RECLAMATION

Managing Water in the West

Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2012

PEER REVIEW DOCUMENTATION
PROJECT AND DOCUMENT INFORMATION

Project Name: Stanislaus River Salmonid Rearing Habitat Modeling

WOID: AF034

Document: Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids

Date: March 27, 2012 Date Transmitted to Client: April 13, 2012

Team Leader: Mark D. Bowen Leadership Team Member: Craig Albertsen

Document Author(s)/Preparer(s): Mark D. Bowen, Mark Gard, Rob Hilldale, Katherine Zehfuss, and Ron Sutton

Peer Reviewer: John Hannon, Bureau of Reclamation, Bay-Delta Office

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain____

Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW
Peer Review restricted to the following Section(s): All Reviewer: J. Hannon

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.

Reviewer: ________________ Review Date: 3-27-12
Signature

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

Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids

Prepared by:

Mark D. Bowen, Ph.D.
Fishery Biologist, Bureau of Reclamation
Fisheries and Wildlife Resources Group

Mark Gard, Ph.D.
Fish and Wildlife Biologist, U.S. Fish and Wildlife Service, Sacramento, California

Rob Hilldale
Hydraulic Engineer, Bureau of Reclamation
Sedimentation and River Hydraulics Group

Katherine Zehfuss, Ph.D.
Fish Biologist, North Wind Services, Inc.

Ron Sutton
Natural Consulting Scientist, North Wind Services, Inc.

Prepared for:

Central California Area Office, Bureau of Reclamation, Folsom, California

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2012

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

ACKNOWLEDGMENTS

Numerous people contributed to the success of this study. Elizabeth Vasquez and Robert Schroeder from the Bureau of Reclamation (Reclamation) Central California Area Office (CCAO) provided financial support. Chelsea Stewart, Melissa Harris, Marissa Novoa, Matt See and Brian Deason from CCAO and John Hannon from Reclamation's Mid-Pacific Regional Office assisted with field surveys. Dave Mello from Reclamation's Mid-Pacific Regional Office provided quality control of field survey techniques and checked accuracy of control point coordinates.

Several Reclamation Technical Service Center (TSC) employees assisted with the Geographic Information System (GIS) effort. Kurt Wille produced the Suitability Index (SI) 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 (compiled MATLAB® program). 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. We also thank Christi Young, Sharon Leffel, Glenna Berg, and Cindy Gray for assistance in editing and formatting. Merlynn Bender was invaluable in the final stages of report preparation.

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

CONTENTS

Tables

Figures

Appendices

Appendix

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.

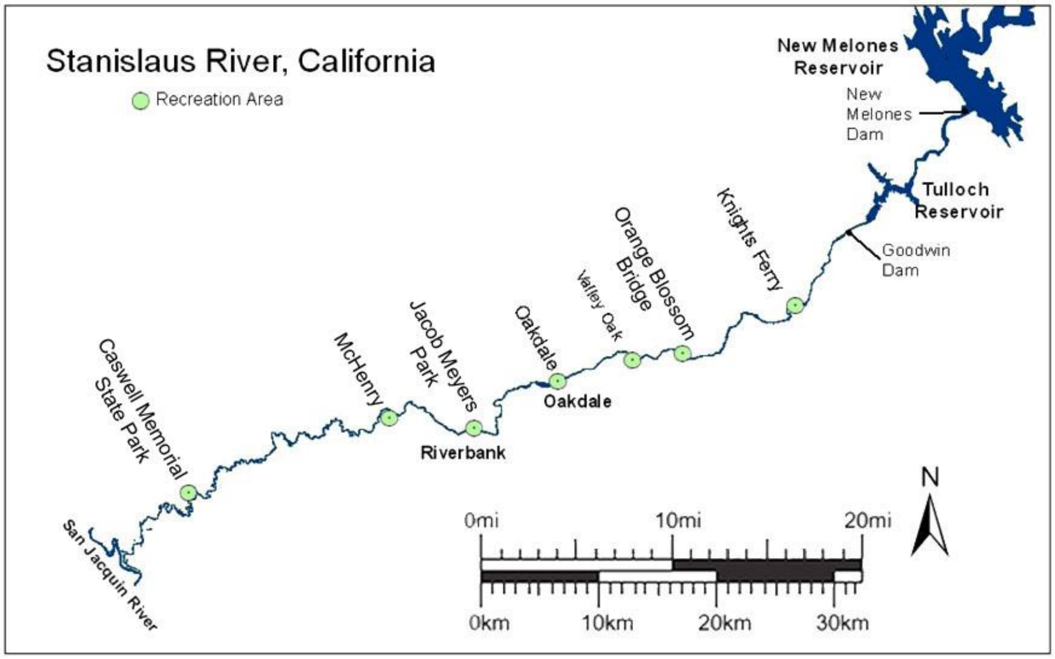

Figure 1 Stanislaus River. Study area includes all the river available to Chinook salmon and anadromous *O. mykiss*: Goodwin Dam to confluence with the San Joaquin River.

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).

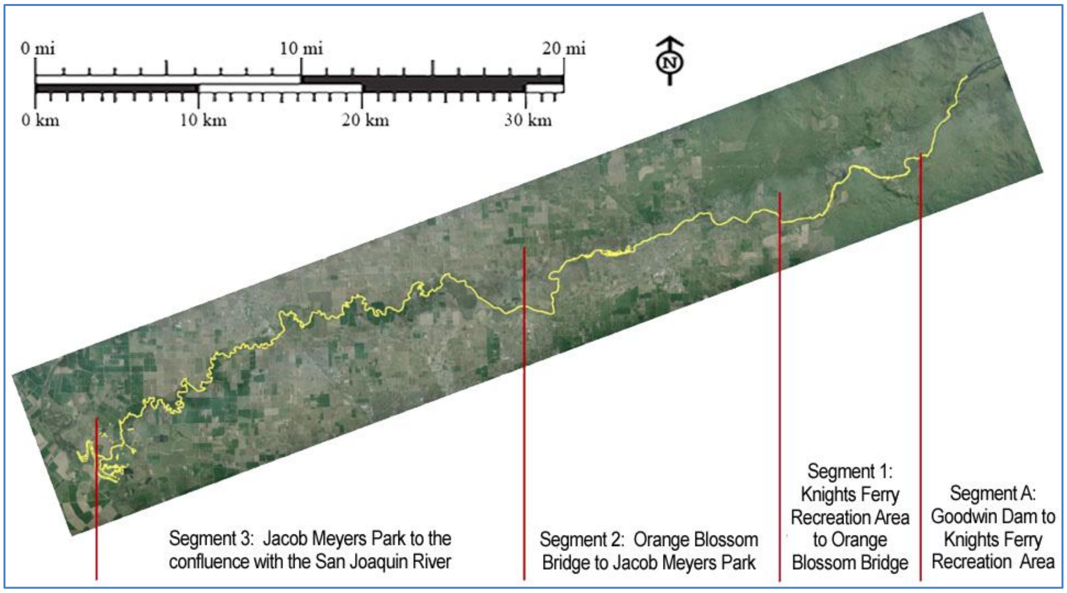

Figure 2 Map of the Stanislaus River with three identified study segments used for the River2D study. Water flows from right to left.

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.

