From: Allison Boucher <aboucher@bendbroadband.com>
Sent: Thursday, February 20, 2014 8:09 PM
To: 'Staples, Rose'; 'Alves, Jim'; 'Amerine, Bill'; 'Asay, Lynette'; 'Barnes, James'; 'Barnes, Peter'; 'Barrera, Linda'; 'Beeco, Adam'; 'Blake, Martin'; 'Bond, Jack'; 'Borovansky, Jenna'; 'Bowes, Stephen'; 'Bowman, Art'; 'Brenneman, Beth'; 'Buckley, John'; 'Buckley, Mark'; 'Burke, Steve'; 'Burt, Charles'; 'Byrd, Tim'; 'Cadagan, Jerry'; 'Carlin, Michael'; 'Charles, Cindy'; 'Cooke, Michael'; 'Cowan, Jeffrey'; 'Cox, Stanley Rob'; 'Cranston, Peggy'; 'Cremeen, Rebecca'; 'Damin Nicole'; 'Day, Kevin'; 'Day, P'; 'Denean'; 'Derwin, Maryann Moise'; 'Devine, John'; 'Dowd, Maggie'; 'Drake, Emerson'; 'Drekmeier, Peter'; 'Edmondson, Steve'; 'Eicher, James'; 'Fargo, James'; 'Fernandes, Jesse'; 'Ferranti, Annee'; 'Ferrari, Chandra'; 'Findley, Timothy'; 'Fleming, Mike'; 'Fuller, Reba'; 'Furman, Donn W'; 'Ganteinbein, Julie'; 'Giglio, Deborah'; 'Gorman, Elaine'; 'Grader, Zeke'; 'Gutierrez, Monica'; 'Hackamack, Robert'; 'Hastreiter, James'; 'Hatch, Jenny'; 'Hayden, Ann'; 'Hellam, Anita'; 'Heyne, Tim'; 'Holley, Thomas'; 'Holm, Lisa'; 'Horn, Jeff'; 'Horn, Timi'; 'Hudelson, Bill'; 'Hughes, Noah'; 'Hughes, Robert'; Noah Hume; 'Hurley, Michael'; 'Jackson, Zac'; 'Jauregui, Julia'; 'Jennings, William'; 'Jensen, Laura'; 'Johannis, Mary'; 'Johnson, Brian'; 'Jones, Christy'; 'Jsansley'; 'Justin'; 'Keating, Janice'; 'Kempton, Kathryn'; 'Kinney, Teresa'; 'Koepele, Patrick'; 'Kordella, Lesley'; 'Le, Bao'; 'Levin, Ellen'; 'Linkard, David'; 'Loy, Carin'; 'Lwenya, Roselynn'; 'Lyons, Bill'; 'Madden, Dan'; 'Manji, Annie'; 'Marko, Paul'; 'Martin, Michael'; 'Mathiesen, Lloyd'; 'McDaniel, Dan'; 'McDevitt, Ray'; 'McDonnell, Marty'; 'Mein Janis'; 'Mills John'; 'Morningstar Pope, Rhonda'; 'Motola, Mary'; 'Murphey, Gretchen'; 'Murray, Shana'; 'O'Brien, Jennifer'; 'Orvis, Tom'; 'Ott, Bob'; 'Ott, Chris'; 'Pavich, Steve'; 'Pool, Richard'; 'Porter, Ruth'; 'Powell, Melissa'; 'Puccini, Stephen'; 'Raeder, Jessie'; 'Ramirez, Tim'; 'Rea, Maria'; 'Reed, Rhonda'; 'Reynolds, Garner'; 'Richardson, Daniel'; 'Richardson, Kevin'; 'Ridenour, Jim'; 'Riggs T'; 'Robbins, Royal'; 'Romano, David O'; 'Roos-Collins, Richard'; 'Rosekrans, Spreck'; 'Roseman, Jesse'; 'Rothert, Steve'; 'Sandkulla, Nicole'; 'Saunders, Jenan'; 'Schutte, Allison'; 'Sears, William'; 'Shakal, Sarah'; 'Shipley, Robert'; 'Shumway, Vern'; 'Shutes, Chris'; 'Sill, Todd'; 'Simsiman, Theresa'; 'Slay, Ron'; 'Smith, Jim'; 'Stapley, Garth'; 'Steindorf, Dave'; 'Steiner, Dan'; 'Stender, John'; 'Stone, Vicki'; 'Stork, Ron'; 'Stratton, Susan'; 'Taylor, Mary Jane'; 'Terpstra, Thomas'; 'TeVelde, George'; 'Thompson, Larry'; 'Tmberliner'; 'Ulibarri, Nicola'; 'Verkuil, Colette'; 'Vierra, Chris'; 'Villalobos, Amber'; 'Wantuck, Richard'; 'Ward, Walt'; 'Welch, Steve'; 'Wenger, Jack'; 'Wesselman, Eric'; 'Wetzel, Jeff'; 'Wheeler, Dan'; 'Wheeler, Dave'; 'Wheeler, Douglas'; Scott Wilcox; 'Williamson, Harry'; 'Willy, Allison'; 'Wilson, Bryan'; 'Winchell, Frank'; 'Wooster, John'; 'Workman, Michelle'; 'Yoshiyama, Ron'; 'Zipser, Wayne'
Cc: Dave Boucher
Subject: Floodplain Hydraulic Assessment

Floodplain Hydraulic Assessment Study:

Although historic recurrence probability might be interesting, the more important analysis would be unimpaired flows recurrence probability. Please add unimpaired flows recurrence probability to the study and compare it to flows since the 1995 Settlement Agreement excluding the flood of 1997. If the flood of 1997 is included, the graph will be misleading.

Allison and Dave Boucher
Tuolumne River Conservancy, Inc.

APPENDIX B

WORKSHOP NO. 2 MEETING NOTES

Don Pedro Project Relicensing
W&AR-21 Workshop No. 2
Final Meeting Notes

Thursday, December 18, 2014

Attendees

Jenna Borovansky – HDR	Ron Yoshiyama – CCSF
Jesse Deason – HDR	Jim Hastreiter – FERC, *by phone*
John Devine – HDR	Robert Hughes – CDFW
Pani Ramalingam – HDR	Dean Marston – CDFW
Rob Sherrick – HDR	Dale Stanton – CDFW
Anna Brathwaite – MID	John Wooster – NMFS, *by phone*
Greg Dias – MID	Mark Gard – USFWS
Bill Johnston – MID, *by phone*	Peter Barnes – SWRCB, *by phone*
Noah Hume – Stillwater Sciences	Chris Shutes – CSPA, *by phone*
Maia Singer – Stillwater Sciences	Peter Drekmeier - Tuolumne River Trust, *by phone*
Jonathan Knapp – CCSF	Patrick Koepele – Tuolumne River Trust, *by phone*
Ellen Levin – CCSF	Nicola Ulibarri – Stanford
Bill Sears – CCSF	

Agenda and Purpose

Following introductions, Jenna Borovansky provided an overview of the meeting agenda. The purpose of the Lower Tuolumne River Hydraulic Floodplain Assessment (W&AR-21) modeling Workshop No. 2 is to review the hydraulic model development, present calibration and validation results, present preliminary results of the habitat analysis, and the study schedule (slide 2).

Background

Jenna provided study background (slide 3).

Study Objectives

Jenna presented the study objectives, namely to analyze floodplain inundation at specified flow intervals and estimate associated floodplain habitat availability for rearing juvenile salmon in the lower Tuolumne River (slide 4). Base case hydrology (1970-2012) from the Operations Model report is used for this study. The completed 2-D floodplain model can serve as a tool for modeling future hydrology scenarios.

Study Methodology

Jenna provided an overview of study methodology (slide 5).

Summary of Workshop No. 1

Jenna presented a summary of material covered at Workshop No. 1, held in February 2014, including recommendations that came out of workshop discussions (slides 6 & 7). The primary recommendations were the following:

- Develop three reaches for TUFLOW model
    - Model A (RM 51.4 – 40)
    - Model B (RM 40 – 21.5)
    - Model C (RM 21.5 – 0.9)
- Based on results of the sensitivity analysis, use a 2-D model cell size of 30 ft or less

Question (Patrick Koepele): What geomorphic characteristics were used to define the three study reaches?

Answer (Pani Ramalingam): Three study reaches were adopted primarily based on run-time considerations for TUFLOW. At a 30-ft cell size, the model run time for the entire lower river would be unreasonably long. Breaking the model into three separate reaches allowed us to optimize model construction, calibration, and run time. Each of the three model segments requires approximately 1-2 hours to run, allowing us to work on them simultaneously.

Answer (Noah Hume): The Tuolumne River has a major slope break from gravel bedded to sand bedded at approximately RM 29. As Pani noted, the river was divided into sub-reaches for computational efficiency.

Hydraulic Modeling Status

Pani Ramalingam presented the model reach extents (slide 8). Rob Sherrick presented a summary of the various cross section data sources used to develop model cross-sections for the 1-D (in-channel) portion of the TUFLOW model (slides 9 &10). While existing data were used where available, a considerable amount of additional cross-section data were collected by TID as necessary. Some of the survey locations of the data sources overlapped in various reaches of the river, allowing for improved spatial accuracy and model validation.

Model Components

Pani presented the TUFLOW hydrologic model components (slides 11-12).

- Ponds and pools – manually digitized and were assigned depths from bathymetry if available or assigned water level from 2012 LiDAR
- Levee like features – derived from LiDAR and captured in the model
- Narrow thin channels – derived from LiDAR and captured in the model
- Mannings ‘n’ (roughness or friction factor used in modeling) was derived from prior vegetation mapping studies and existing aerial photos, 2012 helicopter video and field visit photos.
- Model B – includes culverts near RM 38
- Model C – includes Dennett Dam (~RM 16)

Model Boundary Conditions

Pani described the order of model segment development. Boundary conditions were set from downstream to upstream in order to appropriately include backwater effects from the Tuolumne River-San Joaquin River confluence.

1. Model C – An analysis of backwater effects of San Joaquin River was performed. A range of USGS gage data sources were used to estimate statistical relationships of San Joaquin and Tuolumne River stages and flows (slides 13-16). This analysis revealed that backwater effects can extend up to RM 13. A discharge - water surface elevation curve (rating curve) was developed for use as boundary condition.

2. Model B - Model C was built simultaneously along with Model B and the section upstream of Modesto gage (near RM 16) was calibrated. Results from this model were then used to develop a rating curve for use as a boundary condition. It should be noted that extents of Model B and C overlap.

3. Model A – Normal depth boundary condition was used by extending the model downstream to RM 37.5 so that boundary effects are insignificant at RM 40. It should be noted that extents of Model A and B overlap.

Model Calibration and Validation

Pani described the calibration and validation steps for TUFLOW (slides 17-21). Calibration was accomplished by using a combination of model results, gage flows, and historical images. The 1-D in-channel portion of the model was calibrated first, followed by the 2-D floodplain portion of the model.

Question (Bob Hughes): How did you use Google Earth to calibrate the model?

Answer (Pani Ramalingam): We used existing images of historical flow events across a range of flows to visualize the channel wetted width. This included digitizing a series of air photos from four high flow events in the 1990s that were used in the USFWS (2008) and Stillwater Sciences (2012) floodplain studies. Google Earth also provides historical aerial imagery which allowed the observed inundation extent to be validated against the gaged flows on the date of the photo.

Question (Bob Hughes): Was there any calibration to water surface elevations?

Answer (Pani Ramalingam): Yes, in Model Segment A for RM 49 – 43, the stage data records for 3,000 cfs collected at two sites in the 2011 Pulse Flow Study was used. Water surface elevations were also used to calibrate Model Segment C using the existing USGS rating curve information at the Modesto gage.

Hydraulic Modeling Results

Pani showed inundation examples (slide 22) for Model Segment A, B, and C stepping through model results in 250/500 cfs increments (not shown in slides).

Question (Noah Hume): Are the flows entering from Dry Creek calculated using the rating curve approach for Model C or are the observed inundation areas simply due to backwater effects?

Answer (Pani Ramalingam): Backwater effects.

Question (Bob Hughes): I don't understand the interaction between the 1-D and 2-D components of the hydraulic model. Is the calibration accomplished primarily on the 1-D portion? How does TUFLOW work in general terms?

Answer (Pani Ramalingam): Calibration is undertaken for both the 1-D and 2-D portions [Pani showed a visual of the break line between the 1-D and 2-D models]. The model first undertakes calculations for the 1-D portion. Every 2 seconds the two models communicate with one another to determine if water should be crossing the break line into the 2-D portion of the model. We must begin with accurate flow predictions for the 1-D model; that is why we spent so much time collecting additional cross-section data for the 1-D model.

Habitat Analysis

Noah Hume discussed the habitat analysis approach (slides 23-24). Once the hydraulic model results were ready, we modeled habitat availability using suitability criteria for depth and velocity from the completed IFIM Study (Stillwater Sciences 2013). Cell-specific depth and velocity predictions from TUFLOW were summed across the 2-D model domain to estimate usable habitat area for juvenile and fry life stages of Chinook and *O. mykiss*. Results for Model Segment A are complete. Results are in development for model segments B and C.

Noah provided example results for Model Segment A at Riffle 4A/4B (slides 25-29):

- Habitat suitability is shown in 2,000 cfs increments
- In-channel habitat was excluded from the analysis (addressed by earlier Stillwater (2013) IFIM Study)
- Although there is a lot of inundated floodplain area, most of the suitable habitat is limited to backwater habitats and margins of flooded areas

Noah provided example results for Model Segment A at Bobcat Flat (slides 30-34):

- Hydraulic modeling is challenging in this reach due to the intact mining tailings piles and numerous deep ponds
- Given that, TUFLOW did a good job of representing flows in this reach
- Model results indicate inundation into captured gravel ponds at 7,000 and 9,000 cfs

Next we summed cell-specific habitat suitability for Model Segment A to produce the usable habitat vs discharge curve shown in slide 35.

- Note that usability of floodplain habitat for juveniles averages about 50% of total inundated area and does not fall off very quickly because they possess stronger swimming performance at increased depths and velocities
- In contrast, fry habitat usability drops off relatively quickly to less than 30% at the highest modeled flows
- The character of the usable habitat vs discharge relationships changes as we move from Model A which has some floodplain habitat; to Model B which has comparatively less floodplain habitat; to Model C nearest the San Joaquin River which has some floodplain habitat that becomes inundated at the highest flows.

O. mykiss fry life stages may be found in floodplain habitats, but generally these fish find flow refuge in gravels in main channel. Nevertheless we have included *O. mykiss* in the habitat analysis.

Area-Duration-Frequency Analysis

Noah discussed the aim of the ADF analysis – to determine the periods of maximum inundation occurring over a certain duration and at a certain frequency in the flow record (slides 36-45). This used base case (WY1971–2012) hydrology from the Operations Model (W&AR-02)

- Note that as in the example animations, even at 1,000 cfs there is a fair amount of floodplain habitat due to the presence of backwaters and pond features (e.g., 2 million ft^2).

- On a fairly regular basis (2-4 yr recurrence interval) floodplain habitat is inundated and usable for juveniles/fry.
- Flows above bankfull discharge are associated with increases in habitat.
- As with the usable habitat curves, each model reach will exhibit a slightly different character for the curves.
- For the final report, we may present habitat curves by reach, or we may combine into one lower river set of curves.
- In general, these results are consistent with prior floodplain modeling efforts.

Questions

Question: (Dale Stanton): Why limit yourself to the base case hydrology?

Answer (Jenna Borovansky): Base case hydrology is specified in the study plan, but conceivably other hydrologic scenarios could be run in the model.

Question: (Mark Gard): Would you compare results of the habitat assessment at unimpaired flows to results for base case flows? USFWS had recommended a set of flows in their comments on the study plan – what about those?

Answer (John Devine): The study plan suggests other flow scenarios, but in the FERC licensing process we are only considering the base case. The unimpaired flows represent a pre-project condition. If after FERC review there is still interest in modeling other flows, the model will be available as a tool.

Question (Bob Hughes): How much of the modeling tool will be publically available?

Answer (Jenna Borovansky): HDR has committed to having the TUFLOW model available for interested parties to run on their own. The Districts will work with agencies on the most efficient method for making the model available for use.

Answer (Noah Hume): The habitat suitability analysis is a little more involved but we could potentially provide the 'R' code used.

Answer (Rob Sherrick): The post-processing of the hydrology model results would be different for a new flow series, but TUFLOW results would be the same.

Question: Will the inundation animations be posted on the web?

Answer (Jenna Borovansky): Yes. We have some example animations for Model A that we can post – not all of the animations from today will be available since Pani ran them directly from the model for the workshop presentation.

Action Items

- The Districts will post the PowerPoint and sample animations on the relicensing website, www.donpedro-relicensing.com.
- The Districts will work with agencies to provide the model and habitat analysis files available by request, once the report is finalized.

- Following the meeting, Mark Gard (USFWS) contacted Noah Hume and requested summaries of the inundation area vs. discharge results to be provided in MS Excel format. In addition, when they are available, Mark requested velocity and depth predictions in either spreadsheet or csv format. The Districts will provide this information when the draft report is released for relicensing participant review.

Don Pedro Hydroelectric Project
Floodplain Hydraulic Assessment (W&AR-21)
Workshop No. 2 Agenda

Thursday, December 18
1:00 pm – 4:30 pm
MID Offices, 1231 11th Street, Modesto, CA

Phone number: 866-994-6437
Conference code: 542-469-7994
Link to online meeting: Join Lync Meeting (Lync Meeting Help)

- Review agenda and purpose of the meeting
- Study plan goals and objectives
- Overview of study methodology
  - Study flows
- Summary of Workshop No. 1
- River hydraulic model background
  - 2D TUFLOW model
  - 1D HEC-RAS model
- Model reaches
  - Model A: RM 52.2 to RM 40
  - Model B: RM 40 to RM 21.5
  - Model C: RM 21.5 to the confluence
- Data sources
- River hydraulic model calibration process (RM 52.2 – RM 21.5)
- Habitat analysis status
  - Analysis approach
  - Model A – preliminary results
    - Bobcat Flat example
    - Reach estimated usable area
    - Area-duration frequency analysis
- Next steps and schedule

Don Pedro Hydroelectric Project Relicensing

Lower Tuolumne River Floodplain Hydraulic Assessment (W&AR-21)

December 18, 2014

Agenda and Purpose

- Study Background
- Hydraulic Modeling Status
- Habitat Analysis Status
- Study Schedule

Background

- FERC ordered a hydraulic analysis of the amount of floodplain inundated in its May 21, 2013 Determination
- Draft study plan provided to relicensing participants for comment, and final study plan modified based on relicensing participant comments submitted in September 2013
  - Revised plan based on relicensing participant comment, including expanded study area and added habitat analysis
- FERC approved study plan October 18, 2013

Study Objectives

- Analyze the amount of floodplain inundated between RM 52.2 and RM 0 of the Tuolumne River at flows between approximately 1,000 cfs and 9,000 cfs
- Assess the suitability of inundated floodplain habitat for juvenile salmon rearing
- Evaluate the frequency and period of inundation over a range of flows for the base case (WY 1971-2012) hydrology

Study Methodology

1. TUFLOW model to determine floodplain extents at:
   - 250 cfs intervals from 1,000-3,000 cfs
   - 500 cfs intervals from 3,000-9,000 cfs
2. Determine the maximum continuous wetted area for 7, 14, 21, and 30 day durations
3. Evaluate the Base Case scenario (WR 1971-2012)
4. Estimate depths and velocities in overbank areas from RM 52 to the San Joaquin River and use existing habitat suitability criteria for depth and velocity for juvenile salmonids to quantify the amount of suitable juvenile rearing habitat as a function of flow

February 13, 2014: Workshop No. 1

- Hydraulic Modeling Approach
  - Data Sources
  - TUFLOW Model
  - Overbank vs. In Channel Areas

- Habitat Analysis Approach
  - Sensitivity to grid size

Feb.13 Meeting - Recommendations

- TUFLOW Modeling Plan
  - Model A - RM 52 to 40
  - Model B - RM 40 to 23
  - Model C - RM 23 to 0

- 2D cell Size – 30ft or less

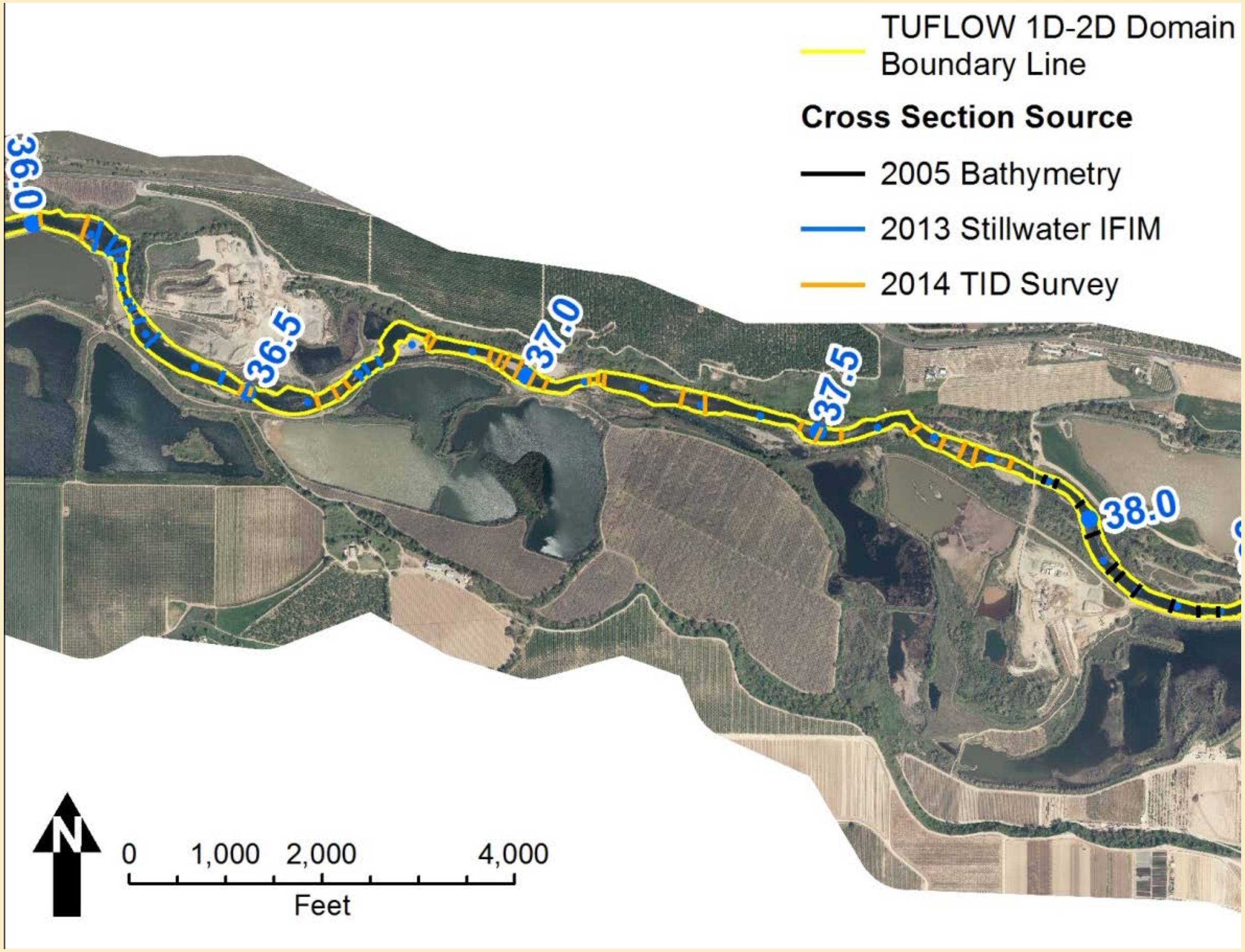
Hydraulic Modeling Status

- **TUFLOW models constructed, calibrated and QCed**
- **Model A – RM 52.2 to RM 40**
- **Model B – RM 40 to RM 21.5**
- **Model C – RM 21.5 to the confluence (RM 0.88)**
  - **San Joaquin River backwater effects analyzed**

