GIS modeling are summarized in table S16. For all life stages and in each river segment of the Stanislaus River, ASH increased slightly with flow (figures 15 through 17). This resulted in maximum habitat occurring at 1,500 cfs for all life stages and river segments (table S-17). One possible explanation for the slight increase in ASH is that minimal off-channel habitat was created as flows increased from 250 to 1,500 cfs. The rare exception to this was at 1,500 cfs, in the KF segment, for example near Honolulu Bar downstream of Horseshoe Recreation Area.

Biological Verification

The initial intent for Reclamation's habitat modeling effort was related to a numerical identification of mesohabitat types, divided into polygons based on velocity and the presence of cover or water's edge. Polygons were mapped in the field using measurements of velocity and depth to identify polygons that fit into specific mesohabitat categories (Stanuslaus River Habitat Use Pilot Investigation, ca. 2008, prepared by the Fishery Foundation for Reclamation). Polygons were mapped at five locations throughout the Stanislaus River, with sites ranging in size from approximately 2,000 to 2,500 feet of channel length. Observations were made over the range of 250 – 1317 cfs (table S-20). Fish surveys were processed in such a way as to provide fish densities for each species and age class using the area of the habitat polygon measured in the field. The numerical modeling would have similarly identified said habitat polygons for the entire river, using the field data to verify the numerical identification of polygons and provide a means for biological verification. However, as previously stated, Recalmation performed a habitat analysis very similar to the methodology of River 2D, which provides a CSI value in each 3.3 x 3.3 foot cell of wetted channel.

The way in which the habitat modeling took place using the GIS spatially explicit model made it difficult to perform a quantitative analysis of model performance based on fish data collected in the manner explained above. A qualitative analysis was performed whereby polygons that were identified in the field to contain densities specific to species and age class of fish were laid over modeled predictions of habitat. This analysis indicated good agreement, based on the coincident spatial location of populated polygons and the prediction of suitable habitat by the model. The results of this qualitative validation are contained in Appendix I.

Table 20 Table showing locations, discharges, and the number of fish observations for the data collected by Fishery Foundation in 2008. The number of fish represented in this graph are combined counts of fry and juvenile Chinook and *O. mykiss*.

Location/Site	Discharge (cfs)	Number of Observations
Two Mile Bar*	500	1,527
	750	3,121
Knights Ferry	250†	1,049
	1,050	4,175
Lover's Leap	500	723
	800†	1,405
Orange Blossom Br.	420	73
	1,317†	27
McHenry	250†	37
	853†	15
* Not modeled for habitat		
† Discharges used for comparison of observed and predicted habitat.		

DISCUSSION

The River2D and the GIS spatially explicit models were were used to predict habitat for flows ranging from 250 to 1,500 cfs. It should be noted that flow releases from Goodwin Dam on the Stanislaus River ranged from 198 to 1,504 cfs during the period of field surveying (figure 18). This indicates a relatively dry period.

The habitat model results are subject to errors in model prediction, WSEL measurement, and discharge measurement. During the modeling and analysis of all the data, it appeared that the accurate measurement of discharge represented the greatest amount of uncertainty. Unsteady flows during surveys, disparity among gage readings, and difficulty in some field measurements due to aquatic vegetation were primary causes for this uncertainty.

Accuracy of riverine fish habitat modeling for small fish in general is limited by the scale and resolution of hydraulic models relative to the biological needs of the fish. An important aspect of using 2D models for habitat studies is for biologists and flow modelers to jointly determine the spatial flow patterns, resolution, and accuracy needed to achieve project goals (Crowder and Diplas, 2000). Biologists are interested in scales relevant to fish, while flow modelers are interested in scales relevant to 2D flow patterns and what can be properly represented based on survey density and channel conditions while considering run time. These scales are occasionally at odds with each other, particularly when the habitat involves small fish. For example, juvenile habitat modeling based on a 1 sq m (10.8 sq ft) cell area may be more realistic biologically than fry habitat modeling. Juvenile chinook make larger foraging forays than fry: observations of fish behavior on the Stanislaus River suggest that juvenile Chinook salmon make foraging forays up to 1m (3.3 ft) and that fry do not move this far to feed (M. Bowen, personal observations). Considering the focal velocity of a salmonid fry, the scale of interest to biologists may be six body lengths, perhaps 0.25 m (0.8 ft). On the other hand, considering attainable survey resolutions and the ability to resolve 2D hydraulic features, a 1 m (3.3 ft) scale is perhaps the best resolution one can expect from a numerical model (Pasternack et al., 2006) that is being evaluated over perhaps 62.1 miles. Thus, although modeling fish habitat in general is a gross approximation of reality, we have more confidence in the results from the juvenile habitat modeling than the fry modeling simply because the larger the fish, the more appropriate it is to apply the scale of the hydraulic models.

One initial shortcoming of this study was the use of the Yuba River HSCs in the Stanislaus River without conducting a transferability or biovalidation test. The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek). Site-specific fish observations on the Stanislaus River would be needed to validate the transferability of these HSCs. Unfortunately, too few fry and juvenile observations could be obtained during this study to apply a validation test. The only other available HSC data for the Stanislaus River are for fry and juvenile fall-run Chinook salmon from the Aceituno study (1990). Figures 19 and 20 compare the fry and juvenile depth and velocity HSC for Chinook salmon from the Yuba River (Service 2010a) and the Stanislaus River (Aceituno 1990). These comparisons show some general similarities (e.g., juvenile velocities < 0.8 m/sec [(2.6 ft/sec]). Velocities <0.8 m/sec (2.6 ft/sec) would typically be found in the Stanislaus River within the range of flows modeled in this study (250 to 1,500 cfs).

The use of the Yuba River HSCs (appendix D) in the Stanislaus River has uncertainties. The GIS methodology in appendix E was criticized in an early review for using the Yuba River HSCs in the Stanislaus River because (1) 3 of the 4 juvenile curves failed bioverification tests, (2) ~40% of the 2D models used to make them failed the 2D model validation tests, and (3) geomorphic conditions on the Yuba River are different than those on the Stanislaus (Greg Pasternack, University of California at Davis, personal communication). The Service addressed the first two issues above in Service (2010b). Specifically, the failure of the bioverification tests was due to a combination of small sample sizes and errors in hydraulic modeling. In addition, the 2D models were not used as inputs to the HSCs. The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek). The Aceituno (1990) criteria were not appropriate to use because flow-habitat relationships based on them would be biased towards low flows because Aceituno (1990) did not use logistic regression, cover, and adjacent velocity.

Chinook fry				**Chinook juvenile**			***O. mykiss* fry**			***O. mykiss* juvenile**		
Flow (cfs)		**sq ft**	**% maximum**		**sq ft**	**% maximum**		**sq ft**	**% maximum**		**sq ft**	**% maximum**
Segment 1-Knights Ferry Recreation Area to Orange Blossom Bridge												
250		48,779	50		37,247	29		79,093	49		81,278	48
800		78,304	81		83,332	65		131,395	81		136,492	81
1,500		97,002	100		128,926	100		162,824	100		168,175	100
Segment 2-Orange Blossom Bridge to Jacob Meyers Park												
250		130,836	85		100,631	47		215,075	92		218,536	93
800		145,011	94		139,387	65		231,380	99		234,959	100
1,500		154,591	100		214,886	100		232,878	100		235,917	100
Segment 3-Jacob Meyers Park to San Joaquin River												
250		196,083	60		127,986	29		273,512	57		273,711	56
800		319,175	98		267,608	61		462,361	96		462,654	95
1,500		325,590	100		439,620	100		484,000	100		484,624	100
Entire river (Segments 1-3)												
250		375,698	65		265,864	34		567,680	65		573,525	65
800		542,490	94		490,327	63		825,136	94		834,105	94
1,500		577,183	100		783,432	100		879,702	100		888,716	100

Table 21 **Area of suitable habitat (ASH) for all life stages in the Stanislaus River using GIS modeling**

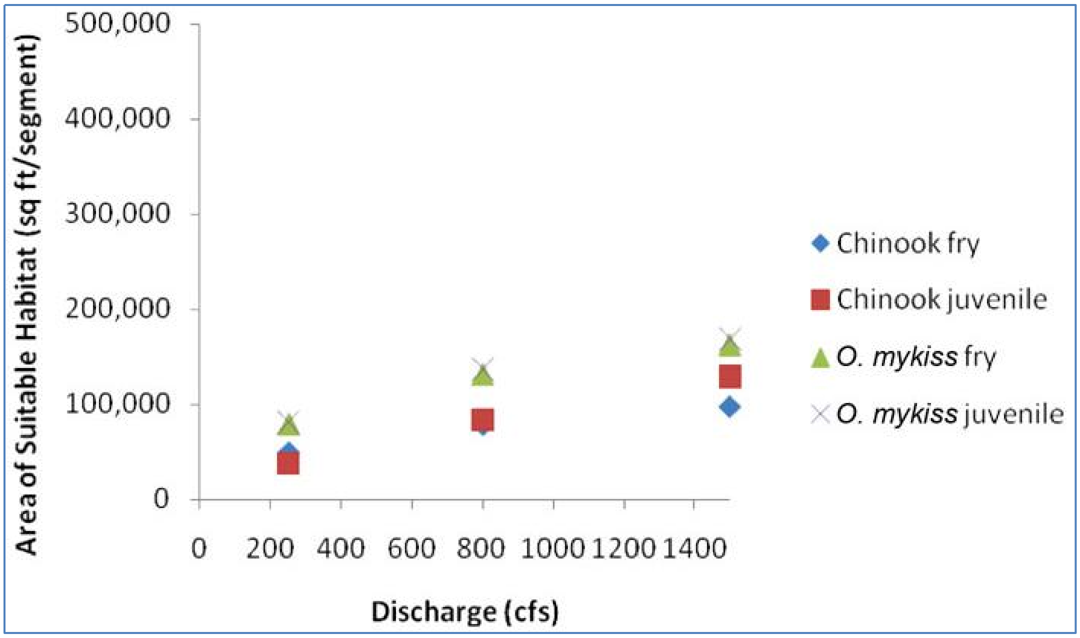

Figure 15 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 1 (Knights Ferry Recreation Area to Orange Blossom Bridge) in the Stanislaus River.

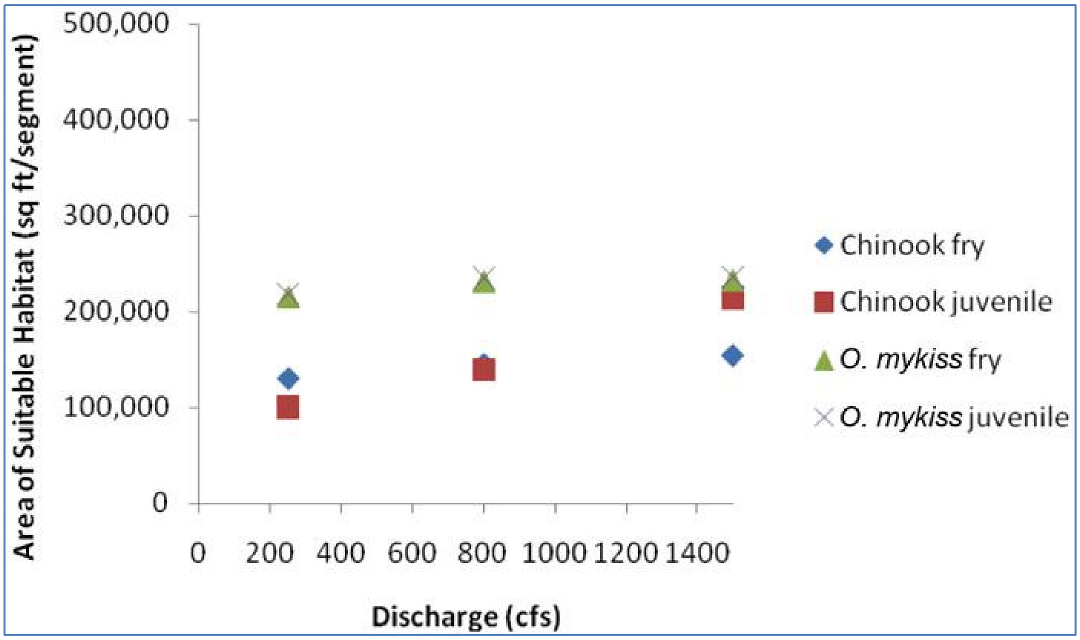

Figure 16 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 2 (Orange Blossom Bridge to Jacob Myers Park) in the Stanislaus River.

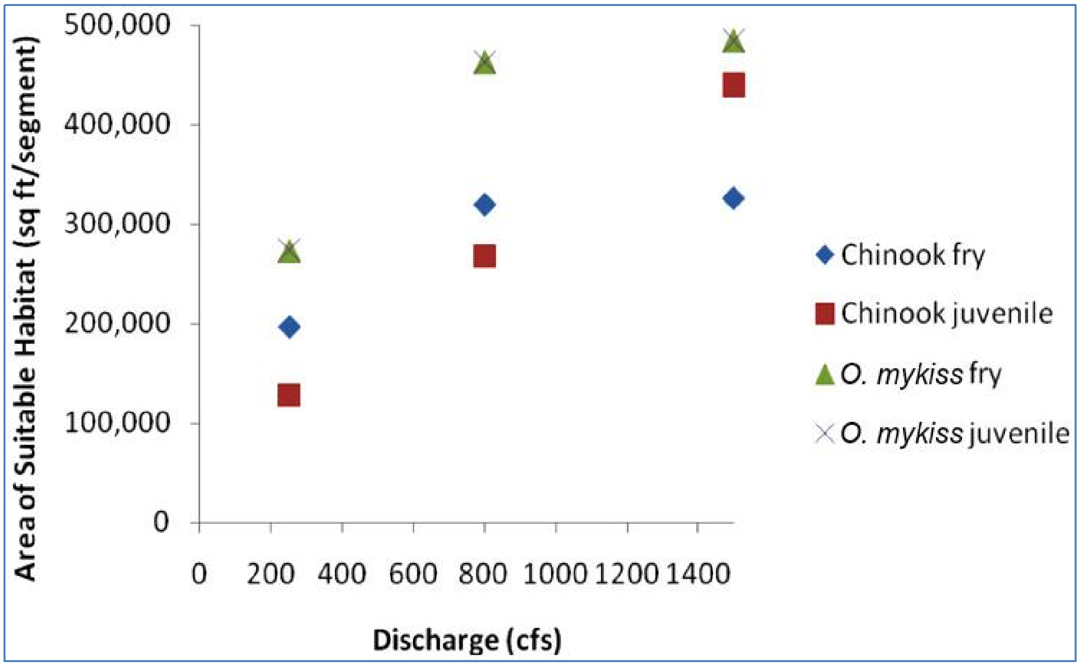

Figure 17 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 3 (Jacob Myers Park to confluence with the San Joaquin River) in the Stanislaus River.

Table 22 Summary of flow-habitat relationships for GIS spatially explicit model on the Stanislaus River: flows (cfs) with the highest area of suitable habitat (ASH). These results are based on three modeled flows: 250, 800, and 1,500 cfs.

Species	Life stage	Segment 1- Knights Ferry	Segment 2- Orange Blossom	Segment 3- Jacob Meyers	Combined Segments 1-3
Chinook salmon	Fry	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
Chinook salmon	Juvenile	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
O. mykiss	Fry	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs
O. mykiss	Juvenile	1,500 cfs	1,500 cfs	1,500 cfs	1,500 cfs

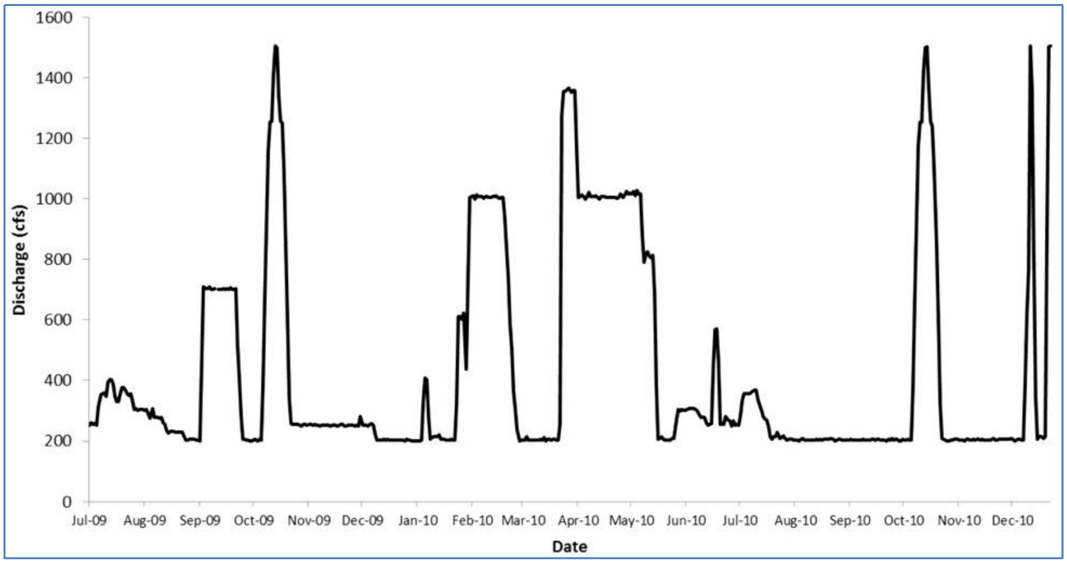

Figure 18 Goodwin Dam flow releases into Stanislaus River during field surveys. These continuous discharge data were obtained from the Goodwin Dam gage (Reclamation Gage (GDW).

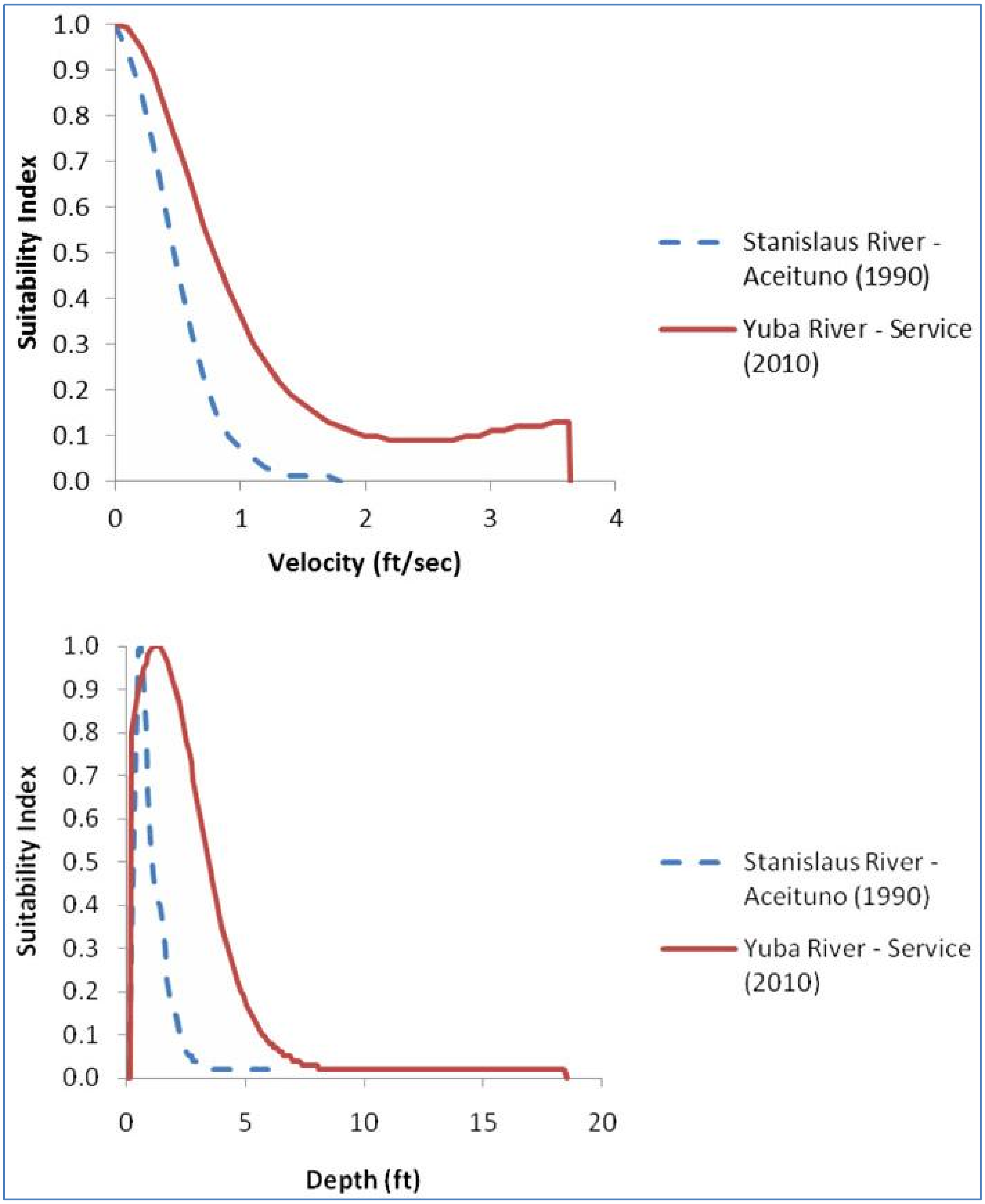

Figure 19 Comparison of fry Chinook salmon velocity (top) and depth (bottom) and habitat suitability criteria from two separate studies.

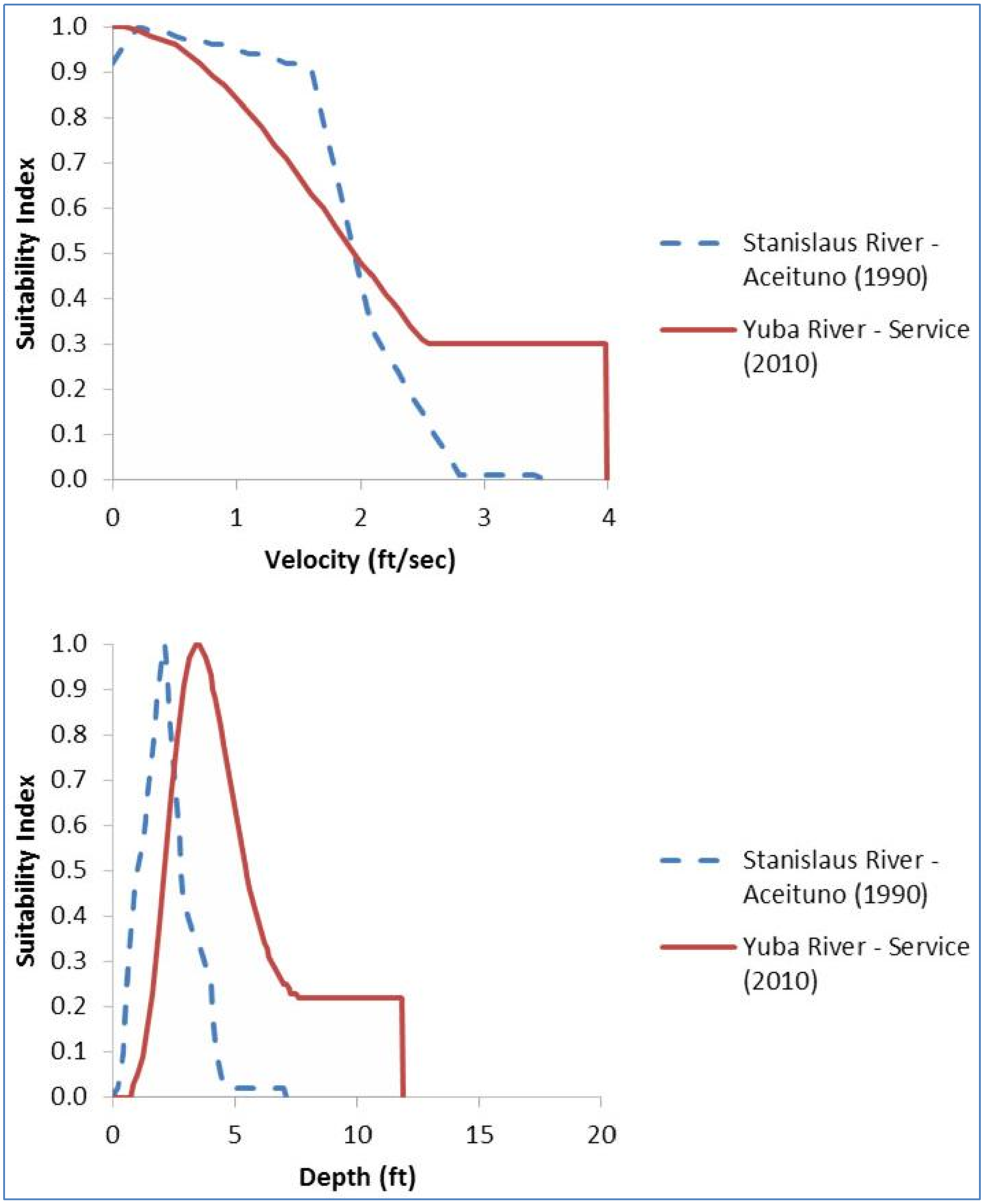

Figure 20 Comparison of juvenile Chinook salmon velocity (top) and depth (bottom) and habitat suitability criteria from two separate studies.

More detailed discussion on the development of HSCs using logistic regression is available from the Service (2010a). In Service (2010a) transferability tests were applied to justify using the Sacramento River HSCs for juvenile velocity. Biovalidation of the use of the Sacramento River HSCs on the Merced River was successful (Gard 2006), suggesting that geomorphic differences between the Yuba and Stanislaus Rivers may not be a problem for application of the Yuba HSCs to the Stanislaus River.

River2D

The River2D-predicted LSR discharge-habitat relationship was determined by channel morphology, the range of discharges studied, and habitat suitability curves, and produced two important results:

1. The combination of the velocity and adjacent velocity habitat suitability criteria (HSC) in the River2D model generally limited fry and juvenile habitat to a band along the channel margins. This band of habitat moved up the banks with increasing flows, resulting in fry and juvenile WUA changes (table 21). The channel morphology in the Stanislaus River is such that increased discharges did not greatly increase wetted area when comparing the range of discharges evaluated for this within-the-banks study (table 23). The lack of significantly increasing the wetted area with increasing discharge created a condition whereby habitat for all life stages changed slightly with increasing discharge.

2. At flows between 250 cfs and 1,500 cfs, the Stanislaus River exhibits minimal increasing wetted area due to steep banks (table 21). At 1,500 cfs, the water was largely, if not completely, contained within the banks. The fact that wetted area increased slightly when flows increase from 250 to 1,500 cfs produced slightly more available space. However, that small increase in available space was counteracted by a decrease in habitat quality due to increasing velocity and depth. Habitat suitability curves used for this study indicate that the optimum velocity for Chinook salmon and *O. mykiss* fry and juveniles is zero (appendix D). As discharge increases in a narrowly confined channel such as the Stanislaus River, increases in velocity are more pronounced, and thus quickly move away from the optimal velocities indicated by the HSCs. Therefore, increasing discharge produced more wetted area, but the habitat quality declined over the same range of discharges. A similar scenario existed for the depth criterion. Optimum depths for Chinook salmon and *O. mykiss*, both fry and juvenile, as indicated by the HSCs, are ≤ 1 m. As discharge increases, there are only small increases in wetted width and these small increases are outweighed by habitat quality deterioration. Therefore, as discharge increases River2D predicts that WUA will decrease slightly.

Reach	Increase in wetted area
Knights Ferry (KF)	38%
Orange Blossom (OB)	31%
Jacob Meyers (JM)	30%
Ripon (RP)	25%

Table 23 Based on the GIS model, changes in wetted area for Stanislaus River from 250 cfs to 1,500 cfs

GIS

The GIS-predicted LSR discharge-habitat relationship was driven by the same factors that determined the River2D results: channel morphology, the range of discharges studied, and habitat suitability curves.

The channel morphology of the Stanislaus River caused limited increases in wetted area when discharge increased from 250 to 1,500 cfs. The small increases in wetted area with increasing discharge created a condition where habitat for all species and life stages evaluated in this project increased slightly. As opposed to River2D, the GIS model predicted a slight increase in area of suitable habitat (ASH) over the range of discharges studied, 250 to 1,500 cfs. This increase in ASH occurred because the increase in wetted area was enhanced by GIS-predicted habitat quality improvement. The habitat quality improvement may be due to how the GIS utilized the distance to edge parameter. To understand how distance to edge functioned, it is compared to the River2D cover parameter in the next section.

Comparison of River2D and GIS Results

Total habitat is compared between River2D and the GIS study in the entire lower Stanislaus River (Segments 1-3) in table S-24 and figures 21 and 22. The most interesting aspect of this comparison is the general trend of decreasing habitat with flow for the River2D model and increasing habitat with flow for the GIS study leading to a convergence of predicted habitat at 1,500 cfs. The differences between the River2D and GIS results can be explained by the differences in methods between the two studies (table S-1) and how Cover (River2D) and Distance to Edge (GIS) are used differently. For both models

Flows (cfs)	Total WUA (ft^2)	% maximum	Total ASH (ft^2)	% maximum
Chinook fry				
250	1,397,099	100.0	375,698	65.1
800	1,038,847	74.4	542,490	94.0
1,500	931,332.5	66.7	577,183	100.0
Chinook juvenile				
250	837,605.6	78.1	265,864.3	33.9
800	1,072,688	100.0	490,327.3	62.6
1,500	920,600.8	85.8	783,431.8	100.0
***O. mykiss* fry**				
250	1,252,068	100.0	567,680	64.5
800	977,818.4	78.1	825,135.5	93.8
1,500	807,169.1	64.5	879,702.1	100.0
***O. mykiss* juvenile**				
250	1,043,696	100.0	573,525.9	64.5
800	984,795.3	94.4	834,105.1	93.9
1,500	774,026.4	74.2	888,715.8	100.0

Table 24 Total habitat in Stanislaus River (Segments 1+2+3) for River2D (weighted usable area [WUA]) and GIS (area of suitable habitat [ASH])

there were differences in predicted habitat related to flow (figures 23 and 24), and within the range of flow studied, no threshold value was predicted by either method.