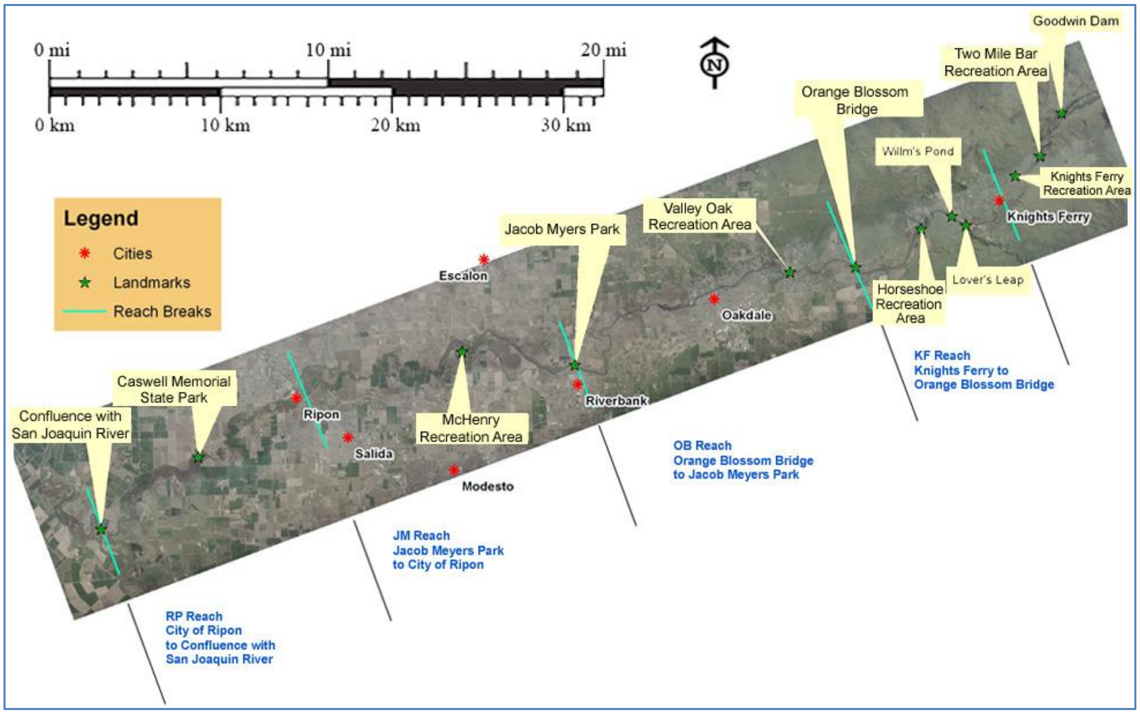

Figure 7 Map of the Stanislaus River with four identified study segments used for the GIS spatially explicit study. Water flows from right to left.

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 $\text{Mesohabitat Unit}_{i,j}$. 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.

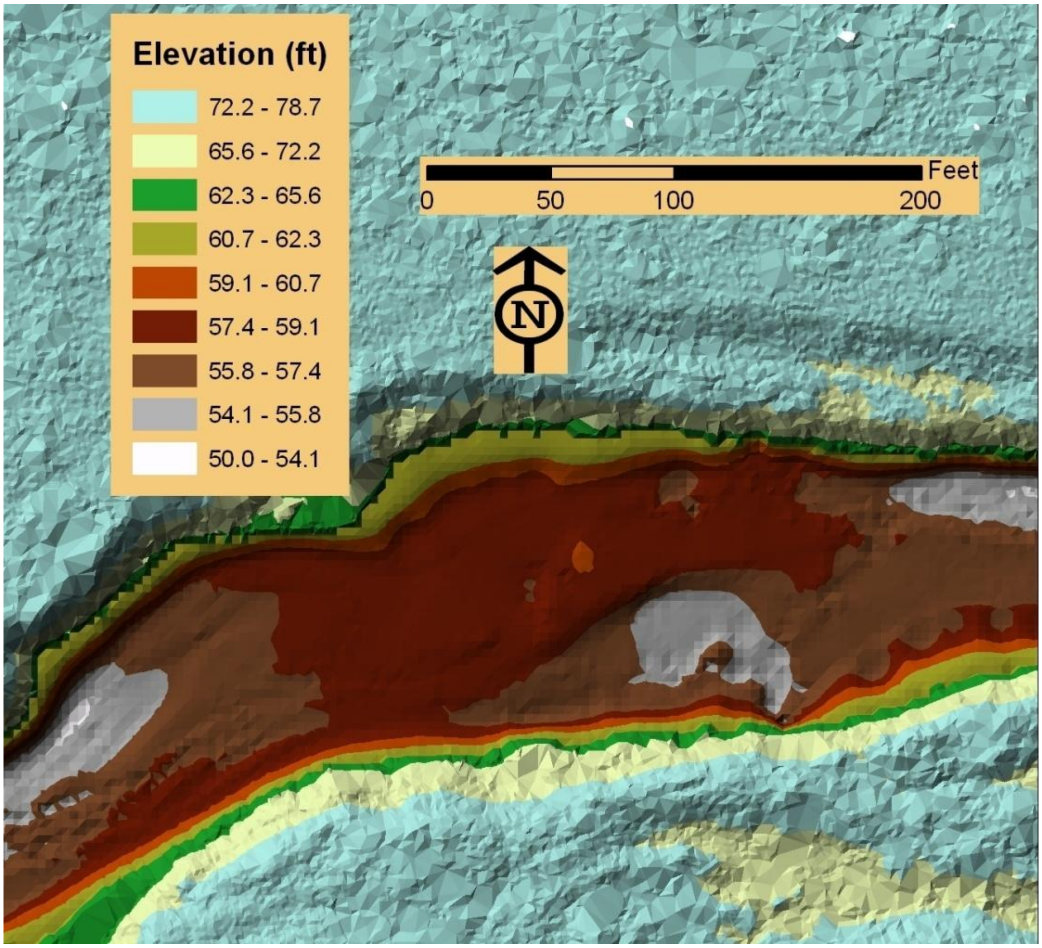

Figure 8 Example of the terrain resulting from point data.

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.

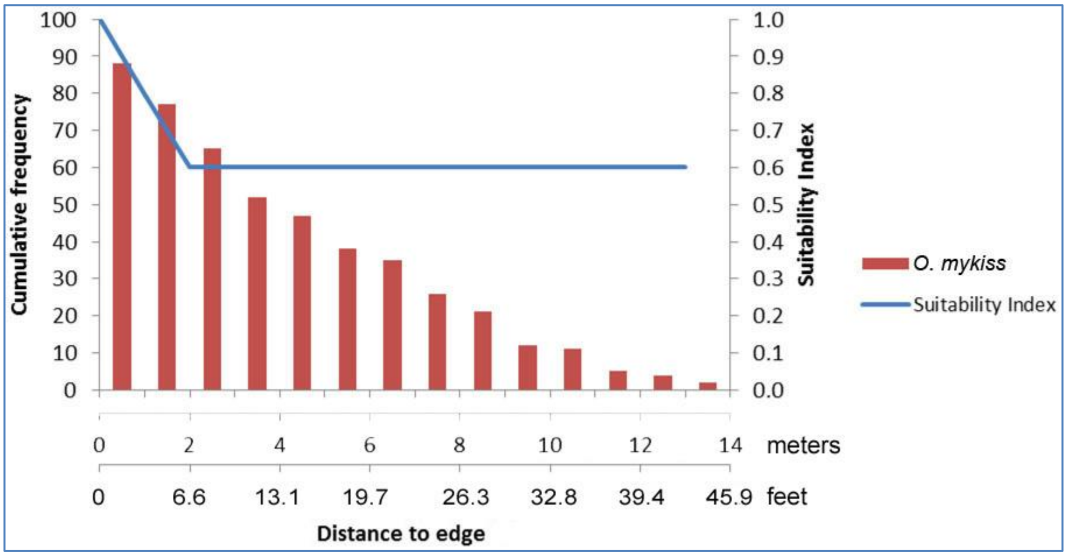

Figure 9 Distance to edge habitat suitability criteria based on cumulative frequency of fish observations (Fishery Foundation, 2010) in the Stanislaus River.

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 is the maximum velocity in a 3 x 3 cell matrix surrounding the cell of interest, (both in units of distance/time), and *d* is the distance between and (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 all nine cells are included, such that the center cell could be , which would result in a equal to 0, also eliminating the possibility that 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.

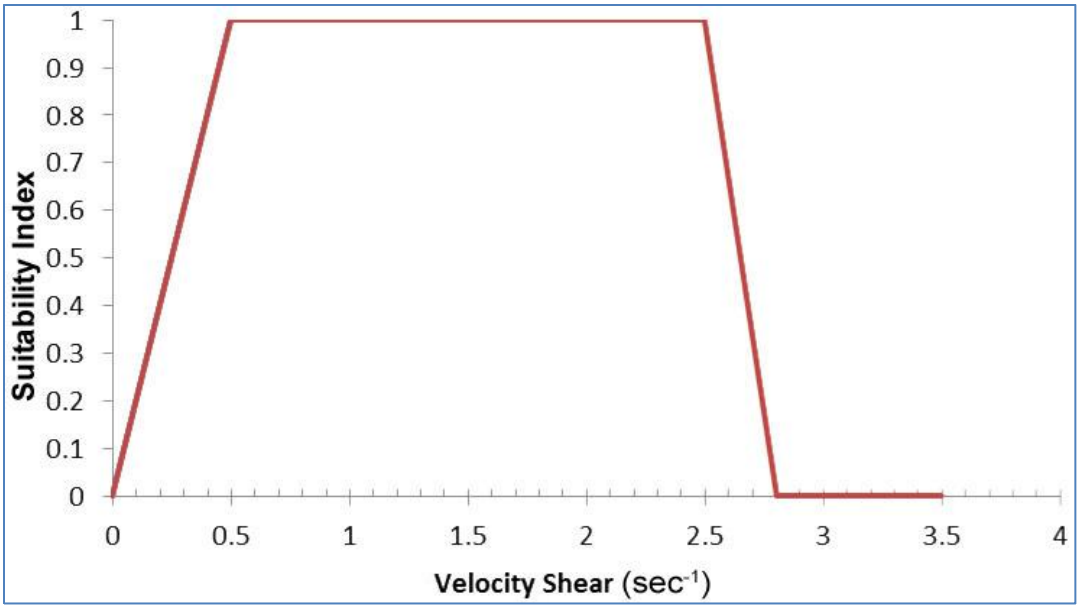

Figure 10 Theoretical shear velocity curve.