1D Cross Section Data Sources

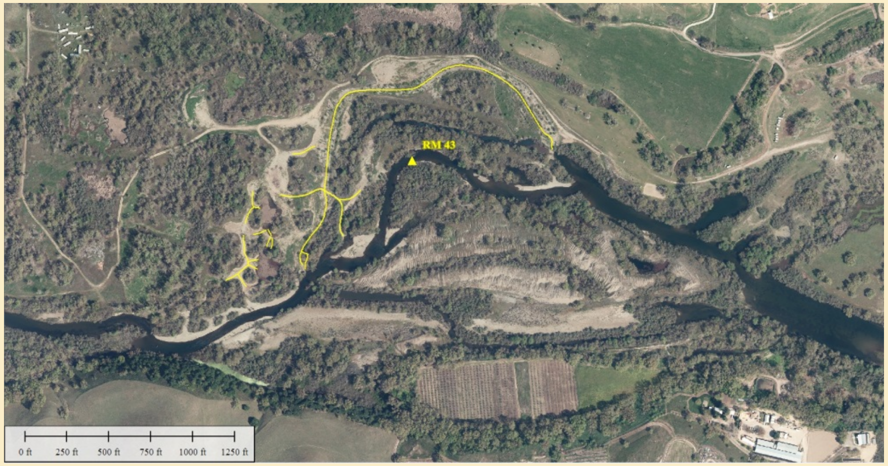
RM (USGS)	RAS Station	Source	Count
0.88-6.31	0.8252-6.3035	2014 DWR-CVFED HEC-RAS Model	28
6.71-22.78	6.715-23.0683	FEMA-CVFED HEC-RAS Model	51
13.99-31.48	13.847-31.9232	2012 HDR Survey	34
4.43-29.54	4.3978-29.98	Interpolated	37
16.13-16.41	15.9601-16.2138	USGS Gage Cross Sections	3
22.59-46.98	22.8536-47.4583	2014 TID Survey	134
24.41-25.86	24.948-26.5125	McBain&Trush SRP 9/10 Restoration	16
30.34-36.74	30.739-37.5818	2013 Stillwater IFIM	19
37.9-45.77	38.9536-46.27	2005 Bathymetry	167
45.78-51.66	46.2985-51.6734	2012 Bathymetry	133
		TOTAL:	622

Sample Cross Section Source Integration



Model Components

- **1D Low flow channel**
- **Ponds & pools**
- **Levee like features**
- **Narrow thin channels**
  - connecting river and overbanks
  - connecting overbank ponds

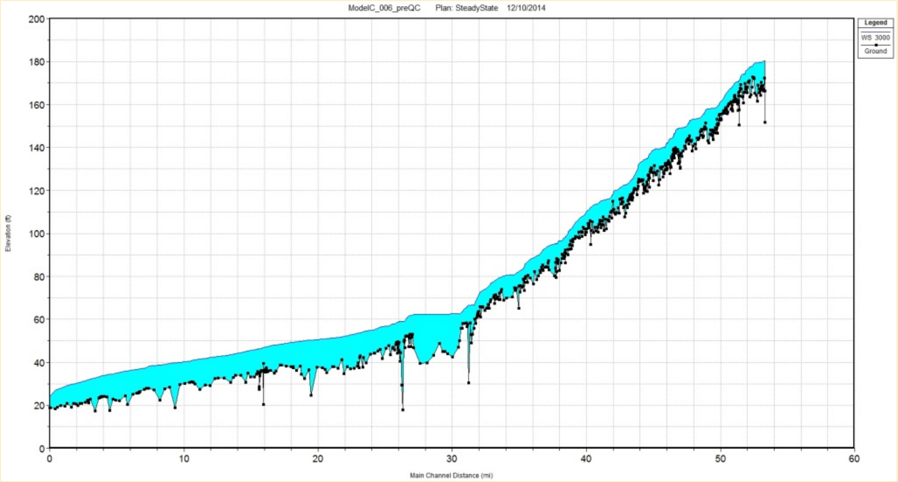


Model Components

- 2D Manning's "n" for overbank areas
- Culverts near RM 38
- Dennett Dam

Model Boundary Conditions

- **Model A – Normal depth**

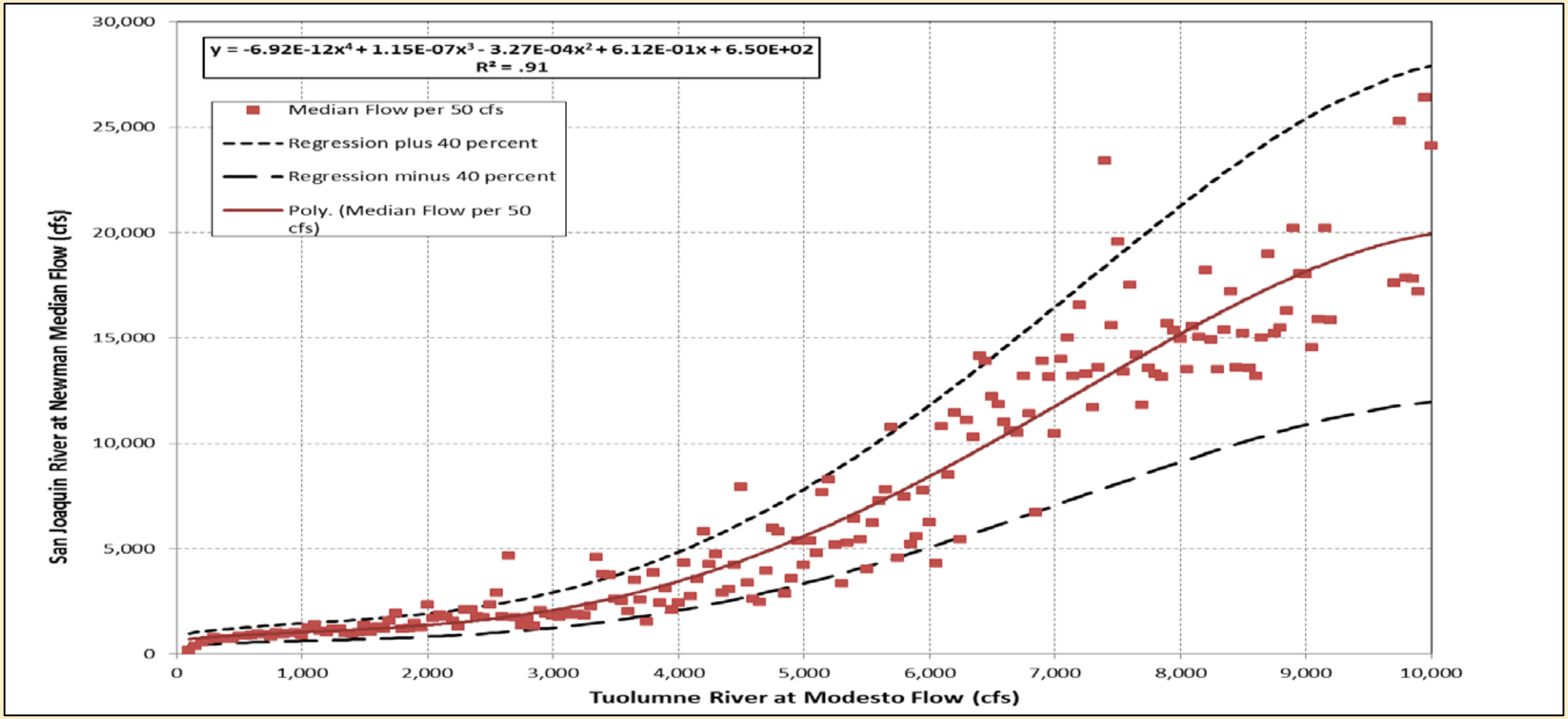


- **Model B – From Model C**
- **Model C – San Joaquin River backwater analysis**

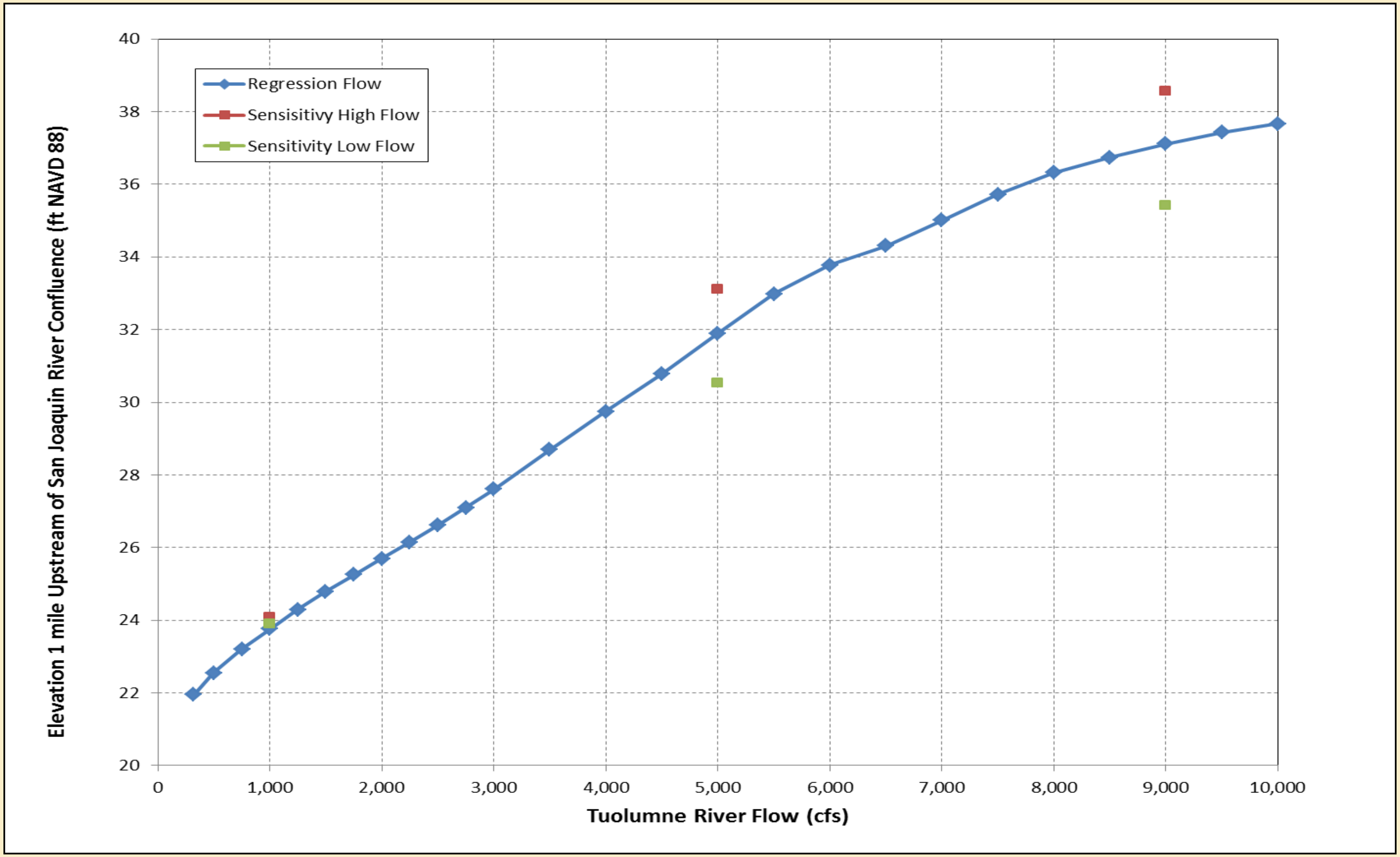
San Joaquin River Backwater Analysis

1. Use existing DWR & FEMA HEC-RAS models
2. Determine extent of backwater effects from San Joaquin River
3. Develop correlated sets of flows for Tuolumne, San Joaquin and Stanislaus Rivers (Water Years 1971 to 2012)
4. Develop a rating curve (elevation-discharge) for downstream boundary condition for Model C

Sensitivity Analysis



Model C Boundary Condition Rating Curve



Model Calibration & Validation

- Google Earth aerial photos (2005-2011)
- TID historic aerial photos (1993-1995)
- USGS gage at Modesto

Model A - Calibration and Validation

TUFLOW Model A - Calibration & Validation Reaches & Data Sources

Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow / Google Earth Imagery Date						RM 50 Side Channel	Bobcat Flat RM 43 Restoration Work	
			1020 cfs	1590 cfs	1960 cfs	2040 cfs	2680 cfs	4030 cfs	490 cfs	5400-6000 cfs	5900-5600cfs
Reach 1	RM 48.5 to RM 51.6	Riffle 4A/4B	24-Jul-11	23-Feb-06		30-May-10	6/29/2005*	-	24-May-09		
Reach 2	RM 46 to RM 48.5	Riffle 5A (Basso Bridge)	24-Jul-11	23-Feb-06	-	30-May-10		11-Jun-05		-	
Reach 3	RM 44 to RM 46	Zanker Property	24-Jul-11	23-Feb-06		30-May-10	-	11-Jun-05	-		
Reach 4	RM 42 to RM 44	Bobcat Flat	24-Jul-11(RM 43 up)	23-Feb-06		30-May-10		11-Jun-05		13-Jun-10	16-Jun-11
Reach 5	RM 38 to RM 42		-	23- Feb-06(RM 40 up)	24-Apr-10	30-May-10 (RM 40 up)		11-Jun-05		-	

*Corrected date per NAIP

Legend

- Calibration Data
- Validation Data
- Limited validation

This data set was used more as a reference. The river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow / TID Historic Inundation Imagery Year		
		3100 cfs	5300 cfs	8400 cfs
Reach 1	RM 48 to RM 51.6	1993	1995	1995
Reach 2	RM 46 to RM 48	1993	1995	1995
Reach 3	RM 44 to RM 46	1993	1995	1995
Reach 4	RM 42 to RM 44	1993	1995	1995
Reach 5	RM 38 to RM 42	1993	1995	1995

Model B - Calibration and Validation

TUFLOW Model B - Calibration & Validation Reaches & Data Sources

Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow* / Google Earth Imagery Date			
			654 cfs	2130 cfs	2620 cfs	4050 cfs
1	RM 20 to RM 40		28-Jul-11	24-Apr-10	-	11-Jun-05
2	RM 20 to RM 25		28-Jul-11	24-Apr-10	10-Feb-06	11-Jun-05

*Previous day average flow to account for travel time from USGS La Grange gage

Legend

Calibration Data
Validation Data
Limited validation

This data set was used more as a reference. The river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow / TID Historic Inundation Imagery Year		
		3100 cfs	5300 cfs	8400 cfs
2	RM 20 to RM 40	1993	1995	1995

Model C - Calibration and Validation

TUFLOW Model C - Calibration & Validation Reaches & Data Sources

A. Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow* / Google Earth Imagery Date		
			900 cfs	3320 cfs	4130 cfs
1	RM 0.88 to RM 16		28-Jul-11	-	11-Jun-05
2	RM 12 to RM 16			10-Feb-06	

*USGS Modesto Gage (RM 16)

Legend

Calibration Data
Validation Data
Limited validation

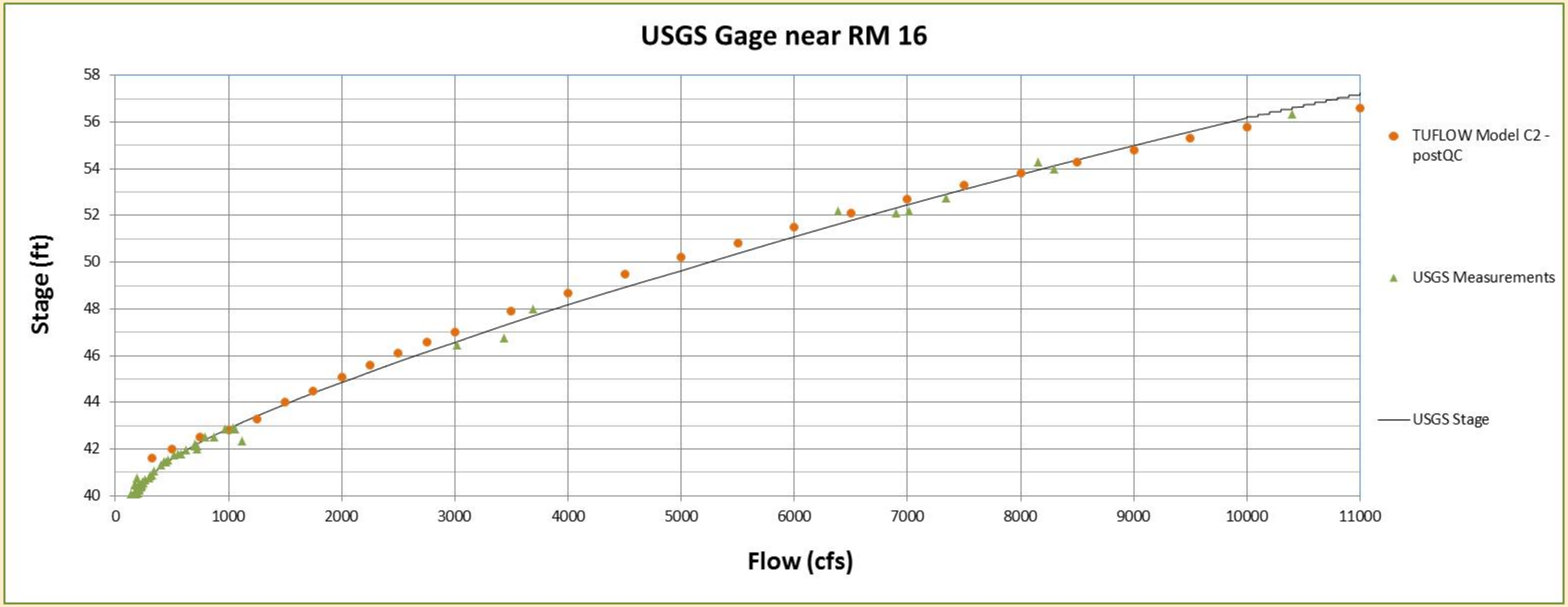
B. TID data set was used more as a reference as the river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow* / TID Historic Inundation Imagery Year
		8322 cfs
2	RM 0.88 to RM 21.5	22-Apr-95

*USGS Modesto Gage (RM 16)

C. The rating curve & stage-flow measurements taken at of USGS Gage located near Modesto (near RM 16) were also used to calibrate the model for range of flows.

Model C - Calibration and Validation

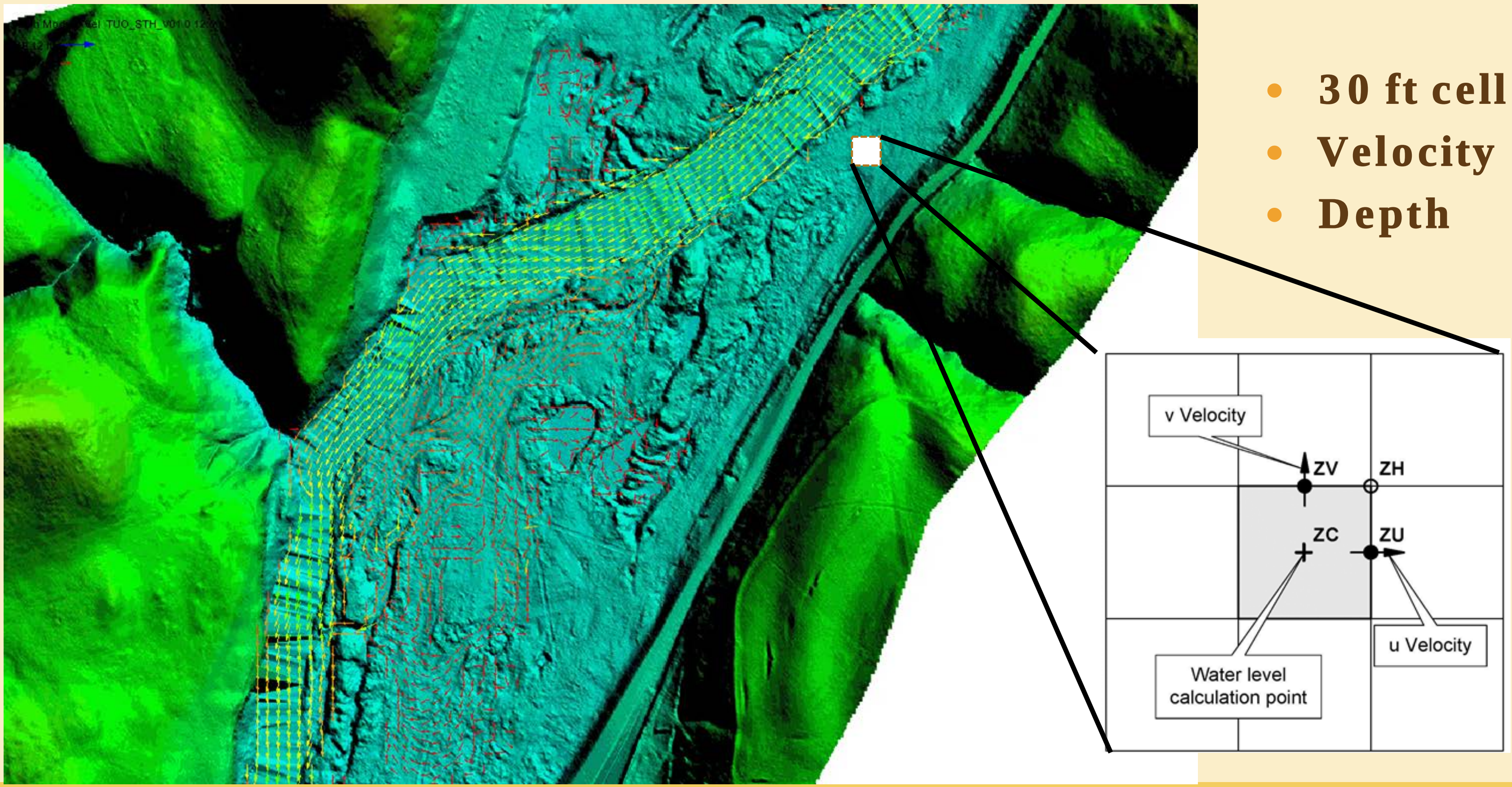


Models A, B & C - Results

- Inundation Extents at various steady flows (Animation)
  - 1000 to 3000 cfs @ 250 cfs interval
  - 3000 to 9000 cfs @ 500 cfs interval
- Simulation of time varying hydrograph (Animation)
  - 1000 to 9000 cfs and back to 1000 cfs
  - Shows flow paths, stranding potential etc.