Cover (River 2D) and distance to edge (GIS) are dealth with differently. In River2D, cover is coded by each habitat type (table S-5) and each has its own suitability (appendix D). In River2D, two parameters that have a high suitability index are fine woody vegetation with overhanging cover and overhung banks. Also in River2D, cobble is a commonly observed cover type and has a suitability index of 0.25. If the proportion of these three parameters goes down relative to other cover types as discharge increases, then the amount of River2D-predicted habitat would decrease. Comparatively, the GIS model predicts cover based on distance to edge. As the discharge increases, the number of GIS-model cells that are within 6.6 ft of an edge would

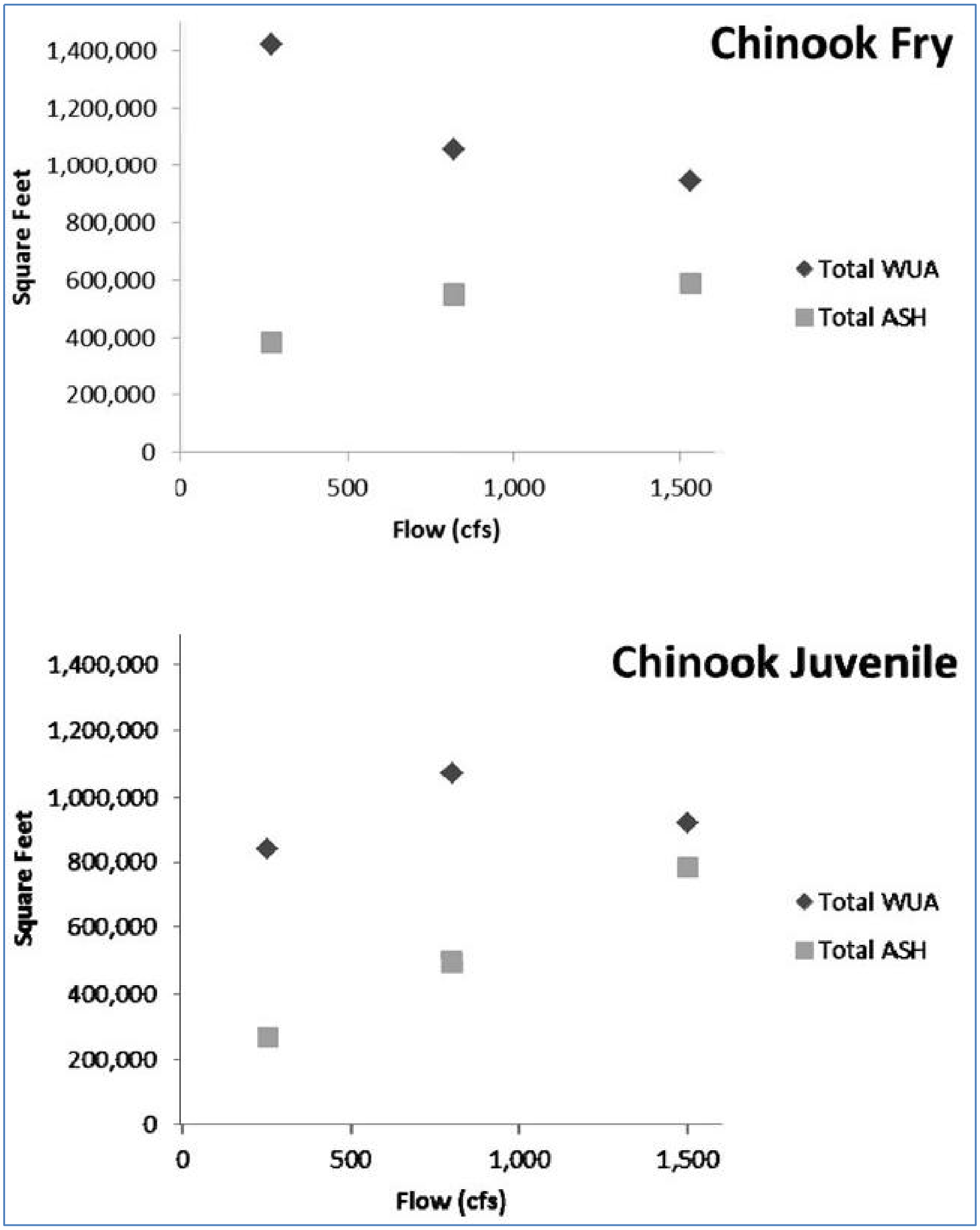

Figure 21 Comparison of Chinook salmon habitat modeling results for the entire lower Stanislaus River (Segments 1-3) between River2D (weighted usable area [WUA]) and GIS (area of suitable habitat [ASH]).

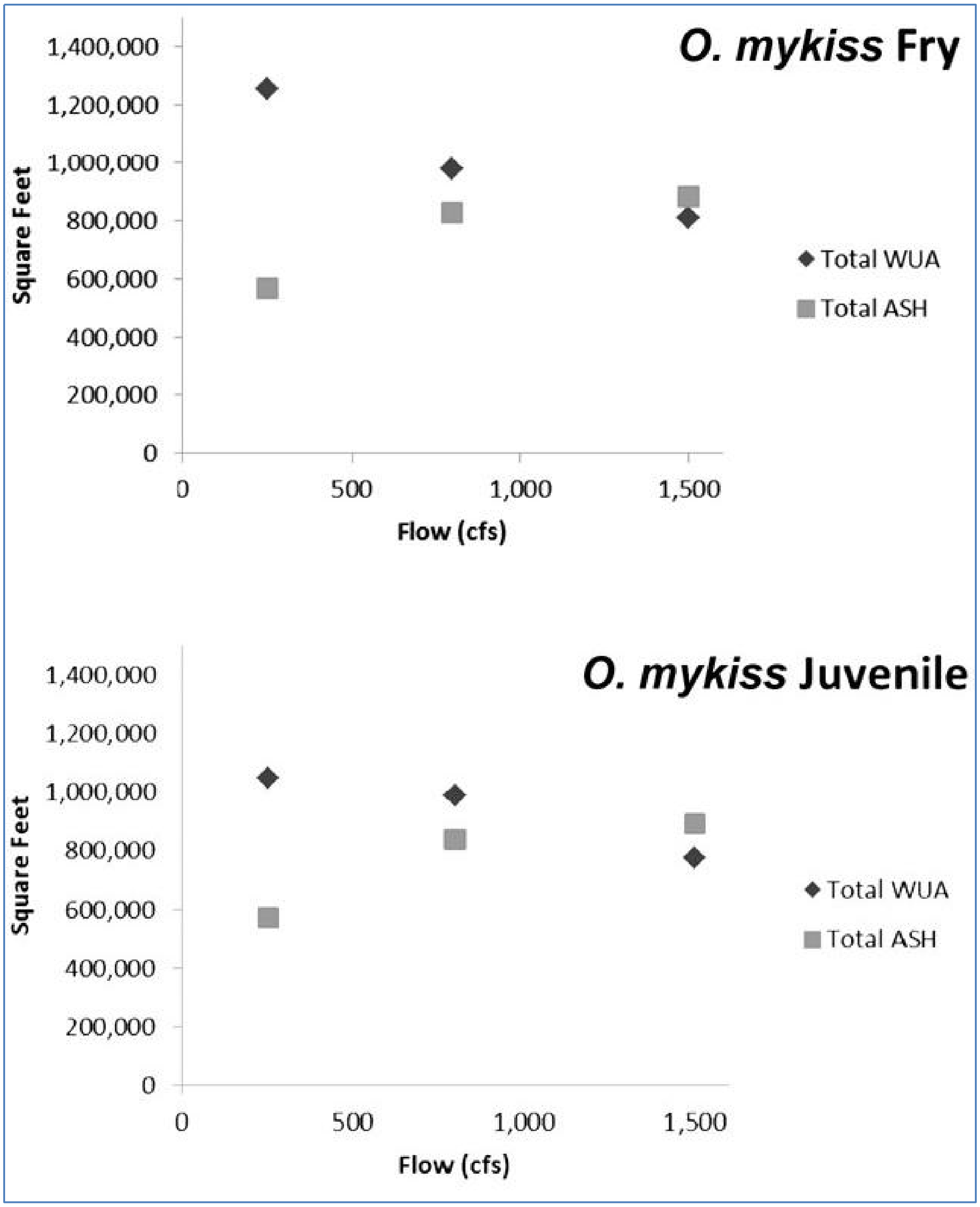

Figure 22 Comparison of *O. mykiss* habitat modeling results for the entire Stanislaus River (Segments 1-3) between River2D (weighted usable area [WUA]) and GIS (area of suitable habitat [ASH]).

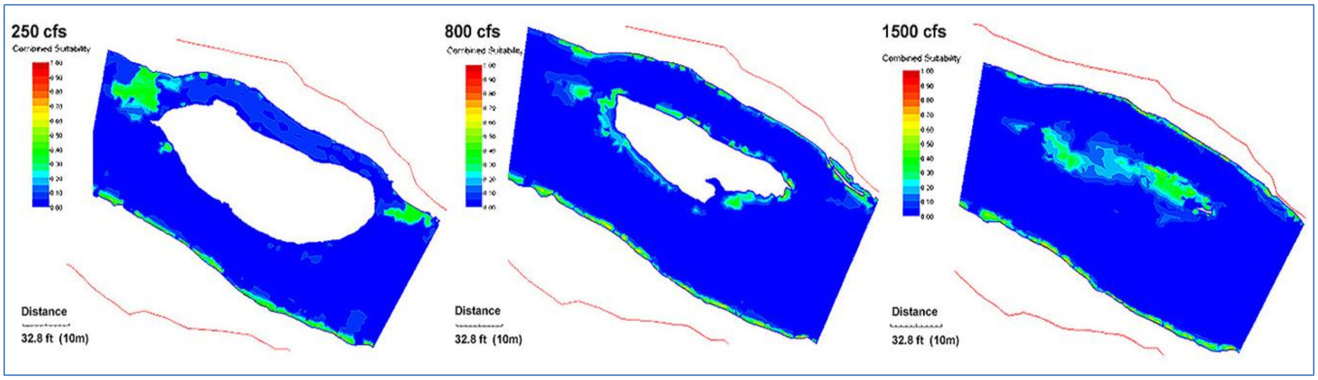

Figure 23 Contour plots of composite suitability index (CSI) results from River2D model for fall Chinook salmon fry at the upper island of the Valley Oak Recreation Area River2D study site at three discharges.

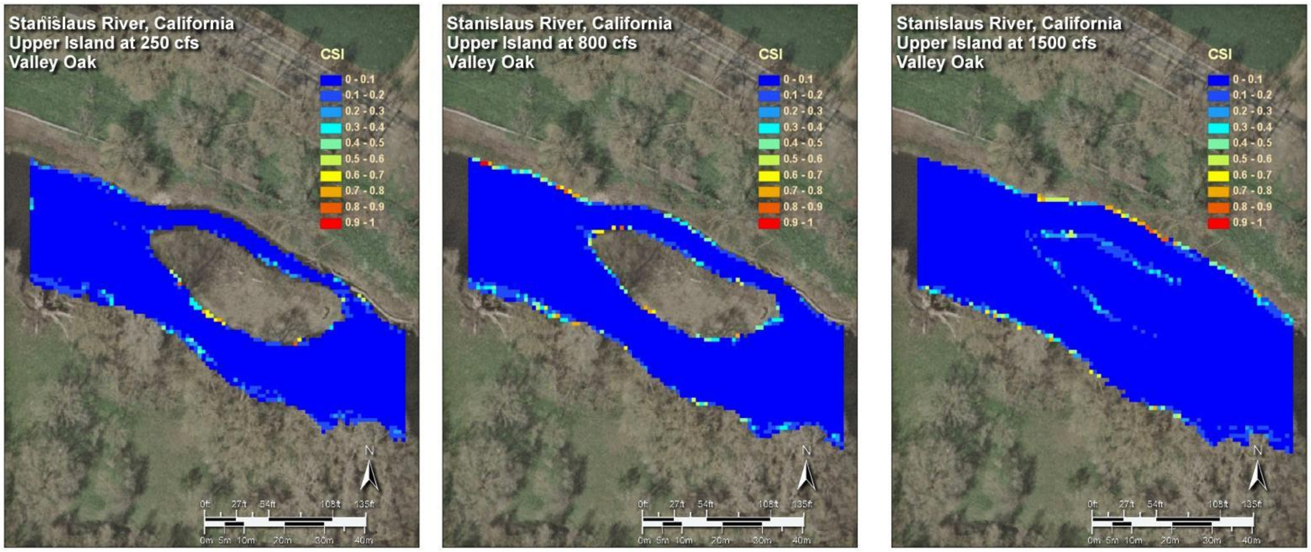

Figure 24 Maps of composite suitability index (CSI) results from GIS model for fall Chinook salmon fry at the upper island of the Valley Oak Recreation Area River2D study site at three discharges. Note: Chinook fry area of suitable habitat was 958 sq ft (at 250 cfs), 1,033 sq ft (at 800 cfs), and 1,184 sq ft (at 1,500 cfs).

increase as indicated by CSI in figure 24, and the number of cells that are greater than 6.6 ft distant from an edge (SI = 0.6) would increase, and the GIS model considers those usable. As a result, the GIS model predicts increasing amounts of habitat with increasing discharge.

Other factors than those we studied may influence the amount or quality of rearing habitat and these factors include temperature, toxicity, and water diversions. For example, temperature could, in certain parts of the area we studied, limit salmonid rearing. Reclamation (2008) provided data that showed that in dry years, temperature may regularly exceed 65°F at the Stanislaus gauge near Ripon, CA. Thus, rearing habit may be limited at this temperature for *O. mykiss* (NMFS, 2009) in the lower portion of the Jacob Meyers Park – Confluence with the San Joaquin River segment of the LSR. Thus, other factors than just discharge should be considered when determining a flow prescription for the lower Stanislaus River.

In conclusion, the two methodologies have differing results. The River 2D model predicts decreasing habitat area with discharge increase. The GIS model predicts increasing habitat area with discharge increase.

Several shortcomings in design have been identified in the document that leave the results hard to interpret. First, the remotely sensed modeling effort (GIS) may have predicted habitat at a scale greater than that at which salmonid fry respond to their environment. Second, the HSCs from the Yuba River may not apply well here because of differences in the Yuba River and the Stanislaus River. Third, the GIS-model was based on theoretical HSCs for Distance to Edge and Velocity Shear.

In an attempt to determine the cause of these differences, sensitivity analyses were run for Sacramento River and Clear Creek HSCs in both models just for the footprint of River 2D sites, and fish observations were analyzed for Scale-up bioverification. These results were also difficult to interpret (appendix I).

Next Steps

An important next step is to determine what is causing the differences in results. Recommendations to explore what is producing the different results include:

- Sensitivity analyses should be conducted that examine various HSCs with both models, including the Yuba River HSCs, the Acetiuno Stanislaus HSCs, and HSCs from other Central Valley streams.
- Reconcile the influence of parameter selection in model performance, specifically the differences between the distance-to-edge (GIS) and cover (River 2D) parameters.
- A step toward increased confidence in these results could result from exploring bioverification and validation tests further. This could potentially include a sensitivity test between the Yuba River (Service 2010a) and

Aceituno (1990) curves.

- Explore the relationship between discharge and wetted area further with River2D. It is possible to determine wetted area for each study segment at all discharges modeled by River2D. A more complete description of wetted area would show if a threshold exists within the discharge range studied, 250 to 1,500 cfs.
- Site-specific observations of Chinook salmon and *O. mykiss* would be useful for the development of habitat suitability curves (HSCs) specific to the Stanislaus River. Salmonids in the Stanislaus River might prefer habitat that exhibit velocities higher than 0 ft/s as the Yuba River HSCs do. For example, Allen and Hassler (1986) found that Chinook salmon juveniles prefer 0.20 ft/sec – 0.79 ft/sec. Site specific HSCs could potentially produce different results than those reported here.
- Model flows from 1,500 cfs to 5,000 cfs with River2D. River2D model results summarized in this report showed little off-channel habitat was created up to and including 1,500 cfs. Since the maximum flow modeled, 1,500 cfs, seldom, or never, overtopped banks throughout the study area, it seems clear that some flow greater than 1,500 cfs would overtop banks and create considerable habitat.

Water temperature was not included in the analysis of usable habitat. The results may show suitable habitat appearing down to the mouth but it is warm there in the summer and would not be suitable. Over-summer rearing habitat for steelhead is limited by temperature to roughly the area upstream of the Highway 120 bridge in most years. Habitat-based summer flow recommendations should be focused on the results from sections of the river with temperatures suitable for steelhead. This would require a much larger level of effort that would include more complicated assumptions to be formulated as model inputs than are presented in this study.

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Appendix A

“Mesohabitat Types” Field Notes from Mark Bowen,
March 31, 2009

MESOHABITAT TYPES

Mark Gard has provided 13 defined mesohabitats: bar complex riffle; bar complex run; bar complex glide; bar complex pool; flat water riffle; flat water run; flat water glide; flat water pool; side channel riffle; side channel run; side channel glide; side channel pool; and cascade. We (Gard, Bowen, and Maisonneuve) today, March 31, 2009, added two more for the Stanislaus River2D modeling: off-channel and gravel pit. They are defined:

> *Off-channel* – A small habitat unit, not part of the main channel, and it is not usually mapped, e.g. small backwaters.
>
> *Gravel pit* – Any old gravel pit filled in with water, usually there is no velocity in the habitat unit and it can be connected to the main stream by a channel. This connecting channel would be considered "off channel" as is the gravel pit. An example of this occurs at the downstream end of McHenry Recreation Area opposite from the Recreation Area beach. Another example is Willms Pond. Willms Pond is a gravel pit but is not "off-channel," so gravel pits can fall into either category. Gravel pits make up less than 5 percent of the total area of habitat.

BAR COMPLEX VS. FLAT WATER

If we consider a cross section of the river, the bar complex (figure A-1) and flat water (figure A-2) types are defined by different channel shapes.

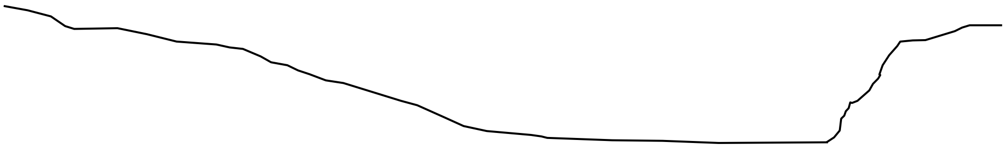

Figure A-1.—A freehand drawing of an example of a bar complex cross-section. The river is deeper on one side of the river. Generally this deeper side is on the side of the bend, and the opposite side from the bar.

The other common type is that of flat water, which has a consistent depth across the channel. We would find this form more often in the downstream (DS) low gradient section.

Figure A-2.—A freehand drawing of an example of a flat water cross-section. The river is roughly symmetrical. Generally this type will occur when the river is straighter and there is less meandering.

The third type is the side channel. It is roughly parallel to the main channel and the side channel carries less than or equal to 20 percent of the total flow of the river.

All three of these habitat types include four mesohabitats: pool, riffle, run, and glide.

The four mesohabitats (pool, riffle, run, and glide) are defined by the gradient, channel shape, and substrate distribution. Each mesohabitat type has to be longer than half of a channel width in order to be considered.

The pool has the lowest gradient of all four mesohabitats. The pool is characterized by a hydraulic control at its downstream end. The upstream margin of the pool lies on a line containing the same absolute bed elevation as the downstream margin. Hence, if the flow from upstream is stopped, the pool would still hold water. Typically, pools have a concave channel, uniform primarily fine substrate and a tranquil water surface.

The riffle has the highest gradient of all four mesohabitats. For a given river, it is shallower than the other types of mesohabitats and with higher water velocity due to its gradient. The run and the glide are characterized by intermediary gradients between the riffle and the pool, with the run having a higher gradient than the glide. The glide usually has fine sediment at the bottom. The glide is also characterized by a glassy water surface. Runs are moderately turbulent, with a disturbed water surface and a mix of substrate sizes (gravel, cobble, and some boulder).

The cross section of a channel can have more than one mesohabitat type as long as the length of these habitats is more than half of the channel.

Appendix B

Photos of River2D Study Sites in the Stanislaus River

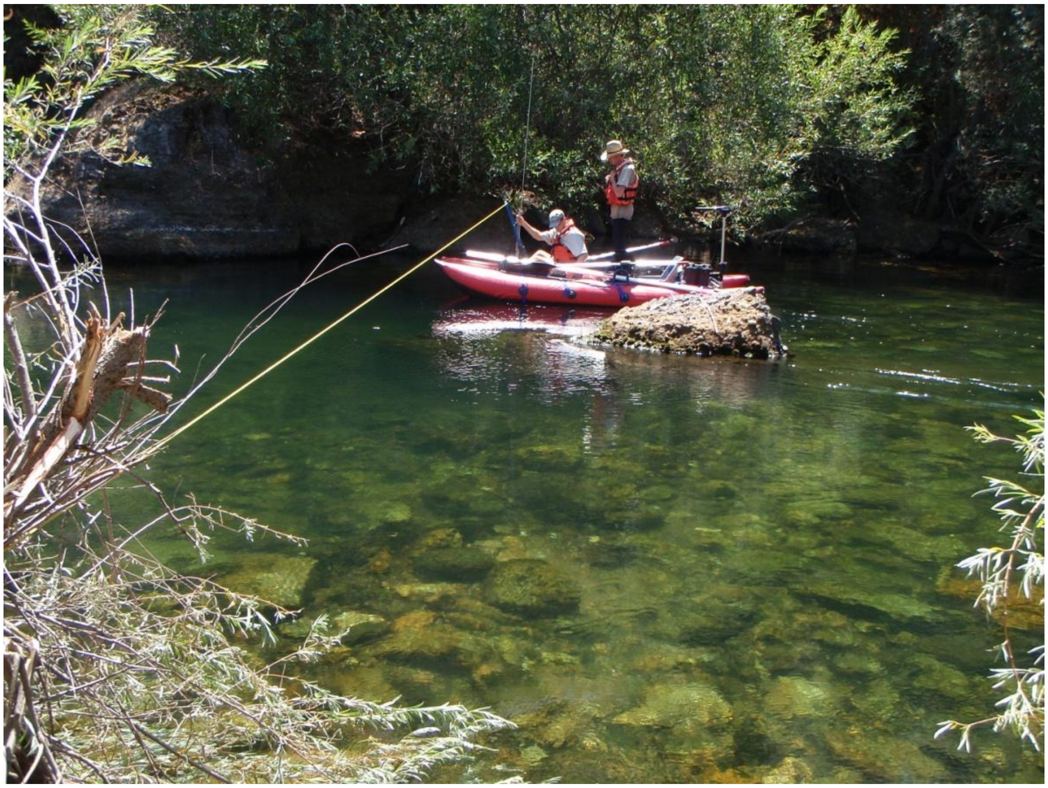

Photo B-1.—Study Site A – Two-mile Bar – lower boundary.

Photo B-2.—Study Site A – Two-mile Bar – lower boundary looking upstream.

Photo B-3.—Study Site A – Two-mile Bar – upper boundary looking downstream.

Photo B-4.—Study Site 1 – Horseshoe Recreation Area – downstream from upper boundary looking upstream.

Photo B-5.—Study Site 1 – Horseshoe Recreation Area – downstream boundary looking upstream.

Photo B-6.—Study Site 1 – Horseshoe Recreation Area – downstream boundary.

Photo B-7.—Study Site 2 – Valley Oak Recreation Area – upstream boundary looking upstream.

Photo B-8.—Study Site 2 – Valley Oak Recreation Area – downstream boundary.

Photo B-9.—Study Site 3 – McHenry Recreation Area– upstream boundary looking downstream.

Photo B-10.—Study Site 3 – McHenry Recreation Area – downstream boundary looking upsteam.

Appendix C

River2D Study Control Points

Table C-1.—Control points used on Stanislaus River at study site A-Two-mile Bar Recreation Area

(Note: elevations not corrected)

Control name	Northing	Easting	Elevation (m)	Elevation (ft)
2mcp1	4190721.057	707281.817	77.129	253.0
2mcp2	4190795.490	707352.202	80.357	263.6
2mcp3	4190831.050	707374.885	79.612	261.1
2mcp4	4190883.592	707388.298	78.312	256.9
CP3	4190799.455	707306.760	82.000	269.0
CP4	4190680.905	707198.242	82.412	270.3
CP5	4190740.874	707286.970	80.994	265.7
CP6	4190748.976	707357.504	76.795	251.9
TR1	4190862.132	707424.563	79.312	260.1
TR2	4190765.612	707323.649	81.009	265.7
TR3	4190815.885	707401.186	76.434	250.7
TR4	4190813.649	707409.046	79.249	259.9
TR5	4190880.949	707382.587	79.632	261.2
TRZ1	4190736.048	707279.019	80.896	265.3
Pin	4190900.477	707392.581	77.632	254.6

Table C-2.—Control points used on Stanislaus River at study site 1-Horseshoe Recreation Area

Control name	Northing	Easting	Elevation (m)	Elevation (ft)
HC100	4187488.829	701286.937	44.314	145.3
HC101	4187522.049	701342.843	47.352	155.3
tr1	4187458.169	701295.964	45.441	149.0
Trzb	4187458.075	701295.963	45.421	149.0
Trzc	4187407.032	701350.151	44.987	147.6
Trzd	4187357.069	701328.709	44.348	145.5
Trze	4187355.279	701281.955	45.073	147.8
Trzf	4187337.467	701285.920	44.010	144.4
Trzg	4187283.080	701228.690	48.070	157.7
Trzh	4187246.365	701263.813	45.395	148.9
Trzi	4187242.066	701198.283	47.529	155.9
Trzj	4187215.241	701210.566	44.721	146.7
Trzk	4187116.780	701109.000	48.271	158.3
trzkk	4187116.828	701108.990	48.255	158.3
Trzl	4187091.773	701118.464	46.276	151.8
Trzll	4187091.784	701118.513	45.943	150.7
Trzm	4187048.613	701137.392	46.850	153.7
trzmm	4187048.071	701137.737	46.385	152.1
trznn	4186986.275	701085.103	50.220	164.7
trzoo	4187026.979	701116.760	45.863	150.4
trzpp	4187030.862	701115.956	45.625	149.7
trzqq	4186963.237	701076.423	50.997	167.3
Trzrr	4186942.874	701049.044	52.068	170.8
Trzs	4186963.963	701003.833	43.843	143.8
Trzt	4186881.962	700992.839	51.927	170.3
Trzu	4186892.298	700986.049	43.773	143.6
Trzv	4186835.777	700887.293	44.904	147.3
Trzw	4186767.841	700805.420	43.383	142.3
trzww	4186784.947	700871.287	43.806	143.7
Trzx	4186719.567	700770.093	44.124	144.7
Trzy	4186715.050	700756.413	44.428	145.7
TRZZ	4186707.098	700575.165	43.545	142.8
TRZZZ	4186686.805	700585.086	43.423	142.4
TRZZZZ	4186740.371	700700.673	43.532	142.8

Table C-3.—Control points used on Stanislaus River at study site 2-Valley Oak Recreation Area

Control name	Northing	Easting	Elevation (m)	Elevation (ft)
VALLEYOAK2	4184434.827	693408.248	39.620	130.0
VO100	4184250.796	693505.336	36.500	119.7
VO101	4184286.167	693525.242	35.745	117.2
VO102	4184271.043	693562.596	36.164	118.6
Tra	4184291.086	693608.213	35.273	115.7
Trb	4184254.638	693531.506	35.542	116.6
Trc	4184267.451	693641.328	33.218	109.0
Trd	4184262.066	693643.894	36.516	119.8
Tre	4184356.883	693763.144	34.959	114.7
Trf	4184360.817	693767.798	35.054	115.0
Trg	4184395.144	693876.822	32.903	107.9
Trgg	4184384.423	693873.162	38.102	125.0
Trh	4184473.613	693935.798	33.007	108.3
Tri	4184477.915	693916.383	33.400	109.6
Trj	4184455.629	693965.303	35.942	117.9
Trk	4184488.655	694020.022	36.561	119.9
Trkk	4184520.739	694061.886	36.401	119.4
Trl	4184463.393	693983.154	35.980	118.0
Trm	4184503.418	693985.885	32.935	108.0
Trn	4184576.680	694108.430	35.356	116.0
Tro	4184604.835	694145.687	36.989	121.3
trppp	4184615.088	694201.207	36.821	120.8
Trq	4184656.783	694187.206	33.282	109.2
Trr	4184618.689	694272.094	36.227	118.8
Trs	4184603.091	694358.273	33.591	110.2
Trt	4184610.314	694386.175	34.179	112.1
Tru	4184573.784	694374.498	33.787	110.8
Truu	4184574.043	694374.957	33.752	110.7
Trv	4184601.874	694395.313	34.584	113.4
Trw	4184572.102	694379.705	34.373	112.7

Table C-4.—Control points used on Stanislaus River at study site 3-McHenry Recreation Area

Control name	Northing	Easting	Elevation (m)	Elevation (ft)
MCHENRY1	4180367.018	675137.210	23.805	78.1
MH100	4180436.292	675091.376	23.393	76.7
Ma	4180428.188	675080.921	23.595	77.4
Mb	4180454.353	675002.931	22.874	75.0
Mc	4180470.605	675089.312	22.539	73.9
mccc	4180483.328	675135.118	19.149	62.8
Md	4180511.932	675083.302	22.088	72.4
mddd	4180512.239	675115.073	22.778	74.7
Me	4180475.124	675162.181	22.762	74.7
Mf	4180471.143	675199.838	22.233	72.9
Mg	4180509.895	675239.631	18.517	60.7
Mgg	4180558.854	675225.284	18.359	60.2
Mh	4180615.283	675163.690	20.014	65.6
Mi	4180604.936	675175.556	18.974	62.2
Mj	4180586.359	675146.994	19.839	65.1

Appendix D

Habitat Suitability Criteria

Table D-1.—Fall Chinook salmon fry rearing. SI is suitability index.

Water velocity (ft/sec)	SI value	Water depth (ft)	SI value	Cover	SI value	Adjacent velocity (ft/sec)	SI value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.36
0.10	0.99	0.1	0.00	0.1	0.10	3.60	1.00
0.20	0.95	0.2	0.80	1	0.25	100	1.00
0.30	0.89	0.3	0.84	2	0.10		
0.40	0.81	0.5	0.90	3	0.54		
0.60	0.65	0.6	0.92	3.7	1.00		
0.70	0.56	0.7	0.95	4	1.00		
0.80	0.49	0.8	0.96	4.7	1.00		
0.90	0.42	0.9	0.98	5	1.00		
1.10	0.30	1.1	1.00	5.7	1.00		
1.30	0.22	1.4	1.00	7	0.25		
1.40	0.19	1.7	0.97	8	1.00		
1.70	0.13	2.2	0.87	9	0.25		
2.00	0.10	2.5	0.78	9.7	0.10		
2.10	0.10	2.6	0.76	10	0.54		
2.20	0.09	2.7	0.73	11	0.00		
2.70	0.09	2.8	0.69	100	0.00		
2.80	0.10	3.5	0.48				
2.90	0.10	3.6	0.46				
3.00	0.11	3.8	0.40				
3.10	0.11	3.9	0.38				
3.20	0.12	4.0	0.35				
3.40	0.12	4.6	0.23				
3.50	0.13	4.7	0.22				
3.62	0.13	4.8	0.20				
3.63	0.00	4.9	0.19				
100	0.00	5.0	0.17				
		5.7	0.10				
		5.8	0.10				
		6.0	0.08				
		6.1	0.08				
		6.2	0.07				
		6.3	0.07				
		6.4	0.06				
		6.5	0.06				
		6.6	0.05				
		6.9	0.05				
		7.0	0.04				
		7.3	0.04				
		7.4	0.03				
		8.0	0.03				
		8.1	0.02				
		18.4	0.02				
		18.5	0.00				
		100	0.00				

Table D-2.—Fall Chinook salmon juvenile rearing. SI is suitability index.

Water velocity (ft/sec)	SI value	Water depth (ft)	SI value	Cover	SI value	Adjacent velocity (ft/sec)	SI value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.02
0.10	1.00	0.7	0.00	0.1	0.24	5.50	1.00
0.20	0.99	0.8	0.03	1	0.24	100	1.00
0.30	0.98	1.0	0.05	2	0.24		
0.40	0.97	1.2	0.09	3	0.24		
0.50	0.96	1.4	0.15	3.7	1.00		
0.60	0.94	1.6	0.23	4	1.00		
0.70	0.92	1.9	0.38	4.7	1.00		
0.80	0.89	2.4	0.68	5	1.00		
0.90	0.87	2.5	0.73	5.7	1.00		
1.00	0.84	2.6	0.79	7	0.24		
1.10	0.81	2.9	0.91	8	1.00		
1.20	0.78	3.1	0.97	9	0.24		
1.30	0.74	3.4	1.00	9.7	0.24		
1.40	0.71	3.5	1.00	10	0.24		
1.50	0.67	3.8	0.97	11	0.00		
1.60	0.63	4.0	0.93	100	0.00		
1.70	0.60	4.1	0.90				
1.80	0.56	4.2	0.88				
1.90	0.52	4.4	0.82				
2.00	0.48	4.5	0.78				
2.10	0.45	5.4	0.51				
2.20	0.41	5.5	0.49				
2.30	0.38	5.6	0.46				
2.40	0.34	6.2	0.34				
2.50	0.31	6.3	0.33				
2.55	0.30	6.4	0.31				
3.98	0.30	7.0	0.25				
3.99	0.00	7.1	0.25				
100	0.00	7.2	0.24				
		7.3	0.23				
		7.5	0.23				
		7.6	0.22				
		11.8	0.22				
		11.9	0.00				
		100	0.00				

Table D-3.—Steelhead/rainbow trout fry rearing. SI is suitability index.