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**

Mesohabitat type	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		
		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**

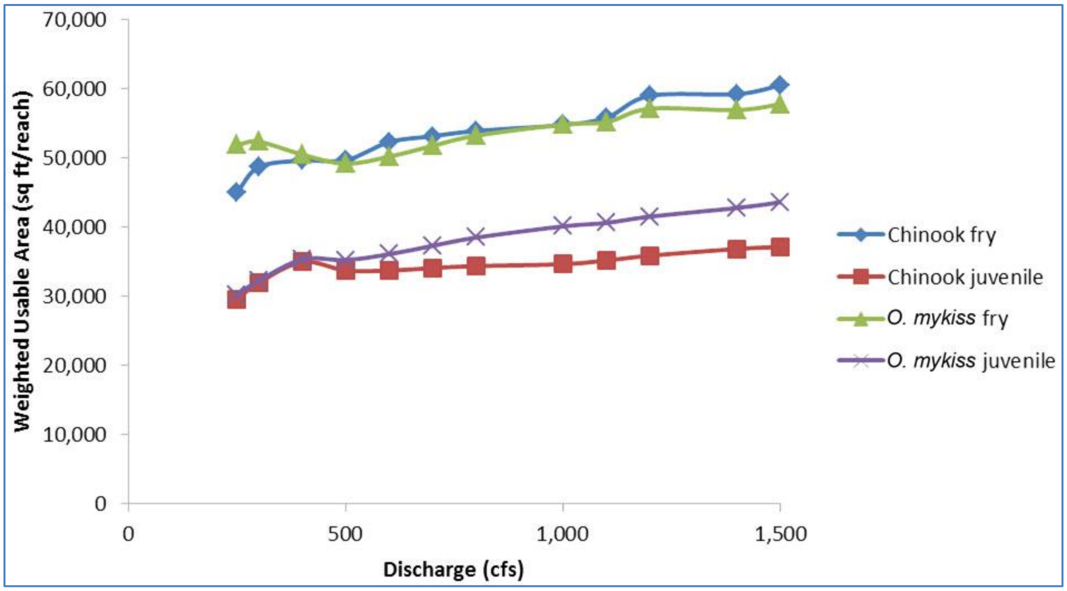

Figure 11 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment A (Goodwin Dam to Knights Ferry Recreation Area) in the Stanislaus River.

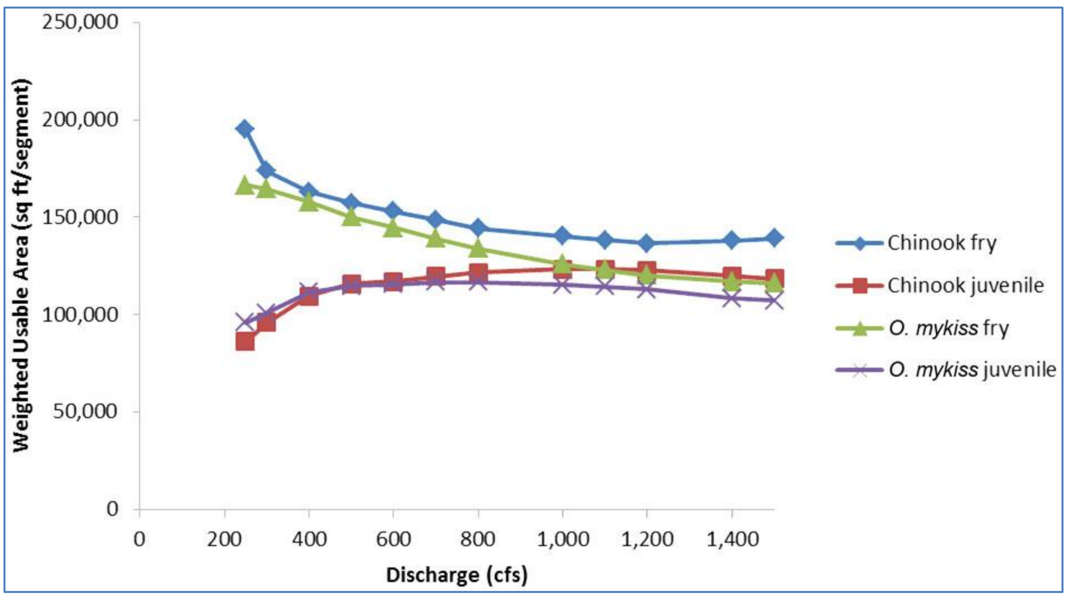

Figure 12 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 1 (Knights Ferry Recreation Area to Orange Blossom Bridge) of the Stanislaus River.

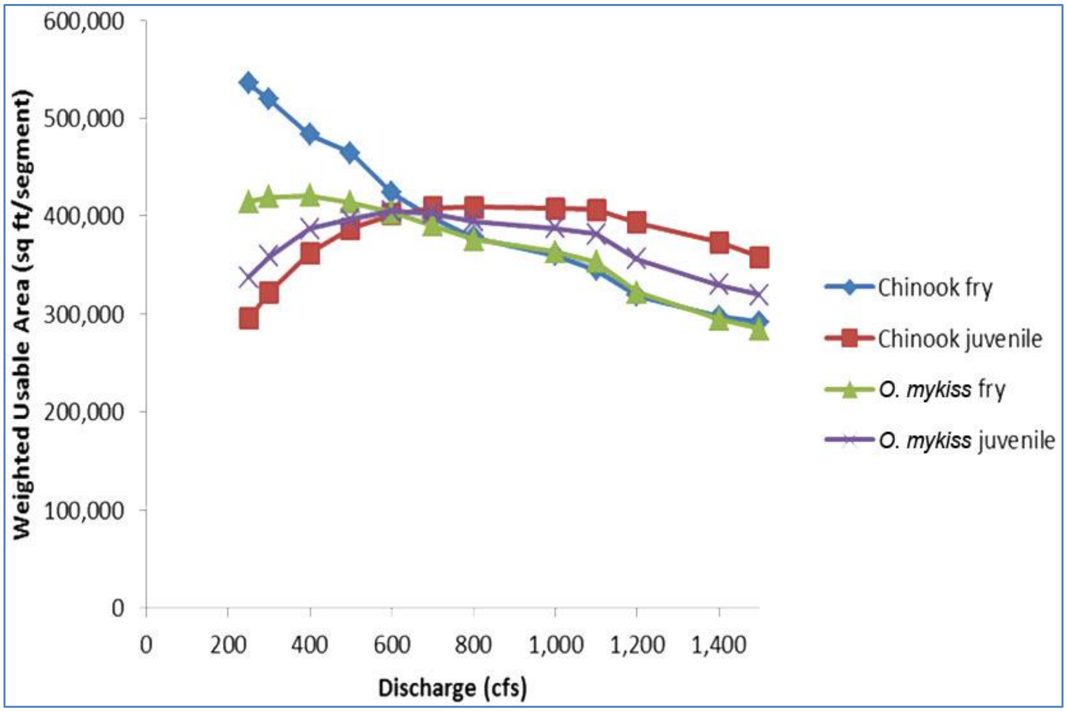

Figure 13 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 2 (Orange Blossom Bridge to Jacob Meyers Park) of the Stanislaus River.