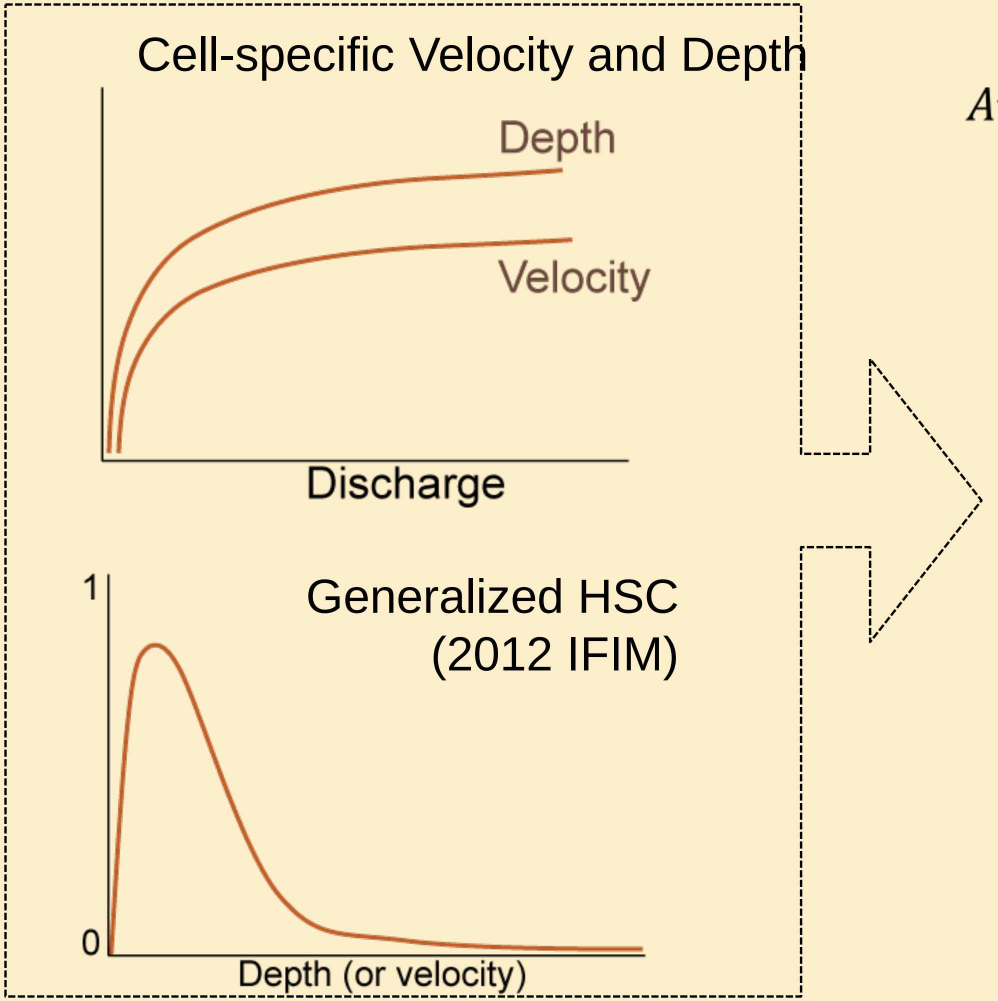
Habitat Analysis

- **Cell-specific Velocity and Depth Predictions**

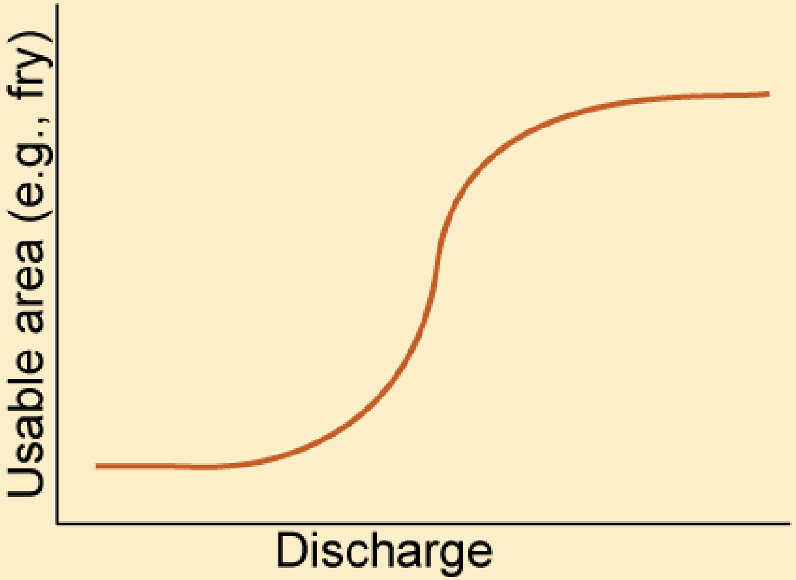


- **30 ft cell size**
- **Velocity**
- **Depth**

Habitat Analysis

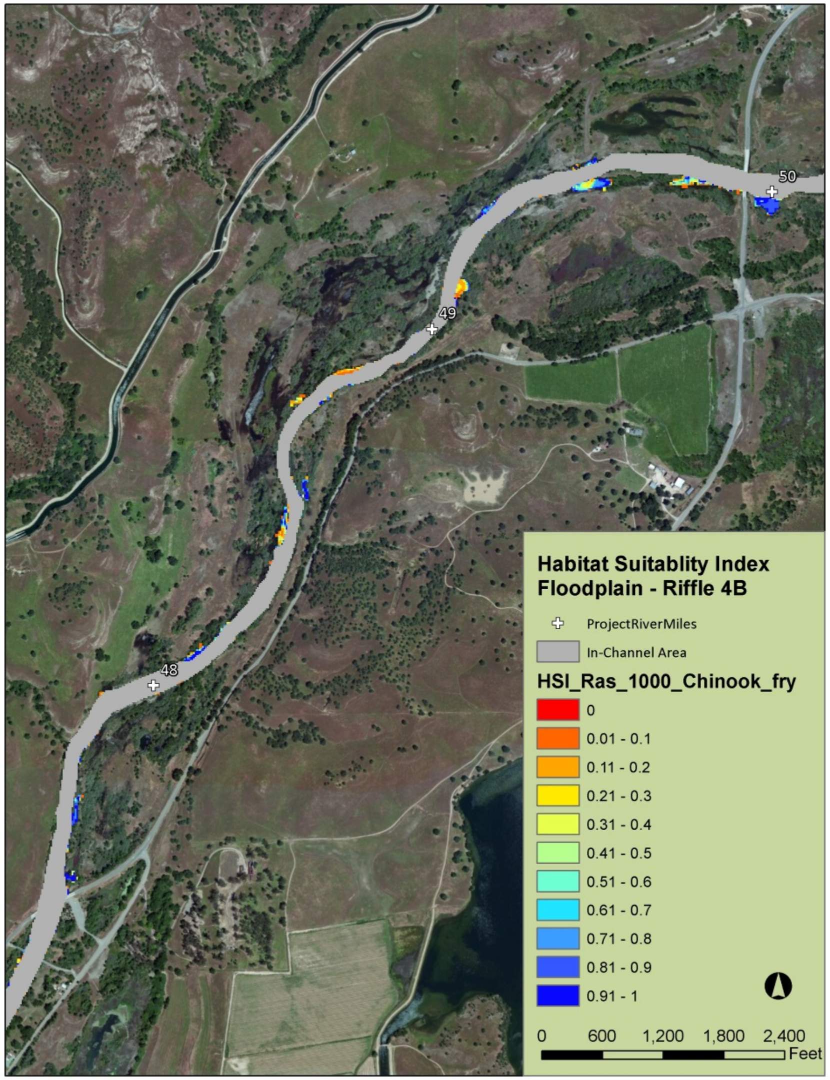


$$Area = \sum_{i=1}^{n} A_i \times HSC(depth, velocity)$$



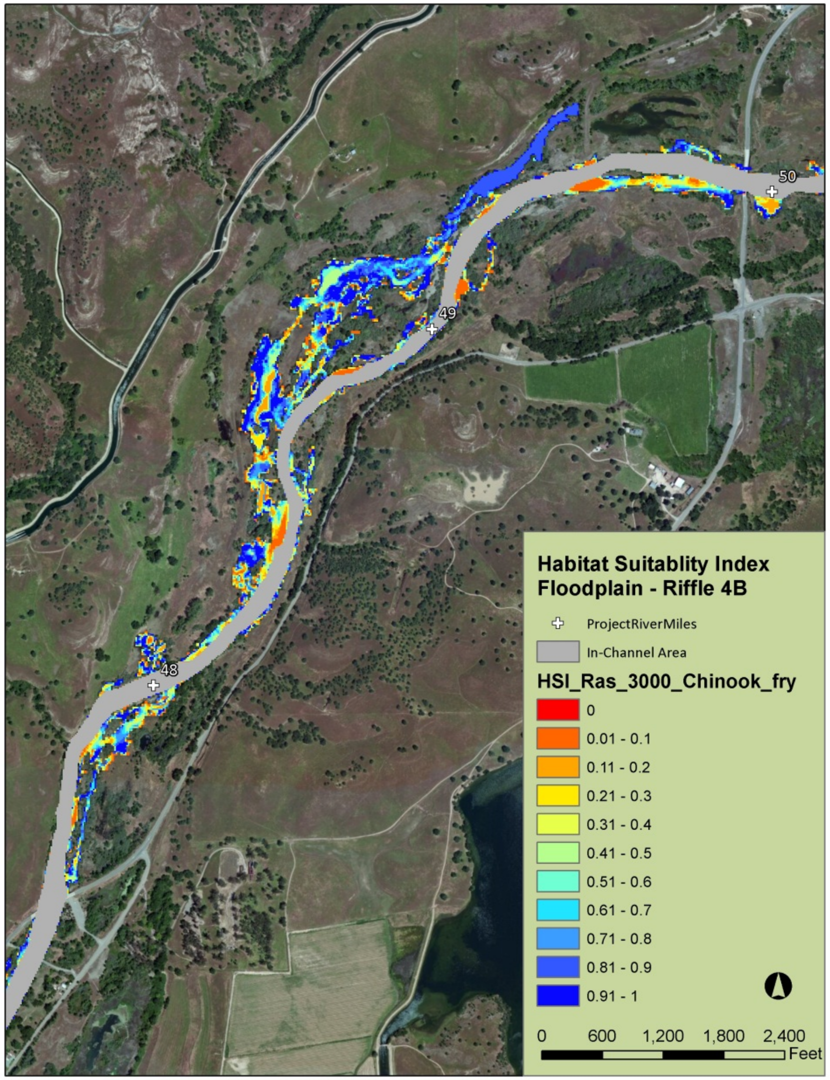
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- Overbank habitat at 1,000 cfs
- Little floodplain inundation evident



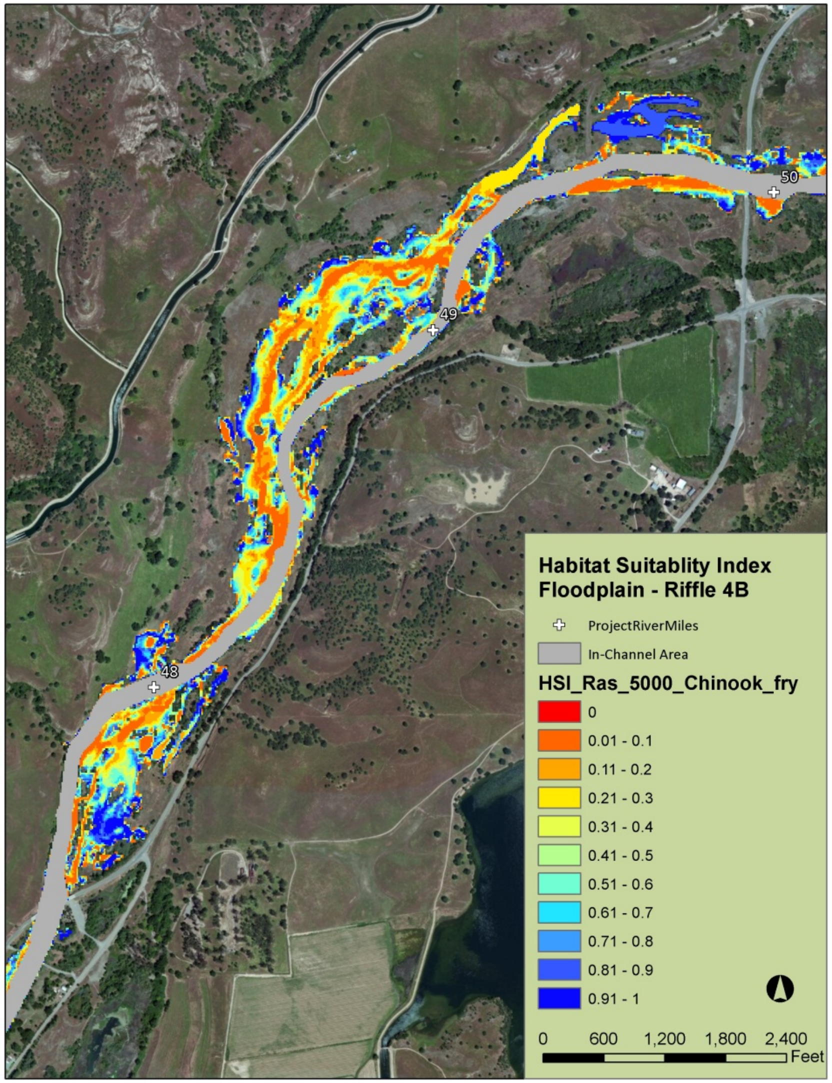
Habitat Analysis Results Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 3,000 cfs**
- **Inundation of side-channels and floodplain**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



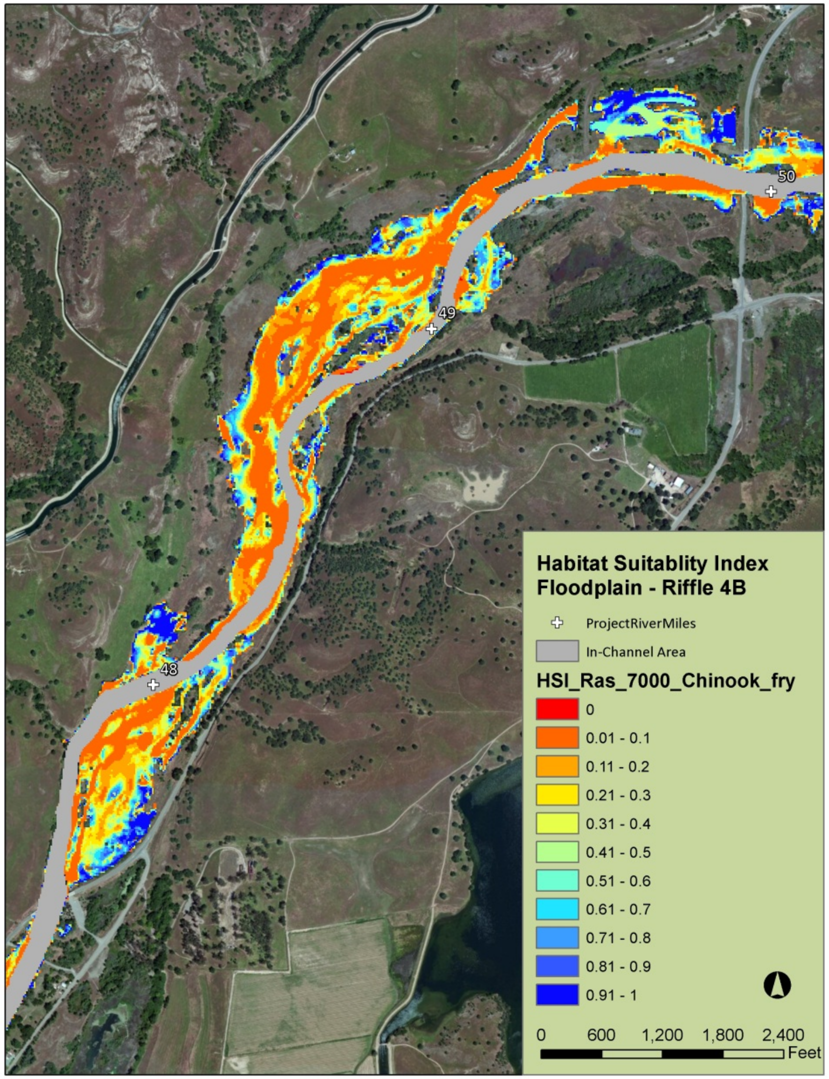
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 5,000 cfs**
- **Broad inundation of floodplain habitat**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



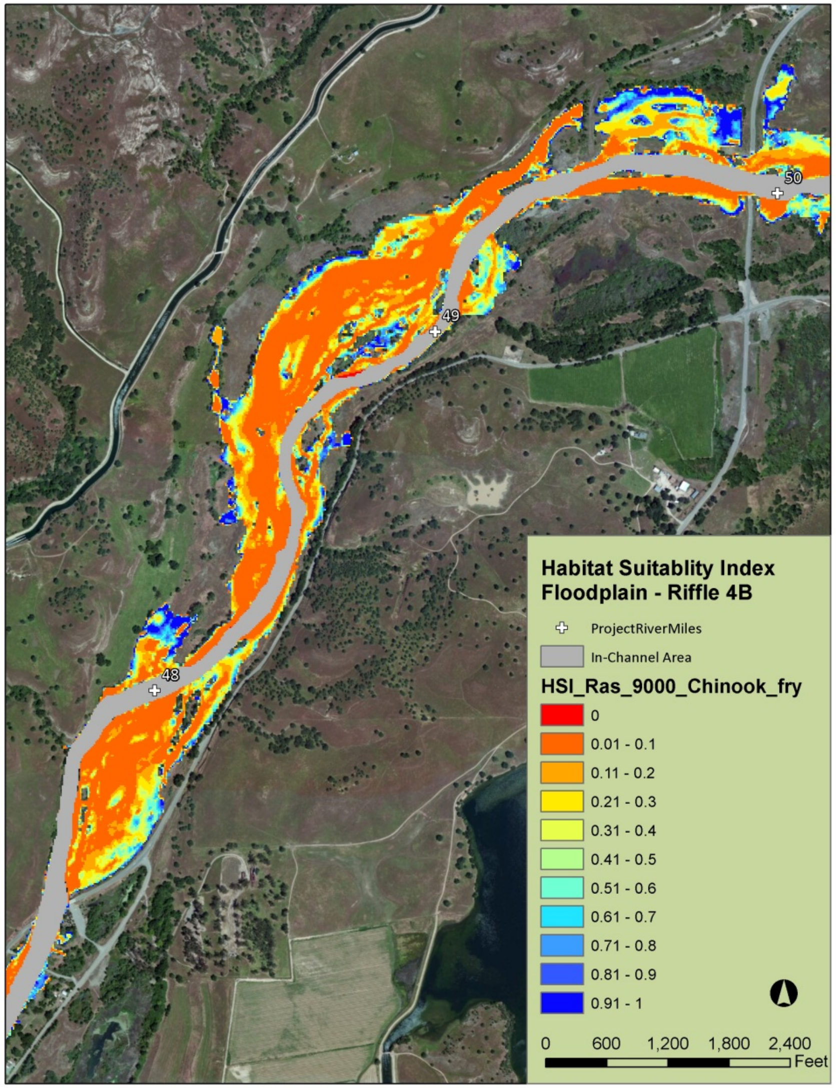
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 7,000 cfs**
- **Broad inundation of floodplain habitat**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



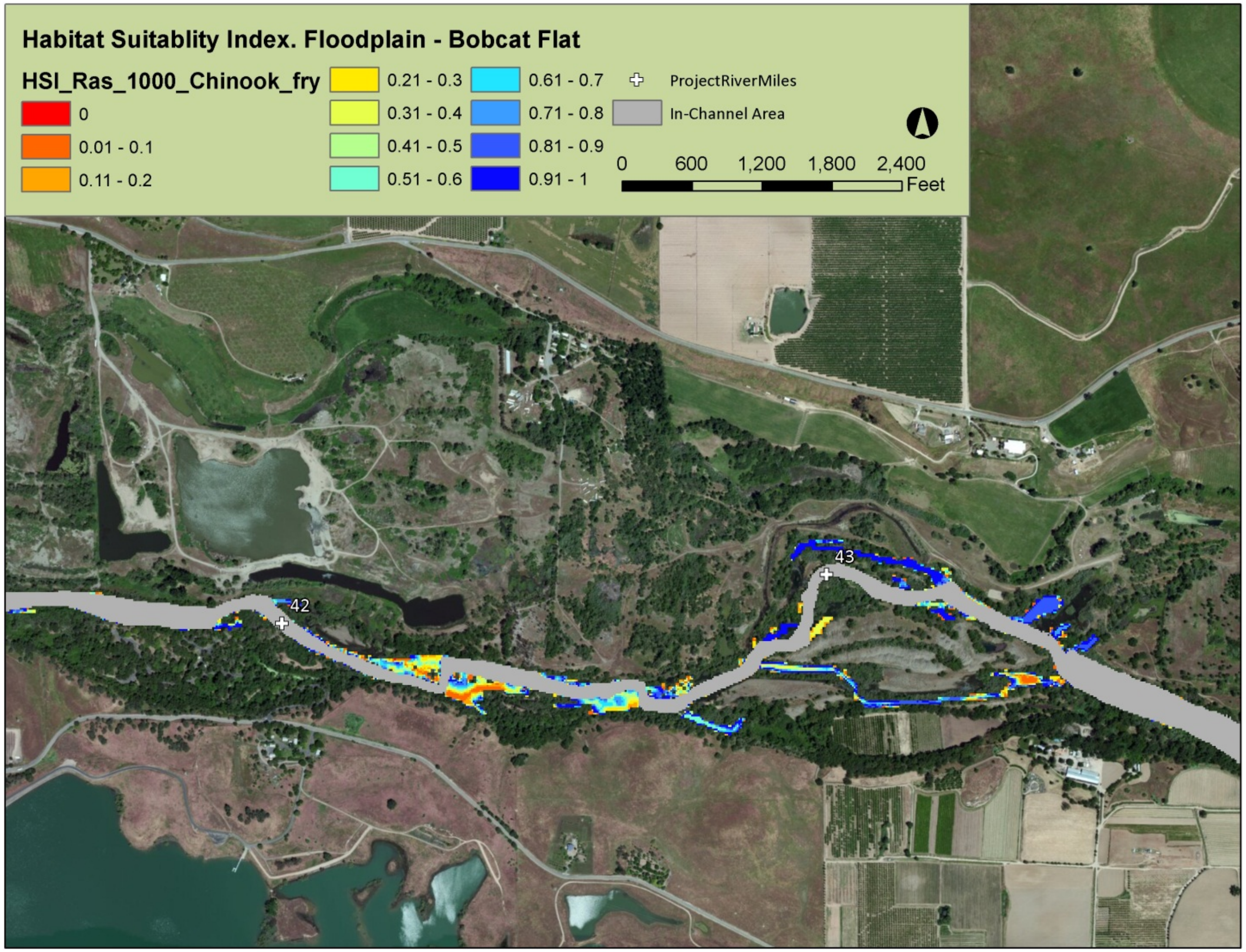
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 9,000 cfs**
- **Broad inundation of floodplain habitat**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