Water velocity (ft/sec)	SI value	Water depth (ft)	SI value	Cover	SI value	Adjacent velocity (ft/sec)	SI value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.17
0.10	1.00	0.1	0.00	0.1	0.12	4.70	1.00
0.20	0.99	0.2	0.47	1	0.57	100	1.00
0.30	0.98	0.4	0.57	2	0.28		
0.40	0.97	0.5	0.63	3	0.28		
0.50	0.96	0.6	0.67	3.7	1.00		
0.60	0.94	0.7	0.72	4	0.57		
0.70	0.92	0.8	0.77	4.7	1.00		
0.80	0.89	1.0	0.85	5	1.00		
0.90	0.87	1.1	0.88	5.7	1.00		
1.00	0.84	1.2	0.91	7	0.28		
1.10	0.81	1.3	0.94	8	1.00		
1.20	0.78	1.5	0.98	9	0.12		
1.30	0.74	1.7	1.00	9.7	0.12		
1.40	0.71	1.9	1.00	10	1.00		
1.50	0.67	2.2	0.97	11	0.00		
1.60	0.63	2.4	0.93	100	0.00		
1.70	0.60	2.5	0.90				
1.80	0.56	2.9	0.78				
1.90	0.52	3.0	0.75				
2.00	0.48	3.1	0.71				
2.10	0.45	3.2	0.67				
2.20	0.41	3.3	0.64				
2.30	0.38	3.4	0.60				
2.40	0.34	3.5	0.57				
2.50	0.31	3.6	0.53				
2.60	0.28	3.7	0.50				
2.70	0.25	3.8	0.46				
2.80	0.23	4.2	0.34				
2.90	0.20	4.3	0.32				
3.00	0.18	4.4	0.29				
3.10	0.16	4.5	0.27				
3.20	0.14	4.6	0.24				
3.30	0.12	4.8	0.20				
3.40	0.11	4.9	0.19				
3.50	0.09	5.0	0.17				
3.60	0.08	5.1	0.16				
3.66	0.07	5.2	0.14				
3.67	0.00	5.9	0.07				
100	0.00	6.0	0.07				
		6.1	0.06				
		6.2	0.06				
		6.3	0.05				
		6.4	0.00				
		100	0.00				

Table D-4.—Steelhead/rainbow trout juvenile rearing. SI is suitability index.

Water velocity (ft/sec)	SI value	Water depth (ft)	SI value	Cover	SI value	Adjacent velocity (ft/sec)	SI value
0.00	1.00	0	0.00	0	0.00	0.00	0.02
0.10	1.00	0.4	0.00	0.1	0.24	5.50	1.00
0.20	0.99	0.5	0.45	1	0.24	100	1.00
0.30	0.98	1.6	0.90	2	0.24		
0.40	0.97	2.0	0.98	3	0.24		
0.50	0.96	2.2	1.00	3.7	1.00		
0.60	0.94	2.5	1.00	4	1.00		
0.70	0.92	3.0	0.94	4.7	1.00		
0.80	0.89	3.5	0.84	5	1.00		
0.90	0.87	5.5	0.32	5.7	1.00		
1.00	0.84	6.5	0.17	7	0.24		
1.10	0.81	8.0	0.07	8	1.00		
1.20	0.78	9.5	0.04	9	0.24		
1.30	0.74	10.5	0.03	9.7	0.24		
1.40	0.71	13.5	0.03	10	0.24		
1.50	0.67	15.0	0.04	11	0.00		
1.60	0.63	15.1	0.00	100	0.00		
1.70	0.60	100	0.00				
1.80	0.56						
1.90	0.52						
2.00	0.48						
2.10	0.45						
2.20	0.41						
2.30	0.38						
2.40	0.34						
2.50	0.31						
2.55	0.30						
3.98	0.30						
3.99	0.00						
100	0.00						

Table D-5.—All species and age classes. SI is suitability index.

Velocity shear (sec^{-1})	SI
0	0
0.5	1
1	1
2.5	1
2.8	0
3.4	0
Distance to wetted edge in m (ft)	**(SI)**
0 (0.0)	1
1 (3.3)	1
2 (6.6)	0.8
>2 (>6.6)	0.6

Appendix E

GIS Spatially Explicit Study Methodology

Prepared by Rob Hilldale, Bureau of Reclamation

CONTENTS

Page

HYDRAULIC MODELING FOR HABITAT SUITABILITY

Over the past decade or more, there has been a significant increase in the application of multi-dimensional hydraulic models to evaluate aquatic habitat in rivers (e.g. Leclerc et al., 1995; Guay et al., 2000; Tiffan et al., 2002; Pasternack et al., 2004; Hardy et al., 2006; Hilldale, 2007; Papanicolaou, 2010). Although three-dimensional (3D) hydraulic models are very useful for evaluating hydraulic properties as they relate to habitat (e.g. Hardy and Addley, 2003; Goodwin et al., 2006) they are typically limited in their application due to intense computing requirements, inadequate bathymetric survey to characterize 3D flow fields, and the lack of 3D habitat utilization data to place the fish at a specified depth in the water column. Depth-averaged two-dimensional (2D) hydraulic models are of particular use in evaluating reach-scale to watershed-scale hydraulic conditions, which drive the organizational framework for riverine habitat (Thomson et al., 2000). Central to the goal of this study is the expansion of the spatial scale over which salmonid habitat is evaluated on the Lower Stanislaus River (LSR), addressing the need to consider the segment scale (> 1,000 channel widths) in habitat assessments (Roni et al, 2001; Hardy and Addley, 2003; Wheaton et al., 2004a, Pess et al., 2003). The purpose for a segment-scale approach is to avoid limiting the analysis to site-scale metrics, which are not likely representative of the entire river. Evaluating habitat over the entire LSR avoids characterizing streams as discontinuous systems (Marcus and Fonstad, 2008), as is done in studies where local results are extrapolated over large spatial scales.

Hydraulic modeling on a segment scale has historically been burdened with a necessary reduction of the resolution at which physical data can be feasibly collected and numerically represented. Advancements in aerial LiDAR and boat-based SONAR data collection methods, along with ever increasing computing capabilities, has greatly improved our ability to evaluate hydraulic conditions over many tens of river kilometers (Pasternack et al., 2009). It is conceded that boat-mounted SONAR surveys of channel bathymetry using RTK GPS are less accurate than those surveys utilizing wading methods with either RTK GPS or a total station. However, proper boat-mounted SONAR surveys utilizing survey-grade RTK GPS positioning provide errors that are generally acceptable given the variability of spatially and temporally transient bed features and the ability to numerically represent hydraulic conditions at the meter-scale.

Although boat-mounted SONAR surveys cannot always access channel margins due to very shallow water and sometimes the presence of debris (as is the case in the Stanislaus River), wading surveys are necessarily limited to wadeable conditions, sometimes severely limiting the ability to obtain bathymetry. Wading surveys are also very labor intensive while boat-mounted SONAR surveys provide greater efficiency and the ability to survey many kilometers in a day, making surveys of a hundred river kilometers feasible.

An important aspect of using 2D models for habitat studies is for biologists and flow modelers to jointly determine the spatial flow patterns, resolution, and accuracy needed to achieve project goals (Crowder and Diplas, 2000a). Biologists are interested in scales relevant to fish, while flow modelers are interested in scales relevant to 2D flow patterns and what can be properly represented based on survey density and channel conditions while considering run time. These scales are occasionally at odds with each other, particularly when the habitat involves small fish. Considering the focal velocity of a salmonid fry, the scale of interest to biologists may be several body lengths, perhaps 0.2 m. On the other hand, considering attainable survey resolutions and the ability to resolve 2D hydraulic features, a 1 m scale is perhaps the best resolution one should expect from a numerical model (Pasternack et al., 2006) that is being evaluated over perhaps 100 km. Considering the data available and the needs for this project, it was decided to construct a set of four hydraulic models covering a total of 90 km with an approximate resolution of 1 m x 2m (lateral and longitudinal, respectively).

Primary Objective

In order to reduce the reliance on New Melones Reservoir for meeting water quality and fishery flow objectives at Vernalis in the San Joaquin River, Reclamation has used a combination of two-dimensional hydraulic modeling and a Geographic Information System (GIS) to determine the relationship between discharge (Q) and salmonid juvenile habitat. With understanding of the salmonid discharge-habitat relationship, Reclamation can work with stakeholders and state and federal agencies to manage flows to meet the intent of Congress.

SRH-2D

Sedimentation and River Hydraulics – Two-Dimensional (SRH-2D), is a two-dimensional (2D) hydraulic, sediment, temperature, and vegetation model for river systems under development at the Bureau of Reclamation (Lai, 2008). A finite volume discretization is applied to the two-dimensional depth-averaged equations (i.e., the depth-averaged St. Venant equations) such that mass conservation is achieved locally and globally (Lai, 2010). SRH-2D adopts very robust and stable numerical schemes with seamless wetting-drying algorithms, resulting in a very stable model with few tuning parameters needed to obtain reliable solutions. The model is particularly suited for river applications, covering subcritical, transcritical, and supercritical flows. SRH-2D has been verified, validated, and successfully applied to numerous flow cases (Lai, 2008).

Survey Data

Airborne LiDAR and Photogrammetry

To obtain terrestrial topography, a bare earth LiDAR survey was performed by Aerometric, Inc. on March 10, 2008 from Goodwin Dam to the mouth of the Stanislaus River at the San Joaquin River. The spot density achieved was 0.5 m. A sidelap of 50 percent improved the penetration through the vegetation canopy to obtain bare earth elevations. The stated vertical accuracy for a flat concrete surface is less than 0.15 m. Realized accuracies are reported in a later section. Two sets of orthorectified aerial photography (RMS = 0.3 m longitude and latitude) were collected on the same date resulting in a 0.3 m pixel size in riparian areas and a 1 m pixel size capturing much of the valley width. The smaller scale photography was used for this project. Average daily discharge in the Stanislaus River on March 10th, 2008 was 11.8 m^3/sec (417 cfs) and 9.6 m^3/sec (339 cfs) at Goodwin Dam (Reclamation, GDW) and Ripon (USGS #11303000) gages, respectively.

Bathymetry Data Collection

The primary bathymetric survey data collection was performed by Environmental Data Solutions, Inc. (EDS). Bathymetry was obtained from Knights Ferry to the mouth of the Stanislaus River at Two Rivers (a total of 90 river kilometers, see figure E-1) in February and March, 2008, with additional surveys conducted in June and July, 2008 to fill in data gaps. The Stanislaus River upstream of Knights Ferry is severely confined, with drops greater than 1 m and a ubiquitous presence of very large boulders, preventing a proper survey using boat-mounted SONAR. The survey used a series of four boat-mounted transducers spaced less than two meters apart in a swath system (figure E-2). RTK GPS positioning was provided by a Leica System 1200. The survey utilized a Crescent VS100 DGPS heading and roll sensor to provide accurate, reliable heading and position information at high update rates. The Crescent VS100 uses moving base station Real-Time Kinematic (RTK) technology to achieve very precise heading and position accuracies. The relative positions of the RTK antenna and fathometers were measured twice daily and entered into the Hypack configuration files. Stated vertical accuracy of the survey was 0.1 m. Realized accuracies are discussed in a later section.

The point density for the SONAR surveyed portion of the channel ranges from 0.3 to 0.4 points per square meter. When the entire wetted portion of the river (as defined by aerial photography and bare earth LiDAR flown March 10, 2008) is used to evaluate point densities, the average is approximately 0.2 points per square meter. The decrease in resolution is due to the inability to survey very near the shoreline throughout much of the river, although every effort was made to do so where feasible. Downed trees line a significant portion of the banks of the Stanislaus River and prevent safe survey access, either by boat or while wading (figure E-3). A plan view of a typical portion of the SONAR survey is shown in figure E-4.

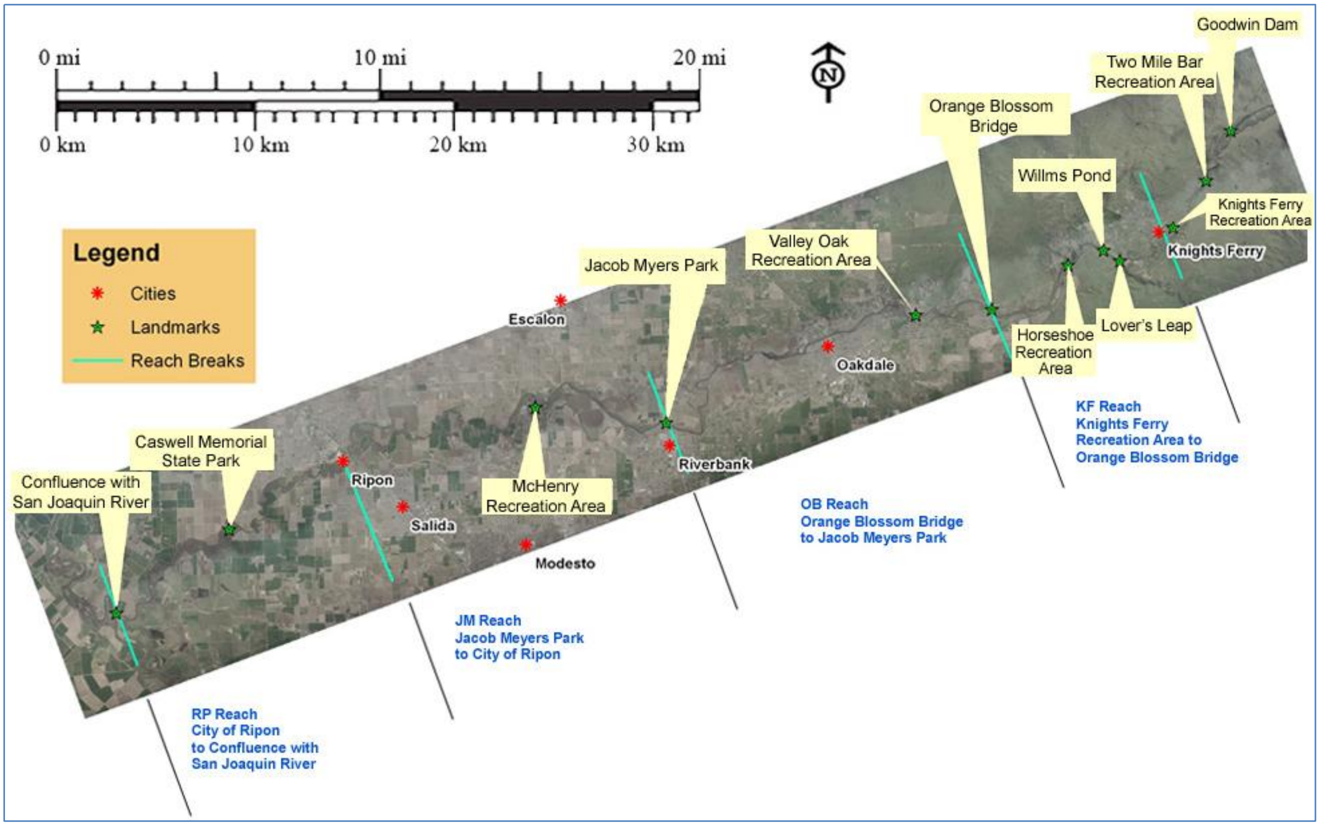

Figure E-1.—Overview of the lower Stanislaus River below Goodwin Dam. The study reach begins at Knights Ferry Recreation Area and ends at the San Joaquin River at Two Rivers Park.

Figure E-2.—Photograph showing the SONAR system used to obtain bathymetry.

Figure E-3.—Examples of woody debris lining the channel, preventing a complete bank-to-bank survey throughout much of the reach.

Figure E-4.—Typical survey coverage, necessarily avoiding woody debris.

Reclamation Hydrographic Surveys

Two separate SONAR surveys were performed by Reclamation personnel in May and November 2008. Discharges during these multi-day surveys were approximately 21 m^3/sec (742 cfs) in May and 7 m^3/sec (247 cfs) in November. These surveys spanned the LSR from Knights Ferry to the mouth at Two Rivers, but were not continuous throughout the reach. The purpose of these surveys was to: (1) Compare the SONAR survey data obtained from EDS; (2) gather velocity measurements for model validation; (3) collect water surface data for calibration, and (4) measure discharge during the data collection. The bed elevations collected during this survey were combined with the bed survey performed by EDS.

Data were collected using a Teledyne RD Instruments Rio Grande Workhorse 1200 kHz acoustic Doppler current profiler (ADCP). Horizontal position was provided by linking the ADCP output to RTK GPS and water surface elevations were constantly recorded. Heading was provided by an internal compass in the ADCP. Depth and velocity data were post processed in AdMap.[1] AdMap is software written in MATLAB® to provide, among other things, a depth and horizontal location for each beam of the ADCP as opposed to using the average depth of all four beams. Comparisons of single beam echosounder and ADCP surveys that split the beams to obtain separate depths using AdMap show a

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[1] AdMap (compiled program in MATLAB® [The Mathworks, Inc., Natick, MA]).

negligible difference (Bauer, 2009). AdMap was also used to provide spatial locations for depth-averaged velocity measurements.

Survey Control and Ground Truth Surveys

Survey control for all aerial, land, and SONAR surveys performed on this project was provided by WH Pacific. Horizontal and vertical datums were NAD 83 and NAVD 88, respectively. The projection is Universal Transverse Mercator (UTM) coordinates (meters), Zone 10-N.

Ground truth surveys were independently performed by WH Pacific (Sacramento, CA) for comparison with the SONAR and LiDAR surveys. The surveyors were instructed to provide ground surveys in areas that are typically difficult for LiDAR and SONAR methods to represent accurately, i.e. steep terrain and for terrestrial LiDAR, under a vegetation canopy. For comparisons of the hydrographic survey, six locations within the study reach were surveyed using a total station, surveying bank to bank in a grid fashion. A 2 m horizontal search perimeter was used for the analysis. In all likelihood the 2 m search radius used for the SONAR data resulted in a larger standard deviation than would have been the case using a smaller search radius. A large search radius in rapidly varying terrain will also affect the number of points with an error < 0.2 m, as is shown in table E-1. Because of the large search radius, the uncertainty of the SONAR survey is likely overstated, and a smaller search radius would decrease the error. For the LiDAR comparison, ground surveys were performed using a combination of RTK GPS and static survey methods. All survey points were in areas of heavy trees or on extreme slopes such as a river bank. A 0.5 m search perimeter was used for the analysis. Results of the ground truth surveys, as reported by WH Pacific, are listed in table E-1.

Table E-1.—Table of ground truth survey results as provided by WH Pacific (Sacramento, CA)

	Error	Standard deviation	Points with error < 0.2 m	Total number of points
LiDAR	+0.015 m	0.13 m	91%	230
SONAR	−0.118 m	0.22 m	62%	726

Supplemental Survey Data for Woody Debris

Streamwood, large boulders, bedrock outcrops, and other instream structures play an important role in channel hydraulics as it relates to habitat (Crowder and Diplas, 2000a; Wheaton et al., 2004b; Senter and Pasternack, 2010). Structure in river channels creates important habitat for drift feeding salmonid species by allowing salmonids to rest in low velocity wake zones and take advantage of faster velocities to feed (Hayes and Jowett, 1994). Including complex river structure in an appropriately sized 2D model mesh influences flow patterns in the vicinity of obstructions (Crowder and Diplas, 2000).

Because it is not feasible to obtain detailed surveys of every piece of streamwood over a 90 km survey, it was necessary to formulate these data. Reasonable assumptions were made regarding the form of streamwood visible through the water surface in the aerial photography. Based on observations while in the field and knowledge of the water surface elevation in the vicinity of streamwood, estimates were made such that these features were included in the bathymetry survey for the Knights Ferry and Orange Blossom reaches. Arriving at reasonable estimations of the streamwood form, which is very common throughout the LSR, is very time consuming. Unfortunately time did not allow for this exercise to take place in the Jacob Meyers and Ripon reaches. Instead, roughnesses were increased in the vicinity of visible large wood.

Bed Material Description

The bed material in the Stanislaus River transitions from an all-gravel bed in Knights Ferry to an all-sand bed at the confluence with the San Joaquin River. Near Knights Ferry the bed is predominantly medium and coarse gravel with occasional large boulders. This transition from gravel to sand begins somewhere between Valley Oak Recreation Area and the city of Oakdale (approximate river kilometer 70, figure E-6). In this reach the riffles are gravel and the runs/glides are primarily sand. The transition from gravel to sand extends a significant distance longitudinally. This transition is mostly complete near Ripon (approximate river kilometer 25), where the Stanislaus River primarily has a sand bed. However, infrequent gravel patches exist downstream of Ripon, forming the occasional bar or riffle features all the way to the mouth. In the sand portions of the Stanislaus River, bedforms are generally limited to ripples. No dunes were observed during channel surveys and are not visible in the survey data.

Modeling Methodology

Reach Delineations

In an effort to treat the LSR as a continuous system, the entire river segment was modeled at a 1 m resolution from Knights Ferry to the mouth at Two Rivers (figure E-1), a total of 90 river kilometers. The study segment was divided into four computational reaches (figure E-1) to maintain manageable mesh sizes and run times. The reaches were not delineated on the basis of geomorphic variables, but rather for practical and computational convenience. These reaches are referred to as: *Knights Ferry* – abbreviated KF, begins near the covered bridge in Knights Ferry, RK 90.0, and ends near the Orange Blossom Bridge, RK 77.6 (figure E-5); *Orange Blossom* – abbreviated OB, begins near the Orange Blossom, RK 77.6 Bridge and ends near Jacob Meyers park, RK 55.6 in Riverbank (figure E-6)*; Jacob Meyers* – abbreviated JM, begins near Jacob Meyers Park in Riverbank, RK 55.6, and ends near the Highway 99 Bridge in Ripon, RK 27.5 (figure E-7); and *Ripon* – abbreviated RP, begins near the Highway 99 Bridge in Ripon, RK 27.5, and ends at the mouth at the San Joaquin River, RK 0 (figure E-8).

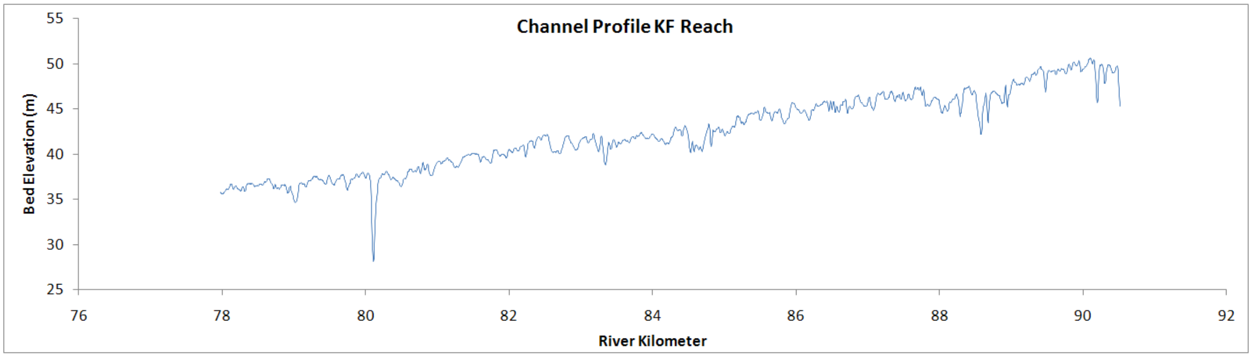

Figure E-5.—Longitudinal profile of the Knights Ferry reach. This is not a thalweg profile.

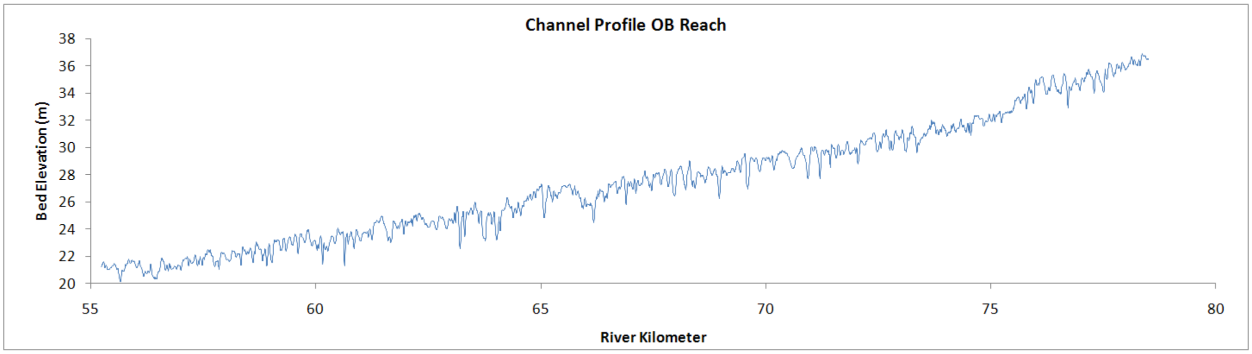

Figure E-6.—Longitudinal profile of the Orange Blossom reach. This is not a thalweg profile.

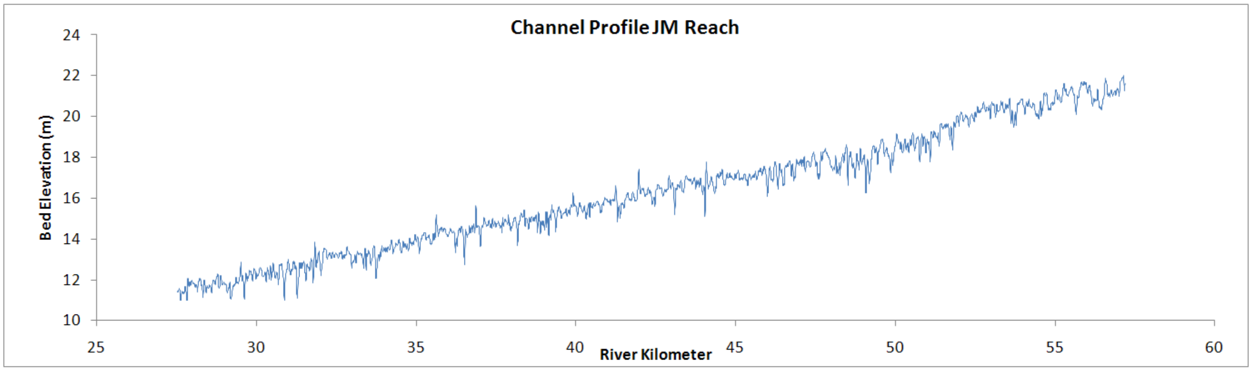

Figure E-7.—Longitudinal profile of the Jacob Meyers reach. This is not a thalweg profile.

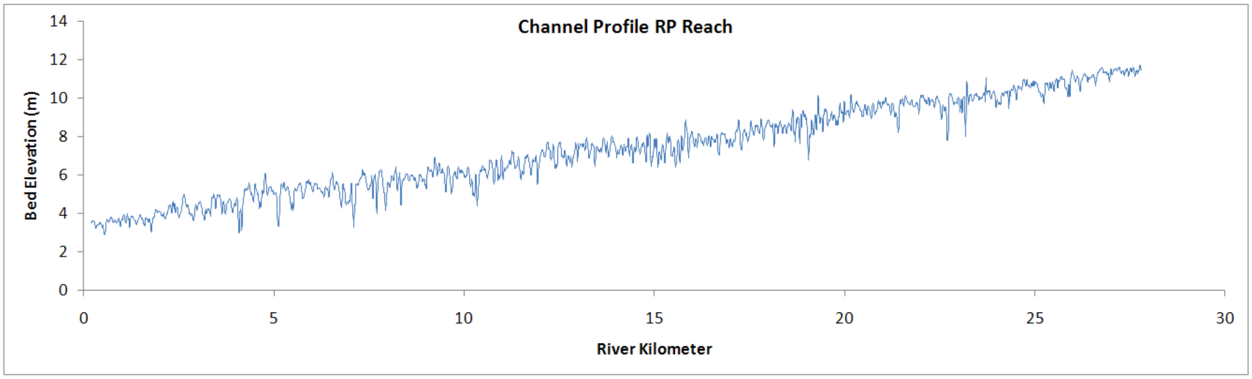

Figure E-8.—Longitudinal profile of the Ripon reach. This is not a thalweg profile.

Digital Elevation Model Development

The most important input to a hydraulic model is the representation of channel form. The topographic representation was accomplished in Arc GIS (ESRI, Redlands, CA) using a combination of raster and terrain surfaces. The mapping began by defining the wetted edge along river banks. This task proved difficult using only aerial photography due to the significant amount of overhanging vegetation on the LSR. To assist with the delineation of the wetted edge, a terrain was constructed using the bare earth LiDAR. The wetted edge was determined to be the junction of the down-sloping bank and the flat surface created by returns from the water surface. Lines were drawn delineating the wetted edge using the terrain and then verified with the aerial photography. These lines were then used to delete all bare earth LiDAR points from the wetted area.

For all reaches, the wetted area was mapped using inverse distance weighted (IDW) interpolation of the SONAR data. Over 40 tests were performed at three sites to determine an appropriate interpolation scheme using isotropic interpolation methods. Although anisotropic interpolations requiring a transformation to a longitudinal coordinate system may improve the overall surface representation (Legleiter and Kyriakidis, 2007; Merwade, 2009), these methods are still being evaluated by Reclamation personnel. The isotropic interpolation tests used in this study included kriging, ordinary and universal; spline, with and without tension, inverse distance weighting, and nearest neighbor. Various parameters available in each of the interpolation schemes were adjusted and optimized. Within a few tests it became apparent that kriging and nearest neighbor interpolations would not provide the appropriate interpolation, limiting the remaining tests to IDW and a tensioned spline. The three sites chosen for the raster interpolation tests were in the upstream, middle, and downstream portions of the LSR and each tested area included a bank-to-bank bathymetric survey. Points along the channel margin were selected for removal and a raster was made of each data set, one complete and one with points removed (figure E-9). Removing points along the channel margin replicates those areas near the banks that were not surveyed due to a lack of access by the boat, primarily because of vegetation and/or shallow water. A misrepresentation of the channel edges can result in a loss of conveyance, altering the hydraulic properties, and can potentially affect the habitat evaluation in these areas. After a 1 m raster was made of each test data set (complete set of points and with channel margin points removed), a statistical comparison was made using the Geostatistical Analyst function in Arc GIS and the mean absolute error was minimized. A comparison was also made with a cross section cut through each raster and compared to survey data. Upon completion of the analysis, bathymetry rasters were then constructed for all four reaches using IDW interpolation with optimized variables.