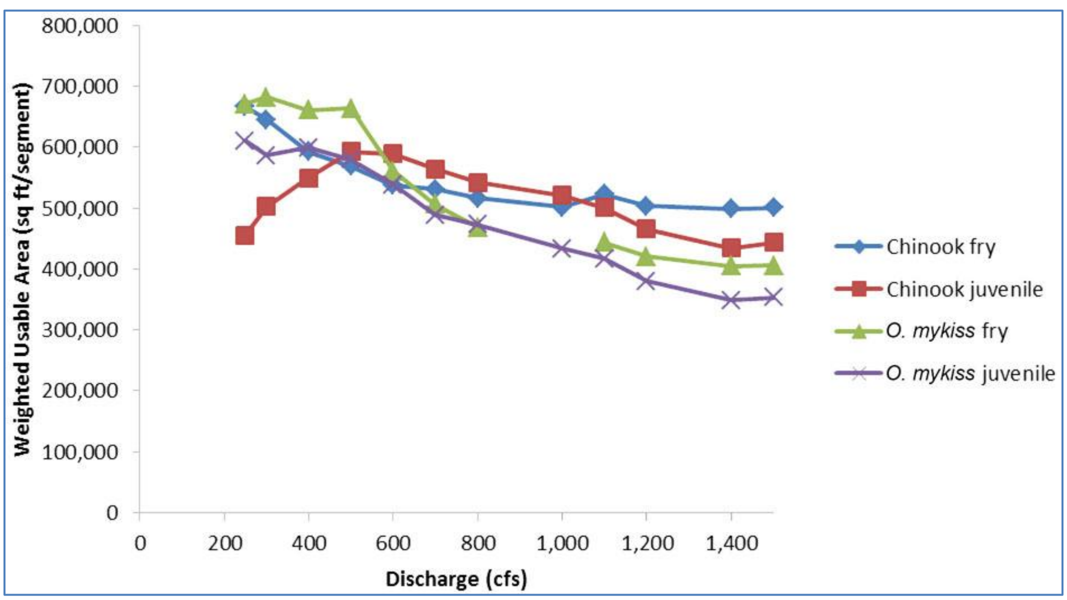

Figure 14 River2D habitat-discharge relationships for fry and juvenile Chinook salmon and *O.mykiss* in Segment 3 (Jacob Meyers Park to the San Joaquin River) of Stanislaus River.

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 H.

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**

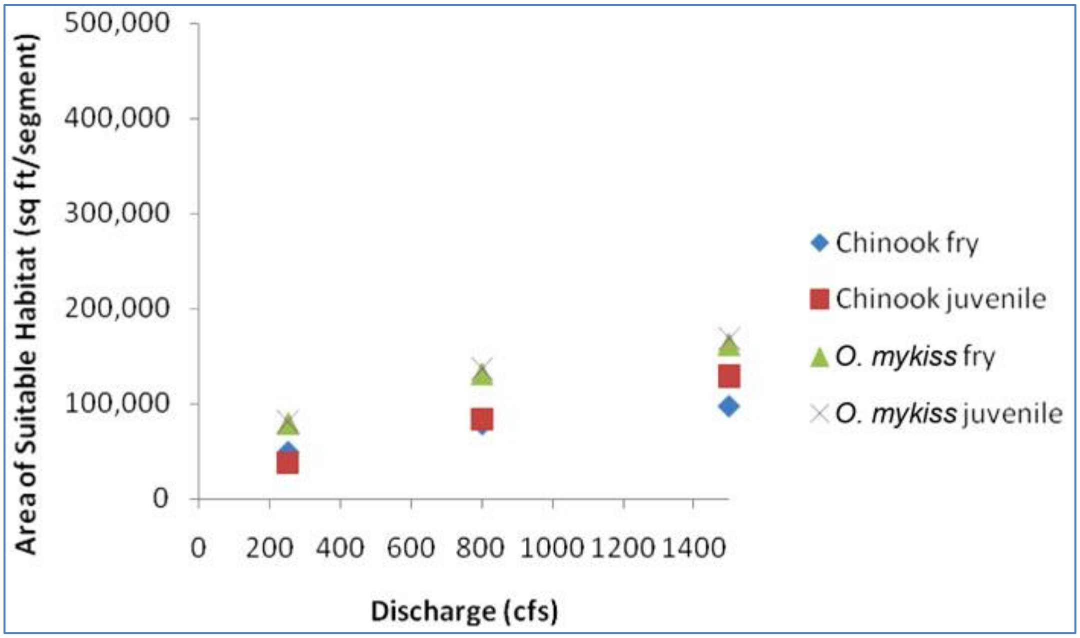

Figure 15 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 1 (Knights Ferry Recreation Area to Orange Blossom Bridge) in the Stanislaus River.

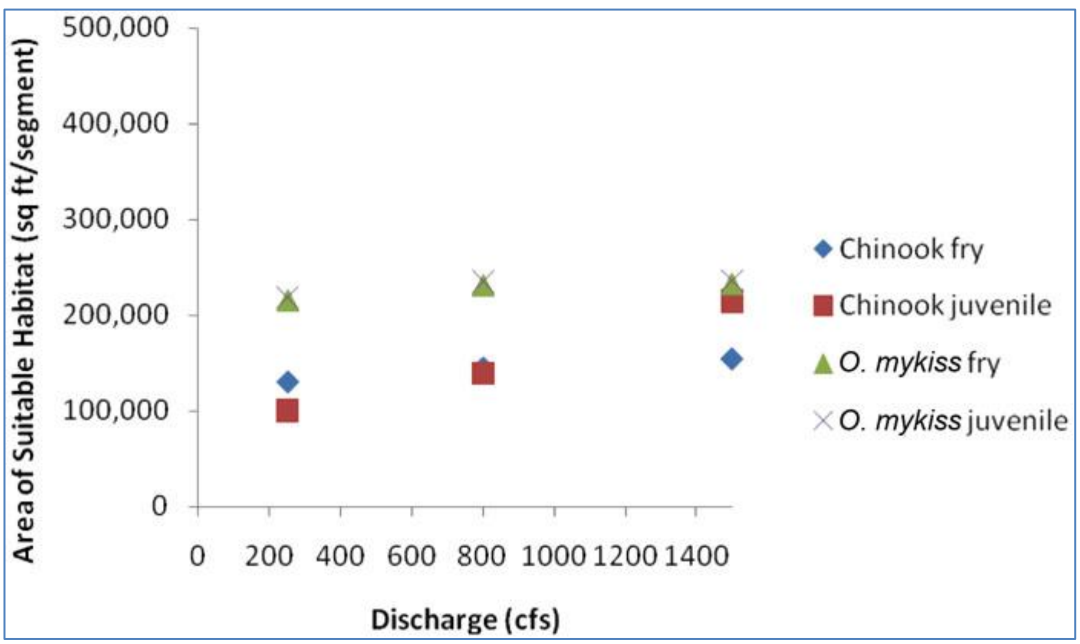

Figure 16 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 2 (Orange Blossom Bridge to Jacob Myers Park) in the Stanislaus River.

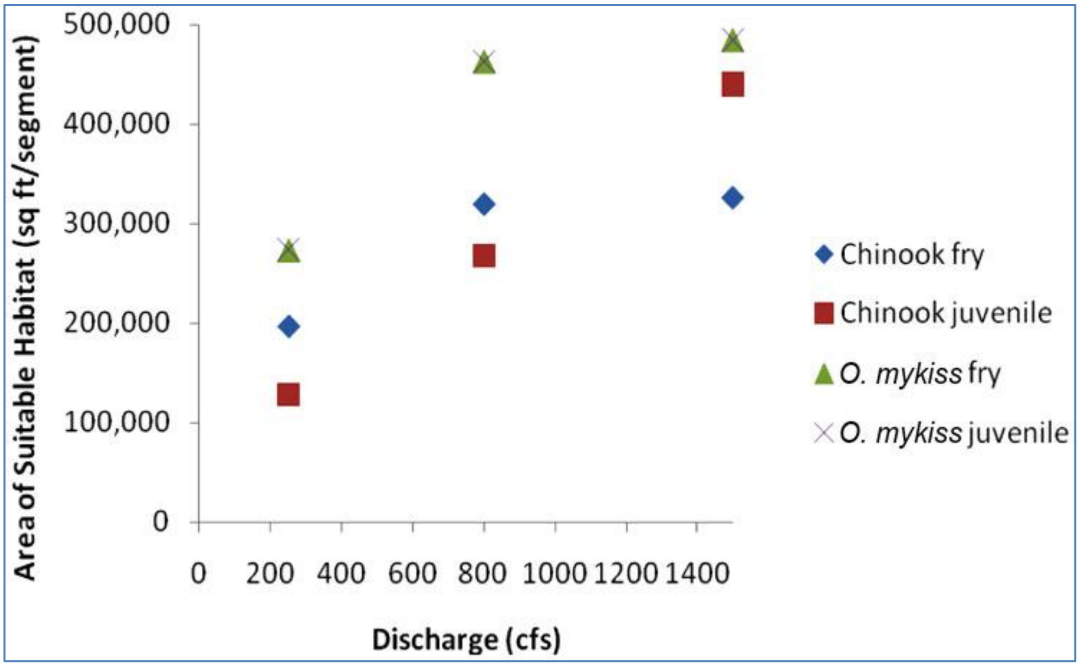

Figure 17 GIS habitat-discharge relationships for fry and juvenile Chinook salmon and *O. mykiss* in Segment 3 (Jacob Myers Park to confluence with the San Joaquin River) in the Stanislaus River.