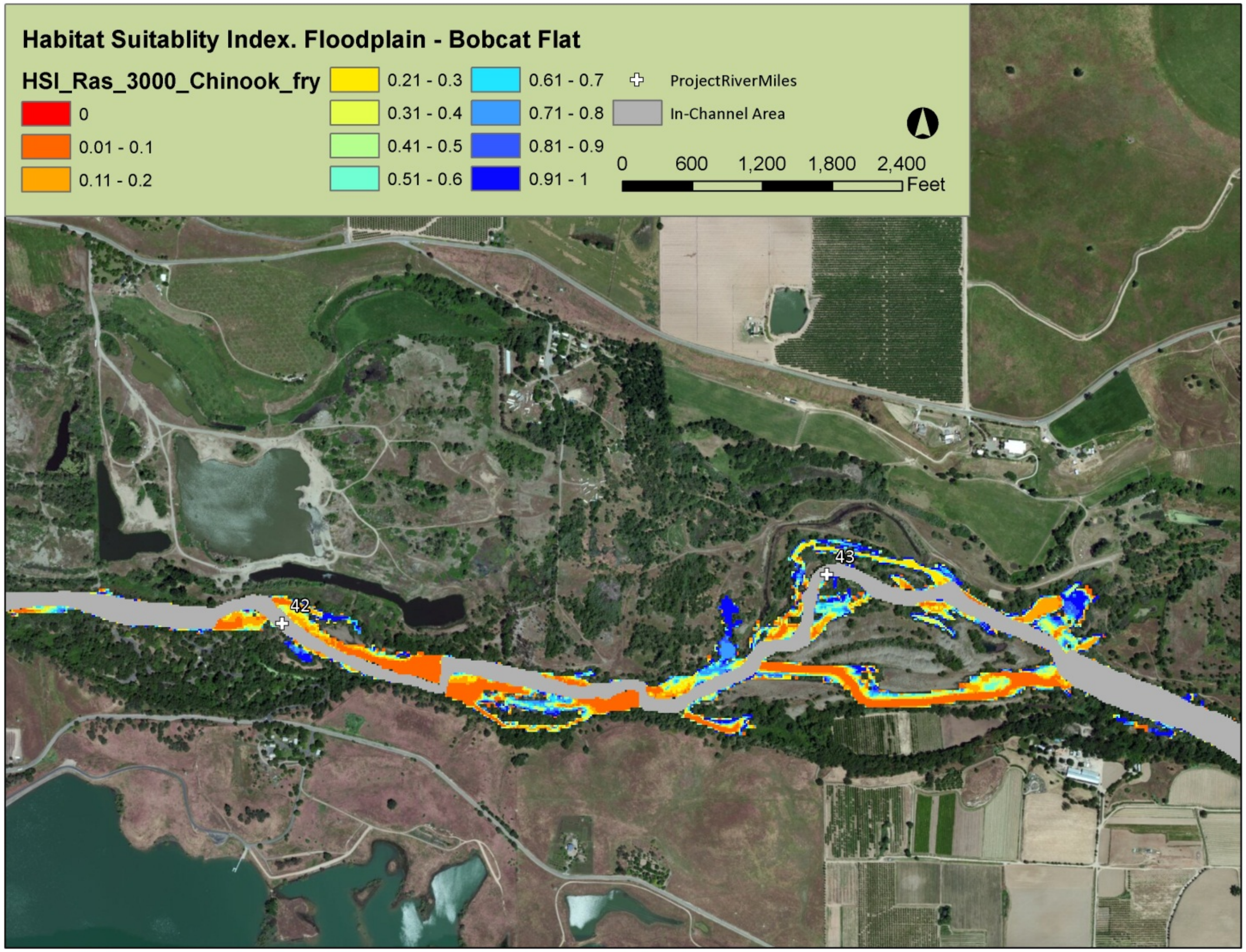
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- **Overbank habitat at 1,000 cfs**
- **Some side channel and backwater habitat evident**



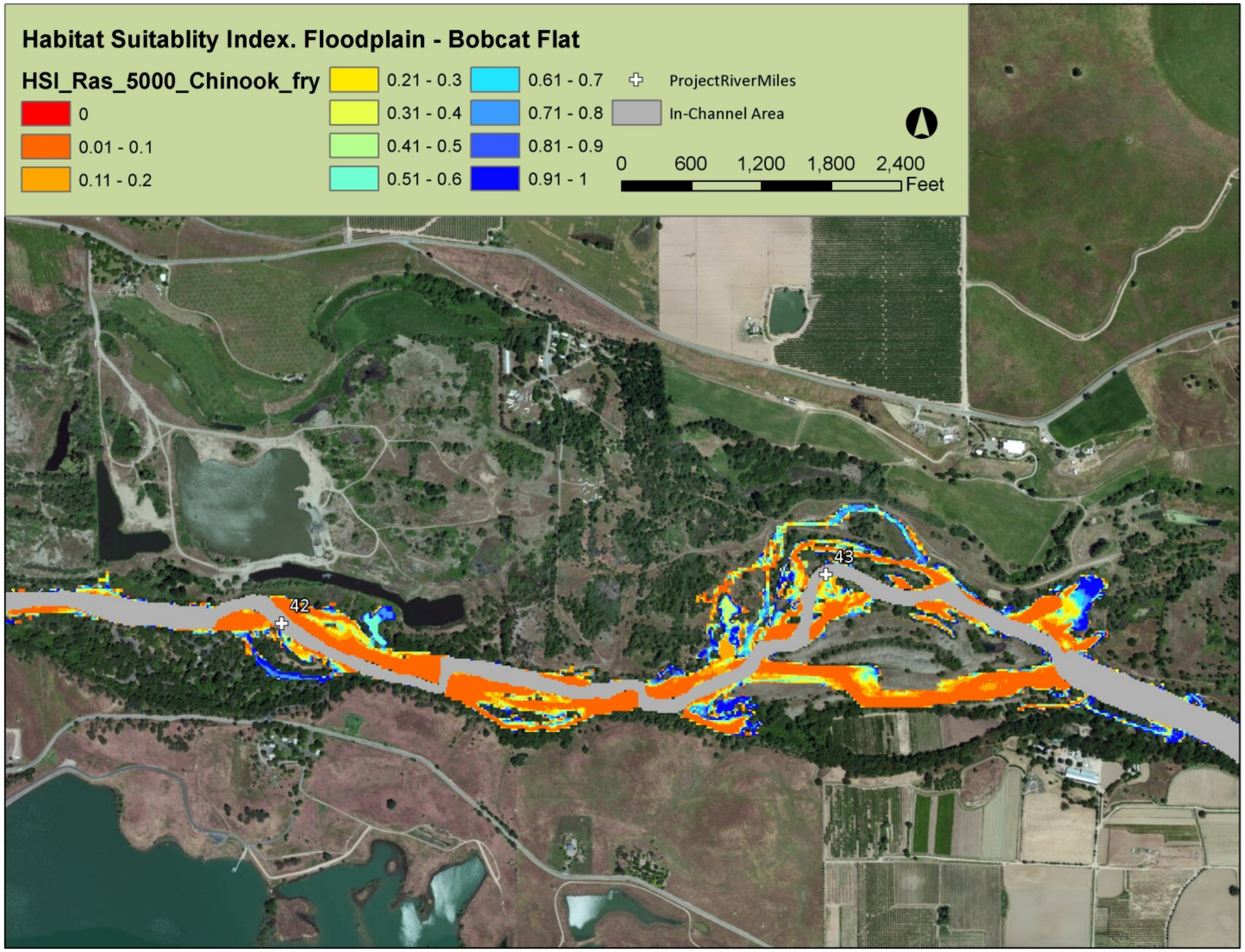
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- **Overbank habitat at 3,000 cfs**
- **Increasing depths and velocities at channel margins limit Chinook fry habitat suitability**



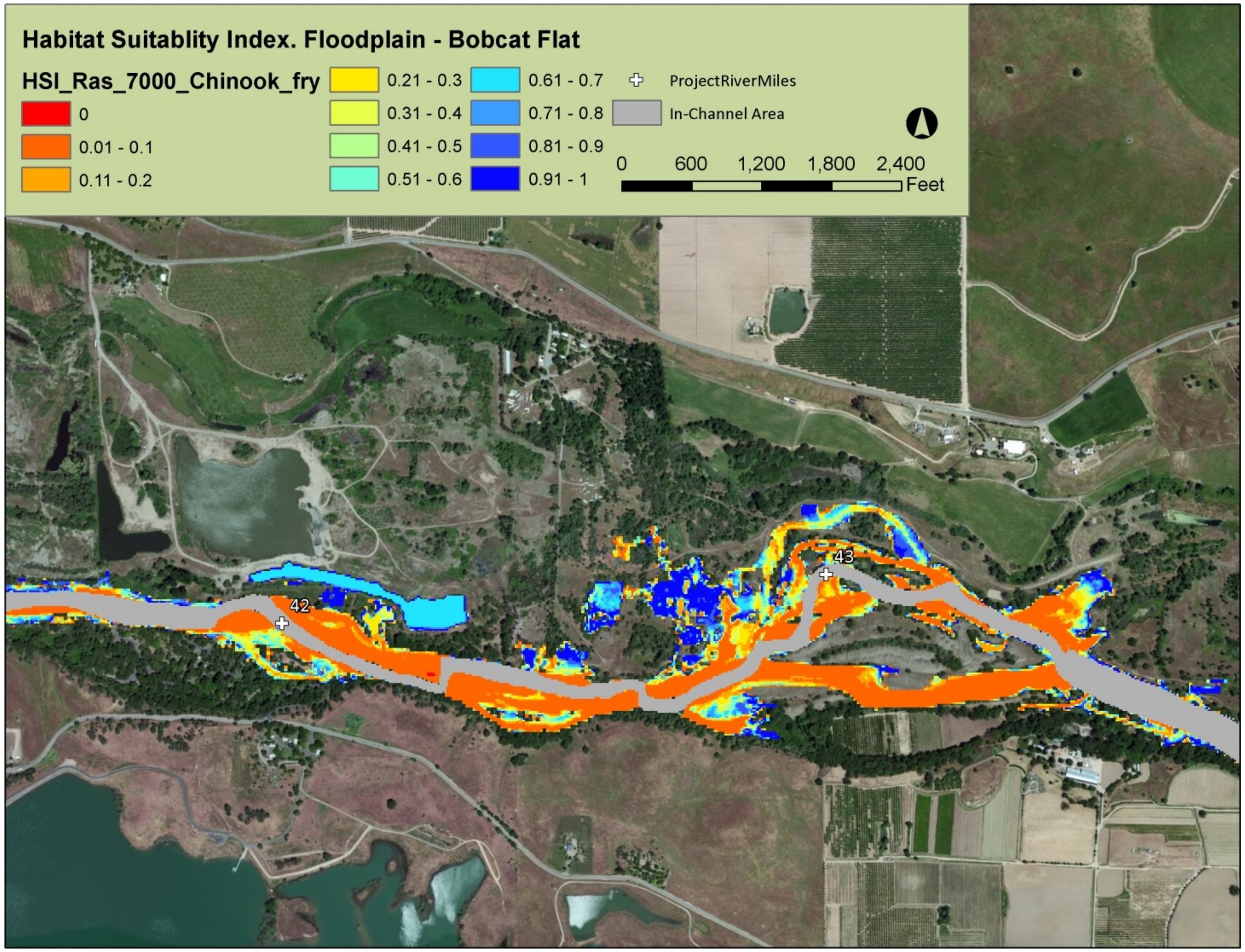
Habitat Analysis Results Example at Bobcat Flat (RM 43)

- **Overbank habitat at 5,000 cfs**
- **Increasing depths and velocities at channel margins limit Chinook fry habitat suitability**



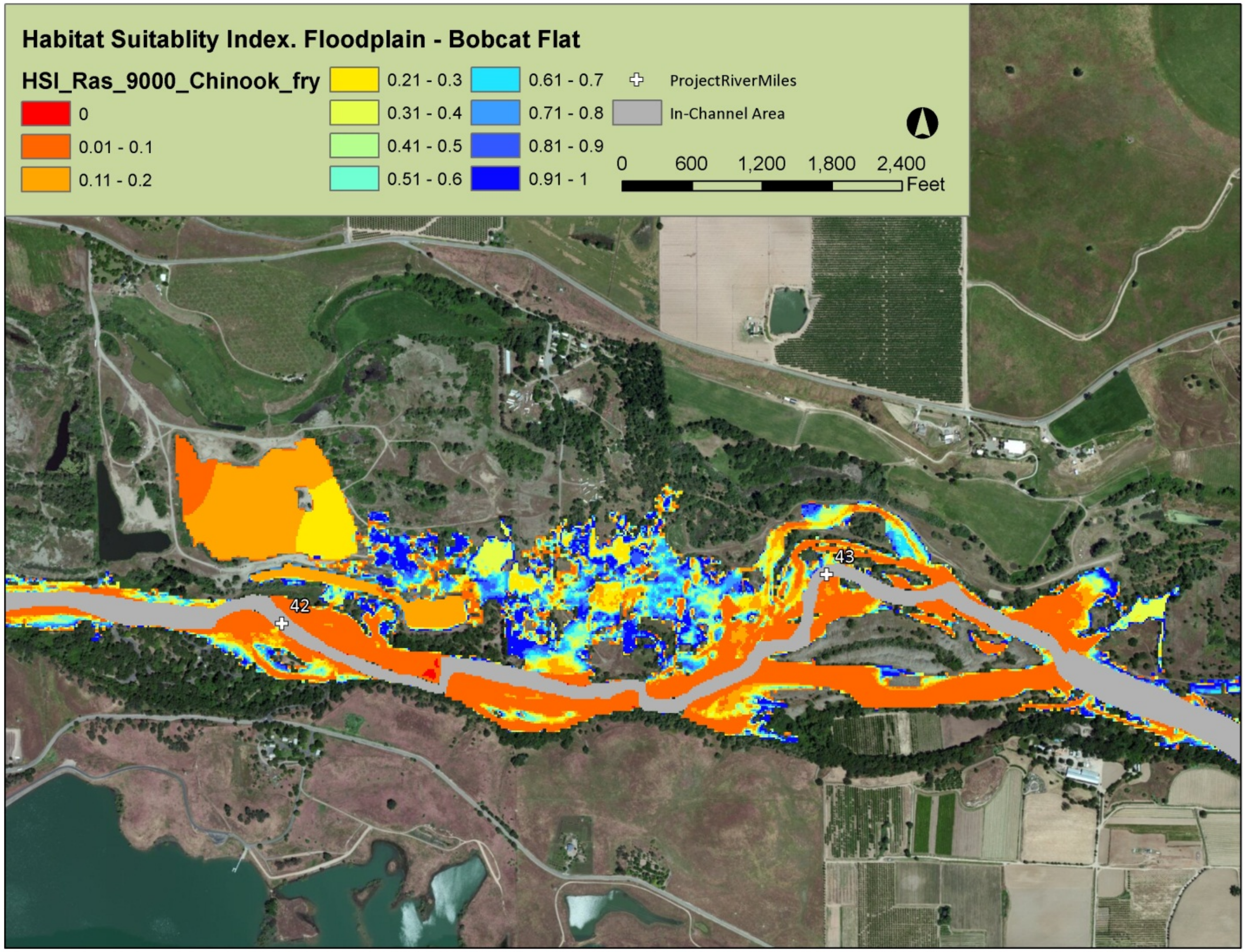
Habitat Analysis Results Example at Bobcat Flat (RM 43)

- Overbank habitat at 7,000 cfs
- Floodplain inundation in tailings areas
- Chinook fry habitat suitability (0-100%) greatest in shallow areas and low velocities



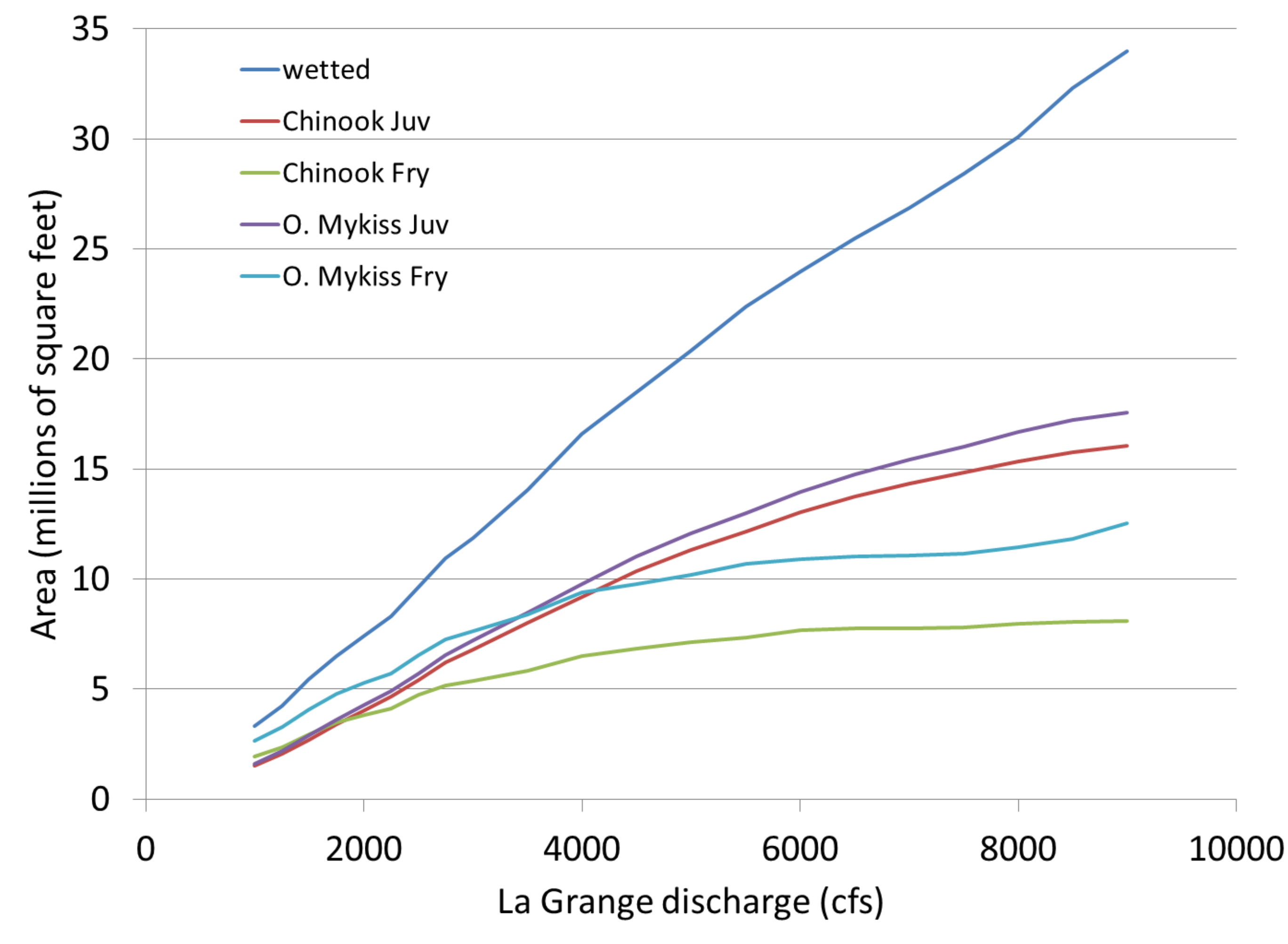
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- **Overbank habitat at 9,000 cfs**
- **Floodplain inundation in tailings areas**
- **Captured mining pit**
- **Chinook fry habitat suitability (0-100%) greatest in shallow areas and low velocities**



Habitat Analysis Results Model A

- **Approx. 60-80% of inundated area usable by Chinook and *O. mykiss* fry at the lowest flows modeled, falling to 30-40% at 9,000 cfs**
- **Approx. 50-60% of inundated area usable by Chinook and *O. mykiss* juveniles**

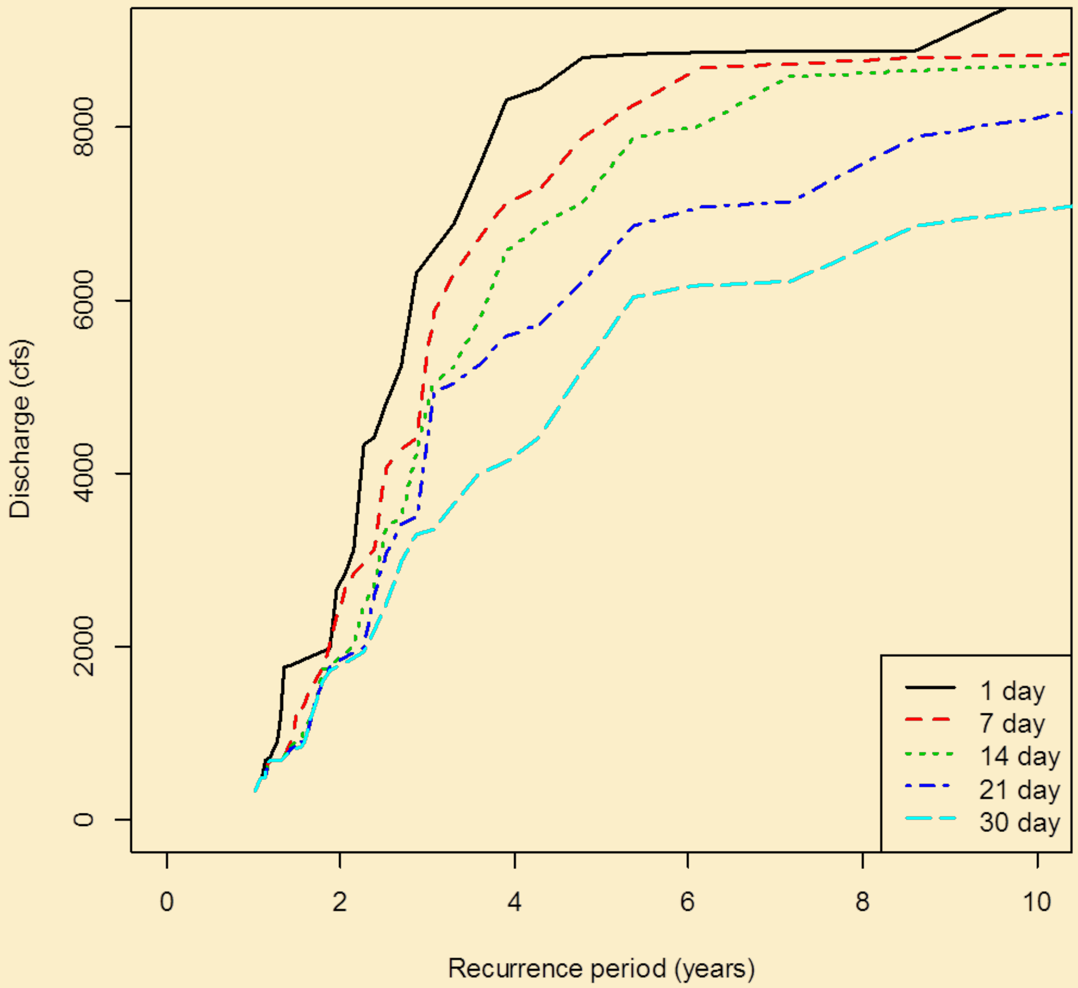


Area-Duration-Frequency Analysis

- Using Base Case hydrology (1971-2012), define floodplain inundation "events" by combinations of:
  - Duration (7, 14, 21, and 30 days)
  - Flow magnitude 1,000–9,000 cfs
- Calculate annual recurrence probabilities of each event (i.e., discharge and duration)
- Combine flow-duration frequency with TUFLOW and HSC analyses to show:
  - Total inundation area-duration-frequency (ADF)
  - Usable habitat ADF by salmonid life stage