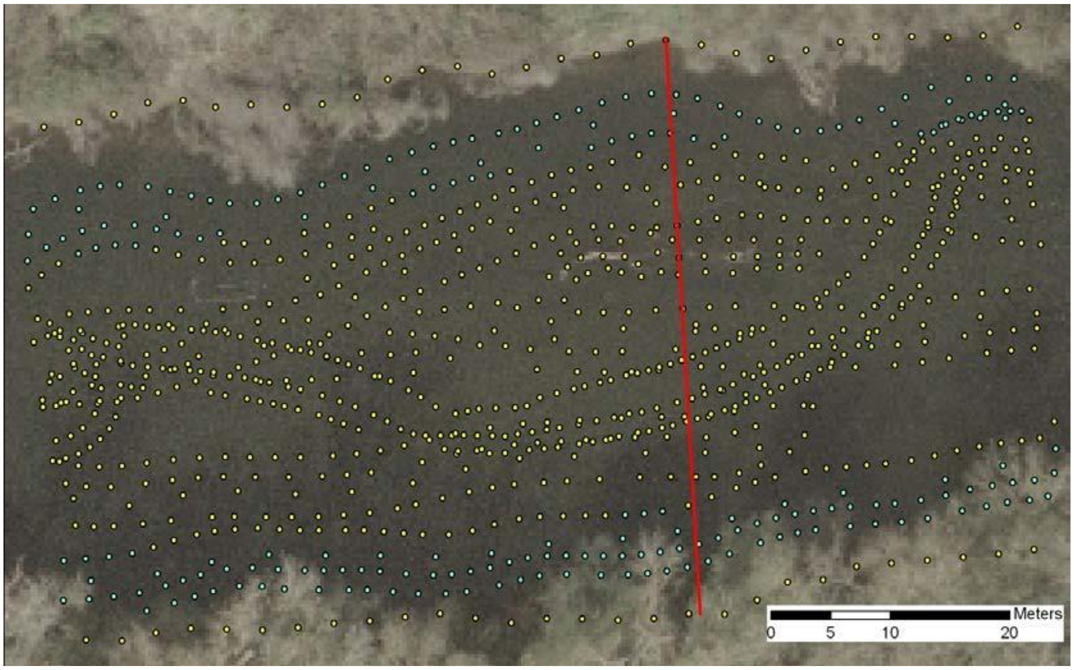

Figure E-9.—Example of the two data sets used for testing the interpolation scheme. The blue points near the channel margins were removed from the analysis and compared to an analysis using all the points. The red line marks the location of the cross section that was used to visually compare the results.

For the KF reach, a raster was made of the terrestrial topography resulting from the bare earth LiDAR data. This raster and the bathymetry raster were then merged to provide a seamless raster surface. For the remaining reaches (OB, JM, and RP) the rasters representing the bathymetry were converted to points, spaced at 1 meter, and combined with the LiDAR point data. A terrain was then built in Arc GIS. The terrain, as opposed to a raster, was used because of the size, and therefore the number of survey points, of the lower three reaches. The linear interpolation of the terrain provides a quality surface provided there is a sufficient point density, which was obtained from the LiDAR survey. Recall that the LiDAR point spacing is approximately 0.5 m. An example of the point data is shown in figure E-10. The resulting terrain is shown in figure E-11.

Generating the Computational Mesh

Surface-water Modeling System (SMS, ver. 10.0.11) software was used to generate the computational mesh, which is the surface input to the 2D hydraulic model. SRH-2D utilized a flexible, hybrid mesh system whereby a combination of triangular and quadrilateral cells were used. This flexible mesh allows for varying resolutions throughout the model and improves efficiencies (Lai, 2010).

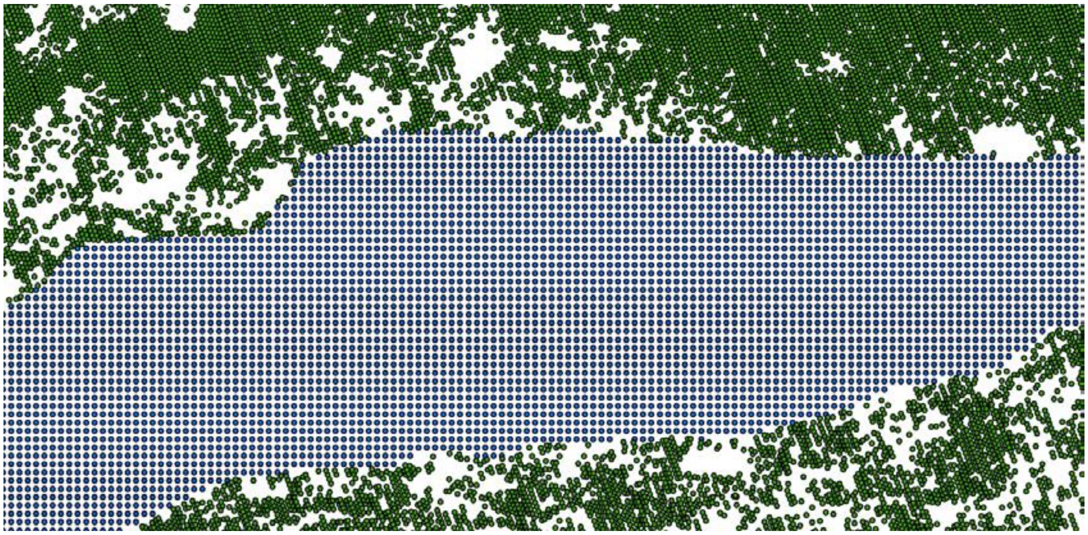

Figure E-10.—Example of the point data used to construct the terrain in Arc GIS. Green points are bare earth LiDAR and blue points are derived from the raster (1 m spacing) created with the SONAR survey data.

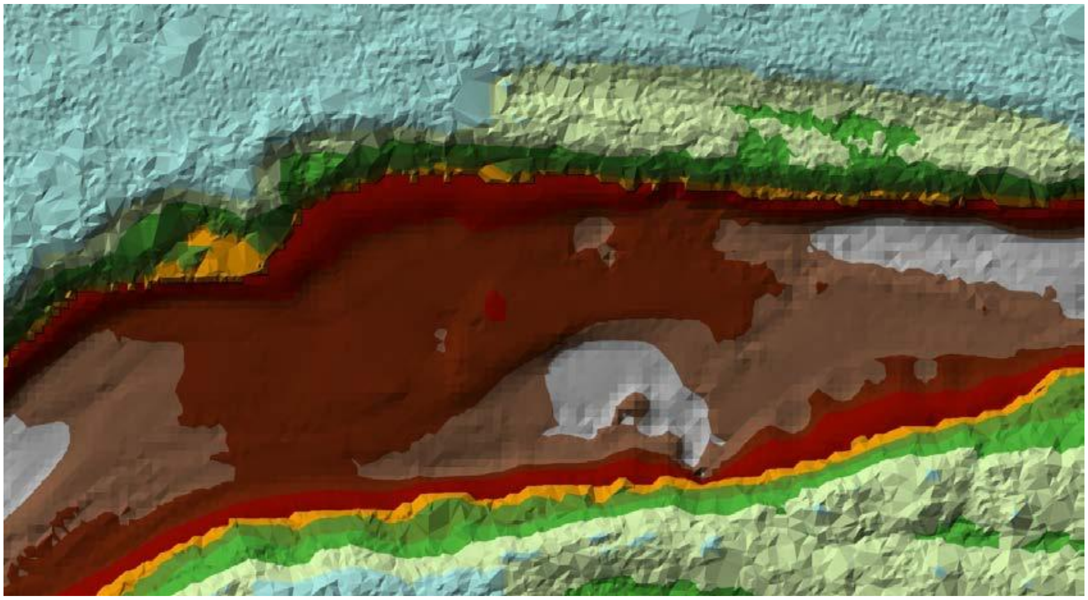

Figure E-11.—Example of the terrain resulting from the point data shown in figure E-10.

The hybrid, flexible mesh provides the ability to create a finer resolution in the channel and a coarser resolution in the floodplain, if desired. This decreases the number of cells in the model, decreasing computation time.

The wetted and near-bank portions of the mesh for all reaches used a 1 m *x* 2 m rectangular mesh, with the long dimension in the longitudinal direction and the short dimension in the lateral direction. This configuration was chosen to reduce the overall number of cells in the mesh, which saves significant computation time and does not sacrifice accuracy, as channel features and hydraulic properties change much less rapidly in the longitudinal direction (Lai, 2010). The resolution of the mesh cells is somewhat greater than that of the average point density of the bathymetric survey, which was 0.3 to 0.4 points per square meter. The mismatch between survey and model resolution could result in an artificially high resolution with an unknown realism, as pointed out by Tiffan et al. (2002). However, the authors concluded that the model resolution chosen was needed to define the channel hydraulics in enough detail and that the difference between the model and survey resolution was small enough to not cause unreasonable interpolations when creating the surface.

Construction of the mesh begins with the water lines created to delineate the wetted perimeter of the channel. These lines are imported from Arc GIS and were the same lines used to form the channel boundary when creating the seamless surface terrain. The meshing begins with the channel and continues to the floodplain. In an effort to minimize the number of mesh cells in the computational mesh, the edge of the mesh was determined by a location that would just contain the wetted width without the modeled flow touching the outer edge. The number of mesh cells in each study segment is shown in table E-2. An example of the mesh is shown in figure E-12.

Table E-2.—Table listing the number of cells in each computational mesh

Segment name	Knights Ferry (KF)	Orange Blossom (OB)	Jacob Meyers (JM)	Ripon (RP)
Number of mesh cells	473,787	718,043	868,132	950,298

Elevations are added to the mesh using a routine written in Visual Basic. This program applies elevations to each mesh node from the terrain created in Arc GIS. SMS possesses this capability however memory errors occur (using the 32-bit version of SMS) when working with more than 3 million points, which was the case in three of the four reaches in this study.

Channel and floodplain roughnesses are applied to the mesh using a series of polygons, which can be generated in Arc GIS or SMS. Roughness values remained constant over all discharges. Six roughness values were used to represent flow resistance (table E-3). The roughness values were based on experience, calibration results, and values published in Barnes (1967). Floodplain vegetation is described as dense and sparse to represent different floodplain conditions. The purpose of increasing the roughness along the channel margins is to replicate the low growing vegetation protruding into the water, which is ubiquitous throughout the LSR (figure E-13).

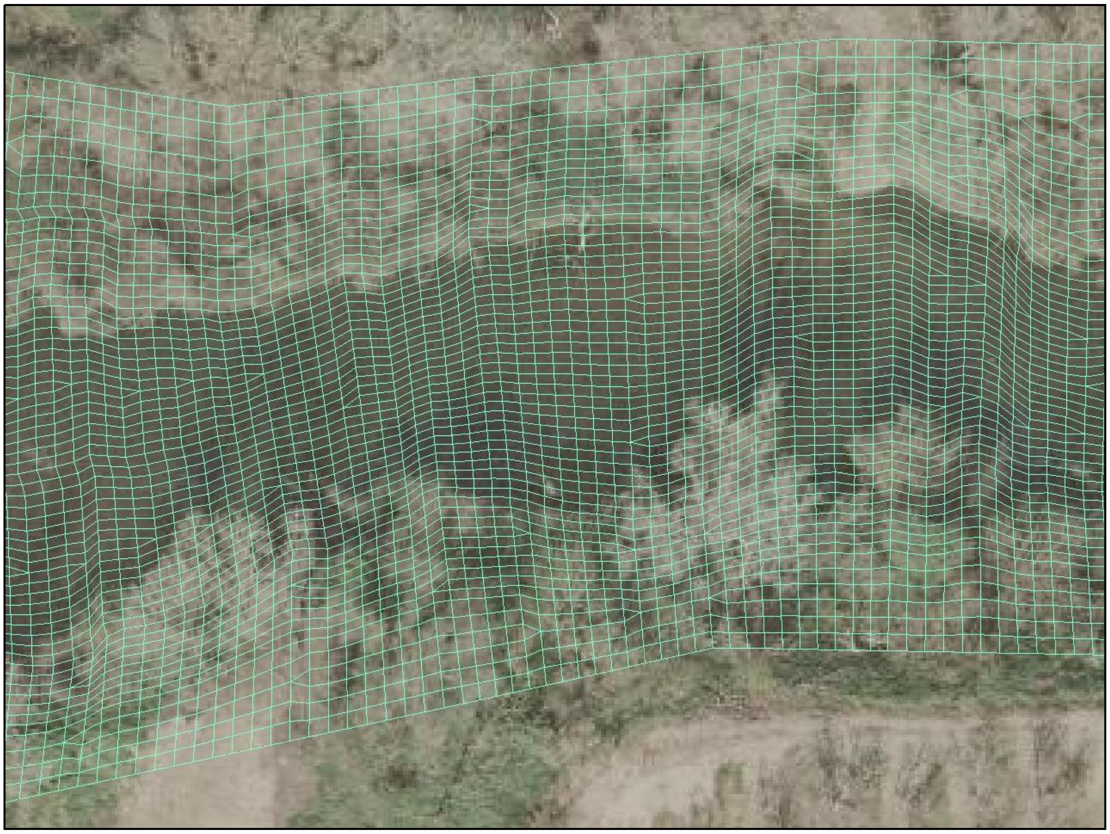

Figure E-12.—Example of the modeling mesh in the OB reach.

Table E-3.—Table of roughness coefficients used throughout the model

	Manning's *n* coefficient					
Reach identifier	**Channel**	**Channel margin**	**Dense floodplain**	**Sparse floodplain**	**Side channel**	**Stream-wood**
KF	0.037	0.065	0.1	0.075	0.04	N/A
OB	0.037	0.065	0.1	0.075	0.04	N/A
JM	0.035	0.065	0.1	0.075	0.04	0.1
RP	0.035	0.065	0.1	0.075	0.04	0.1

Figure E-13.—Example of vegetation encroaching into the channel, increasing flow resistance along the margins.

Modeling Details

Model Parameters and Boundary Conditions

Upon completion of the mesh, it and other parameters are input to the numerical model. Those parameters are: time step, turbulence model selection, boundary conditions, initial condition, roughness values, and solution type, which is steady state for all models related to this project. The time step chosen for a steady state model is less significant than for an unsteady simulation because the steady state solution is not time-accurate, although instabilities will occur if the time step chosen is too large. Sensitivity tests for time step were performed to optimize run time while maintaining a stable solution. A time step of 20 seconds was used for models of all four reaches. The K-E turbulence model was used for all modeled reaches and provides improved results compared to the parabolic model for complex river flows (Wu. 2008). Coefficients used in the K-E turbulence model are taken from Rodi (1993) and are defaults in the model. These defaults were not adjusted for this modeling effort. The inlet (upstream) boundary condition is the discharge being modeled and an assumption regarding the wetted width at the inlet to the model, chosen to be the width of the active channel. The discharges chosen were based on the needs of the project and where habitat needed to be defined. The outlet (downstream) boundary condition is given as a constant water surface elevation for each steady discharge indicated at the inlet. For the KF reach, water surface elevations were determined from measurements taken with a water level logger placed at the downstream boundary in the KF reach. Water level loggers were placed at downstream boundaries of other reaches but were not able to be recovered. The downstream boundary condition for the OB and JM reaches was determined using a HEC-RAS model over a length of a few kilometers. The downstream boundary condition for the RP reach was constant for all flows, representing the boundary condition provided by the San Joaquin River. The water surface elevations used are shown in table E-4. The initial condition for all the models was a dry bed. Roughness values were assigned according to the polygon material type in the mesh (discussed previously).

Table E-4.—List of water surface elevations used for the downstream boundary conditions in the model (the downstream boundary for the RP reach was held constant to represent a single discharge at the San Joaquin River)

Discharge (m^3/sec)	Discharge (ft^3/sec)	Water surface elevation (m)			
		KF reach	OB reach	JM reach	RP reach
7.1	250	37.26	21.91	12.19	4.9
14.2	500	37.38	22.29	12.55	4.9
22.7	800	37.54	22.58	12.89	4.9
34.0	1200	37.76	22.90	13.22	4.9
42.5	1500	37.94	23.12	13.44	4.9

Model-performance monitoring points were placed throughout the model domain and a model-performance monitoring line was placed near the downstream boundary. Monitoring points provide periodic model output at specified locations, while monitoring lines provide the discharge and an average water surface elevation at a cross section specified in the model input. Model completion is determined by water surface elevation and velocity at the various monitoring points and discharge at the monitoring line coming to equilibrium.

Analysis of Potential Model Uncertainties

Sensitivity to Roughness

A theoretical analysis was performed at 7.8 and 37.9 m^3/sec (275 and 1,338 cfs) to evaluate the sensitivity of the model to the selection of roughness values. Sensitivity of water surface elevation to roughness was evaluated over a 2 km reach, while sensitivity of velocity was evaluated at two cross sections within that two-kilometer reach. At the 7.8 m^3/sec (275 cfs) discharge Manning's *n* was decreased from 0.035 to 0.030, resulting in a mean change in modeled water surface elevation of -0.029 m. At the 37.9 m^3/sec (1,338 cfs) discharge, Manning's n was increased from 0.035 to 0.040, resulting in a mean change in water surface elevation of + 0.045 m. Sensitivity to velocity was evaluated at two cross sections in the test segment. The maximum change in velocity at each cross section was 0.018 and 0.026 m/sec for the 7.8 m^3/sec (275 cfs) discharge and 0.025 and 0.023 m/sec for the 37.9 m^3/sec (1,338 cfs) discharge. The changes in velocity are also shown in figure E-14.

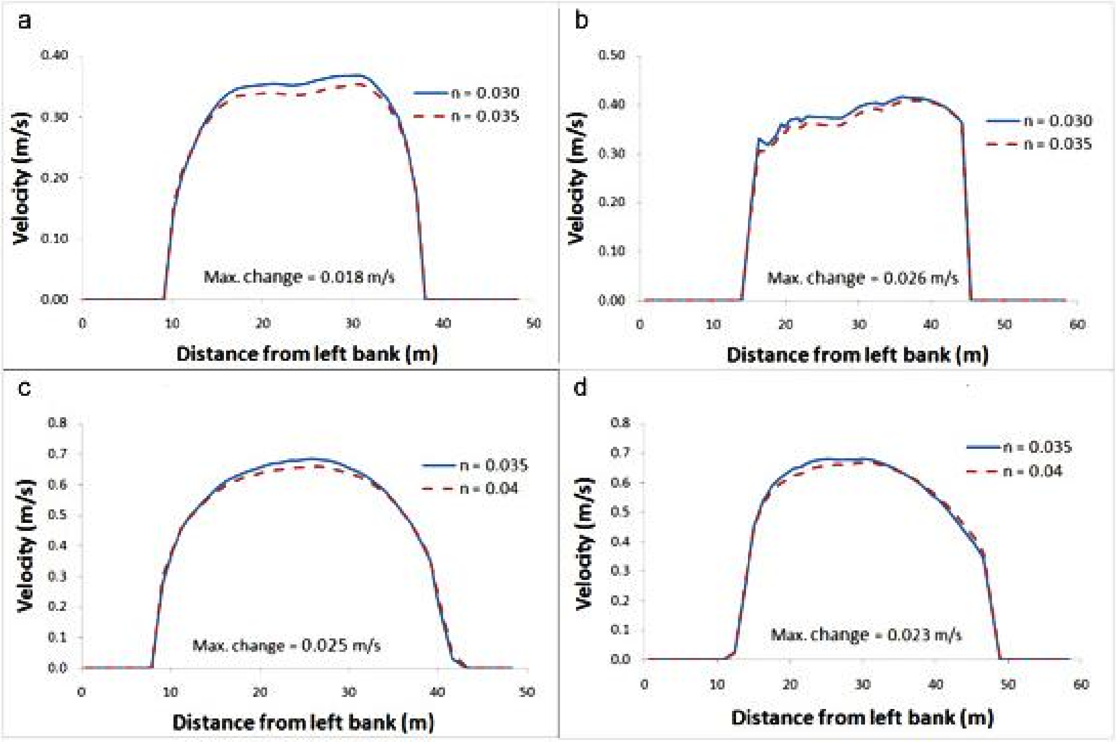

Figure E-14.—Velocity sensitivity to changes in Manning's *n* at two cross sections: (a) cross section 1 (RK 79.4), 7.8 m^3/sec (275 cfs); (b) cross section 2 (RK 80.0), 7.8 m^3/sec (275 cfs); (c) cross section 1 (RK 79.4), 37.9 m^3/sec (1,338 cfs); (d) cross section 2 (RK 80.0), 37.9 m^3/sec (1,338 cfs).

Mass Conservation Checks

One check of model performance and completion is verifying that mass has been conserved throughout the model run. SRH-2D provides the ability to monitor discharge through a cross section at any location within the model domain. To verify mass conservation, a monitoring line is placed very near the downstream boundary. This allows a comparison of discharge exiting the model with the discharge stated as the upstream boundary condition. Satisfactory performance is considered to be less than 1 percent difference between the downstream discharge and the upstream input discharge. These criteria are met for all discharges in all reaches (table E-5).

Table E-5.—Table showing mass conservation at the outlet of each model (difference shown is between the inlet and outlet discharges)

Discharge m^3/sec	Discharge ft^3/sec	Percent difference in discharge			
		KF reach	OB reach	JM reach	RP reach
7.1	250	0.05%	0.2%	0.1%	0.1%
22.7	800	0.02%	0.006%	0.01%	0.009%
42.5	1500	0.03%	0.02%	0.04%	0.1%

Representation of Eddies

Some 2D models fail to represent eddies or flow recirculation as water flows around boulders, bedrock outcrops or other obstructions. A 2D model should indicate eddies in these locations, as these features are important in capturing and representing aquatic habitat. A qualitative check is sufficient when modeling significantly long reaches, as eddies are often too numerous to verify in the field and often contain complexities not captured in a 2D model. Figure E-15 shows such a qualitative representation in the vicinity of a bedrock outcrop in the Knights Ferry reach.

Model Calibration and Validation

A hydraulic model should be verified for accurate representation of hydraulic properties, preferably at or near the discharges at which information will be utilized for the study. However, this is not always possible, especially when large, infrequent floods are being evaluated. The verification data cannot be the same data with which the model was calibrated. Typical performance metrics are water surface elevation, depth, and velocity. Primary statistical factors are mean error, indicating the possible presence of a bias and the standard deviation to show variation about the mean. Model verification should be quantitative however qualitative data can sometimes provide additional verification. The qualitative data could be the inundation of a specific portion of the floodplain or contact with a vertical surface at a known discharge, or hydraulic phenomena such as the presence of eddies or flow reversal at a given location.

One such quantitative measure of acceptable model representation of velocity is a deviation of modeled values less than approximately 30 percent from time-averaged measured values (Pasternack et al., 2006). Another measure of representation is checking the difference between measured and modeled velocities to be less than approximately twice the shear velocity, the anticipated value of velocity fluctuation due to localized turbulence (Nezu and Nakagawa, 1998). The latter metric is demonstrated in this report based on the lack of time averaged field measurements of velocity.

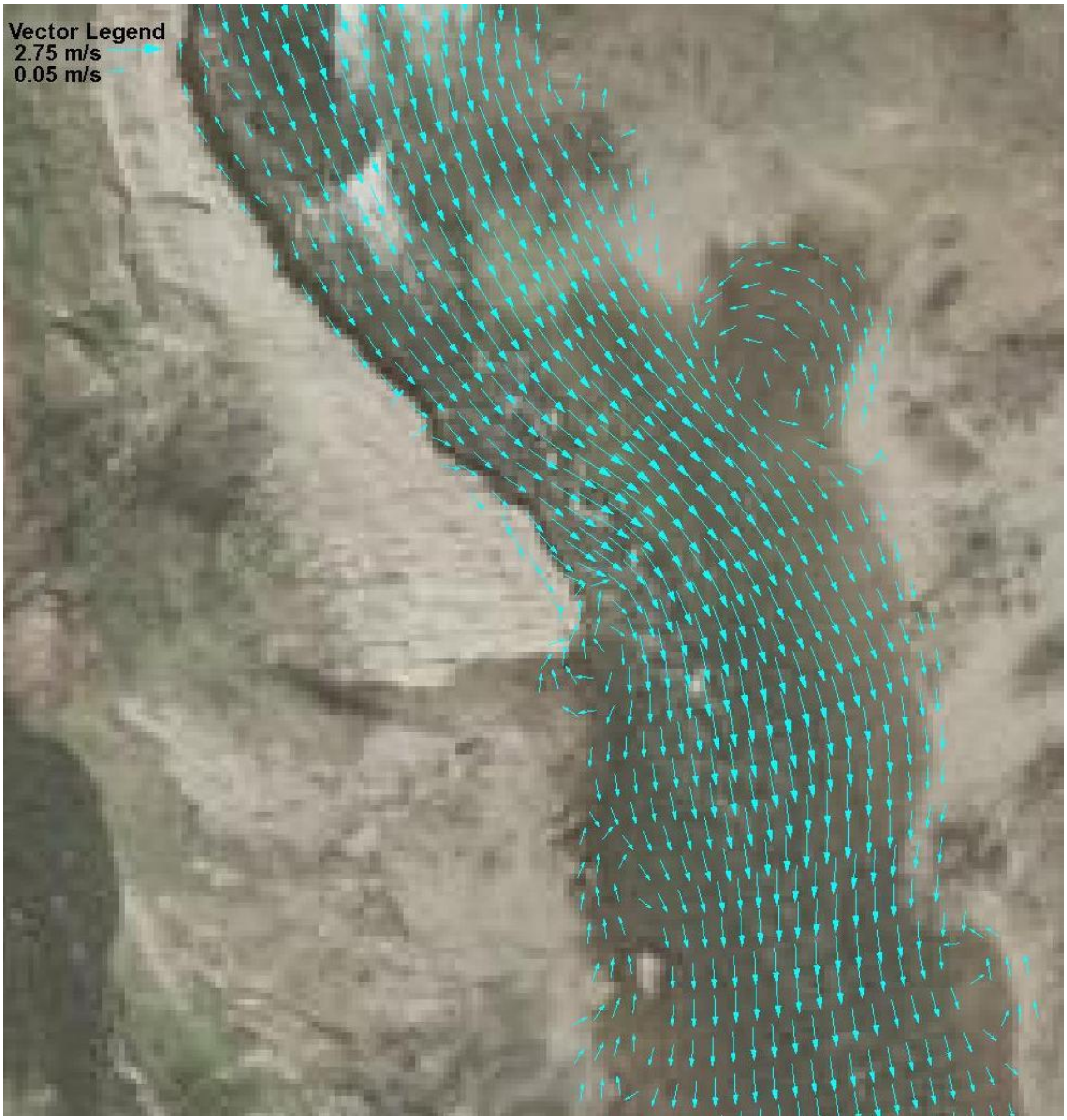

Figure E-15.—Figure displaying the vector representation of eddies in the vicinity of a bedrock outcrop. Discharge is 21.4 m^3/sec (756 cfs).

Error in predicted water surface elevation and/or flow depth should be less than the error in the river channel survey and resulting modeled surface. Similar metrics should be used to compare these errors. Bathymetry measurements with SONAR and RTK surveys have a conflated error of approximately ± 0.10 m based on precisions claimed by manufacturers of SONAR and GPS surveying equipment (Hilldale and Raff, 2008). In reality, SONAR surveys have errors closer to ± 0.15 m. Another test using water surface elevations is whether or not a global bias exists in the comparison of measured and modeled water surface elevations.

Water Surface Elevation

The only significant parameter for calibration in the SRH-2D model is Manning's *n*. During construction of the model, Manning's *n* values were assigned based on experience related to modeling channel hydraulics and familiarity with channel roughness. The previous section demonstrated that WSE and depth only change by < 5 cm with an incremental change in Manning's n of 0.05. That degree of sensitivity is small relative to the uncertainty in the topographic/bathymetry data. Upon completion of a model run using the values specified in table E-3, predicted water surface elevations were then compared to measured values from the Reclamation and EDS surveys. The comparison was carried out by spatially joining the surveyed elevations to the nearest model results for a given discharge. The results of this comparison are subject to errors in model prediction (including model structural limitation, computational mesh design, topographic/bathymetric mapping deficiencies, as well as downstream and/or upstream boundary condition inaccuracy) and errors in water surface elevation measurement for the comparison points. During the modeling and analysis of all the data, it appears that the accurate measurement of discharge represents the greatest amount of uncertainty. Unsteady flows during surveys, disparity among gage readings, and difficulty in some field measurements due to aquatic vegetation are primary causes for this uncertainty. The results of the water surface elevation comparison are shown in table E-6.

Water surface elevation comparisons were able to be made at or close to discharges used to evaluate habitat (7.1, 22.7, and 42.5 m^3/sec [250, 800, and 1,500 cfs]). One exception to that is the JM reach, where comparisons were only made at 7.1 and 22.7 m^3/sec (250 and 800 cfs), which are Reclamation surveys. The project was dependent on the EDS survey for measurements above 28 m^3/sec (989 cfs), and discharges greater than this did not occur during the EDS survey of the JM reach. Releases in the range of 28 m^3/sec (989 cfs) are infrequent on the Stanislaus. Water surface elevation comparisons were made over several kilometers of each reach. Note that there is no consistent bias in the error and that it falls well within the survey error of the bathymetry. This indicates a satisfactory validation.

Model Validation Using Velocity

When the modeling was complete and water surface elevation comparisons had been made, the model results were validated using depth average velocity.

Table E-6.—Table showing the results of the water surface elevation comparison

		Discharge in m^3/sec (cfs)			Error Statistics		
Reach Name	**Date (2008)**	**Model Discharge**	**Measured Discharge***	**Gage Discharge†**	**Mean Error (m)**	**Standard Deviation (m)**	**n ‡**
KF	Nov. 11, 13	7.1 (251)	7.8, 7.9 (275, 279)	7.1, 7.2 (251, 254)	-0.078	0.145	164
	May 7, 8	22.7 (802)	23.1, 20.8 (816, 735)	22.7, 22.8 (802, 805)	0.023	0.073	523
	Mar. 20	34.5 (1,218)	N/A	34.5 (1,218)	-0.020	0.141	34
OB	Feb. 21	9.2 (325)	N/A	9.2 (325)	-0.089	0.051	24
	Mar. 14	13.3 (470)	N/A	13.3 (470)	-0.083	0.076	27
	May 7	21.8 (770)	22.8 (805)	22.7 (802)	0.062	0.083	672
	Mar. 22	36.0 (1,271)	N/A	36.0 (1,271)	0.058	0.056	20
JM	Nov. 14	7.1 (251)	7.6 (268)	7.8 (275)	-0.036	0.077	233
	May 9	22.7 (802)	23.6 (268)	21.8 (770)	-0.018	0.053	339
RP	Mar. 3, 4	7.8 (275)	N/A	7.4, 7.3 (261, 258)	-0.003	0.043	44
	Nov. 10	7.8 (275)	N/A	7.8 (275)	0.033	0.038	132
	May 5	19.8 (699)	19.5 (222)	19.9 (703)	0.027	0.039	549
	Mar. 25 - 28	39.1 (1,381)	N/A	37.9, 39.1, 39.4, 39.4 (1,338, 1,381, 1,391, 1,391)	-0.083	0.064	38

* Instantaneous measurement using ADCP (minimum of 4 cross sections per measurement used to determine discharge, all measurements within 10 percent of the mean).

† Using daily average values from either Goodwin Dam gage (Reclamation - GDW) or Ripon gage (USGS # 11303000), whichever is more appropriate.

‡ n indicates the number of comparison points in the sample.

Velocity measurements were collected during the Reclamation surveys in all reaches at discharges approximately equal to 7 and 21 m^3/sec (247 and 741 cfs). Velocity measurements were made using an ADCP (see Bathymetry Data Collection) and were post-processed using AdMap to obtain depth average velocity and horizontal position. These data were imported to Arc GIS for comparison to model results (figure E-16).