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

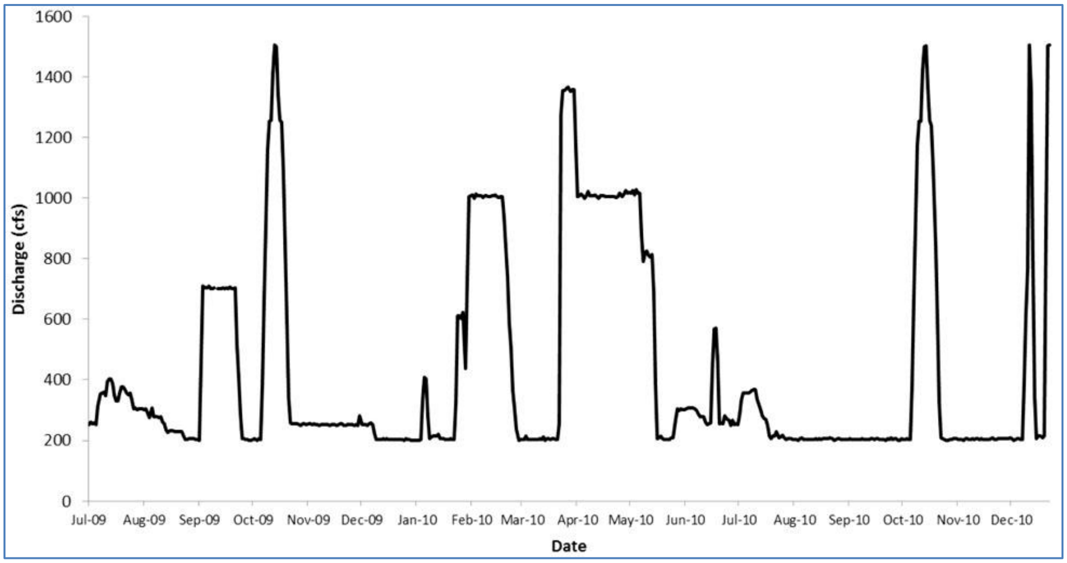

Figure 18 Goodwin Dam flow releases into Stanislaus River during field surveys. These continuous discharge data were obtained from the Goodwin Dam gage (Reclamation Gage (GDW).

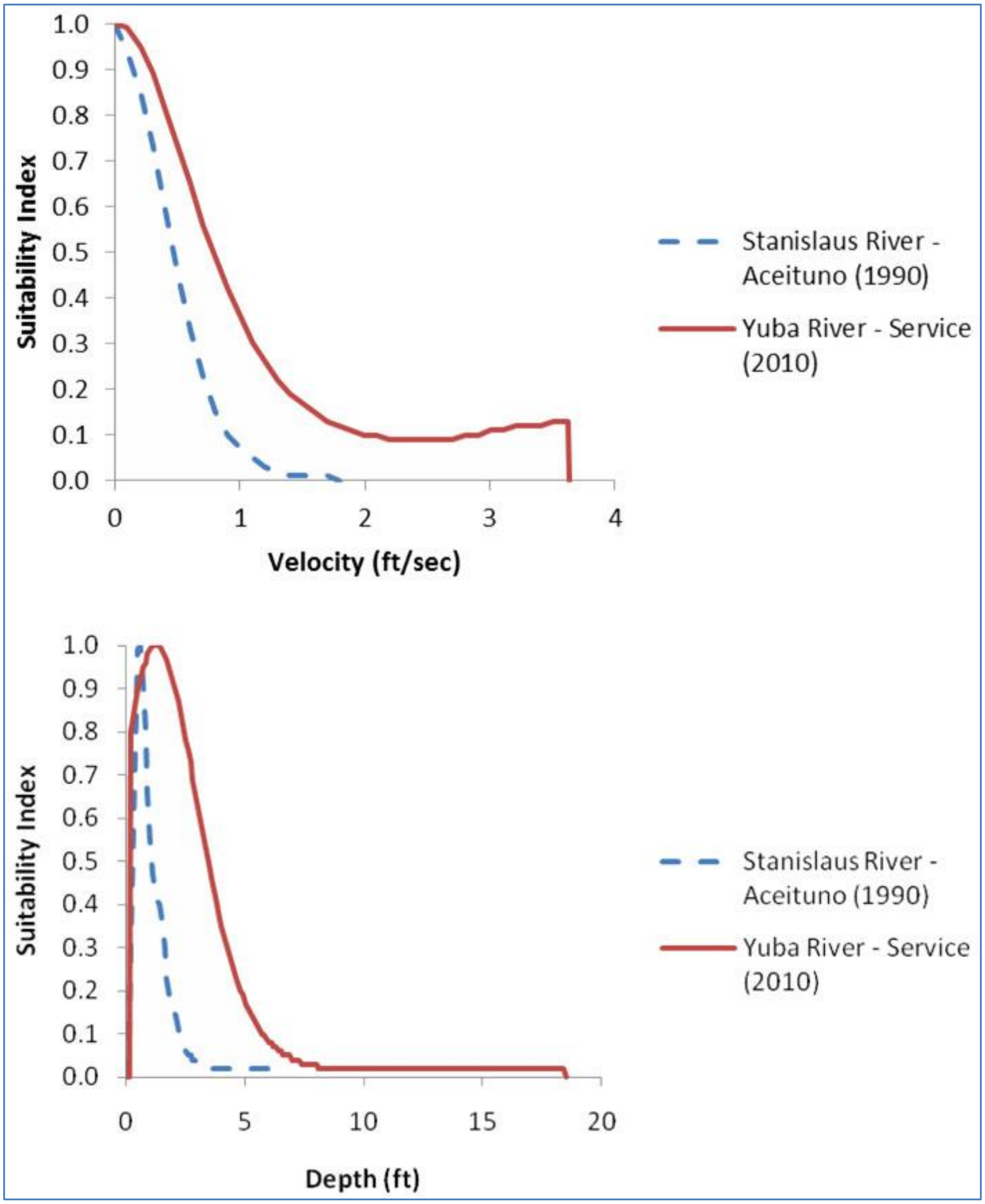

Figure 19 Comparison of fry Chinook salmon velocity (top) and depth (bottom) and habitat suitability criteria from two separate studies.