Flow Frequency Analysis Results

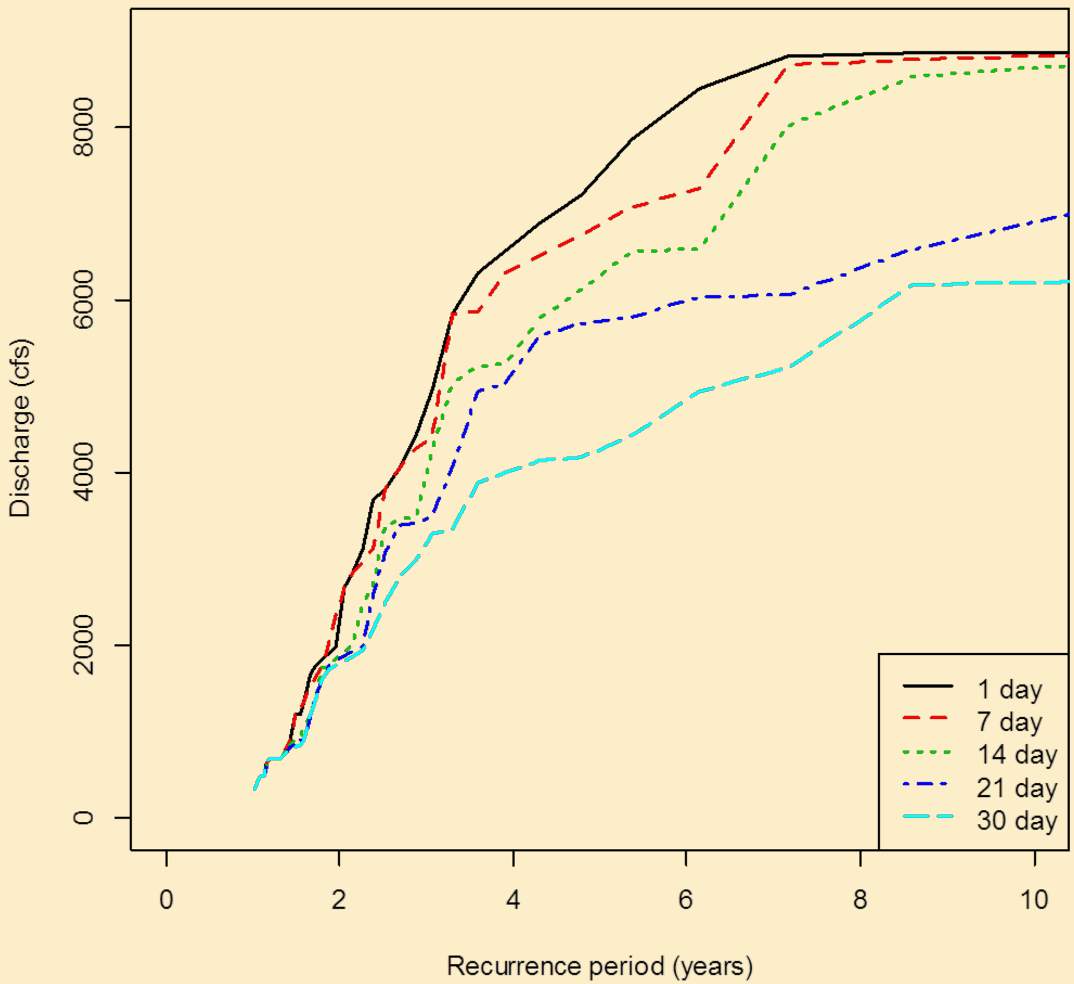
- **Base Case hydrology for 1971-2012**
- **Annual recurrence period for 1,000 – 9,000 cfs discharge**



Flow Frequency Analysis Results

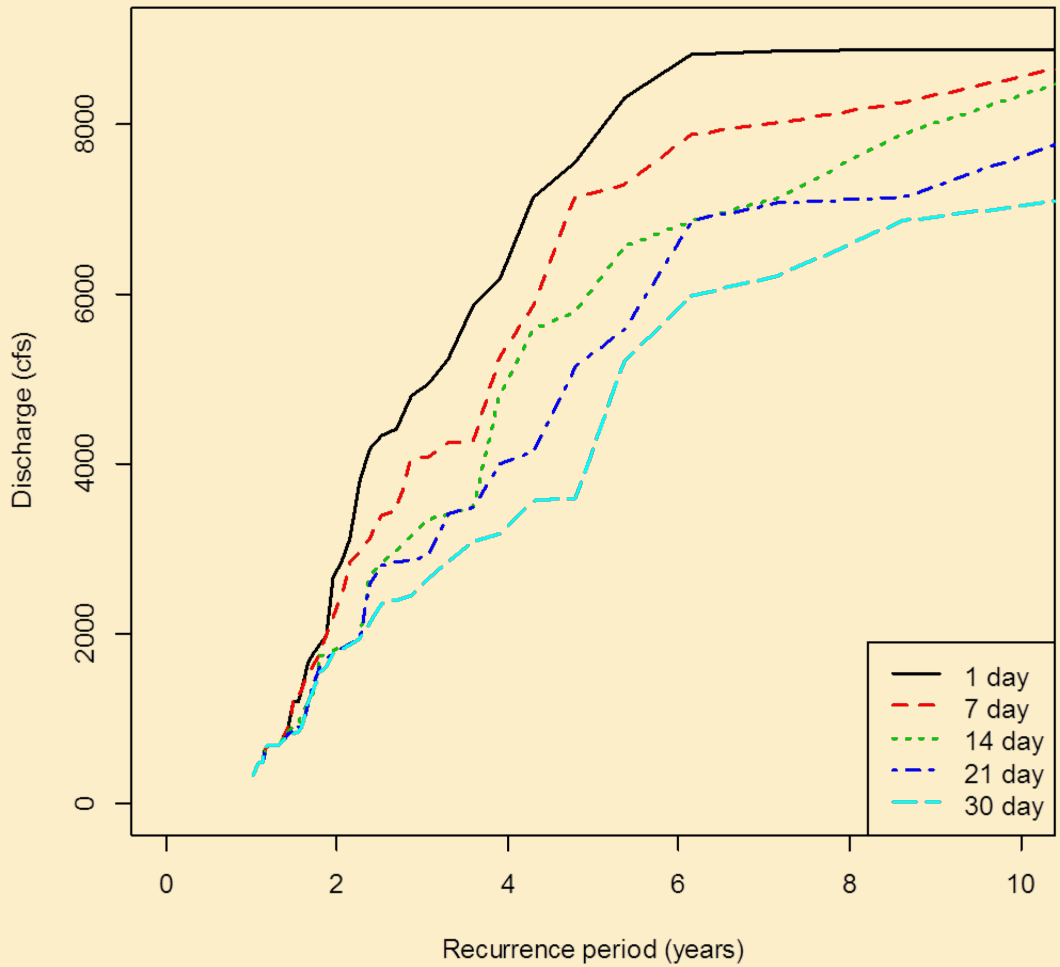
- **Base Case hydrology for 1971-2012**

- **Annual recurrence period for 1,000 – 9,000 cfs discharge between February and May**

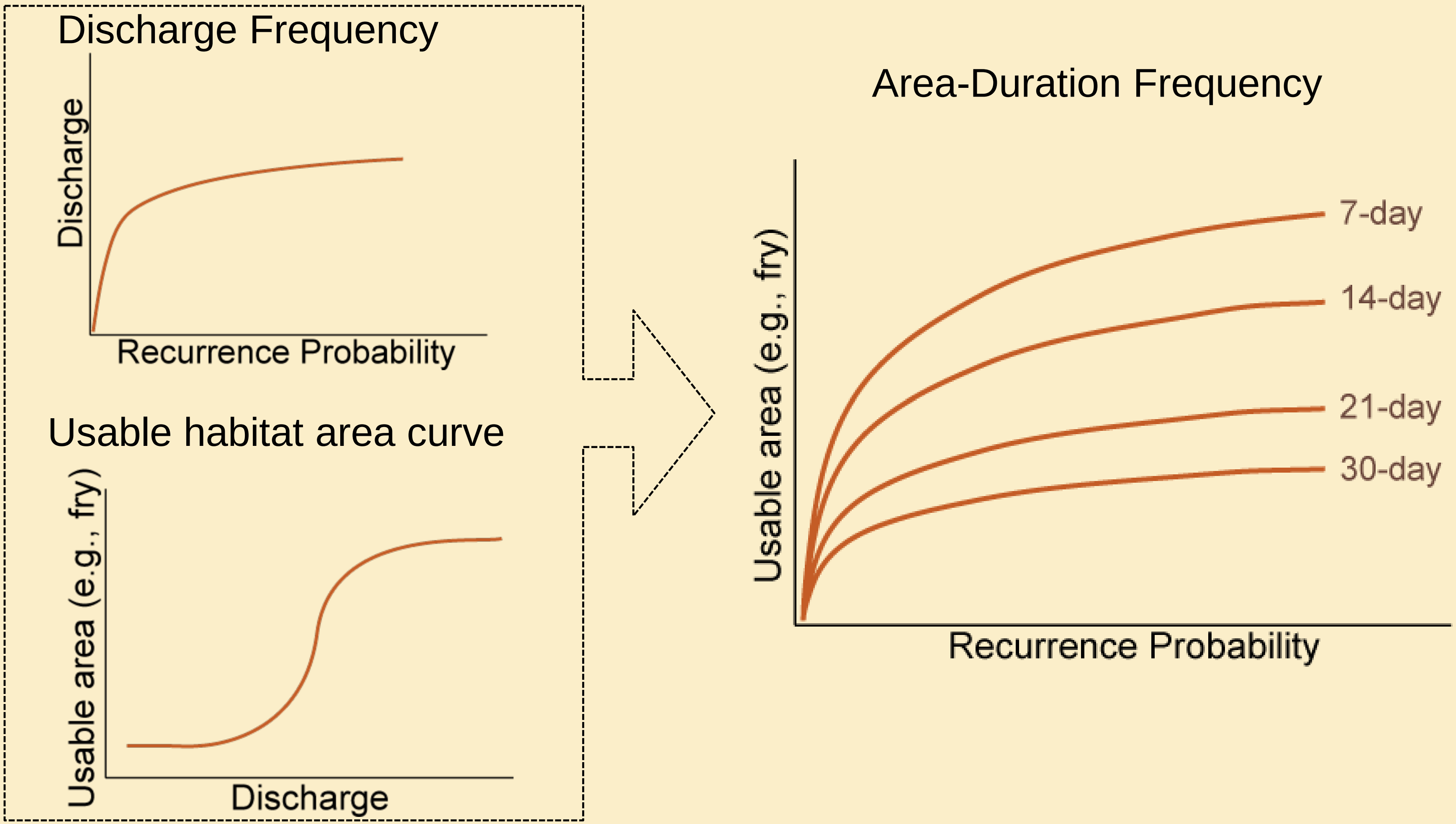


Flow Frequency Analysis Results

- **Base Case hydrology for 1971-2012**
- **Annual recurrence period for 1,000 – 9,000 cfs discharge between March and September**

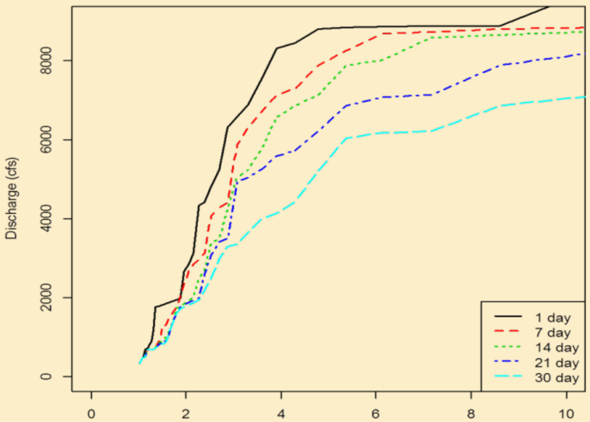


Area-Duration-Frequency Analysis

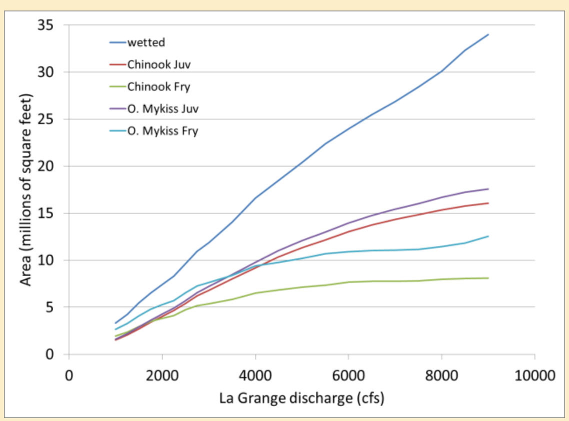


Area-Duration-Frequency Curves to Show Useable Habitat Area

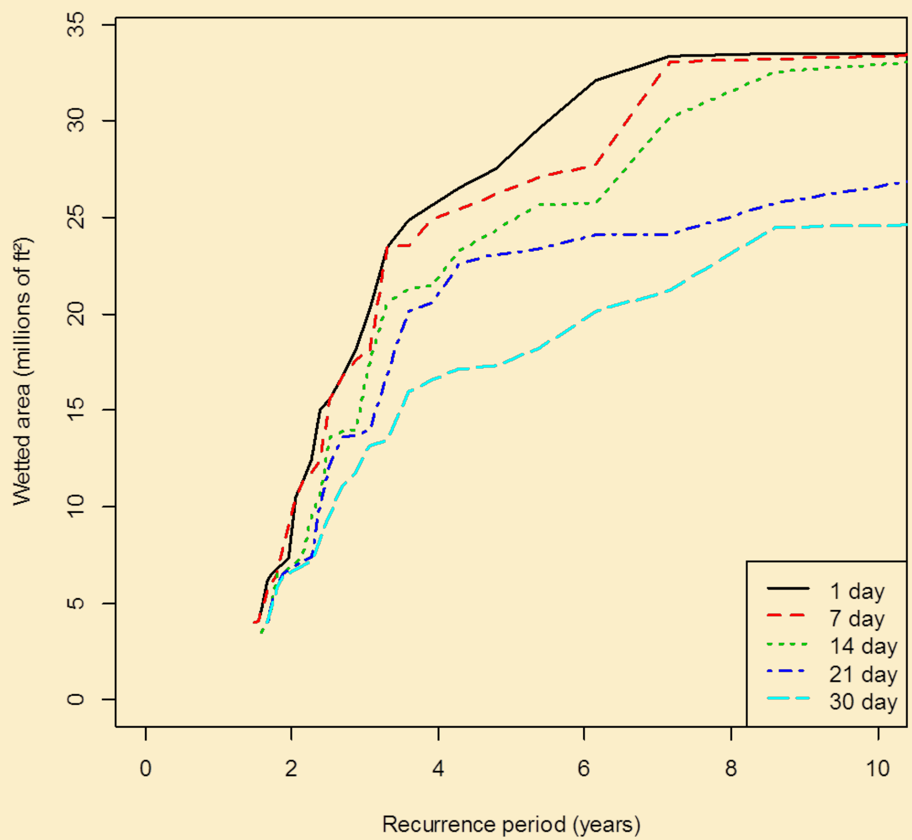
Discharge Frequency



Usable habitat area curve

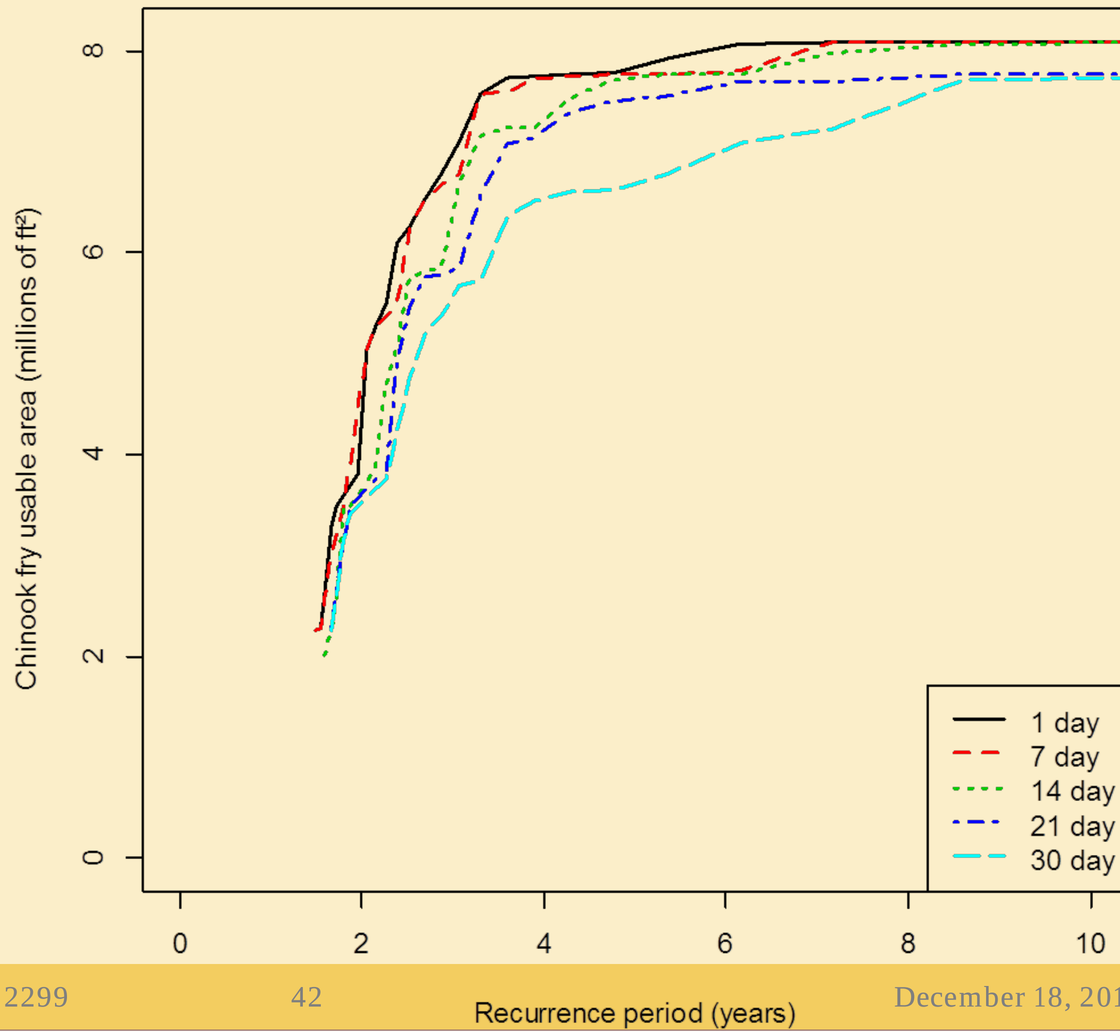


Area-Duration Frequency



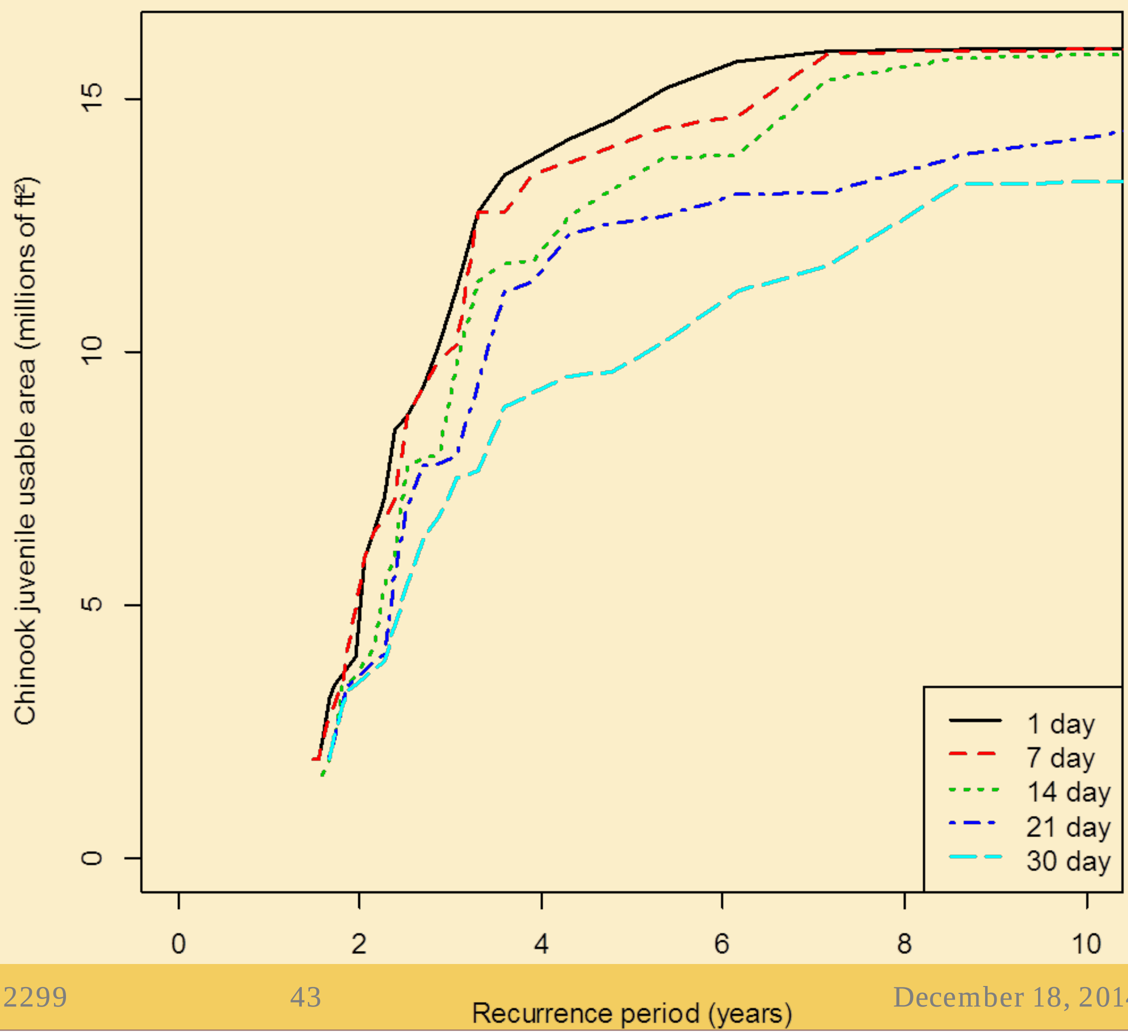
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *February and May***
- **Annual recurrence period for inundation of floodplain habitat for *Chinook fry***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



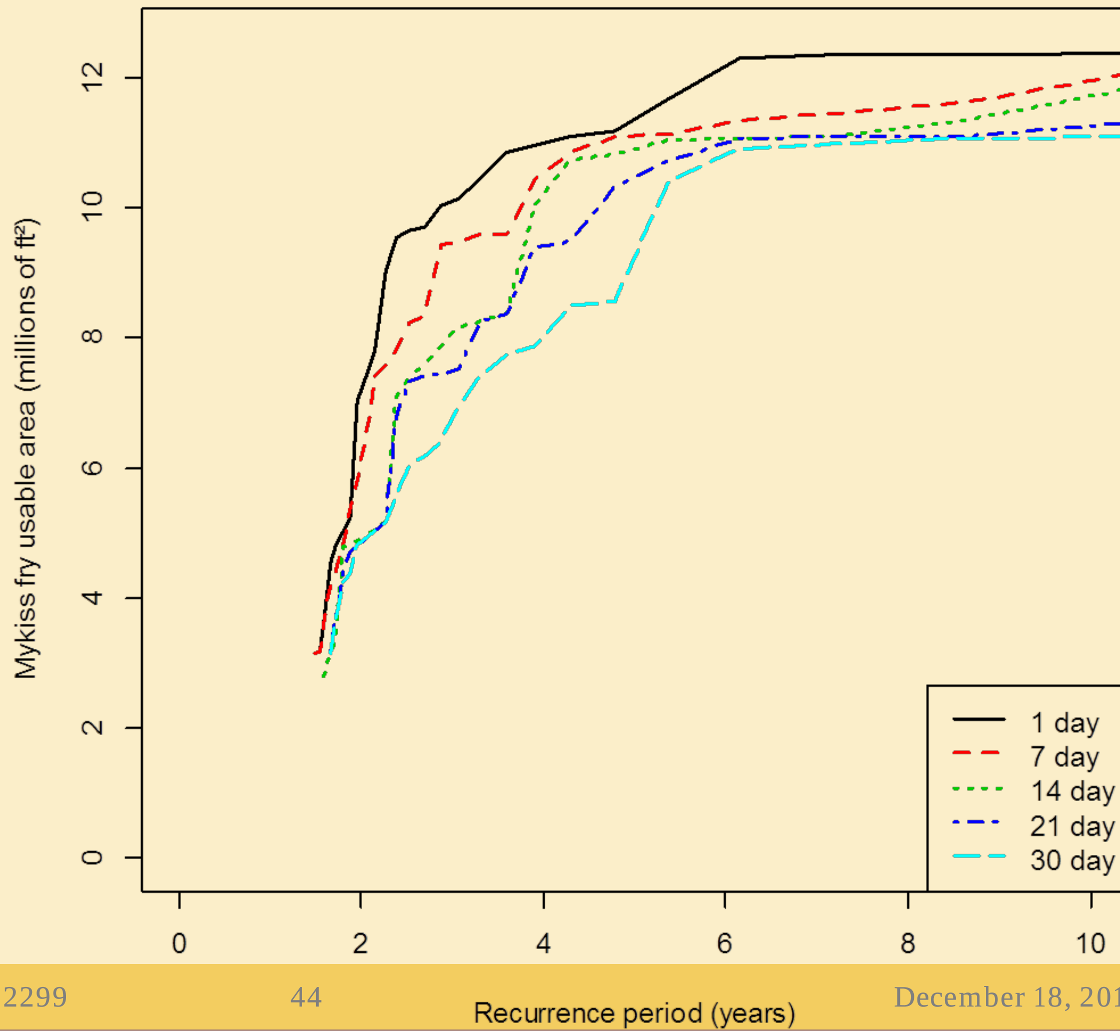
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *February and May***
- **Annual recurrence period for inundation of floodplain habitat for *Chinook juveniles***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