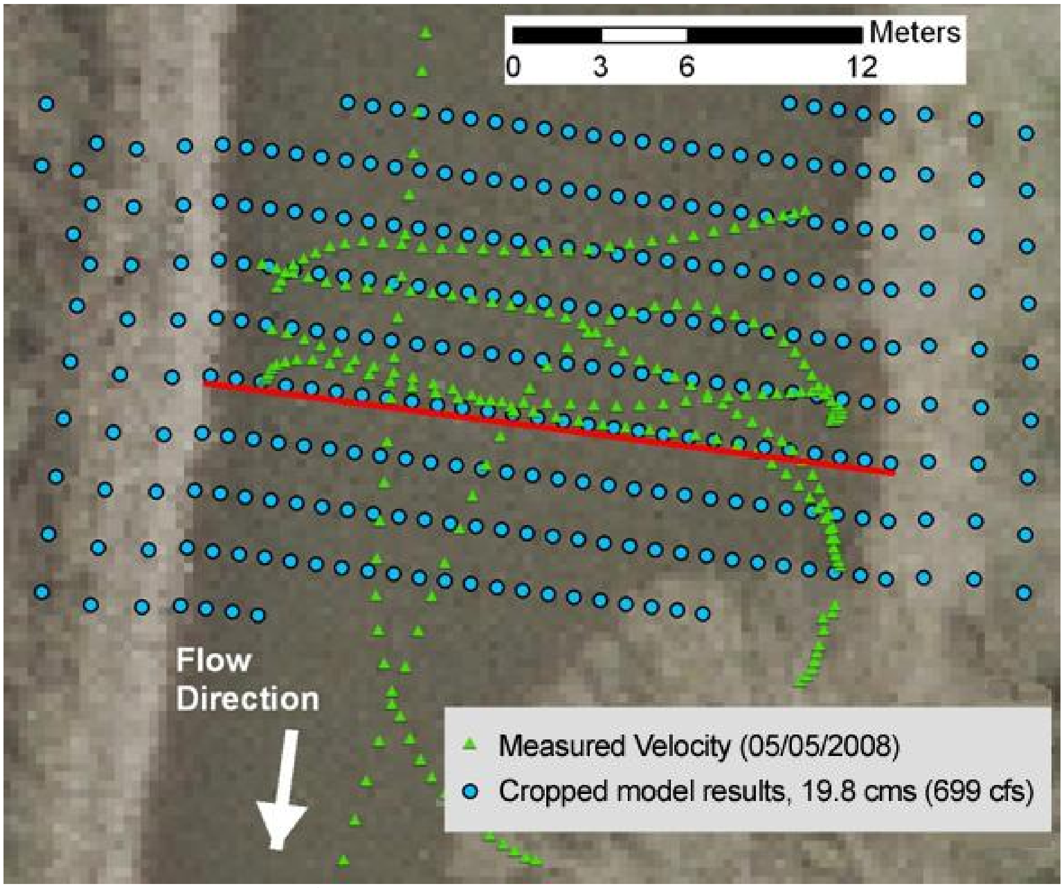

Figure E-16.—Example of velocity data comparison. The red line indicates the points used to obtain cross section data for the comparison.

It should be noted that little of the very shallow and very low velocity habitat was able to be validated with field measurements. This is due to the minimum depth limitation of the equipment available to the researchers for field measurements.

The Rio Grande Workhorse acoustic Doppler current profiler is only capable of velocity measurements in water approximately 1 meter deep or deeper, making shallow measurements of velocity impossible. This model of ADCP is capable of measuring depths of approximately 0.3 m.

Direct comparison of measured and predicted velocities is difficult due to the issue of scale (Lane et al., 1999), both spatially and temporally. This is because the modeled velocity represents a spatially (over one model cell) and temporally averaged quantity while a field measurement from the ADCP is an instantaneous velocity at a single point. Due to the turbulent fluctuations, and in some instances the presence of strong 3D flow patterns (Papanicolaou, 2010), mismatched velocities may not necessarily indicate an improperly modeled velocity. The issue of scale has been addressed in this study by spatially averaging velocity measurements, which also represents a quasi-time averaged value because neighboring data points are taken at different times. It is recognized that the time averaged component of this methodology does not meet typical requirements of stream measurements to properly average velocity fluctuations with a stationary measurement (e.g. Kondolf et al., 2000; Oberg and Mueller, 2007). However the results of this methodology are promising and perhaps deserve further investigation.

A spatial join was performed in a GIS whereby all measured velocity points within 1 m of a model point are joined to a modeled value. The average of the measured data is then compared to the modeled value. This process typically provided a minimum of three measured points to average and sometimes returned ten or more. If the search returned only one or two measured point velocities, that data point was not used in the comparison. Figure E-17 shows the results of this analysis.

The issue of turbulent fluctuations deserves some attention to address the disparity between instantaneous (field measured) and time averaged (modeled) velocities. Because the field measurements did not provide values of turbulence intensities (velocity fluctuations $u', v', and\ w'$ in the longitudinal, lateral, and vertical directions, respectively) velocity fluctuations can be addressed obliquely by examining the friction velocity

$$u_* = \sqrt{ghS}$$

where g is the gravitational constant, h is flow depth and S is the water surface slope. The slope was evaluated over a reach of approximately 100 m and assumes uniform flow at the measurement location. The wide channel assumption is valid in this case, allowing the substitution of depth for the hydraulic radius. The purpose for evaluating the friction velocity is to arrive at an approximation of the turbulent fluctuations in the longitudinal velocity value u' at each site evaluated. Nezu and Nakagawa (1993) indicate that u' scales with u_* and is approximately one to two times the value of u_* over the flow depth (excluding near-bed turbulence), providing some idea of the scale of velocity fluctuations in measured quantities. Knowing an approximate value of velocity fluctuations places the measured and modeled velocity comparison in context, and may indicate what one might expect from such a comparison. The scaling of u_* with u' is valid over a wide range of subcritical and supercritical flows. The u_* values at each data point were averaged across the portion of the cross section for which there are measurements, and designated as the mean friction velocity $\overline{u}_*$.

It can be seen that good agreement between measured and modeled velocity was achieved throughout the LSR, based on error typically less than twice the shear velocity (figure E-17). One exception is in the Jacob Meyer's reach at river kilometer 45.7. The comparison at 7.1 m^3/sec (250 cfs) shows a bias of approximately 10 cm/sec. However the comparison at river kilometer 46.5 indicates good agreement for the comparison at 22.7 m^3/sec (800 cfs). The cause for this bias was not able to be determined, however it should not be assumed that the entire JM reach at 7.1 m^3/sec (250 cfs) is similarly biased. Based on comparisons of water surface elevations and velocity throughout the LSR, this appears to be either an error in measured values or a local occurrence in modeled values due to a misrepresentation of bathymetry.

Creating Habitat Value from Model Output

The SRH-2D model provides the following output at the cell center of each mesh element: point ID, horizontal position, bed elevation, water surface elevation, depth, velocity – X direction, velocity – Y direction, magnitude velocity, Froude number, and bed shear stress. A point shapefile is created in Arc GIS from the output of each model run. Rasters are constructed for modeled values of depth, velocity, distance to water's edge, and velocity shear. The interpolation scheme used is IDW, however the parameters are set such that very minimal interpolation is performed, resulting in a nearly linear interpolation. The limited interpolation insures that the output data are not changed significantly.

Constructing Depth and Velocity Rasters

Depth and velocity rasters are made directly from model output of depth and magnitude velocity. These values are then reassigned using the habitat suitability index (HSI) values as provided by the Yuba River curves (Gard, 2008; figure E-18). Examples of depth and velocity rasters can be seen in figures E-19 and E-20.

Constructing a Distance to Edge Raster

In this modeling effort, distance to edge is defined as the distance to a dry cell, indicating the shoreline of a bank, a mid-channel bar, an island, or anything protruding through the water surface that might create a dry cell, such as woody debris. The process to determine a dry cell begins with a reclassification of the velocity raster, where dry cells are given a value of 1, and all others are 'No Data'. The distance from all wetted cells to the nearest dry cell is determined and all values with distances of 1 and 2 meters are assigned HSI value of 1 and 0.8,

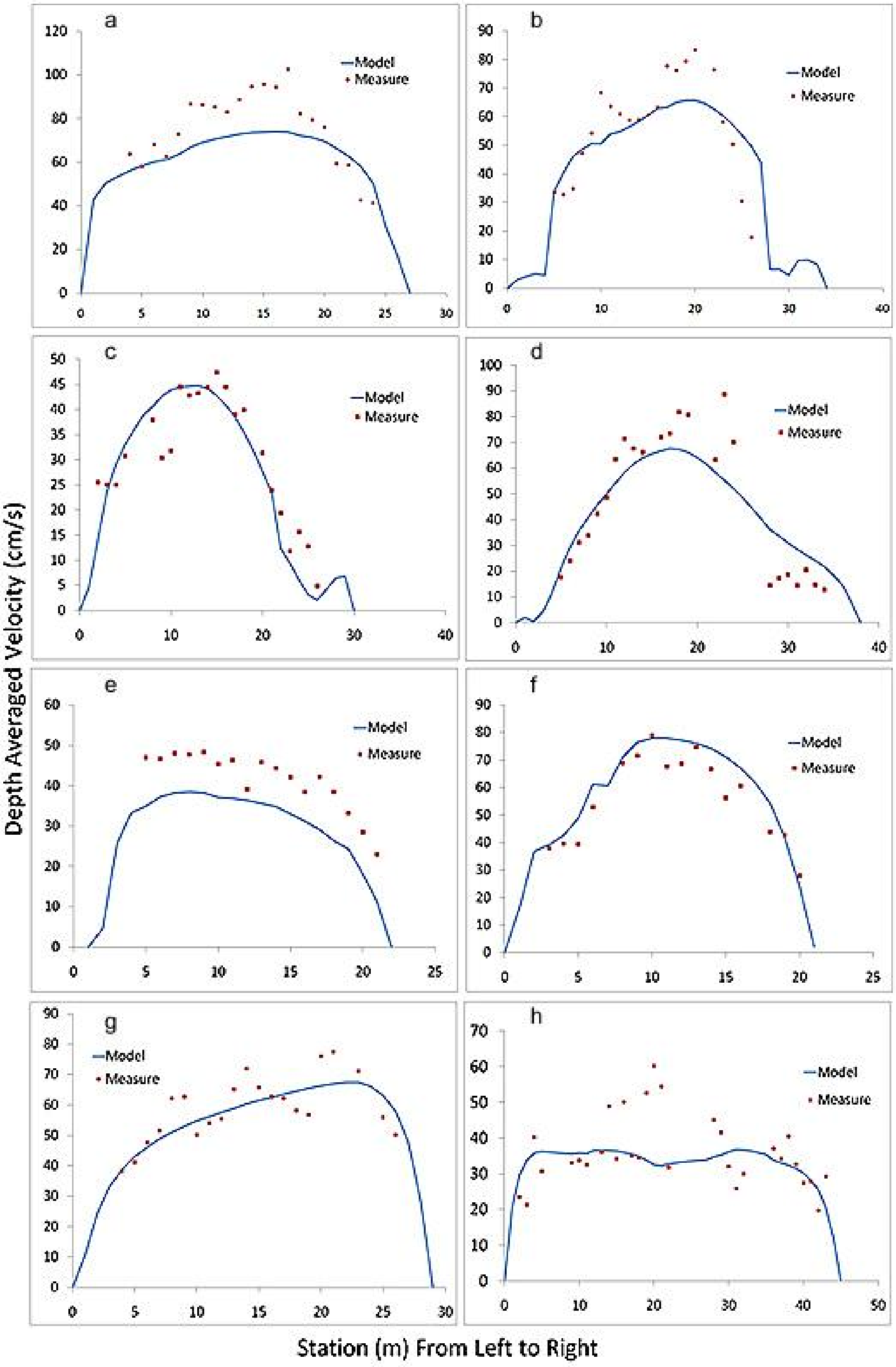

Figure E-17.—Charts of modeled and measured velocity. Values of the mean friction velocity over the measured portion of the cross section are shown: (a) KF segment (RK 89.0), 22.7 m^3/sec (800 cfs); (b) KF segment (RK 78.7), 22.7 m^3/sec (800 cfs); (c) OB segment (RK 77.6), 7.8 m^3/sec (275 cfs); (d) OB segment (RK 77.6), 21.8 m^3/sec (770 cfs); (e) JM segment (RK 45.7), 7.1 m^3/sec (251 cfs); (f) JM segment (RK 46.5), 22.7 m^3/sec (800 cfs); (g) RP segment (RK 1.7), 19.8 m^3/sec (699 cfs); and (h) RP segment (RK 0.2), 19.8 m^3/sec (699 cfs).

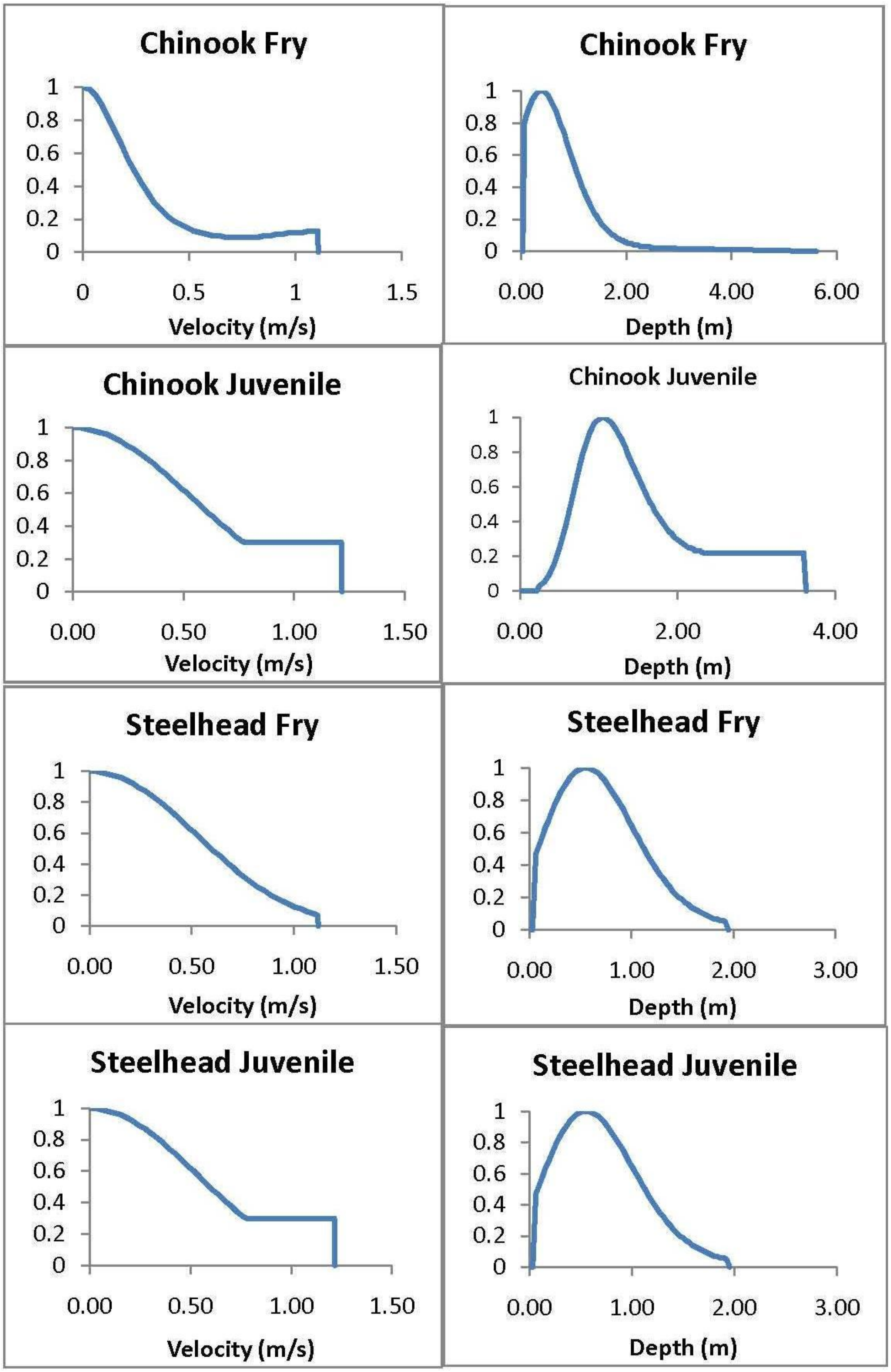

Figure E-18.—Habitat suitability criteria for the Yuba River. Constructed from data in Gard, 2008).

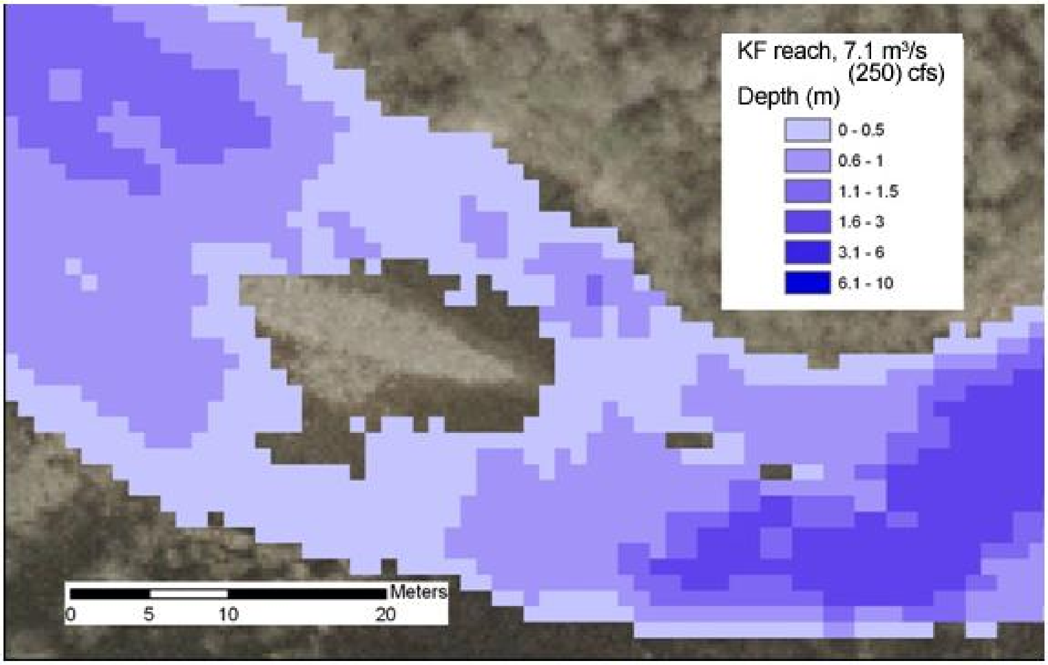

Figure E-19.—Example of a depth raster in the Knights Ferry reach.

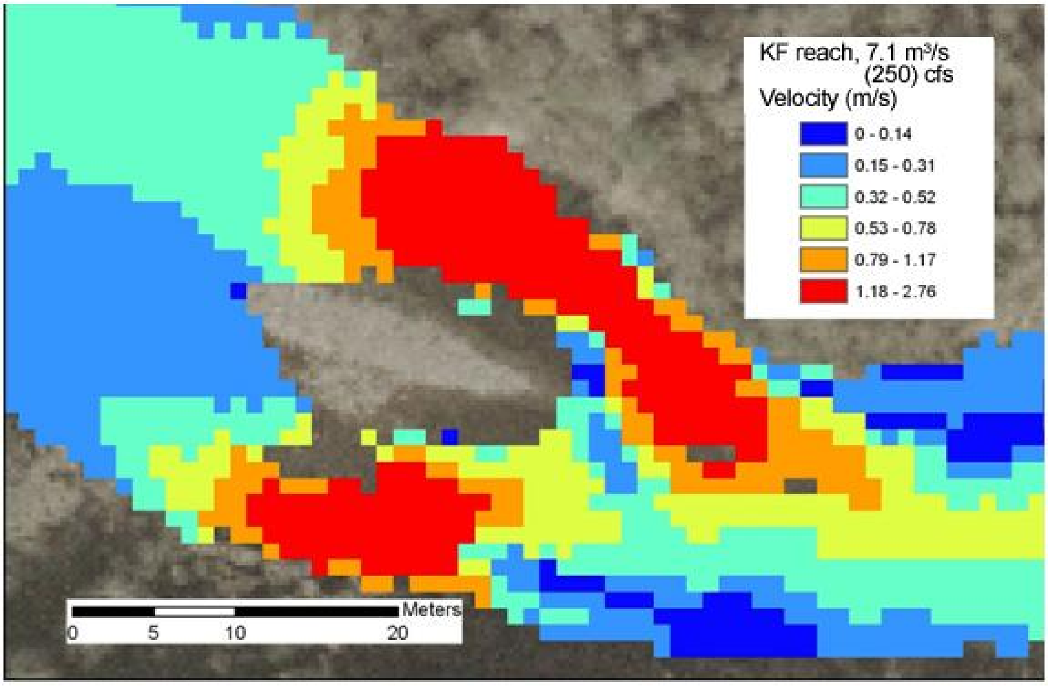

Figure E-20.—Example of a velocity raster in the Knights Ferry reach.

respectively. For distances greater than 2 m from the wetted edge, a HSI value of 0.6 is assigned. This determination is based on 88 observations on the Stanislaus River. The Distance to Edge habitat suitability curve is shown in figure E-21. An example of the distance to edge raster is shown in figure E-22. During the observations, a significant number of fry and juvenile salmonids were observed up to 13 m from the wetted edge, which represents approximately half the channel width of a large majority of the LSR. Based on this observation, it is assumed that the habitat value beyond two meters has a non-zero value across the channel until a 2 m distance-to-edge cell is reached on the opposite side of the channel.

Constructing a Velocity Shear Raster

Some researchers have begun to investigate hydraulic properties in adjacent cells as they pertain to aquatic habitat. Of particular interest is the velocity gradient, because drift feeding salmonids minimize energy expenditure by often swimming in low velocity regions and feeding in nearby higher velocity regions (Hayes and Jowett, 1994; Bowen, 1996). Crowder and Diplas (2000b) evaluated energy gradients related to energy expenditure of a fish moving from a region of lower to higher velocity. Adjacent velocity has also been evaluated for habitat value by Gard (2006), where the fastest velocity within a lateral distance of 0.6 m (orthogonal to the flow direction).

In this project the velocity shear is defined as:

$$V_s = \frac{(V_{max} - V_i)}{d}$$

where V_{max} is the maximum velocity in a 3 x 3 cell matrix surrounding the cell of interest, V_i (both in units of distance/time), and d is the distance between V_{max} and V_i (in units of length). The evaluation results in units of inverse time (s^{-1}). During the search for V_{max} all nine cells are included, such that the center cell could be V_{max}, which would result in a V_s equal to 0, also eliminating the possibility that V_s is negative. This methodology is used because it provides for the ability of a young salmonid to swim in a low-velocity area and feed in a higher-velocity area (Bowen, 1996) and we wished to incorporate this behavior into our habitat estimates. Habitat suitability curve for velocity shear is shown in figure E-21.

We requested a review of this velocity shear methodology from published researchers in the field of salmonid habitat estimation. T hey confirmed that no known velocity shear habitat suitability curve exists. They also confirmed that this method was a reasonable theoretical approach. Our reviewers of the velocity shear methodology were: David Geist, Pacific Northwest National Laboratory, Richland, WA; Ken Tiffan, USGS' Western Fisheries Research Center, Cook, WA; and John Williams, Independent Consultant and Former Executive Director of the Bay-Delta Modeling Forum, Davis, CA.

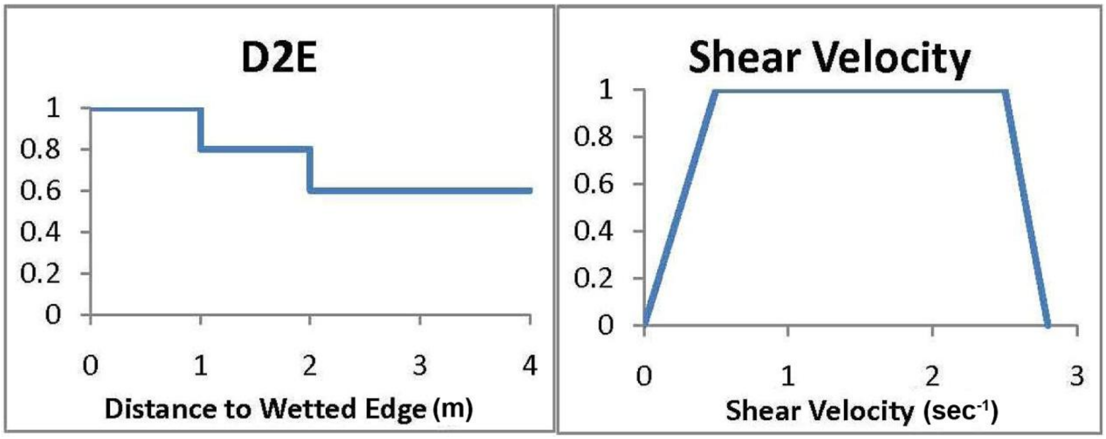

Figure E-21.—Habitat curves developed for this study for Distance to Edge (D2E) and Shear Velocity.

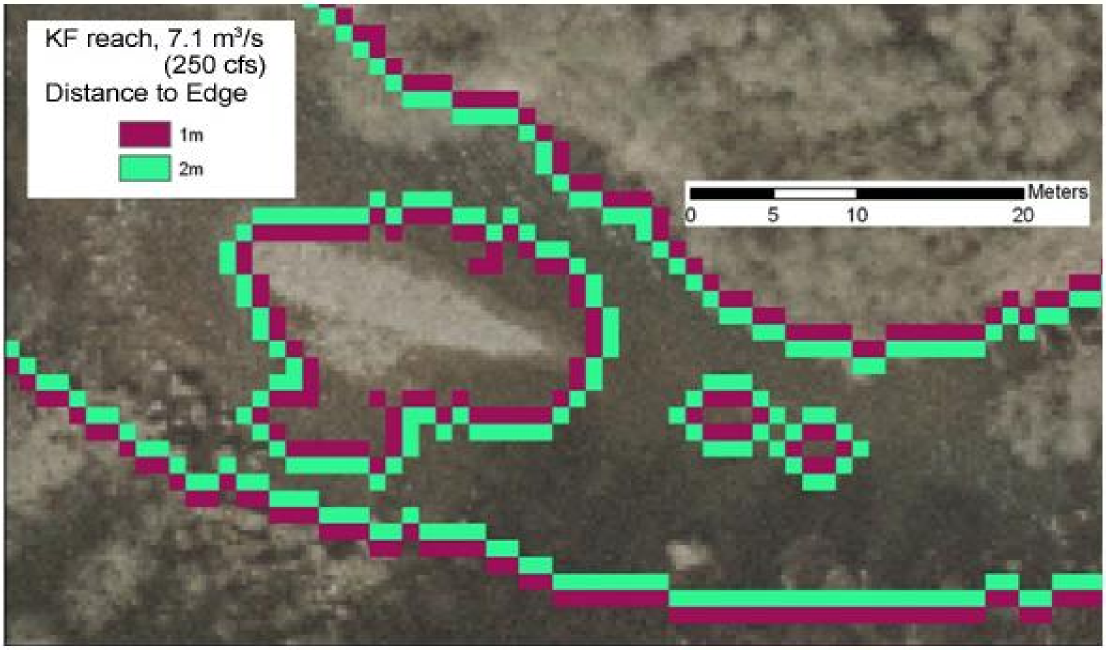

Figure E-22.—Example of a distance to edge raster in the Knights Ferry segment.

Using a remap table in Arc GIS, V_S values are then remapped to fit the values defined in the SI curves shown in figures E-18 and E-21). An example of a velocity shear raster is shown in figure E-23.

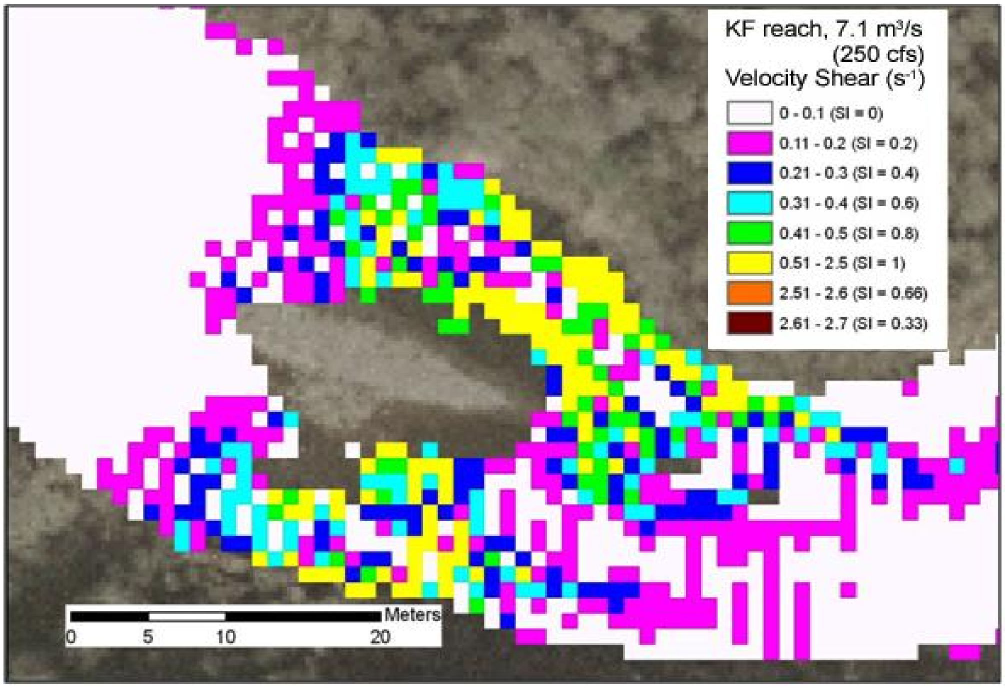

Figure E-23.—Example of a velocity shear raster in the Knights Ferry segment.

Constructing Habitat Suitability Index Rasters for Habitat Analysis

The remapping of the four rasters uses conditional statements to match the piecewise functions of each habitat attribute in the composite. A composite suitability index (CSI) raster is then created, from which suitable habitat is evaluated. The CSI is evaluated as

$$CSI = HSI_{vel} * HSI_{dep} * HSI_{d2e} * HSI_{she}$$

where *HSI is the Habitat Suitability Index value,* and the subscripts are; *vel* = velocity, *dep* = depth, *d2e* = distance to edge, and *she* = velocity shear.

Discussion

The channel morphology in the Stanislaus River is such that increased discharge does not greatly increase wetted area when comparing the range of discharges evaluated for this study (7.1 m^3/sec to 42.5 m^3/sec [250 to 1,500 cfs]). At 42.5 m^3/sec (1,500 cfs) discharges are largely, if not completely, contained within the banks. Some off channel habitat is created at 42.5 m^3/sec (1501 cfs), primarily in the KF reach, for example near Honolulu Bar downstream of Horseshoe Park (figure E-1). Increases in top width with increasing discharge are less prevalent closer to the mouth than nearer the headwaters. Table E-7 shows the increase in wetted area when comparing the range of discharges used in this study (7.1 and 42.5 m^3/sec [250 and 1,500 cfs]). In this study, increases in suitable habitat follow a similar trend to increases in wetted area.

Table E-7.—Table showing the increase in wetted area for the LSR comparing 7.1 m^3/sec (250 cfs) and 42.5 m^3/sec (1,500 cfs)

Reach	Increase in wetted area
Knights Ferry (KF)	38%
Orange Blossom (OB)	31%
Jacob Meyers (JM)	30%
Ripon (RP)	25%

ACKNOWLEDGEMENTS

The project would like to acknowledge the contributions of several people who provided valuable assistance throughout this project. Kurt Wille produced the HSI model that creates habitat rasters. He also provided tremendous advice regarding GIS through many discussions. Travis Bauer and Kent Collins assisted with Reclamation's boat surveys. Travis also assisted with the post-processing of the survey data using AdMap. Mike Sixta and Kendra Russell assisted with GIS digitization of water lines. Mike also constructed one of the model meshes and performed the model runs for the sensitivity analysis.