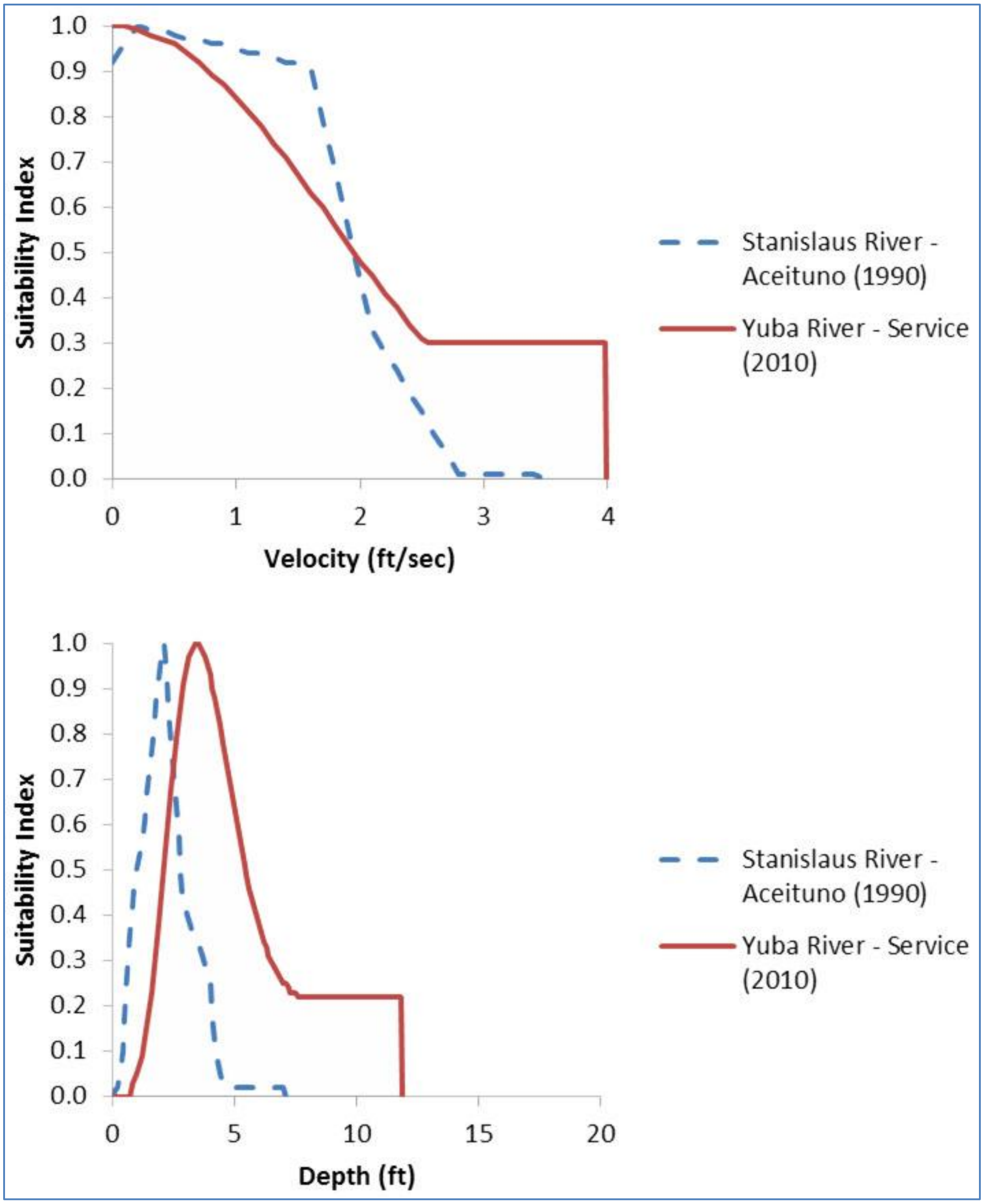

Figure 20 Comparison of juvenile Chinook salmon velocity (top) and depth (bottom) and habitat suitability criteria from two separate studies.

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 $\leq$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

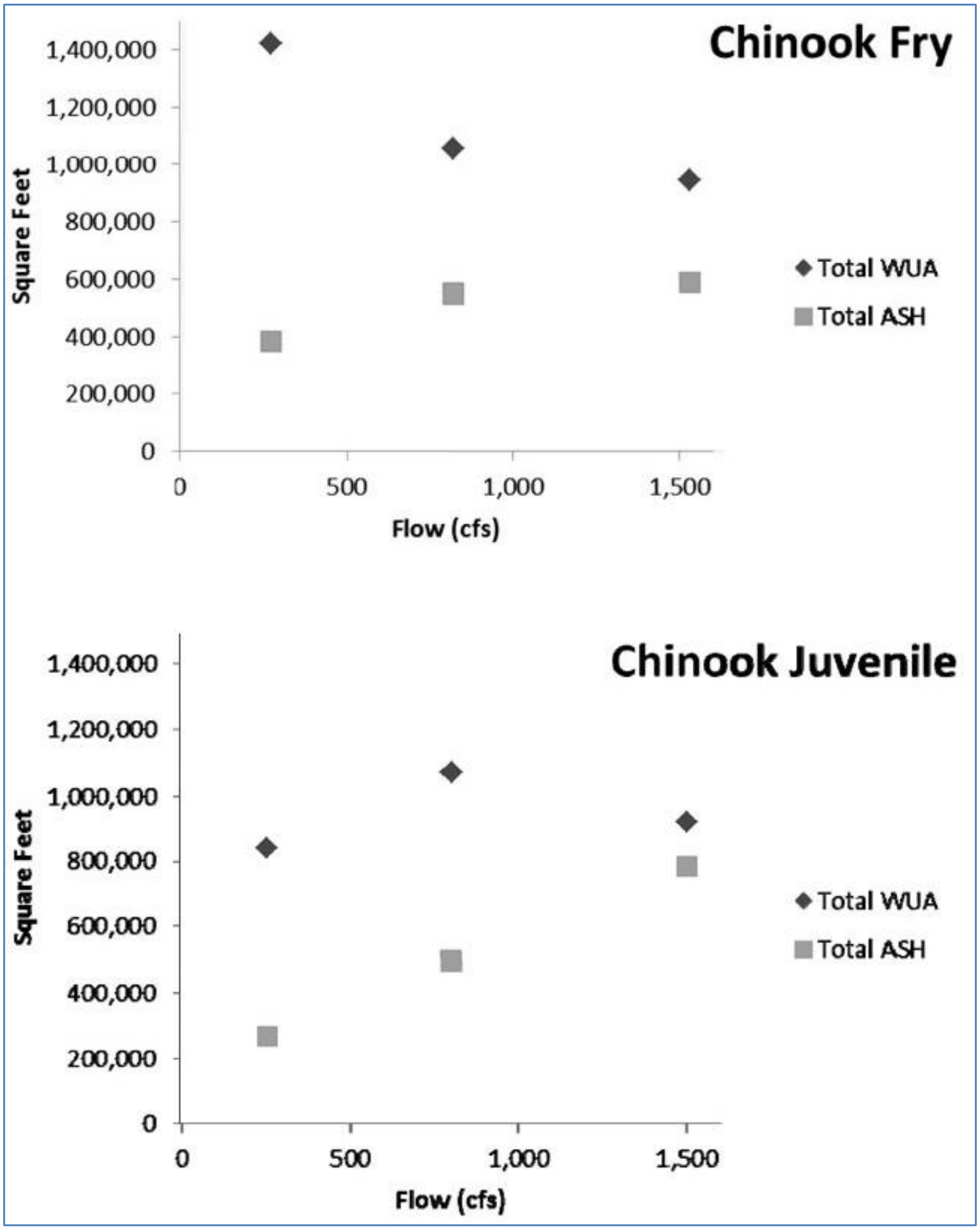

Figure 21 Comparison of Chinook salmon habitat modeling results for the entire lower Stanislaus River (Segments 1-3) between River2D (weighted usable area [WUA]) and GIS (area of suitable habitat [ASH]).