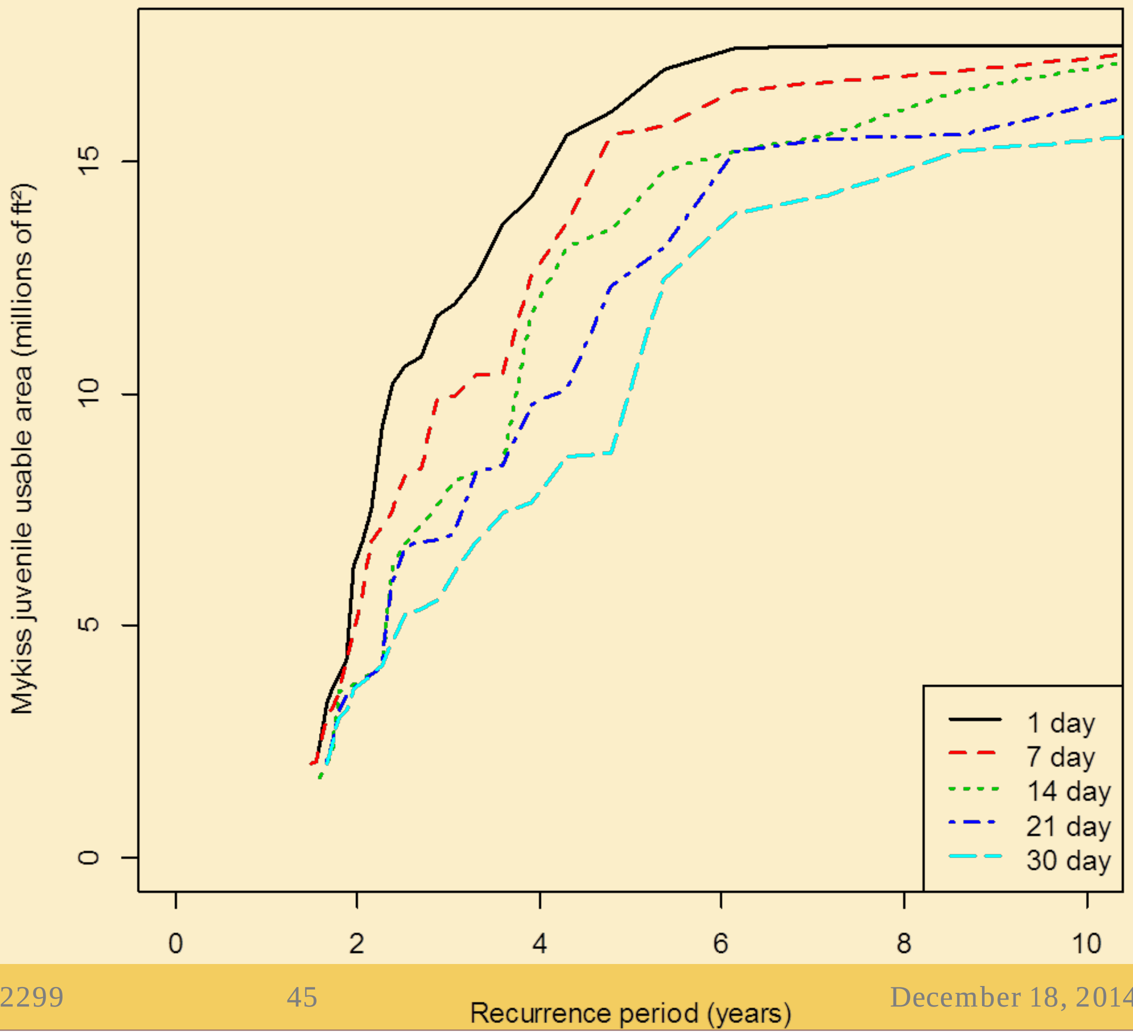
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *March and September***
- **Annual recurrence period for inundation of floodplain habitat for *O. mykiss fry***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *March and September***
- **Annual recurrence period for inundation of floodplain habitat for *O. mykiss juveniles***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



Habitat Analysis Summary

- **Model A – RM 52.2 to RM 40**
  - **Flows above bankfull discharge (1,500-2,000 cfs) associated with large increases in usable habitat for rearing Chinook salmon and *O. mykiss***
  - **For short duration events (e.g., 1, 7 days), approx. 200% increase in usable habitat area occurs between 1.5 to 2 year recurrence periods under the Base Case (WY1971-2012)**
  - **Longer duration inundation events lasting 14-days and occurring at a 4 year recurrence period are associated with usable habitat area increases on the order of 300%**
- **Models B and C to be provided with Draft study report**

Questions?

Photo Credit: Tuolumne River TAC

Floodplain Hydraulic Assessment Schedule

• Draft Report Preparation	November to December 2014
• Draft Report Provided to Relicensing Participants for 30-day review and comment	January 2015
• Relicensing Participant Comments Due	February 2015
• Final Report Filing with FERC	March 2015

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ATTACHMENT B

TUFLOW MODEL CELL SIZE SENSITIVITY ANALYSIS

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1.0 OVERVIEW

This attachment provides figures and tables referred to in the Model Spatial and Temporal Resolution section of the study report.

Figure 1. The extent of the TUFLOW model used for cell size sensitivity analysis. Yellow stars represent the locations of water level measurements recorded at a steady flow of 3,000 cfs for the Pulse Flow Study (Stillwater Sciences 2012).

Table 1. Cell Size Sensitivity Analysis – Hydraulic model results.

S No.	*Observed WSE (ft) 3,000 cfs*	*Difference in WSE for Variuos Cell Size Models**					*Remarks*
		10 ft	20 ft	30 ft	40 ft	50 ft	
1	169.7	0.2	0.2	0.1	0.1	0.0	--
2	168.9	0.5	0.4	0.4	0.3	0.2	--
3	166.9	-0.3	-0.3	-0.4	-0.4	-0.6	Overbank
4	166.8	0.5	0.4	0.3	0.2	0.1	--
5	165.9	0.3	0.3	0.2	0.0	-0.2	--
6	165.2	-0.2	-0.3	-0.3	-0.5	-0.8	--
7	163.0	0.0	-0.3	-0.6	-0.5	-0.8	Overbank
8	162.7	0.3	0.2	0.2	0.1	0.0	--
9	162.5	0.1	0.1	0.0	-0.1	-0.1	--
10	162.3	0.1	0.1	0.0	-0.1	-0.1	--
11	161.8	-0.1	-0.1	-0.3	-0.3	-0.4	--
12	161.6	0.0	0.0	-0.3	-0.3	-0.5	--
13	161.5	0.0	-0.1	-0.1	-0.2	-0.2	--
14	161.5	0.1	0.0	0.0	-0.1	-0.1	--
15	161.3	0.0	0.0	-0.1	-0.2	-0.2	--
16	161.1	-0.1	-0.1	-0.2	-0.3	-0.3	--
17	161.0	-0.2	-0.2	-0.3	-0.4	-0.4	--
18	160.6	0.2	0.1	0.1	0.0	-0.1	--
19	158.2	-0.9	-1.0	-1.1	-1.1	-1.0	Results invalid as this downstream portion is affected by assumed boundary conditions.
20	157.0	-0.9	-0.9	-0.9	-1.0	-1.0	
21	156.9	-0.6	-0.6	-0.6	-0.7	-0.7	
22	156.5	-2.1	DRY	DRY	-1.9	-2.1	
RMSE (ft) (Lines 1 - 21)		**0.4**	**0.4**	**0.4**	**0.5**	**0.5**	
RMSE (ft) (Lines 1 - 18)		**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	

* Model has only overbank geometry and does not include 1D low flow channel, Manning's n and other necessary components for calibration.

Table 2. Cell Size Sensitivity Analysis – Salmonid fry usable habitat estimates.

Cell Size (ft)	Fraction of wetted area (%)					
	Chinook Fry			*O. mykiss* Fry		
	Product	Geo. Mean	Limiting	Product	Geo. Mean	Limiting
10	29	40	32	40	48	42
20	27	39	31	39	47	40
30	27	38	30	38	46	39
40	28	39	31	38	47	40
50	26	38	30	37	46	39

Table 3. Cell Size Sensitivity Analysis – Salmonid juvenile usable habitat estimates.

Grid Size (ft)	Fraction of wetted area (%)					
	Juvenile Chinook			Juvenile *O. mykiss*		
	Product	Geo. Mean	Limiting	Product	Geo. Mean	Limiting
10	32	42	34	35	43	37
20	32	42	34	35	43	37
30	32	41	34	34	42	37
40	33	42	35	35	43	38
50	32	41	34	35	43	37

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ATTACHMENT C

1D/2D DOMAIN BOUNDARY, CROSS SECTION LOCATIONS AND DATA SOURCES

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1.0 SUMMARY

This attachment provides the data sources used to develop the bathymetric geometry of each 1D cross section (Table 1). This attachment also includes a series of maps that depict the locations of each cross section with its associated bathymetric data source as well as the 1D/2D domain boundary line. In producing the map series, the river centerline was altered to match the stream centerline at the time the LiDAR data was collected in 2012. Therefore, the rivers miles in the map series differ slightly from the USGS river miles.

Table 1. Lower Tuolumne River in-channel data sources.

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
0.88-4.40	0.8252-4.3666	CDWR (2014)	20
4.43-4.53	4.3978-4.5003	Interpolated	4
4.70-6.31	4.6664-6.3035	CDWR (2014)	8
6.71-6.94	6.7150-6.9575	FEMA (2013)	2
7.00-7.14	7.0087-7.1473	Interpolated	7
7.21-7.52	7.2192-7.5203	FEMA (2013)	2
7.64-7.79	7.6465-7.7963	Interpolated	4
7.82-10.74	7.8292-10.7413	FEMA (2013)	9
10.87-10.99	10.8658-10.9784	Interpolated	4
11.12-13.78	11.1007-13.6371	FEMA (2013)	8
13.99	13.8470	HDR Field Survey 2012	1
14.12-14.89	13.9709-14.7123	FEMA (2013)	3
15.04	14.8616	HDR Field Survey 2012	1
15.24	15.0666	FEMA (2013)	1
15.50	15.3283	HDR Field Survey 2012	1
15.66	15.4965	FEMA (2013)	1
15.72-15.74	15.5579-15.5776	Interpolated	2
15.84	15.6774	FEMA (2013)	1
15.86-15.93	15.6916-15.7665	Interpolated	4
15.98	15.8150	HDR Field Survey 2012	1
16.00-16.09	15.8351-15.9239	Interpolated	5
16.13	15.9601	USGS (2014a, 2014b)	1
16.17-16.21	15.9890-16.0263	FEMA (2013)	3
16.33-16.35	16.1409-16.1591	Interpolated	2
16.38-16.41	16.189-16.2138	USGS (2014a, 2014b)	2
16.49	16.2793	FEMA (2013)	1
16.53	16.3128	HDR Field Survey 2012	1
16.73	16.4905	FEMA (2013)	1
17.03	16.7579	HDR Field Survey 2012	1
17.16	16.8756	FEMA (2013)	1
17.52	17.1990	HDR Field Survey 2012	1
17.57-18.33	17.2472-17.9689	FEMA (2013)	3
18.46-18.49	18.0953-18.1288	HDR Field Survey 2012	2
18.70	18.3429	FEMA (2013)	1

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
18.98	18.6243	HDR Field Survey 2012	1
19.05-19.25	18.7067-18.9387	FEMA (2013)	2
19.49	19.2343	HDR Field Survey 2012	1
19.61-20.30	19.3709-20.1766	FEMA (2013)	3
20.49	20.3909	HDR Field Survey 2012	1
20.61-20.95	20.5204-20.9159	FEMA (2013)	2
21.02	21.0003	HDR Field Survey 2012	1
21.29	21.3174	FEMA (2013)	1
21.49	21.5672	HDR Field Survey 2012	1
21.63-21.82	21.7322-21.9662	FEMA (2013)	2
22.00	22.1825	HDR Field Survey 2012	1
22.26-22.44	22.4798-22.6904	FEMA (2013)	2
22.50	22.7482	HDR Field Survey 2012	1
22.55	22.8062	FEMA (2013)	1
22.59-22.62	22.8536-22.8826	TID Field Survey	2
22.78	23.0683	FEMA (2013)	1
22.83	23.1392	TID Field Survey	1
22.99	23.3244	HDR Field Survey 2012	1
23.25	23.6137	TID Field Survey	1
23.48	23.9049	HDR Field Survey 2012	1
23.50-23.85	23.9240-24.3337	TID Field Survey	3
23.98	24.4905	HDR Field Survey 2012	1
24.19	24.7347	TID Field Survey	1
24.41	24.9480	McBain and Trush (2004b)	1
24.53	25.0699	HDR Field Survey 2012	1
24.65-24.95	25.1890-25.4942	McBain and Trush (2004b)	5
25.02	25.5663	HDR Field Survey 2012	1
25.03	25.5823	Interpolated	1
25.04	25.5922	TID Field Survey	1
25.07	25.6245	McBain and Trush (2004b)	1
25.09	25.6503	TID Field Survey	1
21.12-25.36	25.6774-25.9475	McBain and Trush (2004b)	5
25.42-25.49	26.0073-26.1223	TID Field Survey	4
25.50	26.1275	HDR Field Survey 2012	1
25.54	26.1658	TID Field Survey	1
25.61	26.2474	McBain and Trush (2004b)	1
25.67	26.3109	TID Field Survey	1
25.71-25.78	26.3528-26.4306	McBain and Trush (2004b)	2
25.79-25.8	26.4409-26.4552	TID Field Survey	2
25.86	26.5125	McBain and Trush (2004b)	1
25.95-25.97	26.603-26.6222	TID Field Survey	2
26.05-27.98	26.7028-28.5435	HDR Field Survey 2012	5
28.23-28.40	28.7500-28.9000	Interpolated	3
28.60-29.47	29.1201-29.9195	HDR Field Survey 2012	3

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
29.54	29.9800	Interpolated	1
29.66-30.15	30.0853-30.5497	TID Field Survey	7
30.25	30.6561	HDR Field Survey 2012	1
30.34-30.42	30.7390-30.8268	Stillwater (2013)	3
30.52	30.9218	HDR Field Survey 2012	1
30.64-31.02	31.0461-31.4475	TID Field Survey	9
31.07	31.4911	HDR Field Survey 2012	1
31.18-31.35	31.6042-31.7817	TID Field Survey	3
31.48	31.9232	HDR Field Survey 2012	1
31.56-31.75	32.0006-32.2089	TID Field Survey	5
31.95-31.97	32.4279-32.445	Stillwater (2013)	2
32.01-36.09	32.4861-36.8374	TID Field Survey	50
36.11-36.45	36.8642-37.2503	Stillwater (2013)	11
36.49-36.67	37.2926-37.5083	TID Field Survey	5
36.70-36.74	37.5353-37.5818	Stillwater (2013)	3
36.82-37.83	37.7200-38.8828	TID Field Survey	21
37.90-41.66	38.9536-42.1508	McBain and Trush (2004a)	60
41.67	42.1600	TID Field Survey	1
41.71	42.1800	McBain and Trush (2004a)	1
41.73-41.76	42.1900-42.2400	TID Field Survey	3
41.78	42.2600	McBain and Trush (2004a)	1
41.80	42.2806	TID Field Survey	1
41.81	42.2900	McBain and Trush (2004a)	1
41.83-41.84	42.3062-42.32	TID Field Survey	2
41.86-41.88	42.3359-42.3543	McBain and Trush (2004a)	2
41.91-42.01	42.3934-42.4897	TID Field Survey	4
42.11-42.27	42.5777-42.7519	McBain and Trush (2004a)	5
42.29-42.3	42.775-42.7834	TID Field Survey	2
42.36-45.77	42.8509-46.2700	McBain and Trush (2004a)	97
45.78-46.92	46.2985-47.4044	TID/MID (2013b)	21

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THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT D

2D OVERBANK MANNING'S N ROUGHNESS COEFFICIENTS

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1.0 ROUGHNESS COEFFICENT EXAMPLES

This attachment supplements the discussion of overbank roughness coefficients in the study report. Table 1 provides roughness coefficient values for different land use and land cover categories.

Table 1. 2D domain roughness coefficient values.

Roughness Value	Description
0.03	Smooth and flat – pavement
0.04	Bare earth with gravel or finer substrate
0.05	Some herbaceous vegetation, grass, or large cobbles
0.06	Backwater areas choked with Water Hyacinth, agriculture, or irregular bedrock
0.07	Sparse permanent vegetation or low lying shrubs
0.08	Oak woodland, Cottonwood, or Aspen with some canopy spacing
0.09	Dense young riparian vegetation
0.10	Permanent dense forest (riparian or upland)
0.15	Low density residential
0.20	Industrial/Commercial
0.35	High density residential or Industrial/Commercial

Below, photos taken during fieldwork by TID in 2014 and images clipped from aerial flyover video flown May 18, 2012, exemplify the most common Manning's n designations used in the study (Figures 1 – 24).

Figure 1. Mannings n is equal to .04.

Figure 2. Mannings n is equal to .04.

Figure 3. Mannings n is equal to .04.

Figure 4. Mannings n is equal to .04.


Figure 5. Mannings n is equal to .04.

Figure 6. Mannings n is equal to .04.

Figure 7. Mannings n is equal to .05.

Figure 8. Mannings n is equal to .05.

Figure 9. Mannings n is equal to .05.

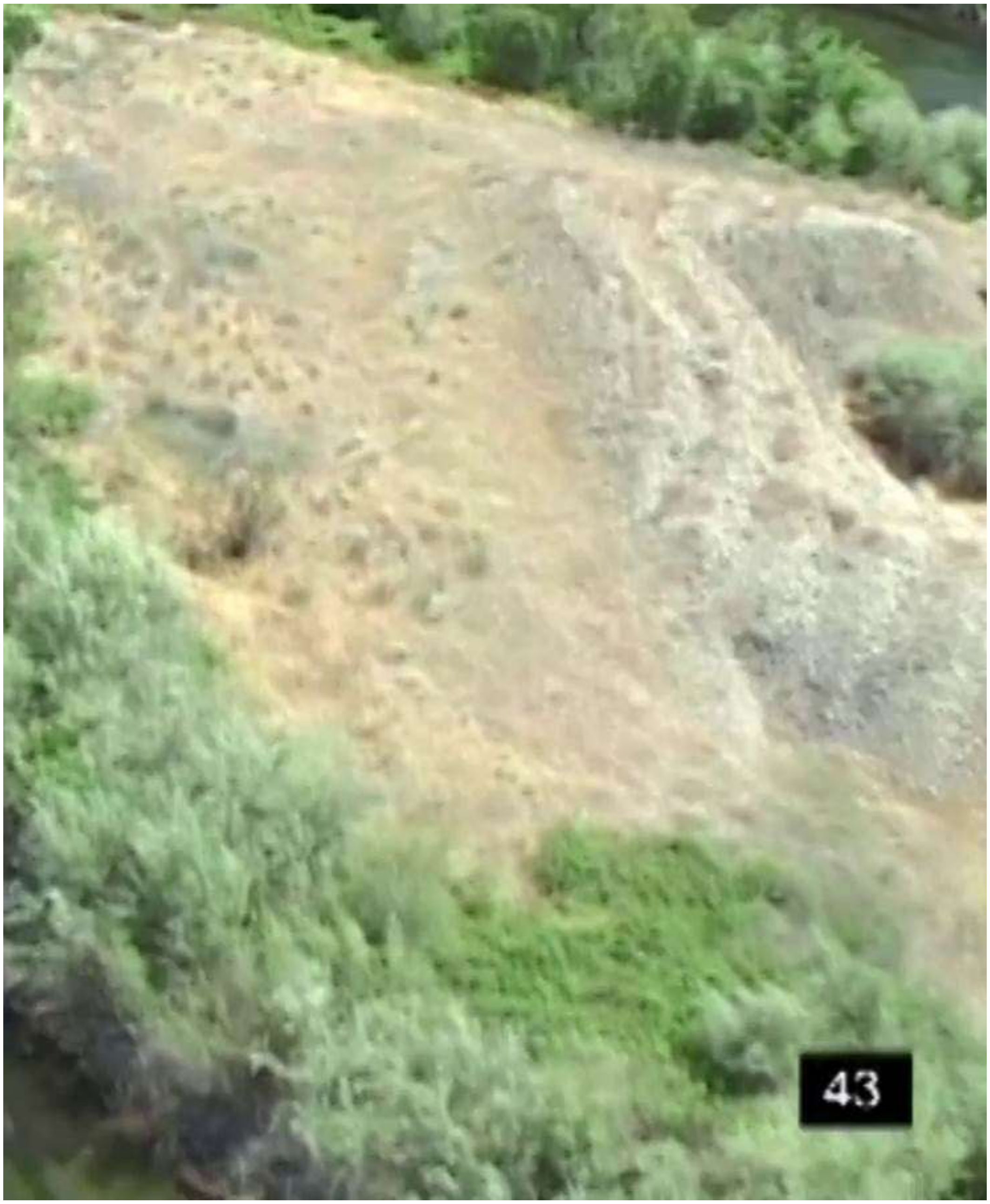

Figure 10. **Mannings n is equal to .05.**

Figure 11. Mannings n is equal to .06.

Figure 12. Mannings n is equal to .06.


Figure 13. Mannings n is equal to .06.

Figure 14. **Mannings n is equal to .06.**

Figure 15. Mannings n is equal to .07.


Figure 16. Mannings n is equal to .08.

Figure 17. Mannings n is equal to .08.

Figure 18. Mannings n is equal to .10.

Figure 19. Mannings n is equal to .10.

Figure 20. Mannings n is equal to .10.

Figure 21. Mannings n is equal to .10.

Figure 22. Mannings n is equal to .10.

Figure 23. Mannings n is equal to .10.

Figure 24. Mannings n is equal to .10.

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THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT E

SAN JOAQUIN RIVER BACKWATER EFFECTS IN THE TUOLUMNE RIVER

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1.0 PURPOSE

As part of the *Lower Tuolumne River Floodplain Hydraulic Assessment* (W&AR-21), 1-D/2-D modeling is being conducted in three separate sub-reaches (Models A, B, and C) to assess juvenile salmonid floodplain habitat along the Tuolumne River from river mile (RM) 52.2 to RM 0 at the confluence with the San Joaquin River (SJR). In support of modeling in Reach C (RM 21.5 to RM 0), the boundary condition assessment presented herein examines the potential range of stage-discharge relationships near the confluence. There are two goals for the boundary condition analysis: 1) to determine the upstream extent of backwater effects in the Tuolumne River due to SJR and Stanislaus River flows, and 2) to develop a representative rating curve near the Tuolumne River SJR confluence to use as the downstream boundary condition for Model C.