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Appendix F

Bed Topography of River2D Study Sites on the Stanislaus River

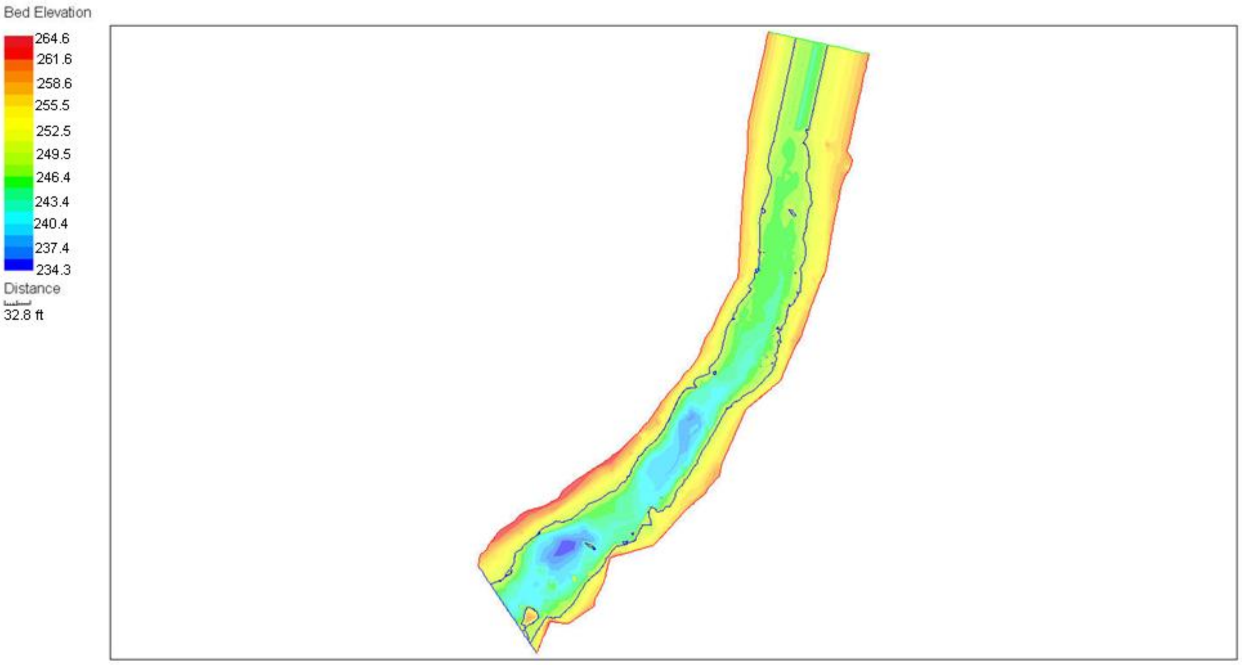


Figure F-1.—Bed topography of Two-mile Bar Recreation Area site.

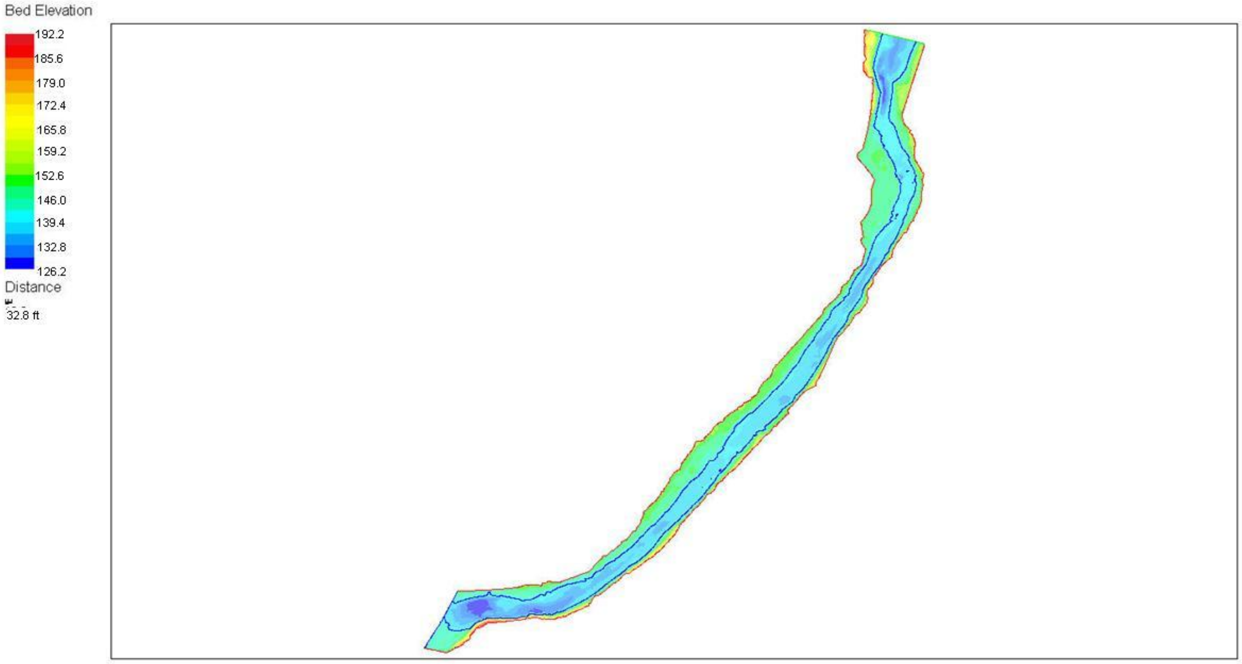


Figure F-2.—Bed topography of Horseshoe Recreation Area study site.

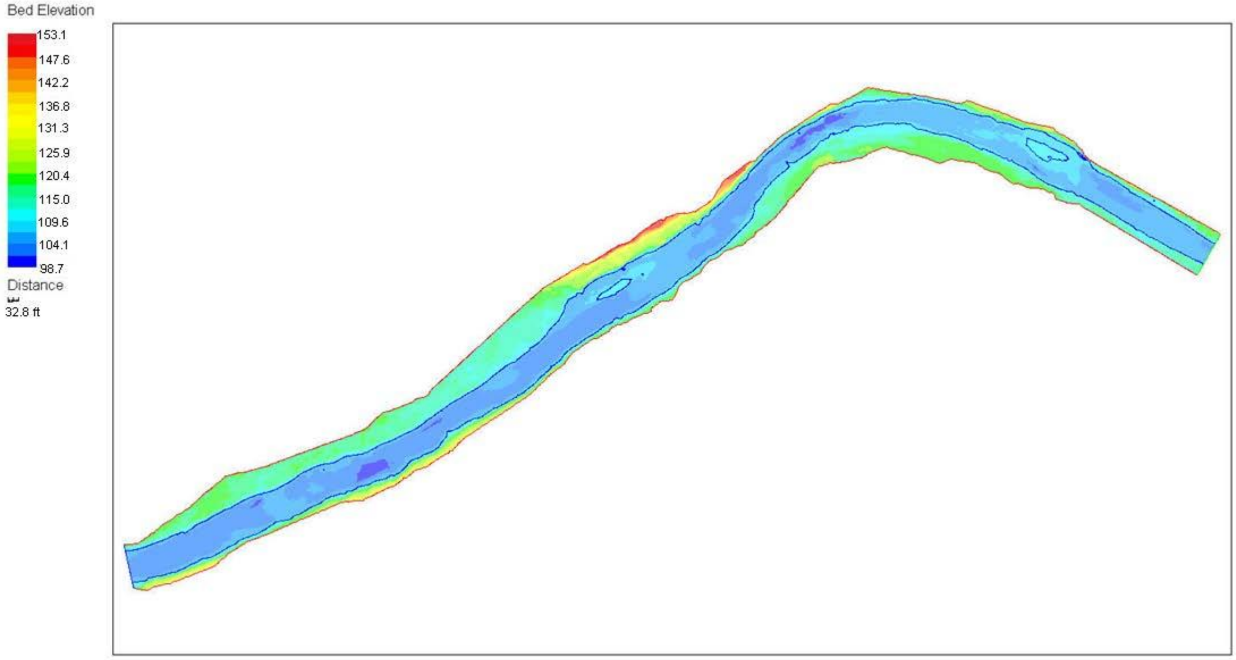


Figure F-3.—Bed topography of Valley Oak Recreation Area site.

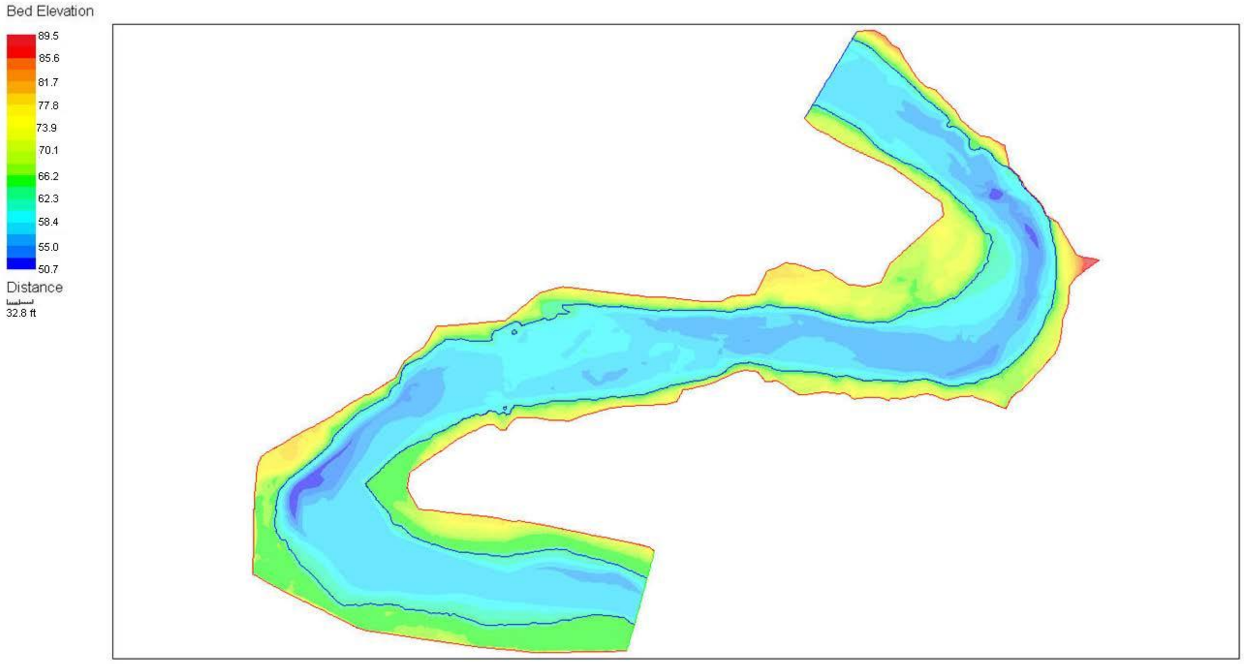


Figure F-4.—Bed topography of McHenry Recreation Area site.

Appendix G

Weighted Usable Area

River2D

Table G-1.—Two-mile Bar study segment A weighted usable area

Flows (cfs)	Chinook fry (ft^2)	Chinook juvenile (ft^2)	*O. mykiss* fry (ft^2)	*O. mykiss* juvenile (ft^2)
250	45,012	29,578	51,856	30,204
300	48,665	31,959	52,329	32,238
400	49,611	34,953	50,465	35,323
500	49,646	33,726	49,146	35,236
600	52,265	33,700	50,169	36,069
700	53,121	34,079	51,725	37,292
800	53,878	34,349	53,189	38,470
1,000	54,749	34,630	54,803	40,092
1,100	55,798	35,173	55,161	40,602
1,200	58,969	35,862	57,088	41,500
1,400	59,199	36,830	56,892	42,756
1,500	60,509	37,113	57,788	43,583

Table G-2.—Knights Ferry (KF) study segment 1 weighted usable area

Flows (cfs)	Chinook fry (ft^2)	Chinook juvenile (ft^2)	*O. mykiss* fry (ft^2)	*O. mykiss* juvenile (ft^2)
250	195,095	86,335	166,554	96,057
300	173,634	96,091	164,483	100,838
400	163,130	109,643	157,926	111,425
500	157,316	115,804	150,224	114,734
600	153,060	116,971	144,566	115,633
700	148,694	119,709	139,053	116,768
800	144,327	121,510	133,842	116,817
1,000	140,255	123,228	125,804	115,399
1,100	138,349	123,206	122,973	114,342
1,200	136,619	122,692	120,250	112,852
1,400	137,862	119,761	116,934	108,454
1,500	139,210	118,466	116,197	107,219

Table G-3.—Orange Blossom (OB) study segment 2 weighted usable area

Flows (cfs)	Chinook fry (ft^2)	Chinook juvenile (ft^2)	*O. mykiss* fry (ft^2)	*O. mykiss* juvenile (ft^2)
250	535,376	295,532	414,417	337,523
300	518,707	322,371	419,782	358,654
400	483,341	362,398	421,055	386,842
500	464,326	387,233	413,882	396,620
600	423,420	401,632	403,922	405,056
700	398,053	408,508	390,670	402,934
800	378,407	409,133	375,933	394,966
1,000	359,876	408,039	363,930	387,828
1,100	344,795	406,269	353,440	381,789
1,200	319,035	393,083	321,971	355,918
1,400	297,490	373,315	294,486	330,090
1,500	291,861	358,312	284,860	319,796

Table G-4.—Jacob Meyers (JM) study segment 3 weighted usable area

Flows (cfs)	Chinook fry (ft^2)	Chinook juvenile (ft^2)	*O. mykiss* fry (ft^2)	*O. mykiss* juvenile (ft^2)
250	666,629	455,738	671,097	610,116
300	644,891	502,337	682,005	585,790
400	592,954	549,496	660,728	598,959
500	568,551	592,250	663,364	579,629
600	537,405	588,528	560,220	538,723
700	530,859	563,971	505,888	488,291
800	516,114	542,044	468,044	473,012
1,000	501,666	520,594	--	433,410
1,100	523,002	500,454	443,244	417,018
1,200	503,465	465,782	420,433	380,200
1,400	499,108	434,441	404,367	348,372
1,500	500,261	443,823	406,112	352,851

Table G-5.—Weighted usable area for study segments 1, 2, and 3 combined

Flows (cfs)	Chinook fry (ft^2)	Chinook juvenile (ft^2)	*O. mykiss* fry (ft^2)	*O. mykiss* juvenile (ft^2)
250	1,442,111	867,183	1,303,923	1,073,900
300	1,385,897	952,757	1,318,599	1,077,520
400	1,289,035	1,056,490	1,290,174	1,132,549
500	1,239,838	1,129,013	1,276,615	1,126,219
600	1,166,151	1,140,832	1,158,878	1,095,481
700	1,130,727	1,126,267	1,087,336	1,045,285
800	1,092,725	1,107,037	1,031,008	1,023,265
1,000	1,056,547	1,086,492	1,002,307	976,729
1,100	1,061,945	1,065,102	974,819	953,751
1,200	1,018,087	1,017,418	919,742	890,471
1,400	993,659	964,347	872,679	829,672
1,500	991,841	957,713	864,957	823,448

Table G-6.—Area of suitable habitat (ASH) for all life stages in the Stanislaus River using GIS modeling

Flow (cfs)	Chinook, fry			Chinook. juvenile			*O. mykiss*.fry			*O. mykiss*. juvenile		
	sq. m	sq. ft	% maximum	sq. m	sq. ft	% maximum	sq. m	sq. ft	% maximum	sq. m	sq. ft	% maximum
Segment 1 – Knights Ferry to Orange Blossom												
250	4,532	48,779	50	3,460	37,247	29	7,348	79,093	49	7,551	81,278	48
800	7,275	78,304	81	7,742	83,332	65	12,207	131,395	81	12,681	136,492	81
1,500	9,012	97,002	100	11,978	128,926	100	15,127	162,824	100	15,624	168,175	100
Segment 2 – Orange Blossom to Jacob Meyers												
250	12,155	130,836	85	9,349	100,631	47	19,981	215,075	92	20,303	218,536	93
800	13,472	145,011	94	12,950	139,387	65	21,496	231,380	99	21,828	234,959	100
1,500	14,362	154,591	100	19,964	214,886	100	21,635	232,878	100	21,917	235,917	100
Segment 3 – Jacob Meyer to confluence with San Joaquin												
250	18,217	196,083	60	11,890	127,986	29	25,410	273,512	57	25,429	273,711	56
800	29,652	319,175	98	24,862	267,608	61	42,955	462,361	96	42,982	462,654	95
1,500	30,248	325,590	100	40,842	439,620	100	44,965	484,000	100	45,023	484,624	100
Entire river (Segments 1–3)												
250	34,904	375,698	65	24,699	265,864	34	32,758	567,680	65	53,283	573,525	65
800	50,399	542,490	94	45,554	490,327	63	55,162	825,136	94	77,491	834,105	94
1,500	53,622	577,183	100	72,784	783,432	100	60,092	879,702	100	82,564	888,716	100

Appendix H

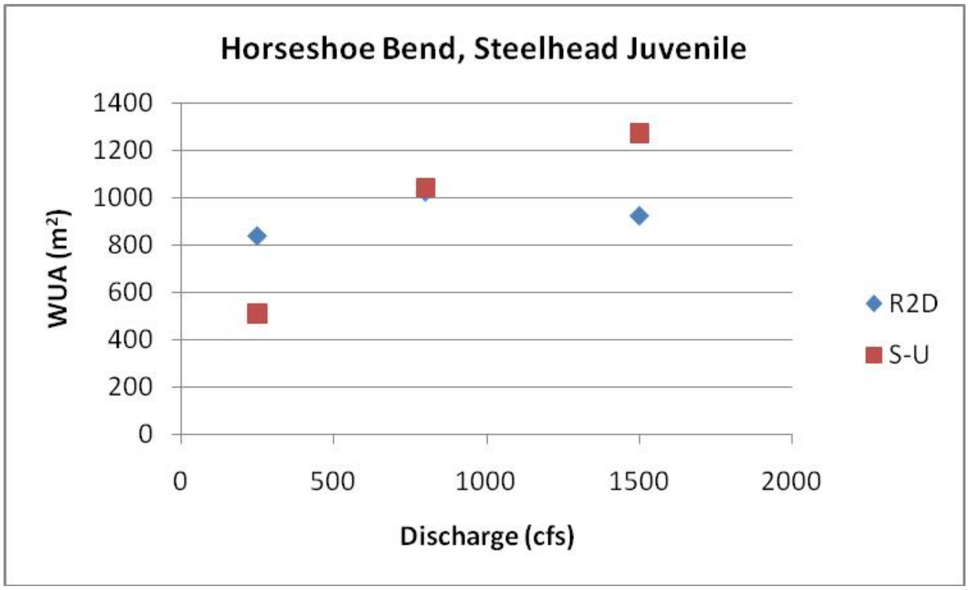
First Level Comparison of the River 2D and Scale-up Model Results

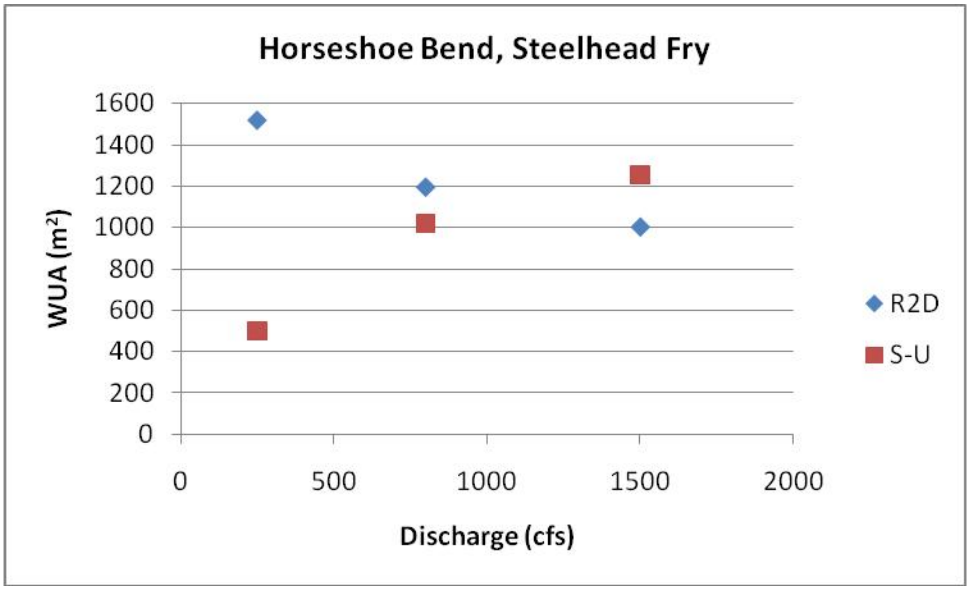
The first level comparison of the River 2D and the Scale-up model was to evaluate the same spatial area. The Scale-up results were trimmed to match the same spatial area that was modeled by River 2D. The idea was that, if the models match when the same spatial area (model footprint) is compared then there is a likely error in the extrapolation made with the River 2D results.

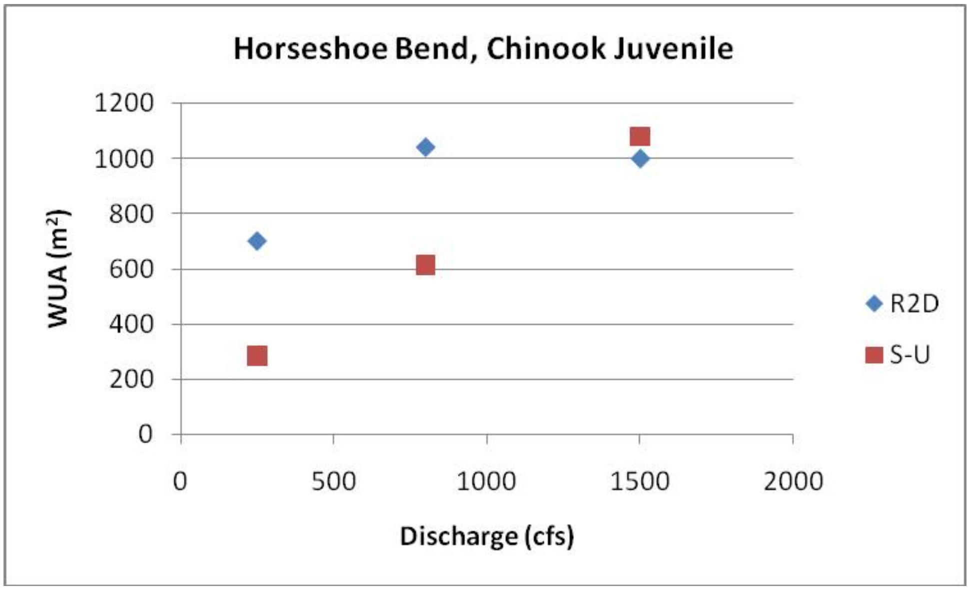
Habitat is defined as Weighted Useable Area (WUA), which is an equivalent calculation reported in the Area of Suitable Habitat (ASH) in Scale-up. Approximately 56 river miles were modeled for the Scale-up study. Approximately 1.6 river miles were modeled using the River 2D study. Results were then extrapolated to represent the entire 56-mile reach.

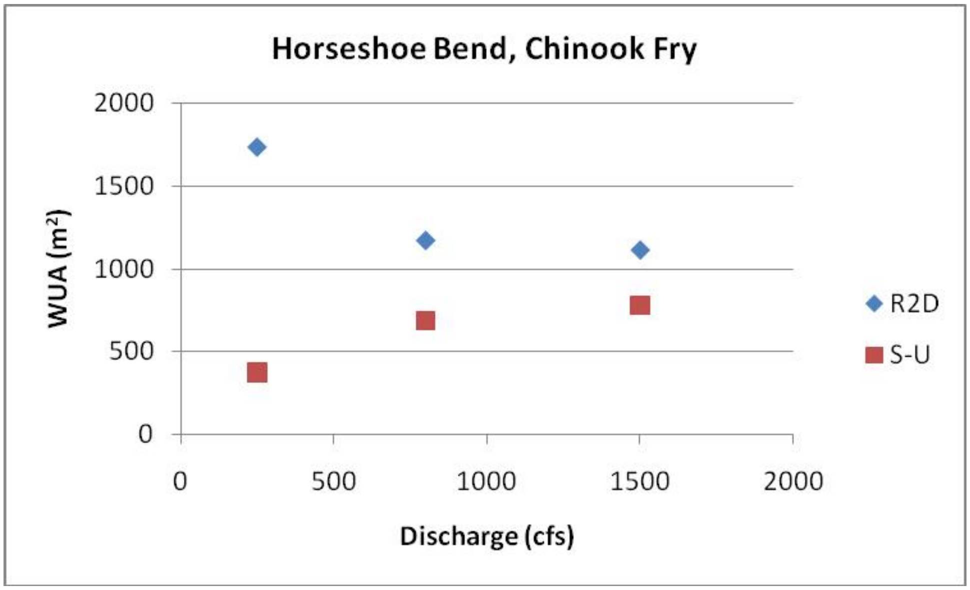
The results of the comparison were inconclusive (see tables below).

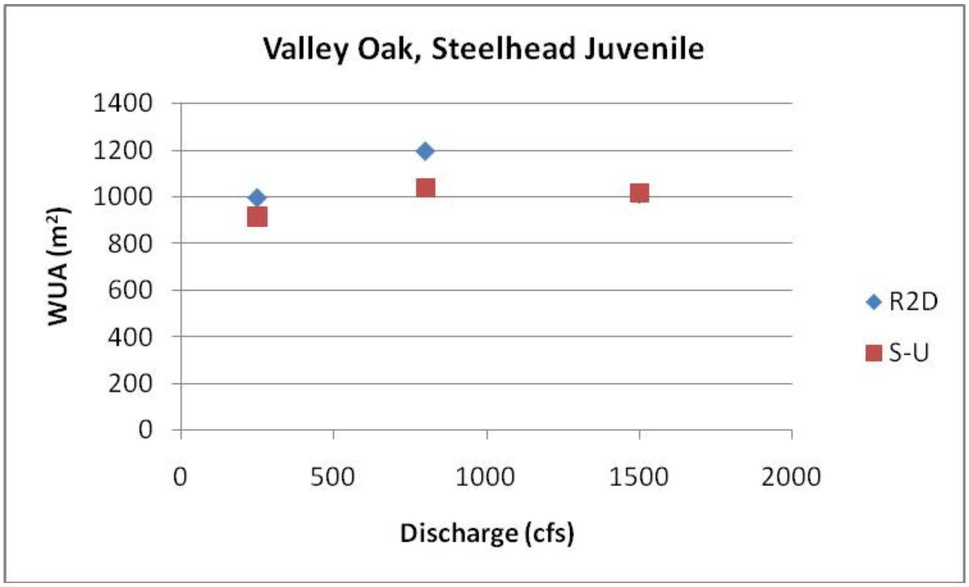
	River 2D results			Scale_up results			
Q (cfs)	Horseshoe Bend	Valley Oak	McHenry	Horseshoe Bend	Valley Oak	McHenry	
250	1737.1	1418.2	415.1	372.5	548.6	107.2	Chinook fry (m^2)
800	1171.7	1078.1	285.4	687.2	606.7	182.3	
1,500	1113.6	1113.6	279.2	779.6	625.1	156.9	
250	702.1	800.8	267.2	285.3	412.8	77.4	Chinook juvenile (m^2)
800	1040.5	1174.7	327.9	613	598.8	137.6	
1,500	999.6	1047.7	252.3	1081	908	261.8	
250	1519.3	1207.4	431.8	500.2	903.9	153.8	Steelhead fry (m^2)
800	1196.4	1101.5	280.2	1020.5	1024.8	248.7	
1,500	1004.6	930.3	236.5	1254.1	1004.5	255.1	
250	842	999.1	357.8	511.2	916.1	153.8	Steelhead juvenile (m^2)
800	1027.7	1198.8	278.2	1044.3	1039.3	248.7	
1,500	926.8	1014.9	199.1	1274.9	1017.7	255.3	

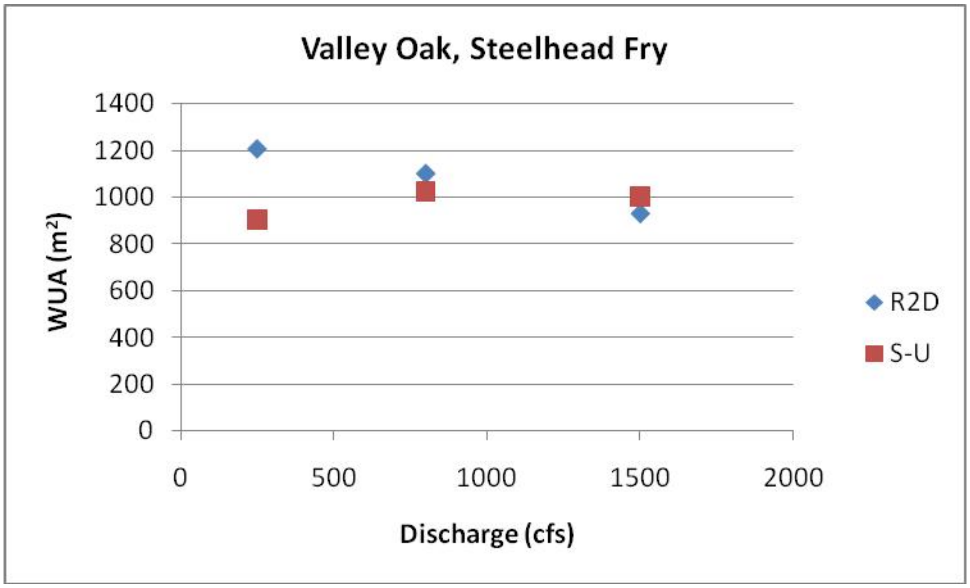

Horseshoe Bend, Steelhead Juvenile
WUA (m²)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

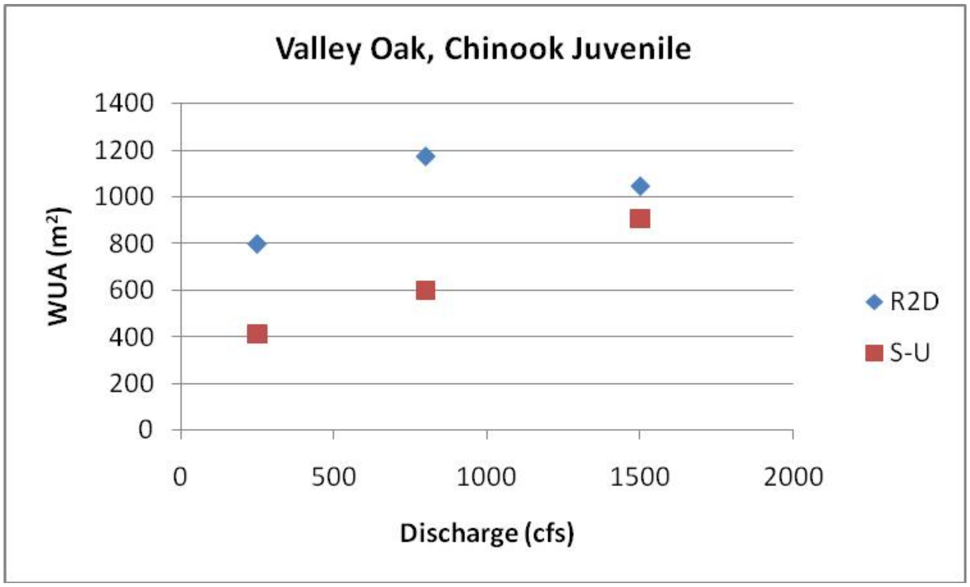

Horseshoe Bend, Steelhead Fry
WUA (m²)
1600
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