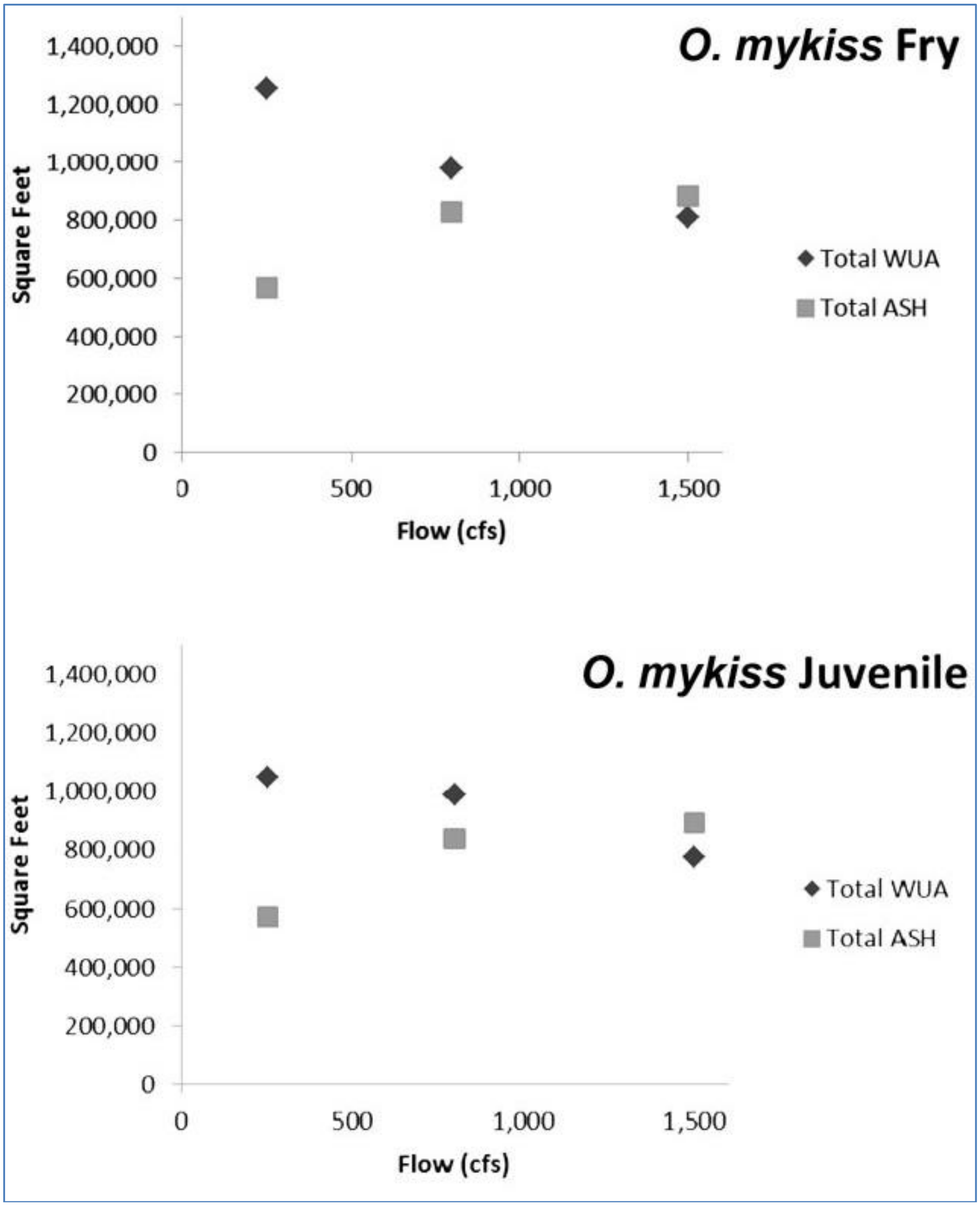

Figure 22 Comparison of *O. mykiss* habitat modeling results for the entire Stanislaus River (Segments 1-3) between River2D (weighted usable area [WUA]) and GIS (area of suitable habitat [ASH]).

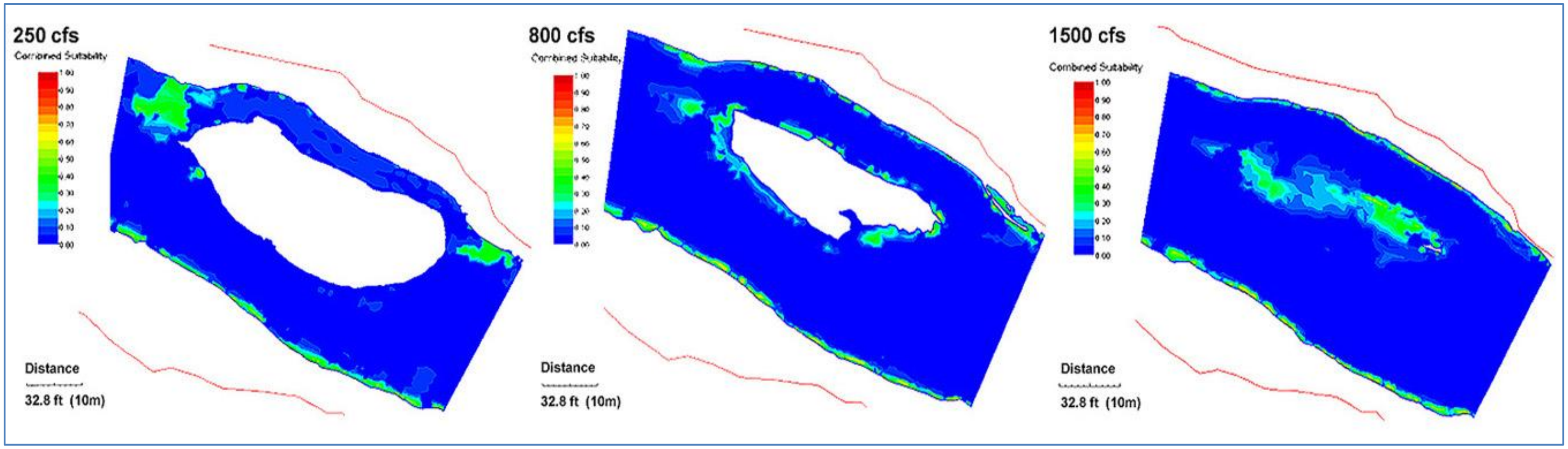

Figure 23 Contour plots of composite suitability index (CSI) results from River2D model for fall Chinook salmon fry at the upper island of the Valley Oak Recreation Area River2D study site at three discharges.

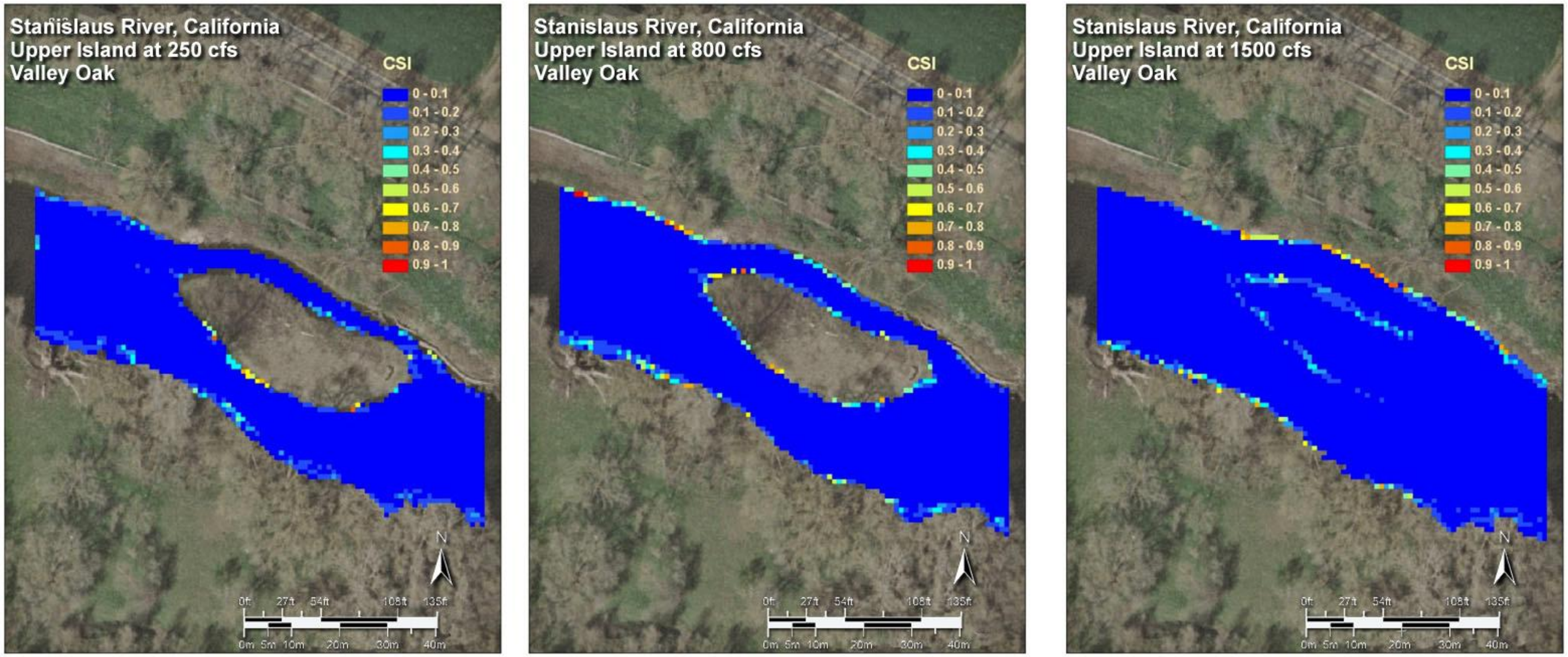

Figure 24 Maps of composite suitability index (CSI) results from GIS model for fall Chinook salmon fry at the upper island of the Valley Oak Recreation Area River2D study site at three discharges. Note: Chinook fry area of suitable habitat was 958 sq ft (at 250 cfs), 1,033 sq ft (at 800 cfs), and 1,184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

REFERENCES

Aceituno, M.E. 1990. *Habitat preference criteria for Chinook salmon of the Stanislaus River, California*. U.S. Fish and Wildlife Service. Sacramento, California.

Allen, M.A. 2000. *Seasonal microhabitat use by juvenile spring Chinook salmon in the Yakima River Basin, Washington*. Rivers 7: No. 4:314–332.

Allen, M.A. and T.J. Hassler. 1986. *Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—chinook salmon*. U.S. Fish and Wildlife Service, Biological Report 82(11.49). U.S. Army Corps of Engineers, TR EL-82-4. Vicksburg, MS.

Bauer, T.R. 2009. *Comparison of ADCP bathymetric survey data*. Draft report, Bureau of Reclamation, Sedimentation and River Hydraulics Group, Technical Service Center, Denver, CO.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.D. Stalnaker, J. Taylor, and J. Henriksen. 1998. *Stream habitat analysis using the Instream Flow Incremental Methodology*. Information and Technical Report USGS/BRD-1998-0004. U.S. Geological Survey, Biological Resources Division.