2.0 ANALYSIS OF TUOLUMNE RIVER BACKWATER EXTENT

The hydraulic analysis combines portions of two existing HEC-RAS flood flow models originally developed by the California Department of Water Resources (DWR) covering the SJR system. One of the DWR flood models includes approximately 6 river miles of the lower Tuolumne River and the other extends approximately 17 river miles further upstream for a total DWR-modeled reach length in the Tuolumne River of approximately 23 miles. The combination of DWR models (combined model) of the SJR extends from the Crows Landing USGS Gage, located 23 miles upstream of the confluence of the Tuolumne River and the SJR River and 11.5 miles downstream of the Merced River, to the Vernalis Gage, located 16.5 miles downstream of the SJR and Tuolumne River confluence. The Stanislaus River, 2.75 miles upstream of the Vernalis Gage, is included in the combined model, which examines the potential influences of flow magnitudes in both the SJR and Stanislaus River on backwater in the Tuolumne River. A map of the model extent and gage locations is shown in Figure 1.

Representative flows and boundary conditions were developed from analyses of the following stream gages:

- USGS 11290000 TUOLUMNE R A MODESTO CA (1895 to present)
- USGS 11303000 STANISLAUS R A RIPON CA (1940 to present)
- USGS 11274550 SAN JOAQUIN R NR CROWS LANDING CA (1995 to present)
- USGS 11274000 SAN JOAQUIN R NR NEWMAN CA (1912 to present)
- USGS 11303500 SAN JOAQUIN R NR VERNALIS CA (1923 to present)

The rating curve (downloaded from USGS) associated with the Vernalis Gage is used to define the water surface elevations at the downstream boundary of the combined model. The Crows Landing Gage is used to verify the water surface elevation of the modeled inflow at the upstream boundary of the combined model. There are no gaged inflows between the Crows Landing Gage and the Tuolumne River confluence.

The Tuolumne River floodplain model being developed as part of W&AR-21 considers flows from 1,000 cfs to 9,000 cfs. The floodplain habitat area would primarily be used by juvenile salmonids during the months of February through May, inclusive. Therefore, the analysis of backwater effects considered SJR flows occurring over this seasonal period. To develop representative sensitivity scenarios for testing the extent of backwater effects on the Tuolumne due to SJR flows, we plotted flows from the SJR Newman gage against flows recorded by the Tuolumne River Modesto gage (RM 16.2) for the months of February through May over the period WY 1971-2012, shown in Figure 2. The Crows Landing gage has a shorter period of record so was not used for the analysis to ensure consideration of the full range of possible flows in the SJR related to flows in the Tuolumne River over the study period. However, the Crows Landing gage defines the upstream boundary of the model so it is important to understand the correlation with flow at this location with flow at the Newman gage, 6.5 miles upstream. The comparison for the available period of record at Crows Landing gage is shown in Figure 3 and indicates some small variability in accretion and losses between the gages, with a linear regression slope of 1.07. This tight correlation indicates that using the range of SJR flows observed at the Newman gage as the HEC-RAS model inflow is justifiable for assessing the extent of backwater effects within the Tuolumne River.

The HEC-RAS model also includes the Stanislaus River, approximately 8 miles downstream of the Tuolumne River. A comparison of flows within the Tuolumne and Stanislaus rivers is shown in Figure 4. This figure indicates wide scatter and minimal correlation between flows.

To test sensitivity of stage within the Tuolumne River to flows within the SJR and Stanislaus River, we developed eight flow scenarios based on the minimum and maximum habitat model flows in the Tuolumne River and the approximate maximum range of observed flows in the SJR and Stanislaus River at those Tuolumne River flows based on visual interpretation of the graph in Figure 2. The minimum flow in the SJR associated with the 1,000 cfs Tuolumne River case was set to 500 cfs, slightly higher than the observed minimum, for model stability. The tested scenarios are outlined in Table 1.

Table 1. Flows selected for boundary condition model sensitivity scenarios.

Scenario Number	Tuolumne River Flow cfs	SJR Flow cfs	Stanislaus River Flow cfs
1	9,000	25,000	7,000
2			500
3		10,000	7,000
4			500
5	1,000	15,000	4,000
6			500
7		500	4,000
8			500

3.0 RESULTS OF BACKWATER ASSESSMENT

A comparison of HEC-RAS model results is shown in Figure 5, which illustrates the water surface profiles on the Tuolumne River from its confluence with the SJR. The profiles indicate that there are essentially no backwater effects occurring on the Tuolumne River upstream of the Carpenter Road Bridge near RM 13.

Table 2 show differences in Tuolumne River water surface elevations at several locations for the cases where flows in the Tuolumne River and SJR were held constant to demonstrate the impact of varying flows in the Stanislaus River. The impact is relatively insignificant, with a maximum difference of 0.27 ft at the first Tuolumne River cross section, approximately 0.5 miles upstream of its confluence, falling to less than 0.2 ft approximately 1.8 miles upstream and less than 0.1 ft about 2.7 miles upstream.

Table 2. Relative stage differences examining potential impact of flow magnitude in the Stanislaus and Tuolumne rivers.

Channel Distance	Scenario 1 Stage minus Scenario 2 Stage	Scenario 3 Stage minus Scenario 4 Stage	Scenario 5 Stage minus Scenario 6 Stage	Scenario 7 Stage minus Scenario 8 Stage
miles	ft	ft	ft	ft
0.5	0.19	0.27	0.05	0.21
1.8	0.03	0.16	0.05	-0.19
2.7	0.03	0.10	0.05	-0.08

Table 3 demonstrates the upstream influence on Tuolumne River water surface elevations due to different flows in the SJR. The results indicate that over the approximate maximum range of observed flows, water surface elevations vary at the confluence by up to 12.2 ft for the lowest study flow of 1,000 cfs in the Tuolumne. The backwater effect of SJR flows extends approximately 10 to 13 miles upstream of the confluence.

Table 3. Relative stage differences indicating potential impacts of flows in the SJR and Tuolumne River.

Channel Distance	Scenario 1 Stage minus Scenario 3 Stage	Scenario 2 Stage minus Scenario 4 Stage	Scenario 5 Stage minus Scenario 7 Stage	Scenario 6 Stage minus Scenario 8 Stage
miles	ft	ft	ft	ft
0.5	3.40	3.49	12.07	12.23
9.0	0.16	0.17	1.13	1.10
10.5	0.10	0.10	0.60	0.58
12.5	0.05	0.05	0.20	0.19
13.5	0.04	0.04	0.10	0.09

4.0 RATING CURVE DEVELOPMENT

The 2-D hydraulic model of the Tuolumne River floodplain being developed in the W&AR-21 study will require a stage-discharge rating curve to represent the downstream boundary condition at the confluence of the Tuolumne River and SJR for the range of study flows being examined. The impact analysis demonstrates that the backwater effects of the SJR on the Tuolumne River can extend up to approximately RM 13, indicating that habitat analysis within this region may be substantially influenced by the choice of rating curve. To determine a representative stage-discharge rating curve we first establish a table of flows in the SJR and Stanislaus Rivers for each of the 21 model flows in the Tuolumne River (every 250 cfs from 1,000 cfs to 3,000 cfs, and every 500 cfs from 30,000 cfs to 9,000 cfs) and then use the HEC-RAS model to simulate elevations at the confluence.

To determine a correlation of flows between the Modesto gage (Tuolumne River) and the Newman Gage (SJR), we calculated the median flow in the SJR for every 50 cfs in the Tuolumne River. For example, for a Tuolumne River flow of 100 cfs, we found the median of all SJR flows associated with Tuolumne River flows between 75 cfs and 125 cfs. Figure 6 shows the relationships for the months of February through May, the primary months of interest for habitat analysis, and for all months for water years 1971 to 2012. A fourth order polynomial relationship provides the best fit regression between the data sets and works well for both the target habitat months and consideration of all months.

We applied the same analysis for the more scattered flows in the Stanislaus River and found a power relationship to be the best fit. This relationship is less important because the influence of flow variability on water surface elevation within the Tuolumne River is small. Note that sensitivity runs indicated that the downstream boundary condition on the SJR, represented by the rating curve at the Vernalis Gage, has no impact on water surface elevation in the Tuolumne River.

Table 4 provides the regression results in the SJR and Stanislaus River for each study flow in the Tuolumne River based on the regression equations shown in Figures 6 and 7. The flows in the SJR are also prorated based on the linear correlation between flows at the Newman and Crows Landing gages shown in Figure 3 to adjust for the location of the upstream boundary of the HEC-RAS model. The water surface elevation in the Tuolumne River, shown in the final column, at approximately RM 0.9 is the downstream boundary location for the 2-D model.

Table 4. Regression flows used to develop boundary condition rating curve.

Tuolumne River Flow	SJR Flow	Stanislaus River Flow	Tuolumne River Water Surface Elevation at RM 0.9
cfs	cfs	cfs	ft
320	872	459	22.0
500	949	580	22.6
750	1,038	716	23.2
1,000	1,115	832	23.8
1,250	1,188	935	24.3
1,500	1,267	1,028	24.8
1,750	1,359	1,114	25.3
2,000	1,470	1,194	25.7
2,250	1,608	1,270	26.2
2,500	1,778	1,341	26.6
2,750	1,985	1,410	27.1
3,000	2,233	1,475	27.6
3,500	2,867	1,599	28.7
4,000	3,699	1,714	29.7
4,500	4,738	1,822	30.8
5,000	5,983	1,925	31.9
5,500	7,420	2,023	33.0
6,000	9,025	2,117	33.8
6,500	10,762	2,207	34.3
7,000	12,586	2,294	35.0
7,500	14,438	2,378	35.7
8,000	16,250	2,460	36.3

Tuolumne River Flow	SJR Flow	Stanislaus River Flow	Tuolumne River Water Surface Elevation at RM 0.9
cfs	cfs	cfs	ft
8,500	17,941	2,538	36.7
9,000	19,421	2,615	37.1
9,500	20,588	2,690	37.4
10,000	21,328	2,763	37.7

6.0 SENSITIVITY ANALYSIS

To investigate sensitivity of the rating curve we assumed a "high flow" and "low flow" relationship between flows in the Tuolumne River and SJR based on plus-and-minus 40 percent of the flow determined from the regression equation shown in Figure 8. An analysis of the median absolute deviation (MAD) indicates an average (and median) deviation of approximately 30 percent. We chose a broader range of plus-and-minus 40 percent to envelope most of the median flows. Sensitivity flows and water surface elevations for selected study flows in the Tuolumne River are given in Table 5. The rating curve with sensitivity results shown for several flows is displayed in Figure 9. The results indicate insignificant differences at the lowest study flow of 1,000 cfs and a range of 3.2 ft at the highest study flow of 9,000 cfs. The difference in elevation for the 9,000 cfs sensitivity flows drops to less than 0.1 ft approximately 11 miles upstream from the confluence.

Table 5. Sensitivity results for selected study flows.

Tuolumne River Flow	SJR Regression Flow/Elevation		SJR High Flow/Elevation		SJR Low Flow/Elevation	
cfs	cfs	ft	cfs	ft	cfs	ft
1,000	1,115	23.8	1,561	24.1	668	23.9
5,000	5,983	31.9	8,376	33.1	3,589	30.5
9,000	19,421	37.1	27,191	38.6	11,652	35.4

7.0 DATUM ADJUSTMENT

The DWR model and the W&AR-21 Model C were developed using different sets of surface elevation data for the overbank regions. (The channel portion of both models is based on the same set of survey data.) Both surfaces are derived from high-resolution LiDAR data flown in different years. The DWR surface was processed using ground controls based on the Geoid03 model, while the W&AR-21 study used the Geoid09 model. The geoid is a model of global mean sea level that is used to measure precise surface elevations. The elevation differences between the two geoid models vary with location. In the vicinity of the Tuolumne and San Joaquin River confluence the Geoid03 surface is 0.373 ft higher than the Geoid09 surface.

A comparison of elevations of semi-permanent features, such as roads and levees, near the confluence shows approximately 0.4 f to 0.5 ft difference between the two models. For example, the left bank of the downstream boundary cross section from Model C is 0.40 ft higher and the levee beyond the left bank is 0.44 ft higher than the DWR model. To account for this elevation difference the rating curve was adjusted for flows above the banks (greater than 6,500 cfs) to be 0.40 feet higher. Figure 9 shows the elevation difference between the two surfaces.

8.0 CONCLUSIONS

The analysis demonstrates that the backwater effect of flows in the SJR can extend up the Tuolumne River a maximum of approximately 13 miles near the Carpenter Road Bridge for the flows being considered in the W&AR-21 study. This may affect the floodplain habitat estimated to occur by the Tuolumne River TUFLOW model. Flows in the Stanislaus River have a very small backwater effect on the Tuolumne River.

Using the flow regressions developed between stream gages in the San Joaquin, Stanislaus and Tuolumne rivers as described above, the resulting Figure 10 provides a representative stage-discharge rating curve to be used for the TUFLOW model downstream boundary condition.

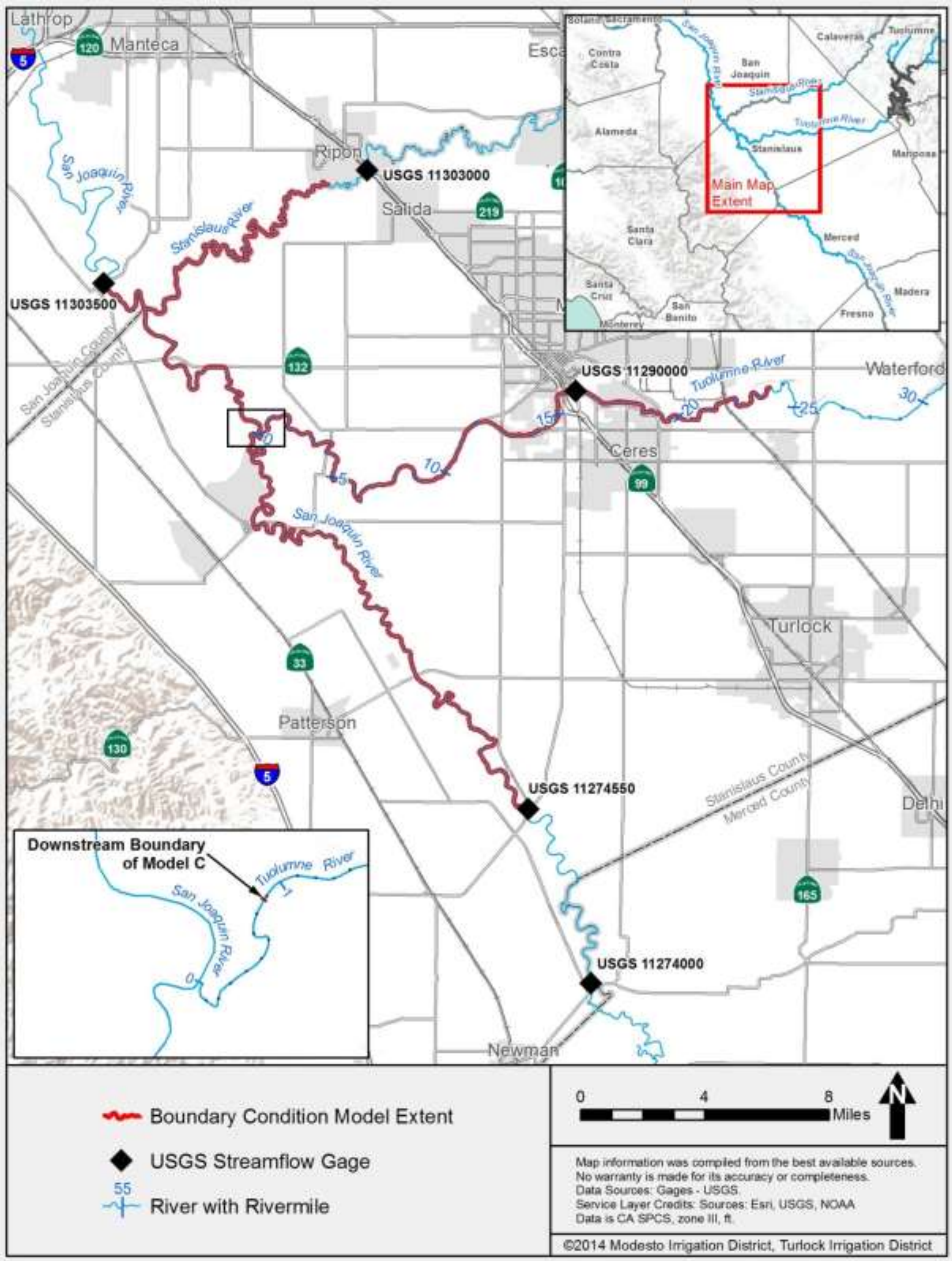

Figure 1. **Location map depicting boundary condition model extents, USGS gage locations and the location for the rating curve.**

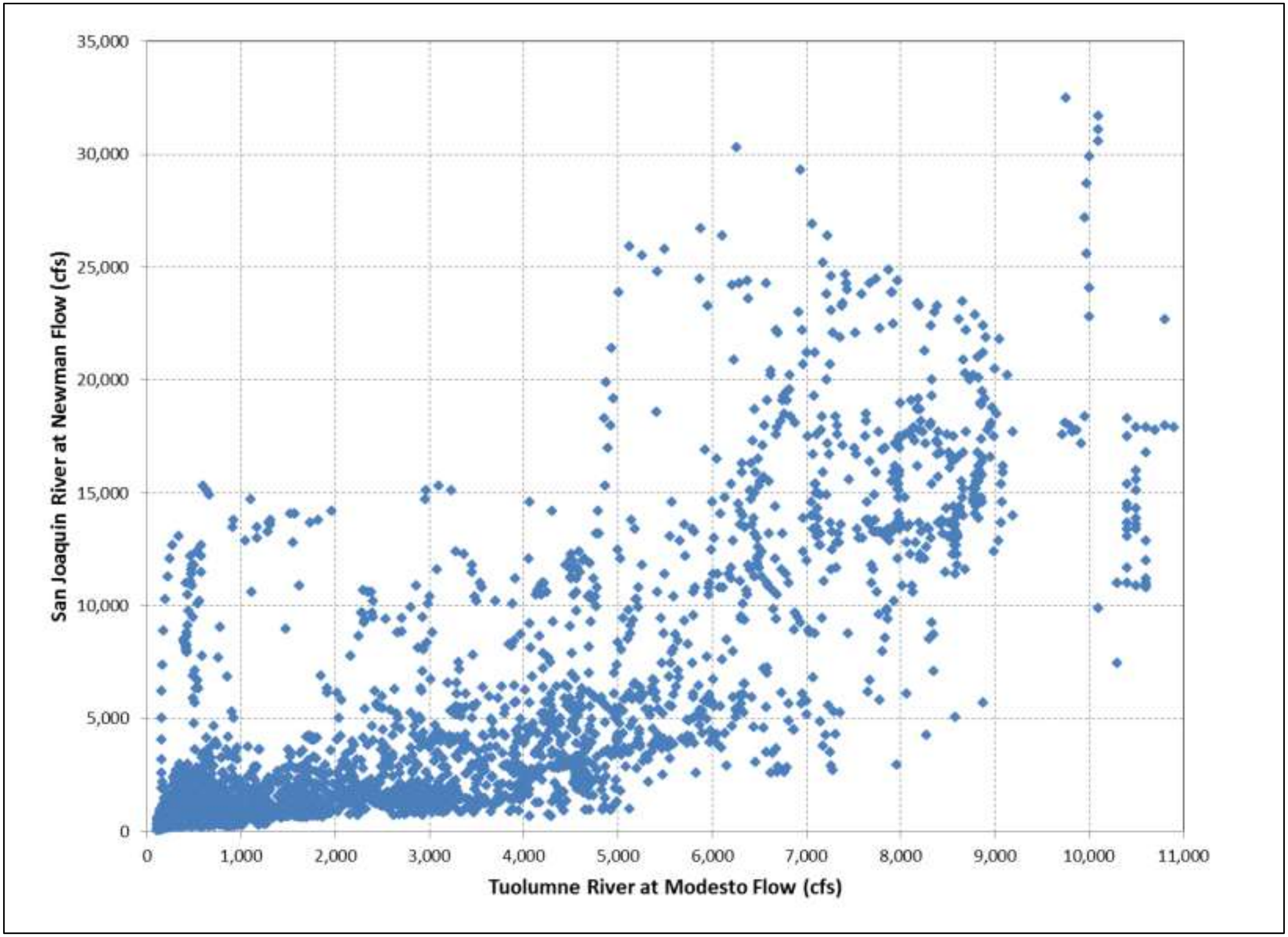

Figure 2. **Comparison of flow in San Joaquin and Tuolumne Rivers, February through May, WY 1971-2012.**

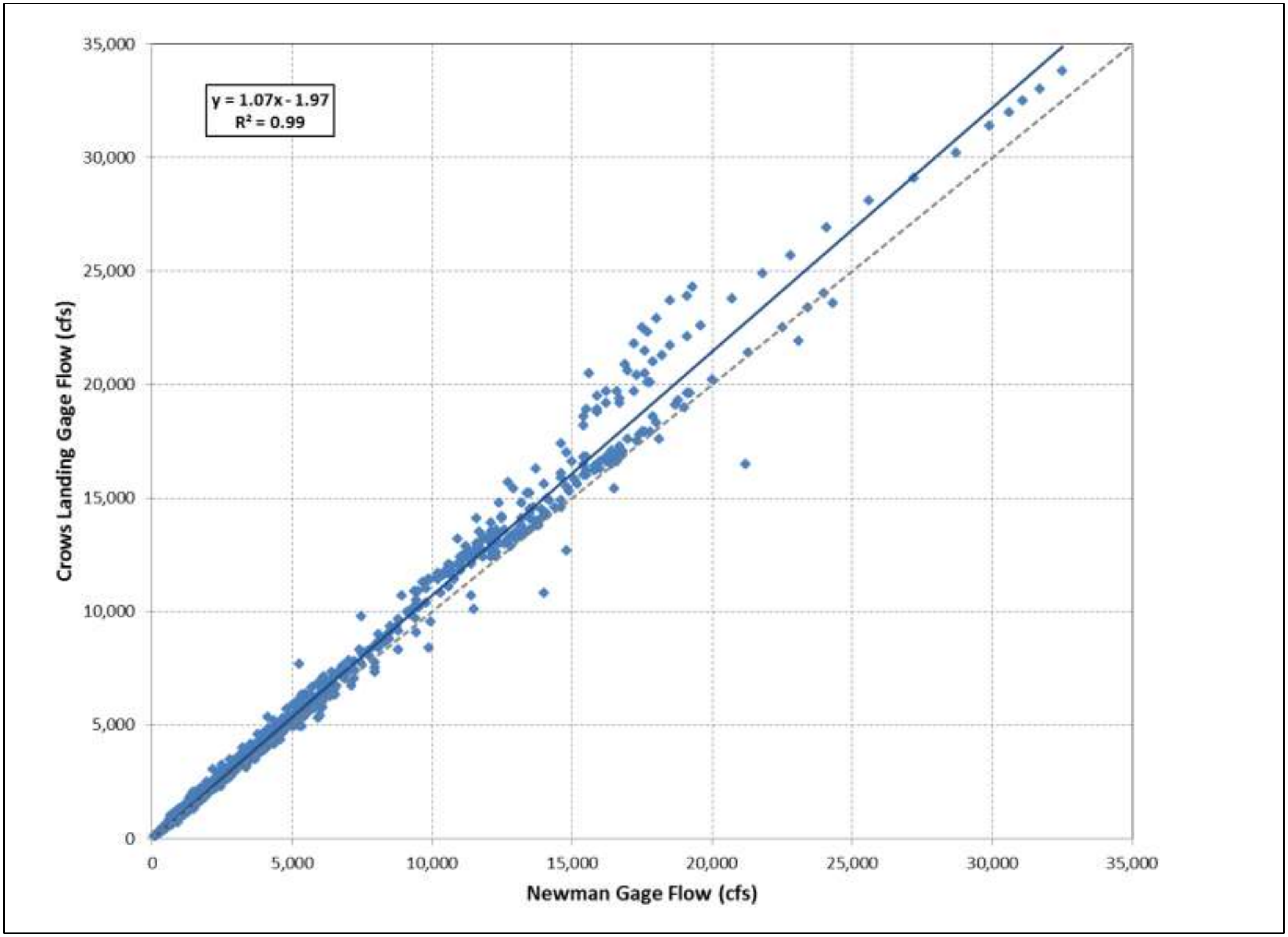

Figure 3. **Comparison of Crows Landing and Newman Gage flow, February through May, 1996 to 2014.**