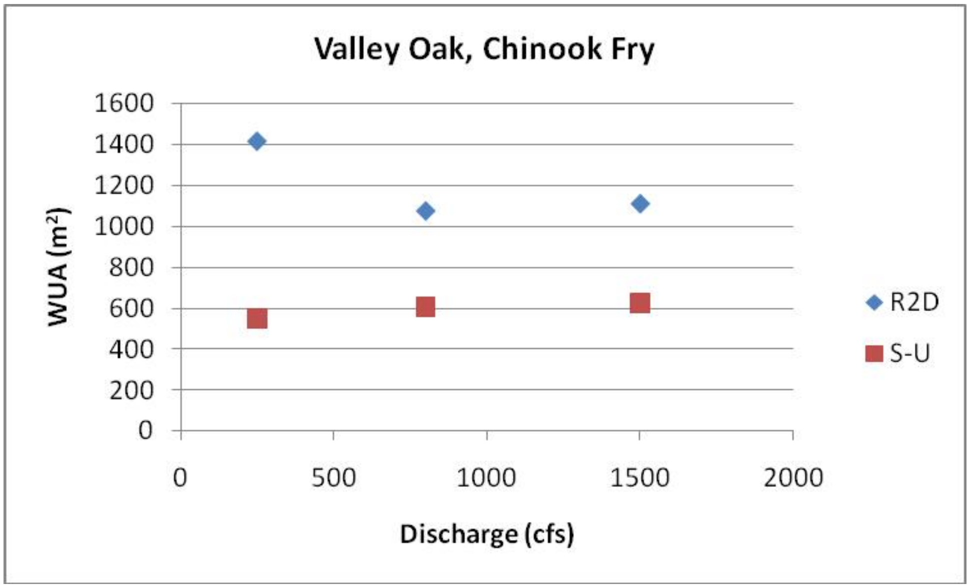

Horseshoe Bend, Chinook Juvenile
WUA (m²)
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U

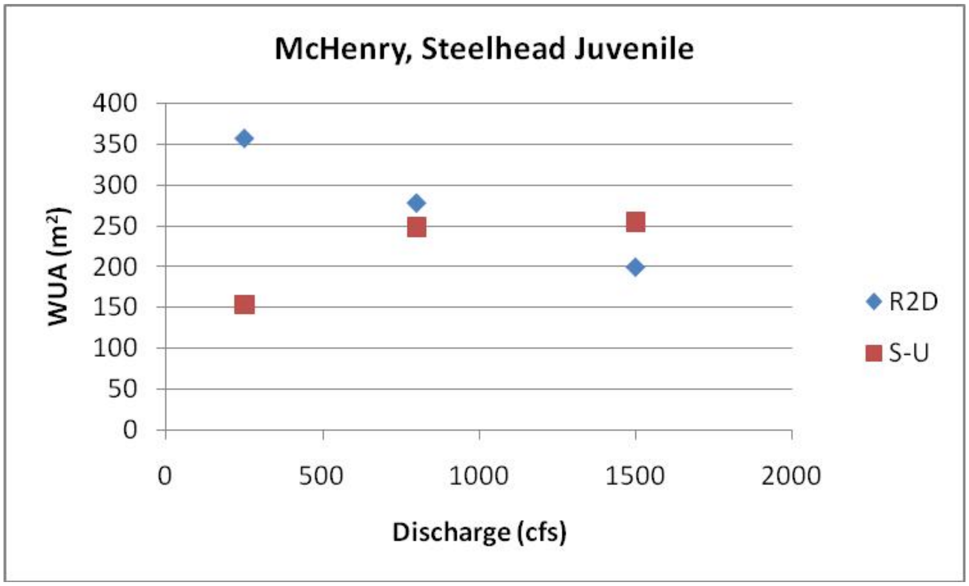

Horseshoe Bend, Chinook Fry
WUA (m²)
2000
1500
1000
500
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U

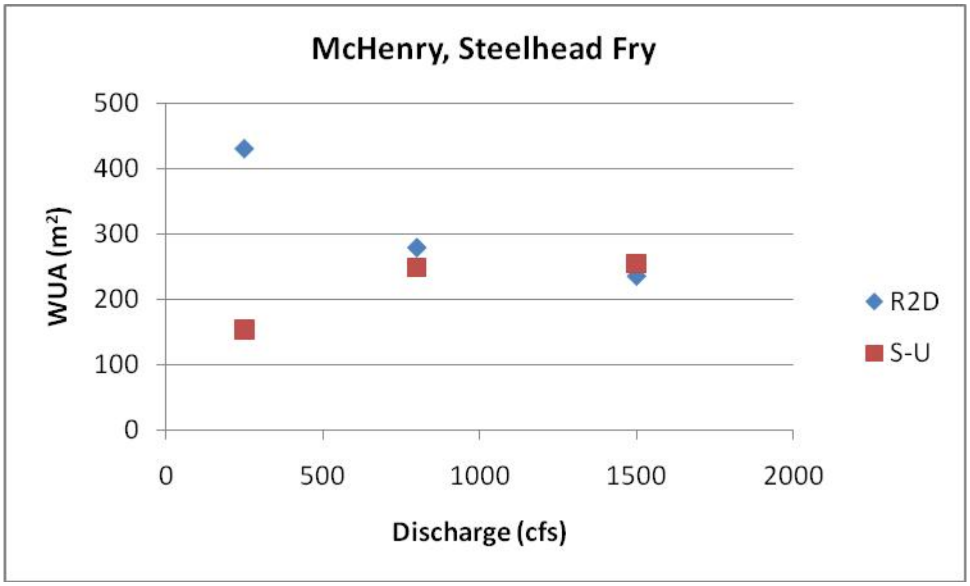

Valley Oak, Steelhead Juvenile
WUA (m²)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U

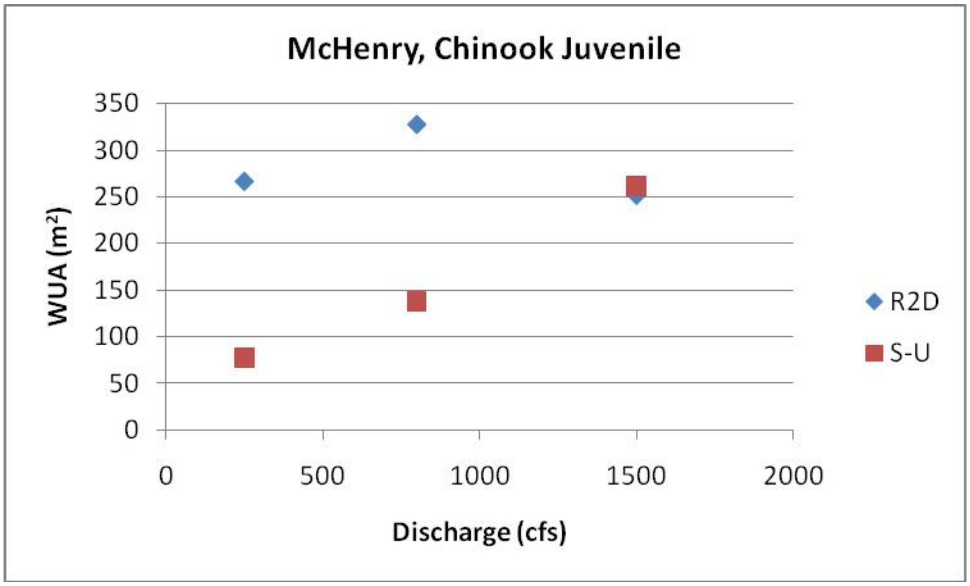

Valley Oak, Steelhead Fry
WUA (m²)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U

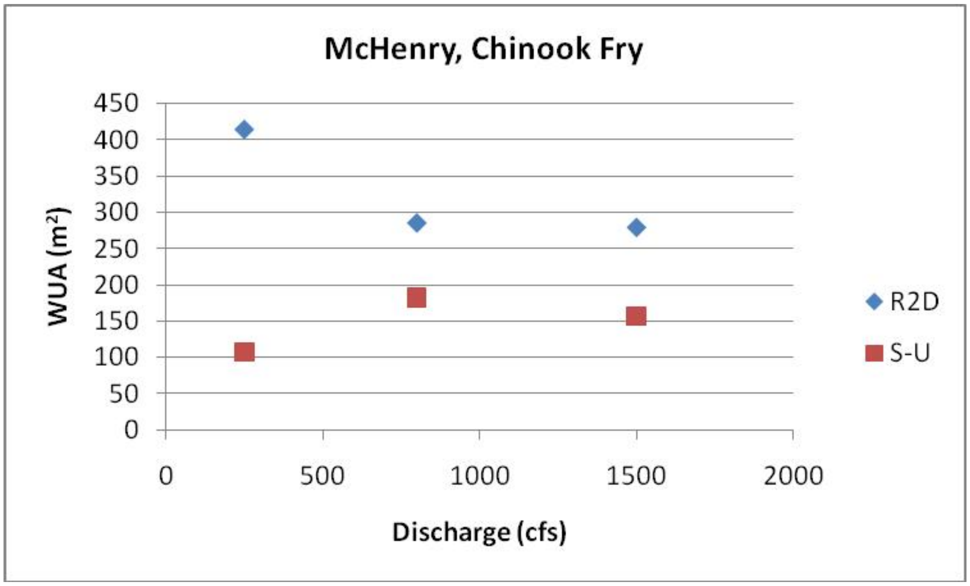

Valley Oak, Chinook Juvenile
WUA (m²)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U


Valley Oak, Chinook Fry
WUA (m²)
1600
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U


McHenry, Steelhead Juvenile
400
350
300
250
200
150
100
50
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U


McHenry, Steelhead Fry
500
400
300
200
100
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U


McHenry, Chinook Juvenile
WUA (m²)
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U


McHenry, Chinook Fry
WUA (m²)
450
400
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
Discharge (cfs)
◆ R2D
■ S-U

APPENDIX I

Biovalidation of the Stanislaus River Scale-Up Study Modeling results.

Date: July 10, 2012

by:
Robert C. Hilldale, MS, PE
Sedimentation and River Hydraulics Group
Bureau of Reclamation, Technical Service Center
Denver, CO

A biovalidation has been performed for habitat modeling on the Stanislaus River, documented in a draft report titled "Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids" (October, 2011). Although two methods of modeling habitat were used in this report, the following biovalidation was evaluated for the habitat modeling performed by Reclamation using the SRH-2D hydraulic model and Arc GIS. This modeling effort is referred to as 'scale-up' in the draft report, as opposed to the R2D (River 2D) methodology, also contained in the same report. Briefly, the River 2D methodology modeled salmonid habitat at three sites between Knights Ferry and the mouth of the Stanislaus River, extrapolating results from those three sites to the entire river. The Scale-Up study modeled habitat continuously from Knights Ferry to the mouth, a distance of approximately 56 river miles.

This Biovalidation uses fish data collected by the Fishery Foundation of California (FFC), June through July, 2008 (documented in Stanislaus River Salmonid Habitat Use Pilot Investigation, prepared for Reclamation by the FFC, ca. 2008). Fish data were collected such that densities of steelhead fry, steelhead juvenile, Chinook Fry, and Chinook juvenile were documented within mesohabitat polygons, mapped in the field by the FFC based on the presence or absence of an edge bordering the polygon, and binned velocity values (0 – 0.5 ft/s, 0.5 – 2 ft/s, and > 2 ft/s). The mesohabitat polygons were categorized as HVE, HVNE, MVE, MVNE, LVE, LVNE (e.g. High Velocity with Edge, Medium Velocity No Edge, etc.). An edge polygon is considered any habitat that falls within two meters of an object intersecting the water's surface, which includes the water's edge, overhanging vegetation, woody debris, boulders and human made objects such as bridge pilings and weirs.

The biovalidation was expected to yield both a qualitative and a quantitative analyses. However a meaningful quantitative analysis has eluded the author in the limited time available for the development of a solution. The following pages contain a qualitative biovalidation of the Scale-Up habitat modeling results using the mesohabitat polygons and fish density data collected by FFC.

Figure 1 is an example of the mesohabitat polygons used in this validation. In an effort to find a quantitative answer, fish density was plotted against the mean Composite Suitability Index (CSI) value ($CSI = HSI_{vel} * HSI_{depth} * HSI_{D2E} * HSI_{vs}$, where the subscript D2E refer to distance to edge and vs refers to velocity shear). These parameters were plotted against each other to produce a meaningless relationship (Figure 2). Perhaps a near future effort could involve a logistic regression to determine if predicted high quality habitat is correlated to locations of higher density fish populations. It has not been determined if such a correlation exists.

The qualitative biovalidation is contained in figures 3 – 11. Polygons containing fish at any density were plotted over predicted habitat for the appropriate species and life stage. Some polygons are not exactly coincident with the wetted perimeter of the model results. This can result from inexact terrain representation of the near bank topography or a mismatch in survey control used in the field study vs. the channel survey. It is likely that both instances are true.

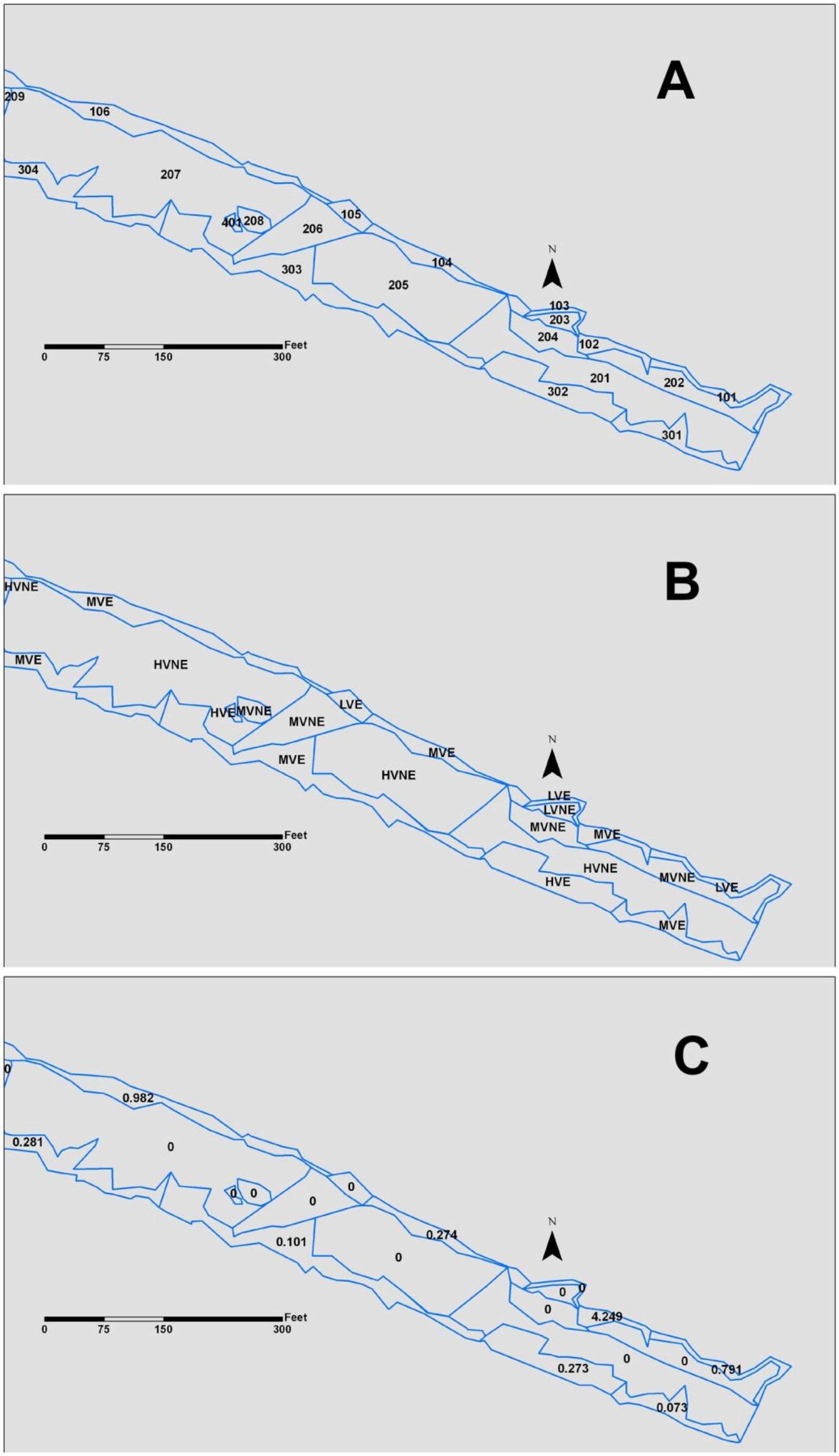


Figure 1: Example of a mesohabitat polygon mapped at Lovers Leap at 800 cfs. A – Mesohabitat ID number, B. – Mesohabitat type, C. – Density of Chinook juveniles.

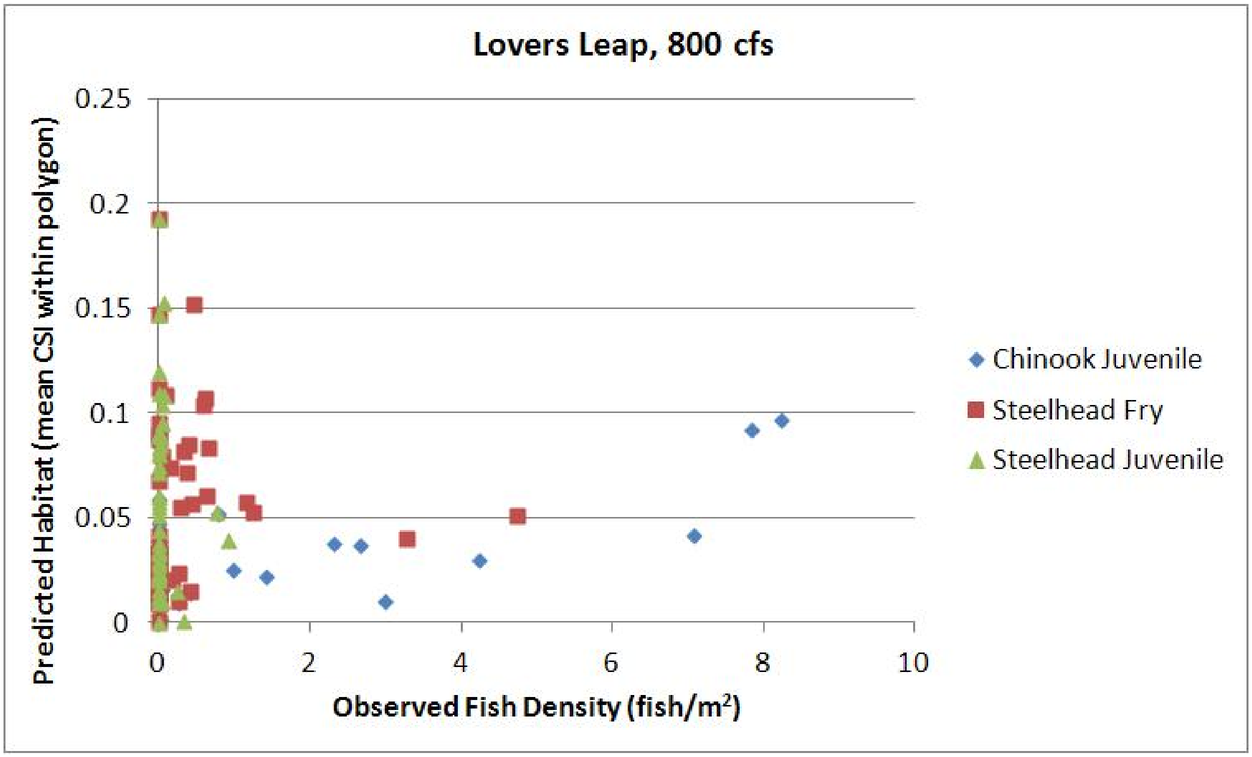


Figure 2: Plot of observed fish density vs. mean CSI value in each polygon.