Bowen, M.D. 1996. *Habitat selection and movement of a stream-resident salmonid in a regulated river and tests of four bioenergetic optimization models.* Dissertation. Utah State University, Logan, Utah.

Bowen, M.D., R. Sutton, and E. Young. 2003. *Anadromous salmonid habitat in three watersheds of the Columbia Basin Project*. U.S. Department of the Interior, Bureau of Reclamation, Ephrata Field Office, Ephrata, WA.

Conder, A.L. and T.C. Annear. 1987. *Test of weighted usable estimates derived from a PHABSIM model for instream flow studies on trout streams*. North American Journal of Fisheries Management 7: 339-350.

Crowder, D.W. and P. Diplas. 2000. *Evaluating spatially explicit metrics of stream energy gradients using hydrodynamic model simulations*. Canadian Journal of Fisheries and Aquatic Sciences 57: 1497–1507.

Deason, B., M. Bowen, R. Hilldale, R. Sutton, K. Zehfuss, and J. Hannon. 2007. *Discharge to habitat relationships for anadromous salmonid juveniles in the Stanislaus River*. Draft Study Plan 2007. Bureau of Reclamation, Folsom, California.

Fausch, K.D. and R.J. White. 1981. *Competition between brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) for positions in a Michigan stream*. Canadian Journal of Fisheries and Aquatic Sciences 38: 1220–1227.

Firor, S., M. Love, ,M. Furniss,, A. Llanos, K. Moynan, J. Guntle, B. Gubernick. 2006. *Swim speeds table from* FishXing Version 3.0.07. http://www.stream.fs.fed.us/fishxing/index.html.

Fishery Foundation of California. 2010. *Stanislaus River salmonid habitat use pilot investigation*. Draft. Prepared for Bureau of Reclamation Mid-Pacific Region Central California Area Office, Folsom, California.

Gallagher, S.P. and M. F. Gard. 1999. *Relationship between Chinook salmon (Oncorhynchus tschawytscha) redd densities and PHABSIM-predicted habitat in the Merced and Lower American Rivers, California*. Canadian Journal of Fisheries and Aquatic Sciences 56: 570–577.

Gard, M. 2006. *Changes in salmon spawning and rearing habitat associated with river channel restoration*. International Journal of River Basin Management 4: 201–211.

Gard, M. 2009. *Comparison of spawning habitat predictions of PHABSIM and River2D models*. International Journal of River Basin Management 7:55-71.

Guay, J.C., D. Bosclair, D. Rioux, M. Leclerc, M. Lapointe, and P. Legendre. 2000. *Development and validation of numerical habitat models for juveniles of Atlantic salmon (Salmo salar)*. Canadian Journal of Fisheries and Aquatic Sciences 57: 2065–2075.

Hardy, T. B. and C. Addley. 2003. *Instream flow assessment modeling: Combining physical and behavioural-based approaches*. Canadian Water Resources Journal 28: No. 2 1–10.

Hardy, T.B., T. Shaw, R. Addley, G.E. Smith, M. Rode, and M. Belchik. 2006. *Validation of Chinook fry behavior-based escape cover modeling in the lower Klamath River*. International Journal of River Basin Management 4: No. 2, 1–10.

Hayes, J.W. and I.G. Jowett. 1994. *Microbial models of large drift-feeding brown trout in three New Zealand rivers*. North American Journal of Fisheries Management 14: 710–725.

Hilldale, R.C. 2007. *Using bathymetric LiDAR and a 2-D hydraulic model to identify aquatic river habitat*. Proceedings of the World Environmental and Water Resources Congress, ASCE Conference Proceedings 243: 117 (2007). DOI: 10.1061/40927(243)117.

Kerr, J. E. 1953. *Studies on fish preservation at the Contra Costa steam plant of the Pacific Gas and Electric Company*. State of California, Department of Fish and Game Fish Bulletin 92.

Lai, Y.G. 2008. *SRH-2D, version 2: Theory and user's manual*. Bureau of Reclamation Report. Sedimentation and River Hydraulics Group, Technical Service Center, Denver, Colorado.

_____ 2010. *Two-dimensional depth-averaged flow modeling with an unstructured hybrid mesh*. Journal of Hydraulic Engineering 136: No. 1, January.

Leclerc, M., A. Boudreault, J.A. Bechara, and G. Corfa. 1995. *Two-dimensional hydrodynamic modeling: a neglected tool in the Instream Flow Incremental Methodology*. Transactions of the American Fisheries Society 124: 645-662.

Marcus, A. and M. Fonstad. 2008. *Optical remote sensing of rivers at sub-meter* resolutions and *watershed extents*. Earth Surface Processes and Landforms 33: 4–24.

Merwade, V. 2009. *Effect of spatial trends on interpolation of river bathymetry*. Journal of Hydrology 371: 169–181.

National Marine Fisheries Service. 2009. *Biological opinion and conference opinion on the long-term operations of the Central Valley Project and the State Water Project*. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Region, Long Beach, California.

Nezu, I. and H. Nakagawa. 1993. *Turbulence in open channel flows*, A.A. Balkema, Rotterdam, Netherlands.

Papanicolaou, A.N., M. Elhakeem, D. Dermiss, and N. Young. 2010. *Evaluation of the Missouri River shallow water habitat using a 2D hydrodynamic model*. River Research and Applications. In press. available on-line at http://onlinelibrary.wiley.com/doi/10.1002/rra.1344/abstract.

Parasiewicz, P. 2007. *Arena: The mesohasim model revisited*. River Research and Applications 23: 893–903.

Pasternack, G.B., A.T. Gilbert, J.M. Wheaton, and E.M. Buckland. 2006. *Error propagation for velocity and shear stress prediction using 2D models for environmental management*. *Journal of Hydrology* 328: 227–241.

Pasternack, G.B., P. Bratovich, G. Reedy, T. Johnson, D. Massa, J. Bergman, C. Purdy, and C. Campos. 2009. *Linking geomorphic processes and ecologic functions over long channel segments and retaining fine details – let's have our cake and eat it too*. Fall AGU meeting. Abstract #H53I-01.

Reclamation (Bureau of Reclamation). 2008. *Biological assessment on the continued long-term operations of the Central Valley Project and the State Water Project*. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. *A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in pacific northwest watersheds*. North American Journal of Fisheries Management 22: 1–20.

Smith, L. S., and L.T. Carpenter. 1987. *Salmonid fry swimming stamina data for diversion screen criteria*. Fisheries Research Institute, University of Washington, Seattle, Washington.

Snider, W.M., D.B. Christophel, B.L. Jackson, and P.M. Bratovich. 1992. *Habitat characterization of the Lower American River*. California Department of Fish and Game, Sacramento, California.

Steffler, P. and J. Blackburn. 2002. *River2D two-dimensional depth averaged model of river hydrodynamics and fish habitat*. Introduction to depth averaged modeling and user's manual. University of Alberta, Edmonton, Alberta, Canada.

Sutton, R., R. Hilldale, D. Varyu, and A. Bell. 2010. *Sandy Bar Creek Study, Klamath River*. Technical Memorandum No. 86-68290-10-04, Bureau of Reclamation.

Tiffan, K.F., R.D. Garland, and D.W. Rondorf. 2002. *Quantifying flow-dependent changes in subyearling fall Chinook salmon-rearing habitat using two-dimensional spatially explicit modeling*. North American Journal of Fisheries Management 22: 713–726.

Wheaton, J.M., G.B. Pasternack, and J.E. Merz. 2004. *Spawning habitat rehabilitation – I: Conceptual approach and methods*. International Journal of River Basin Management 2: No. 1, 3–20.

U. S. Fish and Wildlife Service. 2010a. *Flow-habitat relationships for juvenile spring/fall-run Chinook salmon and O.mykiss/rainbow trout rearing in the Yuba River*. Final Report U.S. Fish and Wildlife Service, Sacramento, California.

U. S. Fish and Wildlife Service. 2010b. *Flow-habitat relationships for juvenile spring/fall-run Chinook salmon and O.mykiss/rainbow trout rearing in the Yuba River*. Response to Comments. U.S. Fish and Wildlife Service, Sacramento, California.

Waddle, T. and P. Steffler. 2002. *R2D_mesh - mesh generation program for River2D two dimensional depth averaged finite element*. Introduction to Mesh Generation and User's Manual. U.S. Geological Survey, Fort Collins, Colorado. http://www.River2D.ualberta.ca/download.htm

Wu, W. 2008. *Computational river dynamics*, Taylor and Francis Group, London, UK.