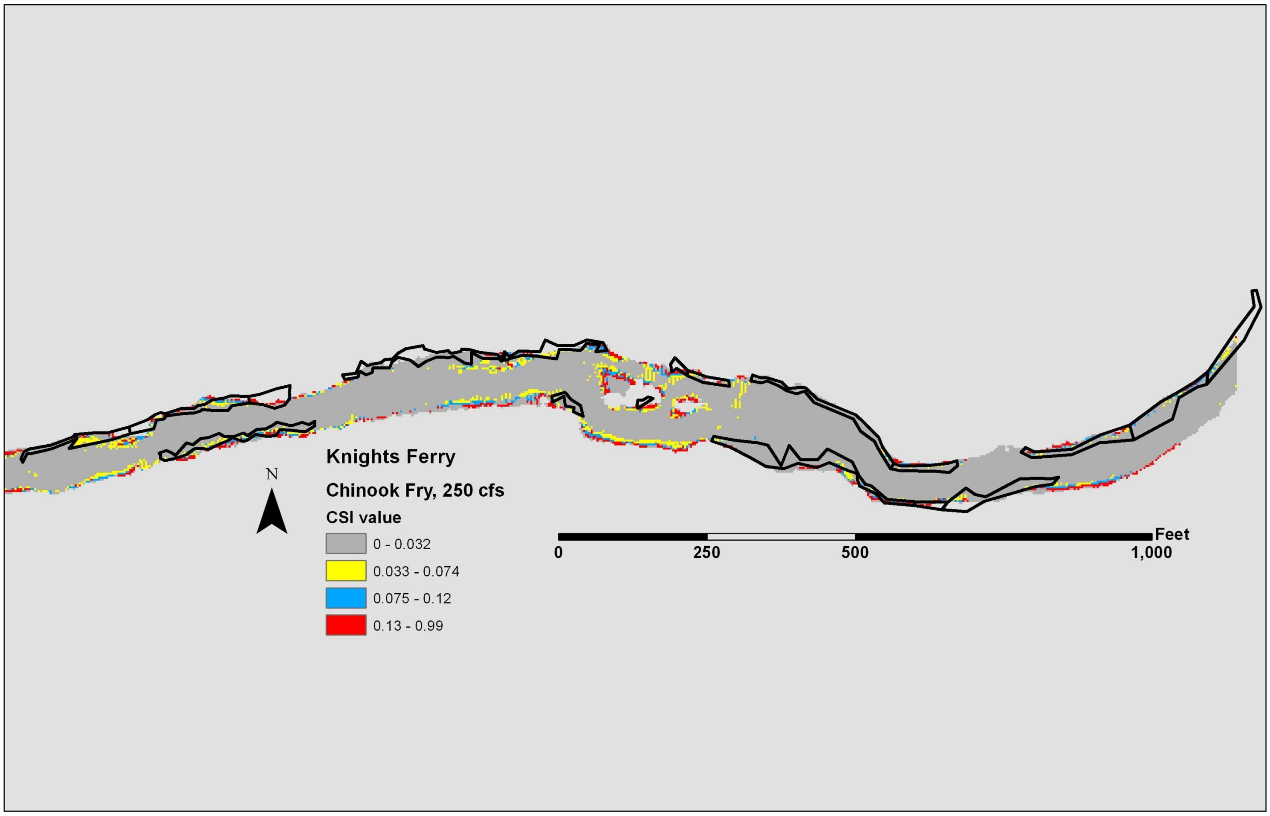


Figure 3: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

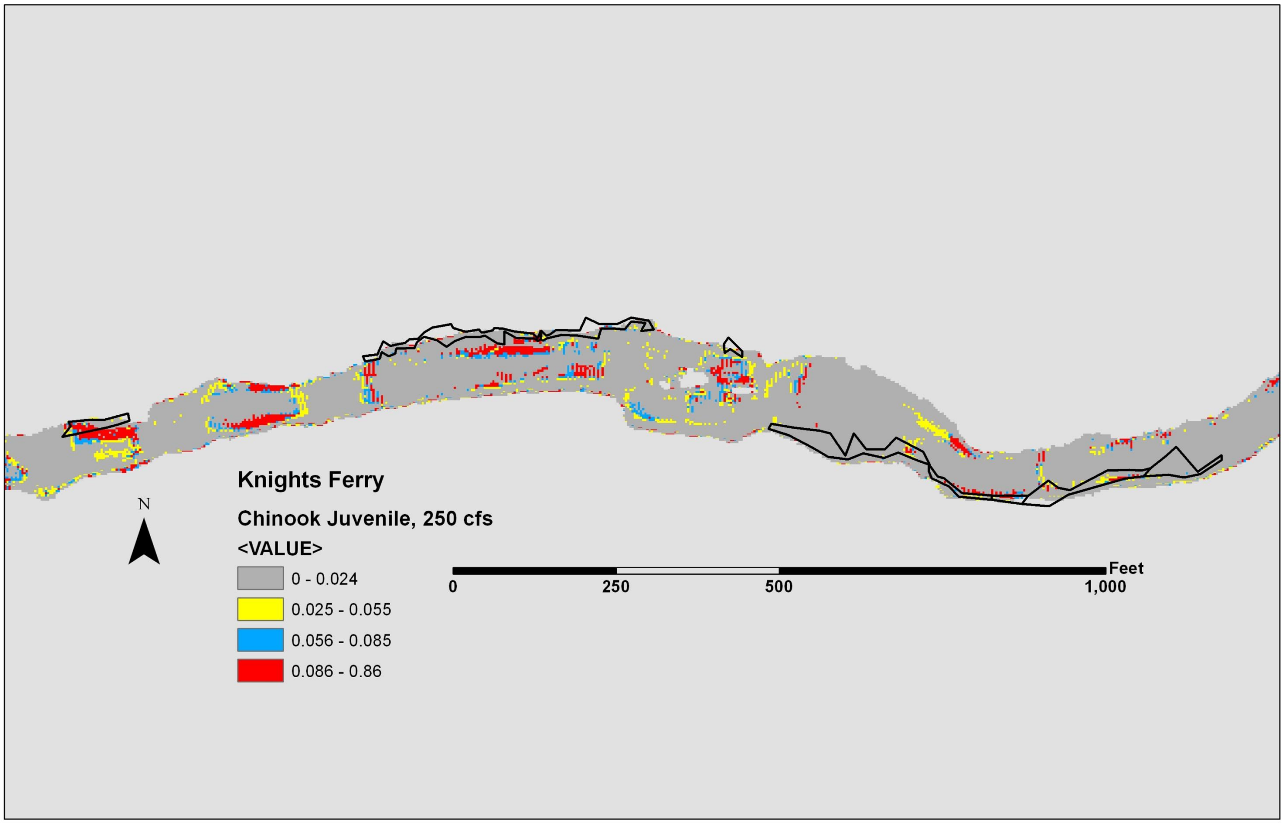


Figure 4: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

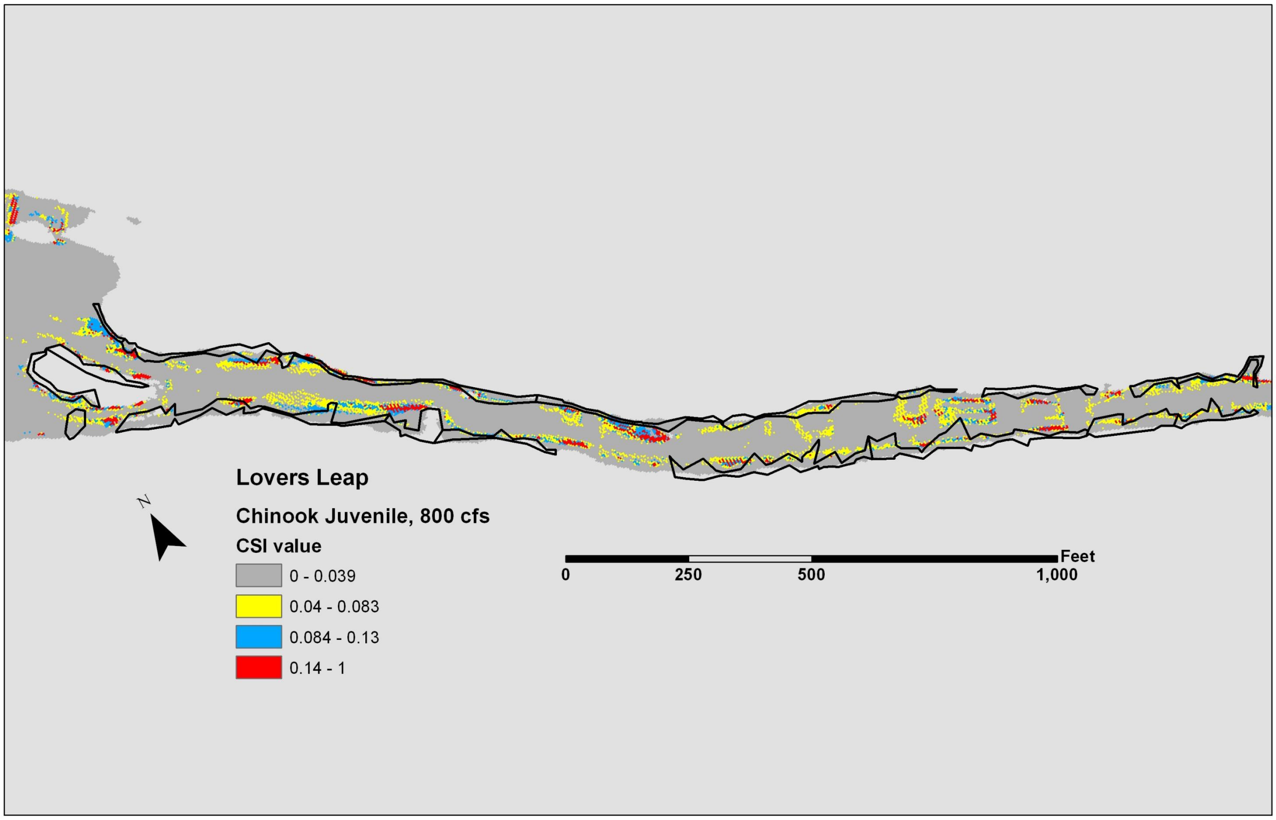


Figure 5: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

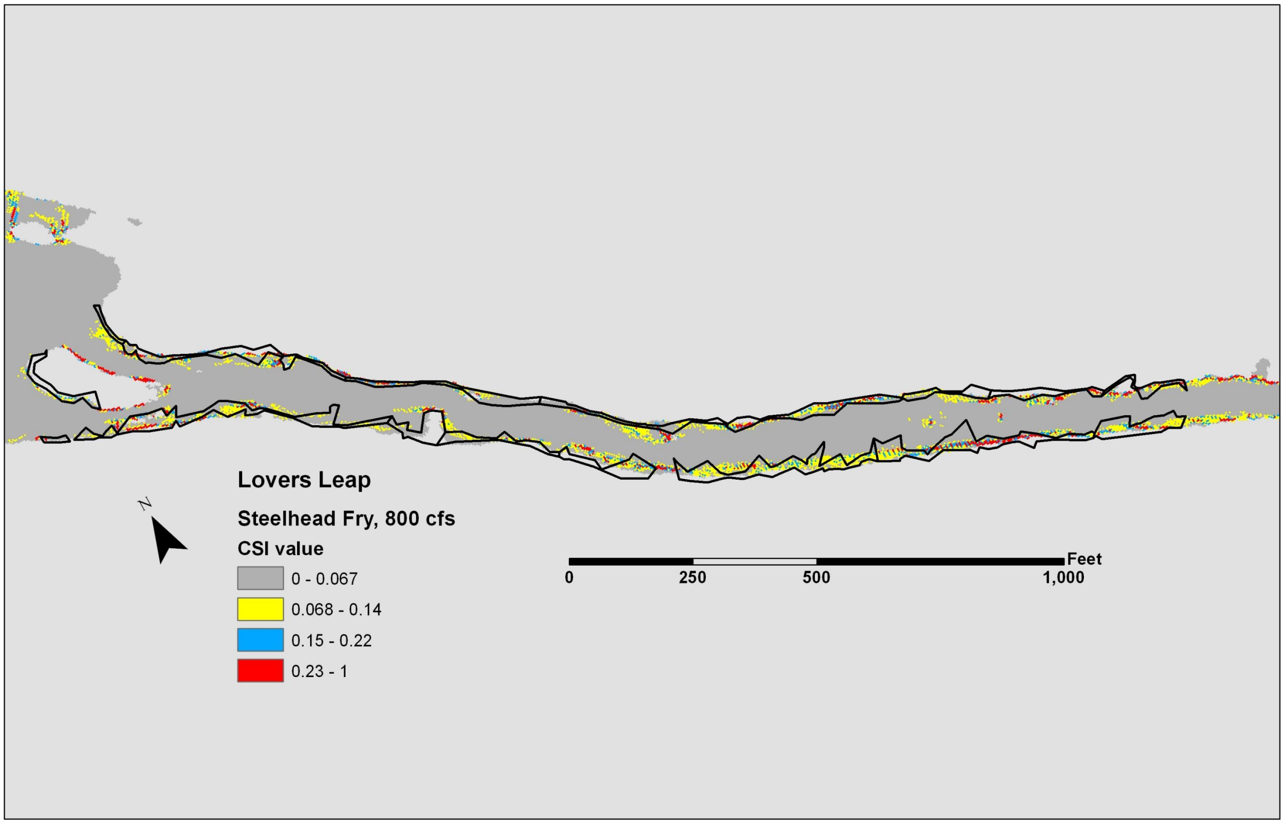


Figure 6: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

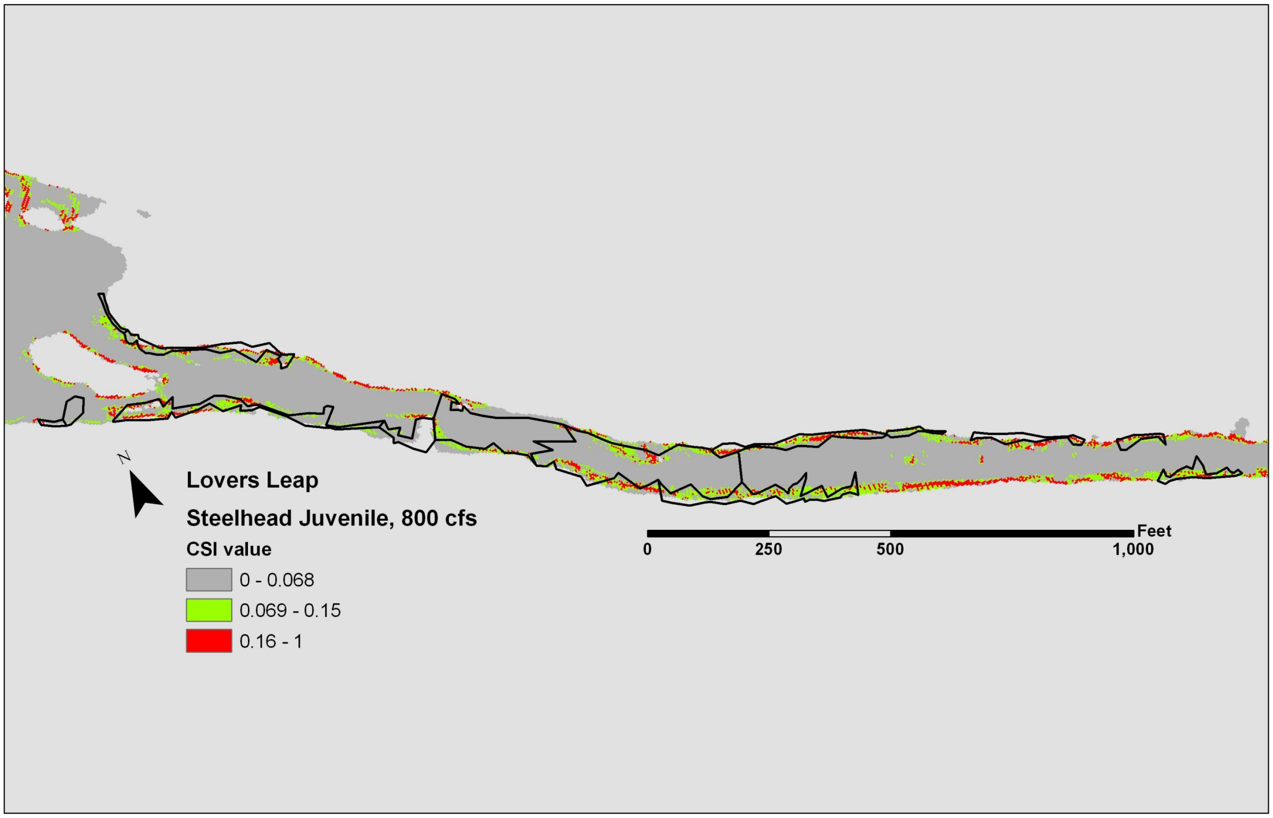


Figure 7: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

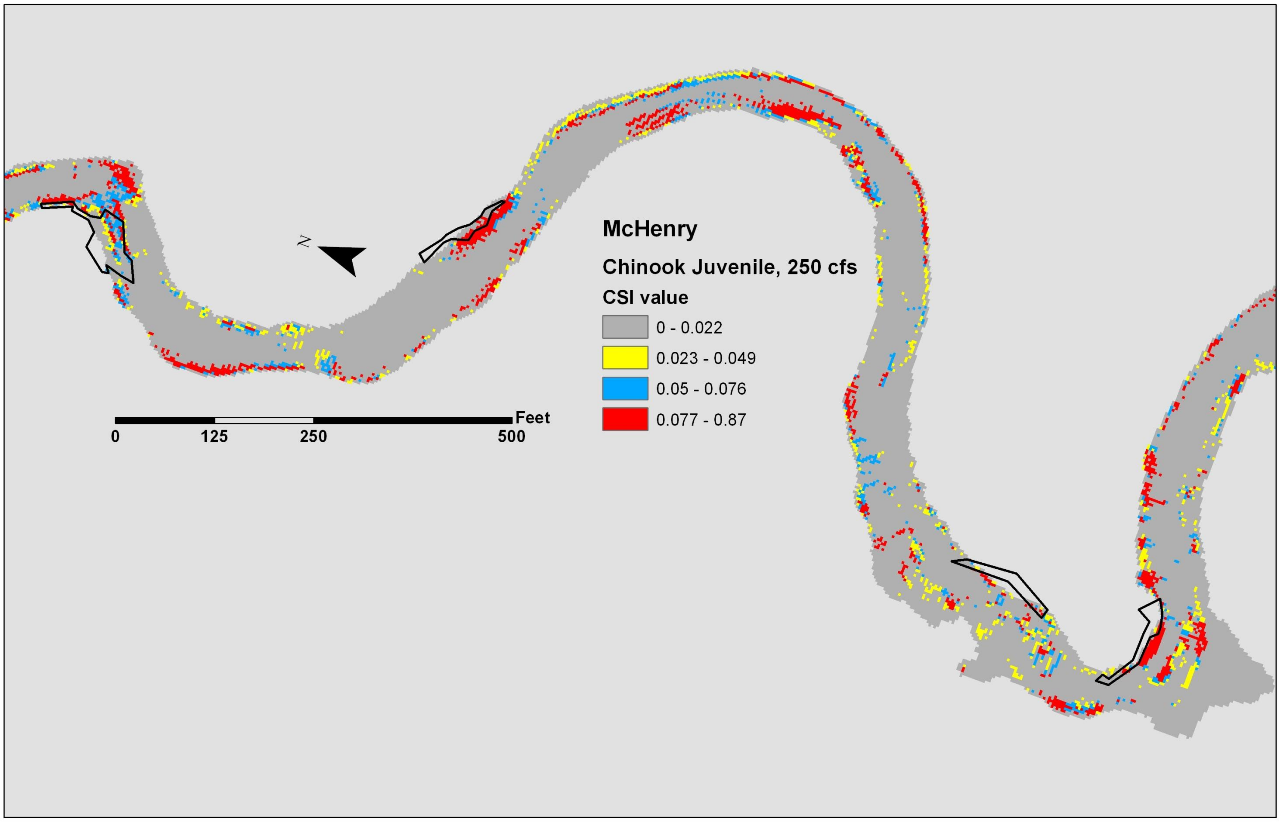


Figure 8: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

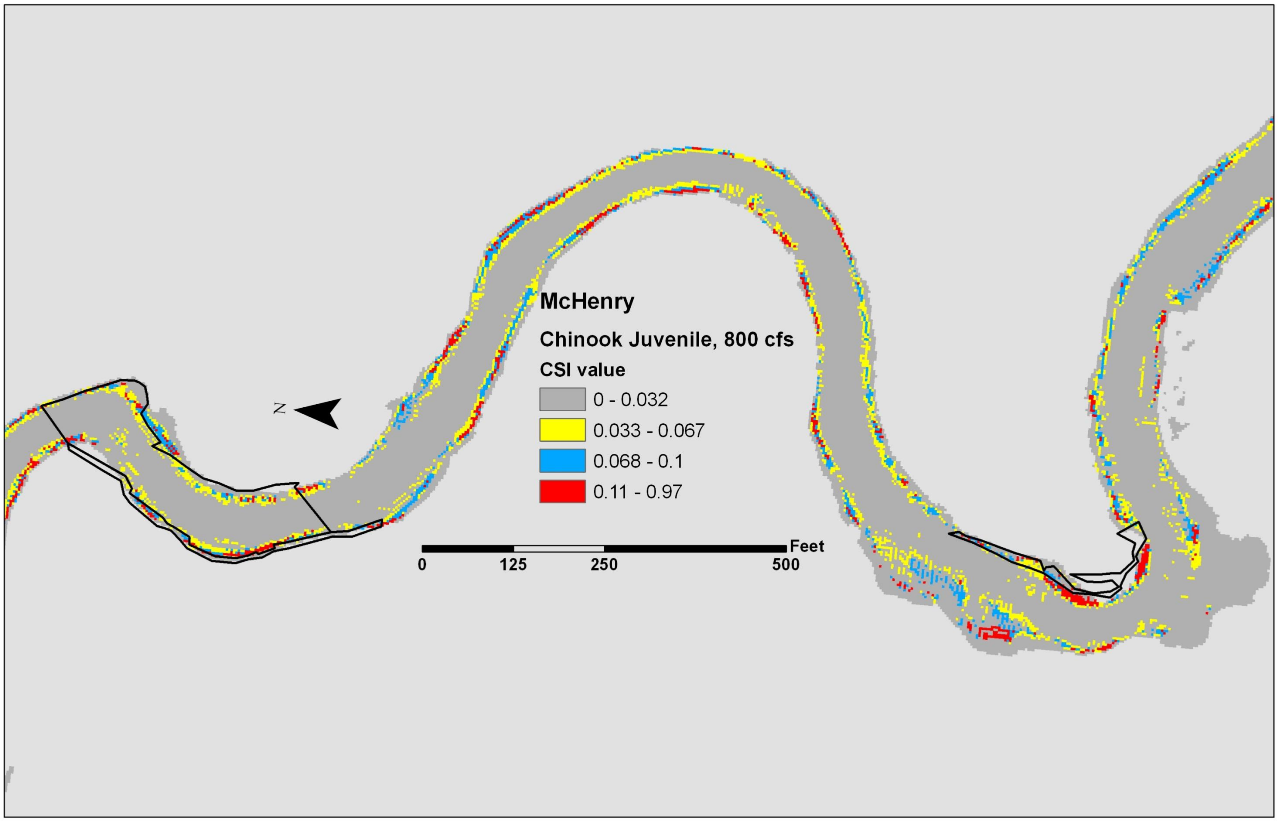


Figure 9: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

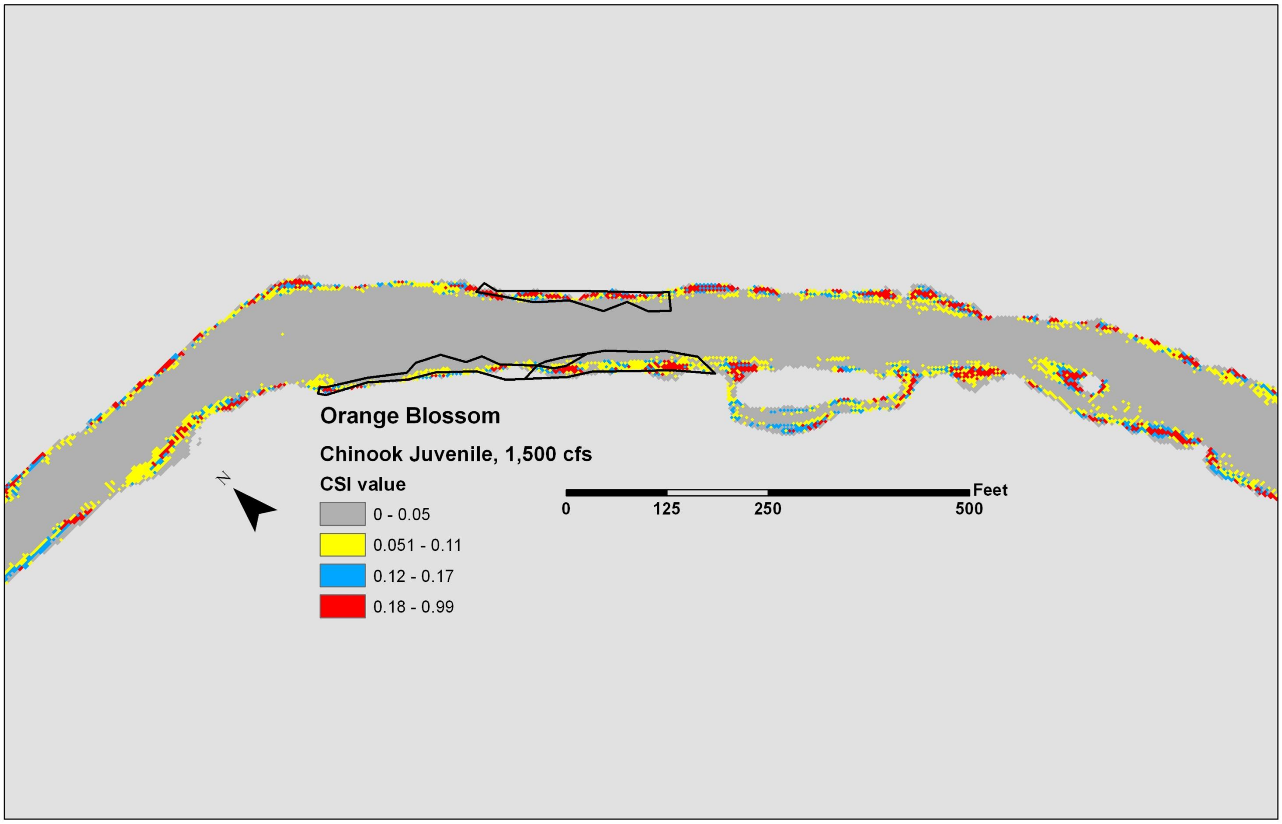


Figure 10: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

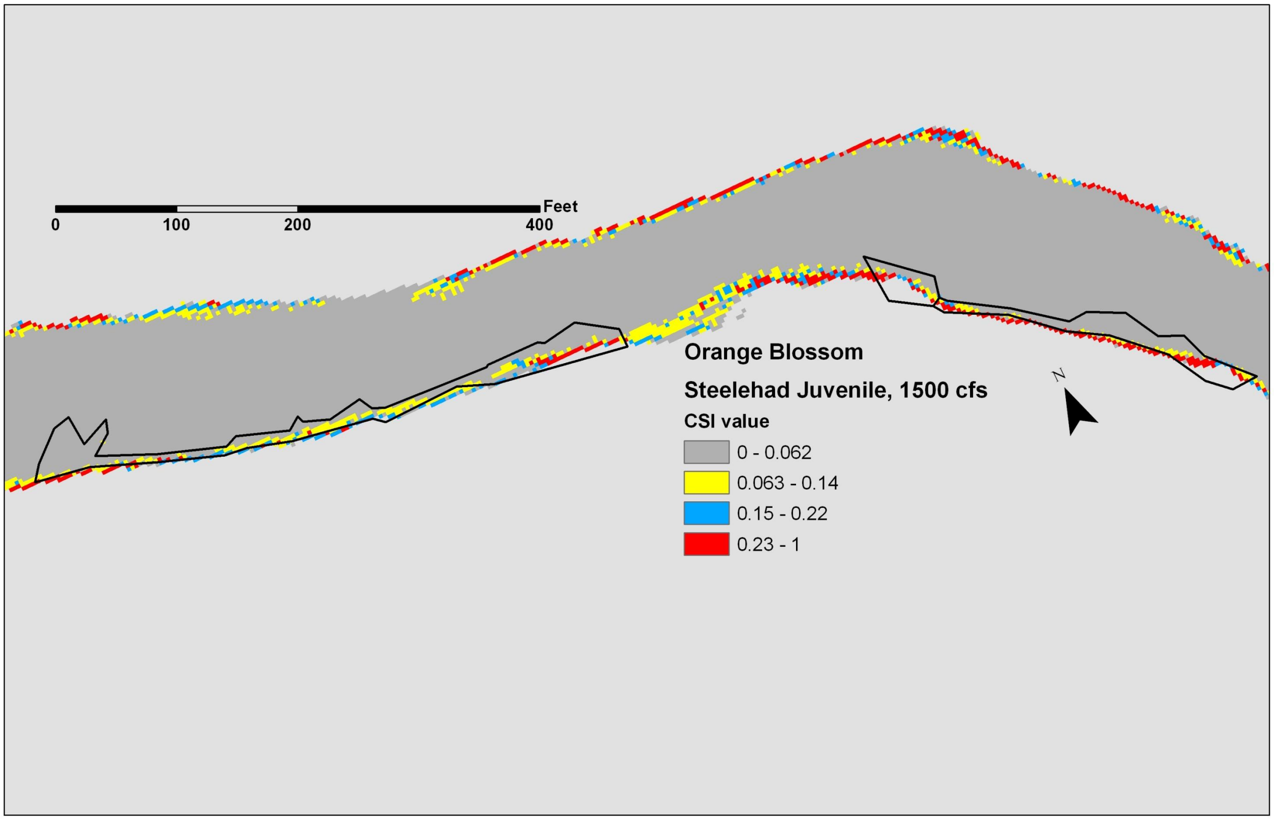


Figure 11: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

APPENDIX J

STANISLAUS RIVER DISCHARGE-HABITAT RELATIONSHIPS FOR REARING SALMOIDS

Response to Reviewer Comments

Reviewing Agency	Comment	Reclamation Response
FWS 1	The report states that the most important finding of the study is that both models predicted little change in habitat within the modeled flow. However, table 20 and figures 21-22 show seemingly substantial changes in habitat. It would be helpful to contextualize the results by providing estimates of what level of change would be considered substantial (via literature or experience or other similar streams) or statistically significant (via appropriate methods).	Characterization of findings has been revised.
FWS 2	Explore (at least in the discussion) other factors that influence habitat suitability, including temperature. For example, the scale up study shows a 5 fold increase in Area of Suitable Habitat for Segment 3 between 200 cfs and 1400 cfs for Chinook salmon juveniles and an increase for the other life stages for Chinook and steelhead as well. Are the temperatures in Segement 3 suitable for salmonid rearing and so increasing flows would realistically translate into more suitable rearing habitat?	This is beyond the scope of this project.
FWS 3	Explore the effects of Habitat Suitability Curves (HSCs) on results of both models. Our preference would be to conduct site-specific surveys of fry and juvenile Chinook salmon and steelhead to develop HSCs specific to the Stanislaus River. In the absence of site specific HSCs, sensitivity analyses should be conducted that examine various HSCs with both models, including the Yuba River HSCs, the Aceituno Stanislaus HSCs, and potentially HSCs from other Central Valley streams. For example, the report plots	The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek). This is beyond the scope of this project.

	the HSCs in the Aceituno study and the Yuba curves, which appear different. Yet, the study falls short of conducting the necessary sensitivity analysis to demonstrate whether different HSCs alter the results of the models. The extent to which the HSCs change the results, would assist in determining whether resources should be allocated to generate river-specific HSCs for the Stanislaus River.	This is beyond the scope of this project.
FWS 4	Extend the simulated flows above the current 1,500 cubic feet per second (cfs to at least 5000 cfs.	This is beyond the scope of this project.
	Expanding the simulated flows to 5000 cfs would enable analysis of floodplain habitat availability and condition, the most valuable habitat for juveniles. Floodplain HSCs should also be developed and used in the models. Expanding modeled flows to include flows above bankfull would also illustrate how results of the two models may differ (or converge) as flows increase.	This is beyond the scope of this project.
	Include flows ranging up to 5000 cfs in the development of Stanislaus specific HSCs. Currently, the River 2D model is being expanded to include flows up to 5,000 cfs, but there are currently no plans to expand the scale-up study; thus, the performance of the two models cannot be compared at higher flows. • Expanding the simulated flows to 5,000cfs would enable analysis of floodplain habitat availability and condition, the most valuable habitat for juveniles. Floodplain HSCs should also be developed and used in the models. • Expanding modeled flows to include flows above bankfull would also illustrate how results of the two models may differ (or converge) as flows increase.	This is beyond the scope of this project.

	Include flows ranging up to 5,000 cfs in the development of Stanislaus specific HSCs.	
FWS 5	Further reconcile/explore the distinct differences between model results with respect to discharge-habitat relationships.	This is beyond the scope of this project.
	Further reconcile the influence of parameter selection in model performance, specifically the differences between the Distance-to-edge (GIS) and cover (River 2D) parameters. The report attributes the different results to the way the two models incorporate habitat cover. They go on to hypothesis, that if the proportion of two types of habitat cover changes with increased discharge, then this could explain the pattern observed in the River 2D results. We recommend the authors look at the model output of River 2D and support or refute this as the actual factors in the model driving the results. It is unclear how good the assumption that distance to edge is a good proxy for habitat (e.g., cover). Fish observations would go far in helping to determine this. How important is the distance to edge parameter in determining ASH (e.g., provide a sensitivity or loading of factors in determining suitable habitat)?	This is beyond the scope of this project.
	Can parameters be modified to be included in the other model (e.g., incorporate D2E in River 2D and cover in GIS)? This would allow the authors to examine the degree to which the differences between the two models are due to the differences in how each model simulates cover.	It is not feasible to map cover to 56 river miles of stream (GIS).
	Further explore bioverification and validation tests. Given the potential utility of this model(s) as a management tool, a comprehensive biological surveying effort would inform both HSC development and model performance, ultimately increasing	This is beyond the scope of this project. Tested whether models match

	confidence in the tool. Habitat, depth, and velocity for 250, 800, and 1,500 cfs in common areas of River 2D and Scale-up.	when the same footprint was compared; if they matched up then there is likely error in the extrapolation made with River 2D results. Results from this testing were inconclusive.
FWS 6	Bioverification – plotting fish observations in GIS.	The sample size that was available was too small. Results were inconclusive. With additional fish observations, this may lead to clearer results.
FWS 7	Calculate habitat at 250, 800 and 1,500 cfs in both models just for footprint of River 2D sites using depth and velocity – if get different results for two models, differences are due to hydraulic modeling. If get different results for testing habitat, depth, and velocity at the flows in common areas but same results for modeling footprint of River 2D sites using depth and velocity, differences are due to cover and adjacent velocity versus distances to edge and shear.	This would require a larger level of effort that was not part of the scope of this project.
FWS 8	Do sensitivity analyses with Sacramento River and Clear Creek HSCs (run for 250, 800 and 1,500 cfs in both models just for footprint of River 2D sites.	Results were inconclusive.
FWS 9	Provide more information and background on why both approaches (River 2D model and scale-up study) were developed and how (specifically) they are complementary. The report needs an improved conceptual framework for both (1) how the use of both approaches can inform management, and (2) how the differing results should be interpreted with respect to flow management on the Stanislaus River. • The report states that the most important finding of the study is that both models predicted little change in habitat within the modeled flow range. However, table 20 and figures 21-22 show seemingly substantial changes in habitat. It	Additional background information has been added to the report. Mention of the models being complementary to one another has been removed from the document. Justification did not support the characterization of the models in this way.

	would be helpful to contextualize the results by providing estimates of what level of change would be considered substantial (via literature or experience on other similar streams) or statistically significant (via appropriate statistical methods). Explore (at least in the discussion) other factors that influence habitat suitability, including water temperature. For example, the scale up study shows a five-fold increase in Area of Suitable Habitat for Segment 3 between 200 cfs and 1,400 cfs for Chinook salmon juveniles and an increase for the other life stages for Chinook and steelhead as well. Are the temperatures in Segment 3 suitable for salmonid rearing and so increasing flows would realistically translate into more suitable rearing habitat?	This is beyond the scope of this report.
FWS 10	The report repeatedly states "the modeling methods complemented each other well and provide a strong basis for any new flow prescription in the Stanislaus River". Provide further explanation of "complements" and more specifics as to how the complementary models could potentially be utilized, either individually or in tandem, given the model limitations and differing results.	Removed this language and revised text.
FWS 11	FWS suggest the following series of analyses be performed to examine (1) sensitivity of model results to the habitat suitability curves (HSCs) and (2) why results differ between the two modeling approaches: (1) Do sensitivity analyses with Sacramento River and Clear Creek HSCs (run for 250, 800 and 1,500 cfs in both models just for footprint of River2D sites). (2) Three potential sources of differences between 2 models: 1) are River2D sites representative of the entire river; 2) cover and adjacent velocity versus distance to edge and shear; 3) hydraulic	FWS's recommendations could provide some additional clarity. Reclamation would be in support if FWS intends on performing the additional analysis and providing the results as supplementary information for this report.

	modeling. To evaluate these: a. Calculate habitat at 250, 800 and 1,500 cfs in both models just for footprint of River2D sites - if result same for the 2 models, difference between models because River2D sites were not representative of entire river. b. Calculate habitat at 250, 800 and 1,500 cfs in both models just for footprint of River2D sites and just using depth and velocity criteria - if get different results for two models, differences are due to hydraulic modeling. If get different results for a) but same results for b), differences are due to cover and adjacent velocity versus distance to edge and shear. These analyses are in addition to the comments listed above - the first addresses the second bullet point under comment #2, the second addresses the first bullet point under comment #4. 2a tested by clipping out the footprint of the River 2D sites from the scale-up model and examining results from both models for the same river reaches. The results of both models were different, suggesting that the next analysis step should be to evaluate 2b. If results for both models are the same for 2b, that suggests that the differences between the two models are due to the differences in using cover vs. distance to edge and adjacent velocity vs. shear. If results for both models are different for 2b, that suggests that the differences are due to hydraulic modeling. A completed bioverification analyses using available fish data was done, but sample size was not sufficient and results were inconclusive. Additional information on these	

	analyses is available.	
FWS 12	The report should be captioned "Preliminary" as it does not resolve the fundamental issue of habitat versus flow.	The project is complete. Any additional analysis would be considered supplemental to the final report.
FWS 13	Revise the wording of goal 3 in the report summary and introduction	"Strong" has been removed from the text.
FWS 14	Note the 1,500 cfs cap on the analysis and overtly recognize that neither model has been used to evaluate habitat for flows above 1,500 cfs. This should be done in the summary, intro, and discussion.	The report only discusses flows at 1,500 cfs. The results are listed in the report.
FWS 15	The report should provide comparisons as to how amount of juvenile rearing habitat differs from other similar watersheds, and how much habitat is necessary for "doubling".	This is beyond the scope of this report.
FWS 16	The tables and figures need to be relocated to their appropriate sections. They appear to have drifted during editing, so that the GIS plots are now appearing in the discussion section rather than GIS results.	The plots are in the correct sections; they are being referred to differently in each section.
FWS 17	The HSC sensitivity analyses should be included as an appendix, or more completely described (just above Next Steps in the Discussion section). Bullet 2 under Next Steps was described as completed in the section above.	Added as Appendix J
FWS 18	Bullet 1 under Next Steps has already been completed. This should be discussed above and removed from the next steps section.	Bullet 1 deleted from the report. This has been discussed in response to comment FWS 5.
NMFS 1 – page #1, paragraph 3	12 modeled flows? This statement is confusing without some sort of explanation: Chinook fry – 250 cfs, 800 cfs, and 1,500 cfs; Chinook juvenile – 250 cfs, 800 cfs, and 1,500 cfs; steelhead fry – 250 cfs, 800 cfs, and 1,500 cfs; steelhead juvenile – 250 cfs, 800 cfs, and 1,500 cfs	Incorrectly characterized it as "12 modeled flows". Both methods used 250 cfs, 800 cfs, and 1,500 cfs. Terminology has been revised.
NMFS 2 – page #2, table 1.	These segment names don't match up fully with the segment names in Tables S-2 and S-3. What about changing (in Table S-1) the River 2D segments to A, 1, 2, and 3; and the GIS segments to 1, 2, 3a and 3b? That would match up better.	Terminology has been revised.
NMFS 3 –	The text and caption in Table S-3 suggest that	See response to NMFS 1.

page #2, table 1	three discharges were modeled in the GSI approach. Clarify here on in the text.	Terminology has been revised.
NMFS 4 - page #3	Why are we using Yuba River as the habitat suitability criteria?	The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek).
NMFS 6, page 4; paragraph 3.	Might be good to qualify "optimal" with "optimal habitat, within the range of flows modeled, ...". Maybe you can just be very explicit early on that "optimal" in this report means a local optimum within the modeled range, rather than repeat it each time.	Text has been revised.
NMFS 9, page 6, paragraph 2.	Why is the Stanislaus being modeled from Yuba River data? Further in the report this seems to be addressed, but I think there should still be concerns, especially given the variance in geographic locales.	The Yuba River HSC were used because they were developed using the current state-of-the-art for developing habitat suitability criteria (logistic regression, cover, adjacent velocity) and were from the most similar river to the Stanislaus River (versus the Sacramento River and Clear Creek).
NMFS 10, page 6, paragraph 4	Seems like changes are on order of 400,000 to 600,000 sq. feet. Is this a "small" effect? Looks (Fig 21 and 22) as if flow effect can reduce max hab by 30% or more; if hab is limiting even at max level, an additional 30% or more reduction may be very significant?	Revised text.
NMFS 11, page 8, paragraph 3	I have not yet had a chance to review the 2010 Yuba papers -- need to think more about this issue in terms of interpreting the results. I understand this has already been discussed extensively within FWS and USBR. Ideally, as has been commented by others, we can (in the future) apply these tools using Stan-based habitat use information.	Text deleted as it did not answer how the problems were addressed. Added text of why the Yuba HSCs were used. This is beyond the scope of this project.

NMFS 23, page 63, paragraph 5	again, why "small"? in absolute terms? relative terms? both?	Text revised.
Reclamation Bay-Delta Office	Using habitat discharge values for the different life stages of the different species and for the different river sections have error bars around the 'mean' estimates. The error could be useful to quantify the range of values that the model produces when different HSCI curves are used.	This was not part of the scope of the project.
Reclamation Bay-Delta Office	Discussion with FWS on comment FWS 2 - For example, the scale up study shows a 5 fold increase in Area of Suitable Habitat for Segment 3 between 200cfs and 1400cfs for Chinook salmon juveniles and an increase for the other life stages for Chinook and steelhead as well. Are the temperatures in Segment 3 suitable for salmonid rearing and so increasing flows would realistically translate into more suitable rearing habitat?	This is beyond the scope of this project
Reclamation Bay-Delta Office	Discussion with FWS on comment FWS 3 - For example, the report plots the HSCs in the Aceituno study and the Yuba curves, which appear different. Yet, the study falls short of conducting the necessary sensitivity analysis to demonstrate whether different HSCs alter the results of the models. The extent to which the HSCs change the results, would assist in determining whether resources should be allocated to generate river-specific HSCs for the Stanislaus River.	This is beyond the scope of this project.
Reclamation Bay-Delta Office	Discussion with FWS on comment FWS 4 – Floodplain HSCs should also be developed and used in the model.	This is beyond the scope of this project.
Reclamation Bay-Delta Office	Discussion with FWS on comment FWS 5 - The report attributes the different results to the way the two models incorporate habitat cover. They go on to hypothesis, that if the proportion of two types of habitat cover changes with increased discharge, then this could explain the pattern observed in the River 2D results. Recommend authors look at the model output of River 2D and support or refute this as the actual factors in the model driving the results. In is unclear how good the assumption that distance to edge is a good proxy for good habitat (e.g., cover). Fish observations would	This is beyond the scope of this project.

	go far in helping to determine this. How important is the distance to edge parameter in determining ASH (e.g., provide a sensitivity or loading of factors in determining suitable habitat)?	

Note: NMFS seconded FWS' concerns and comments, and included editorial recommendations within the report.