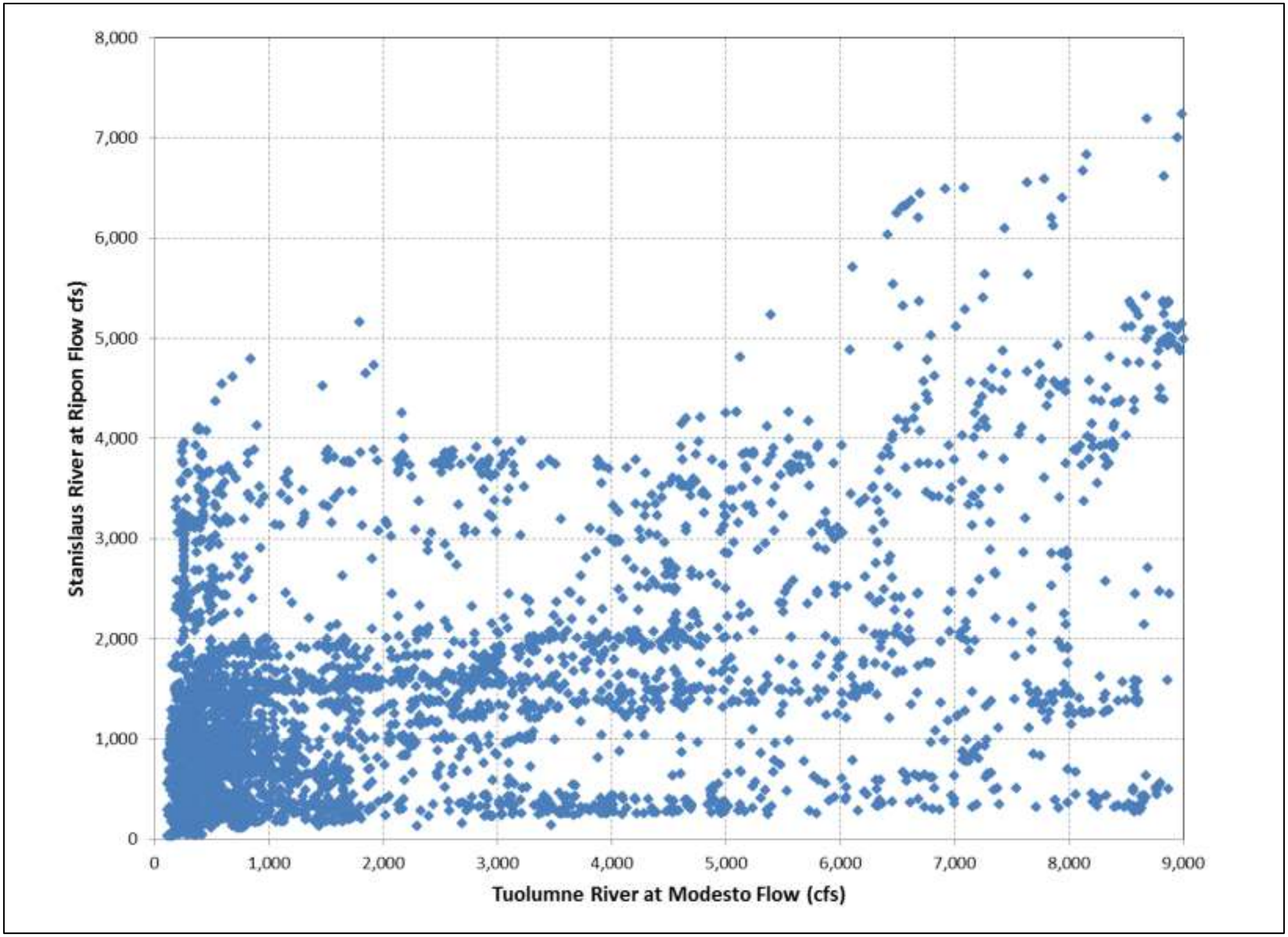

Figure 4. Comparison of flow in Tuolumne and Stanislaus Rivers, February through May, WY 1971 to 2014.

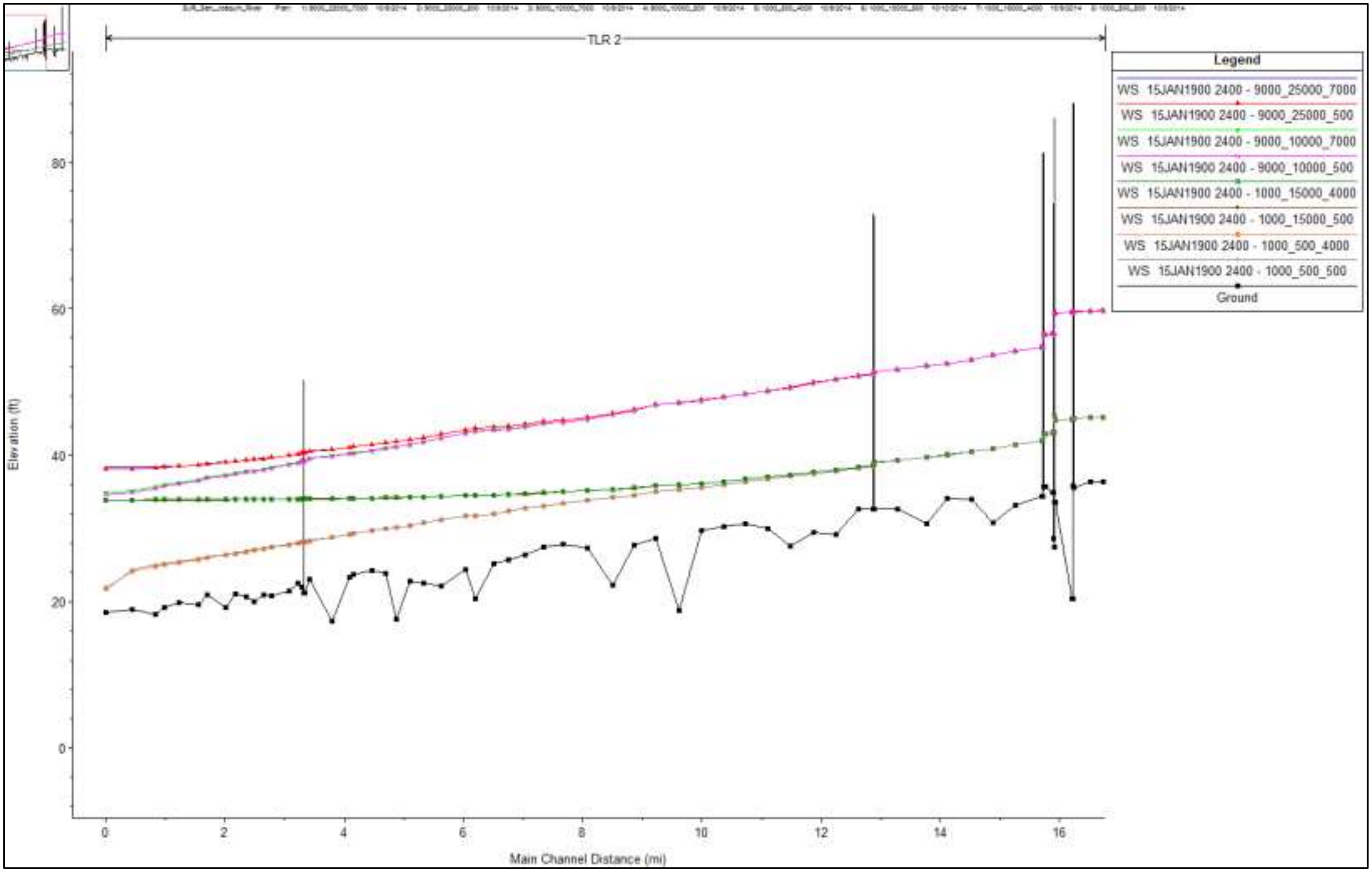

Figure 5. **HEC-RAS water surface elevation profiles for sensitivity scenarios For Tuolumne Reach from confluence with the San Joaquin River.**

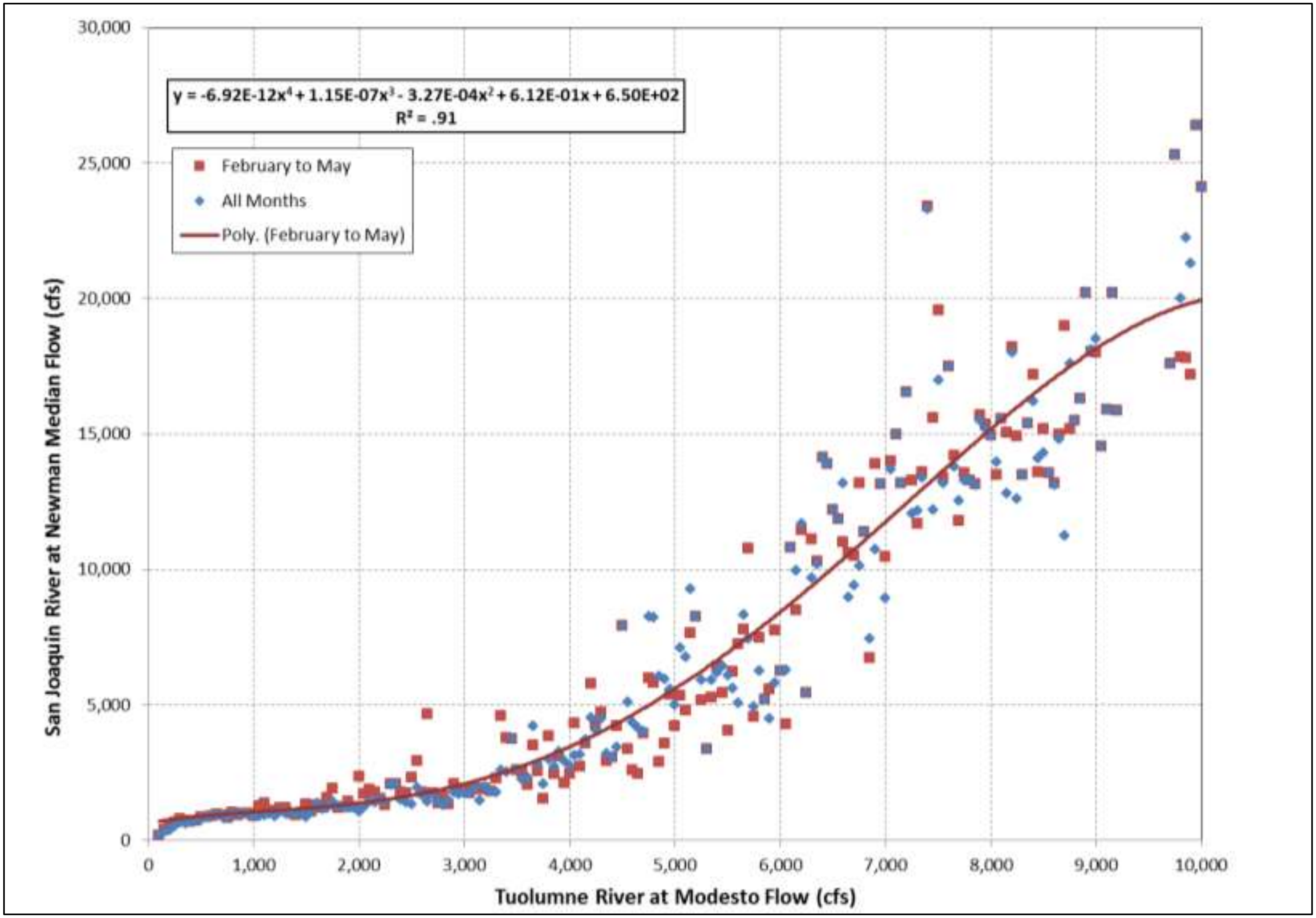

Figure 6. **Correlation of median flow in San Joaquin River for 50 cfs intervals of flow in Tuolumne River, Water Years 1971 to 2012.**

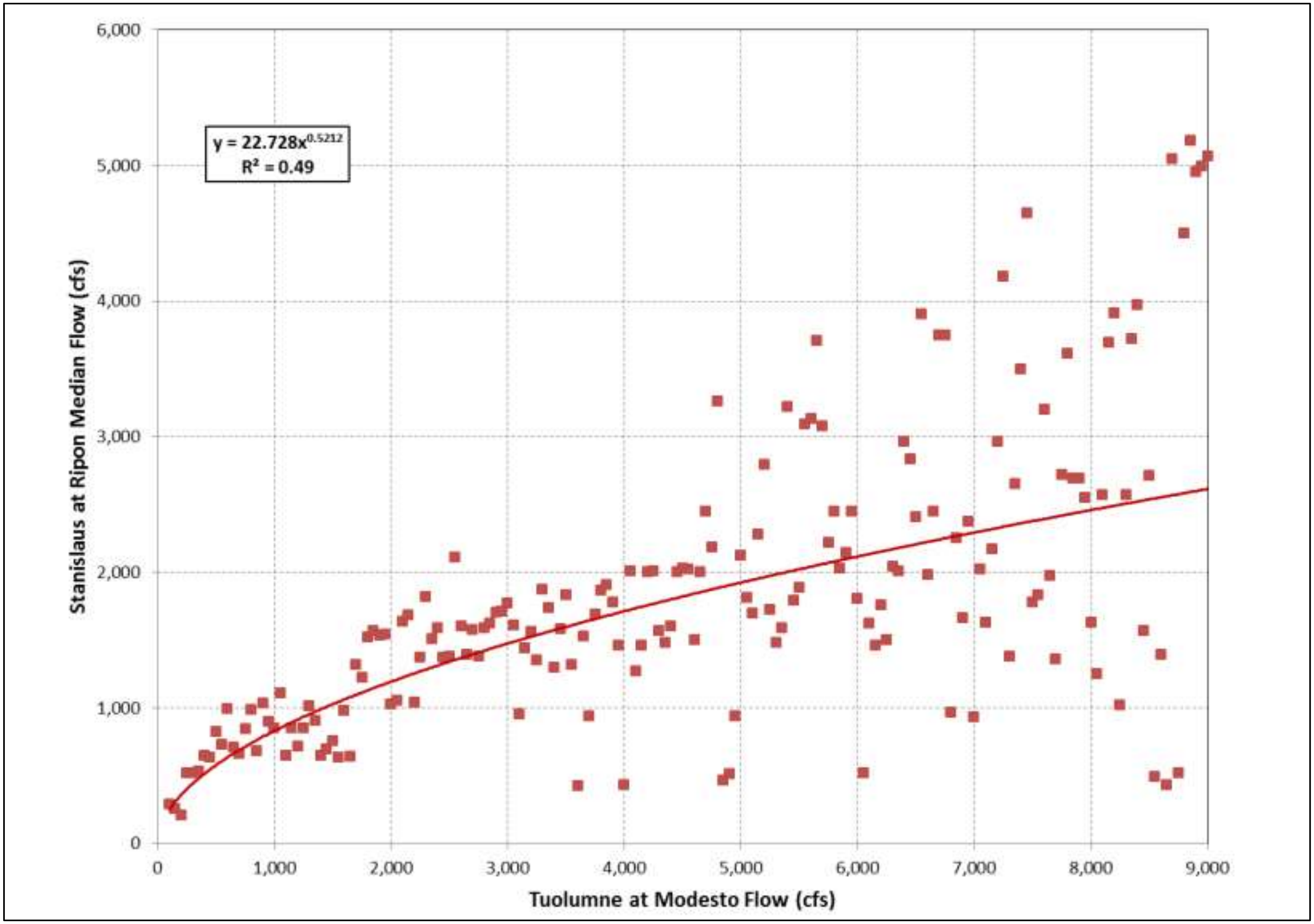

Figure 7. Correlation of flow in Tuolumne with median flow in Stanislaus River for 50 cfs intervals, Water Years 1971 to 2012.

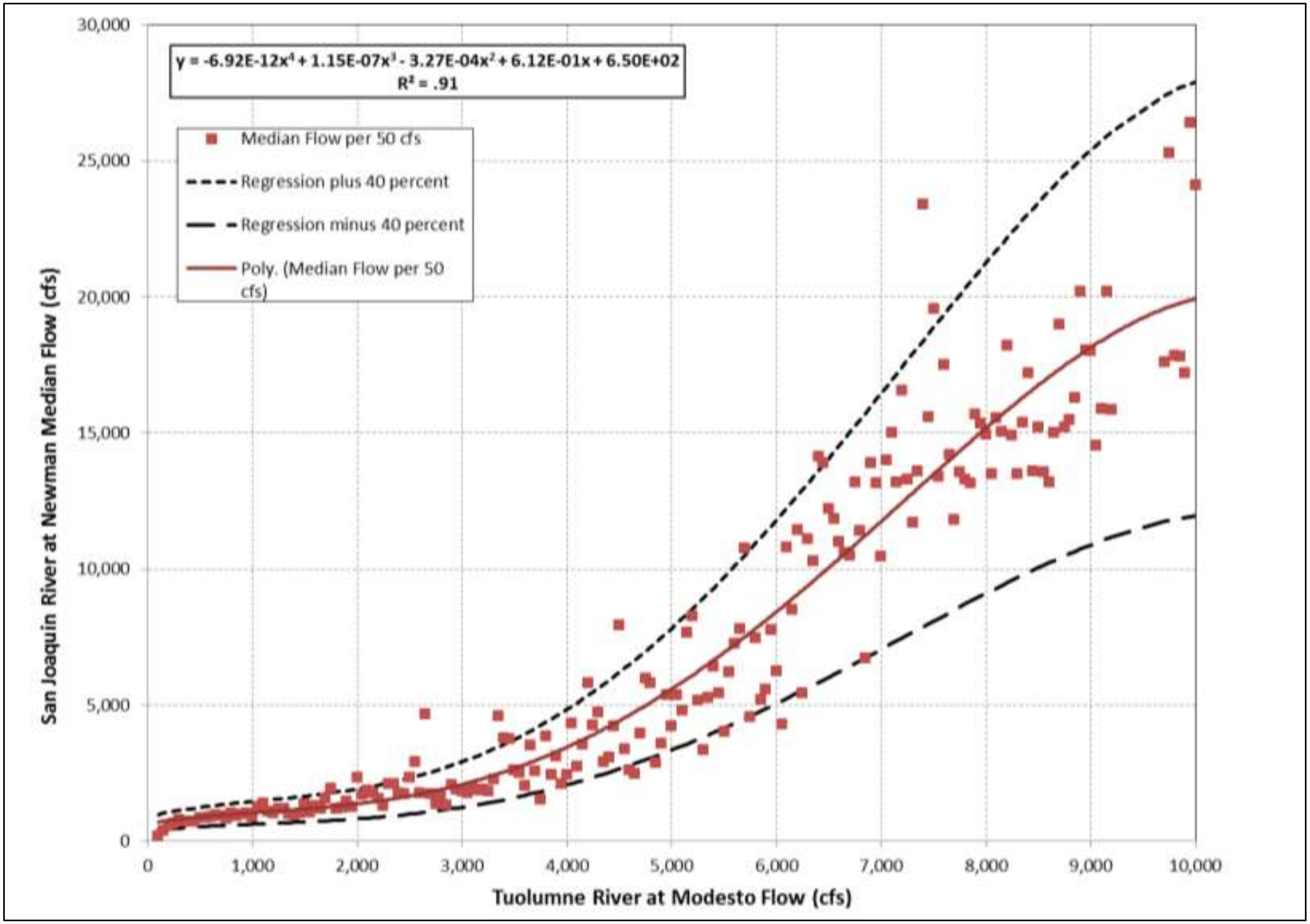

Figure 8. **Sensitivity analysis curves relating median flows in San Joaquin River for 50 cfs intervals of flows in Tuolumne River, Water Years 1971 to 2012.**

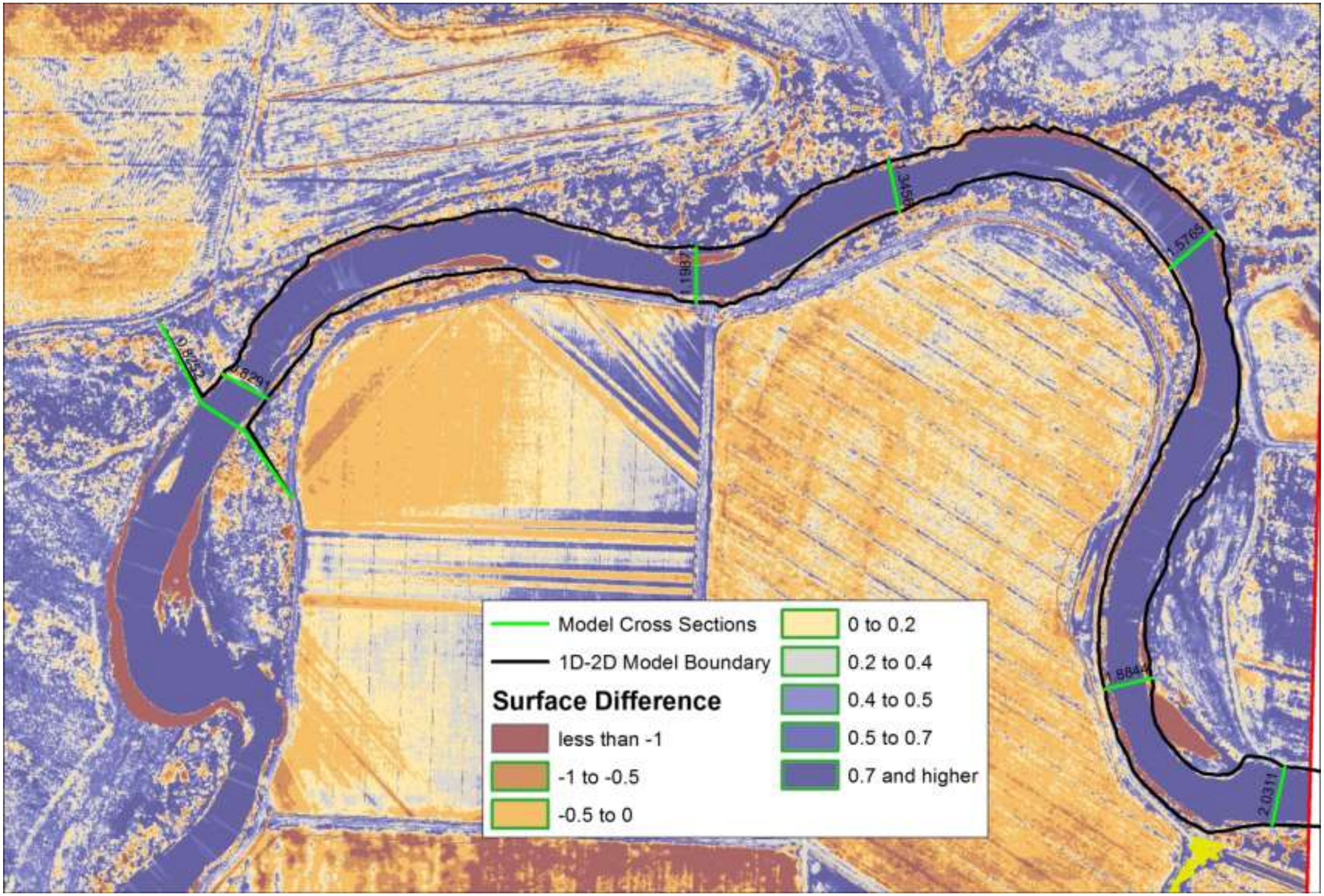

Figure 9. Difference in model terrain surfaces between DWR and W&AR-21 Model C. Levee features are consistently 0.4 to 0.5 ft higher, while some farmland areas have been eroded or compacted.

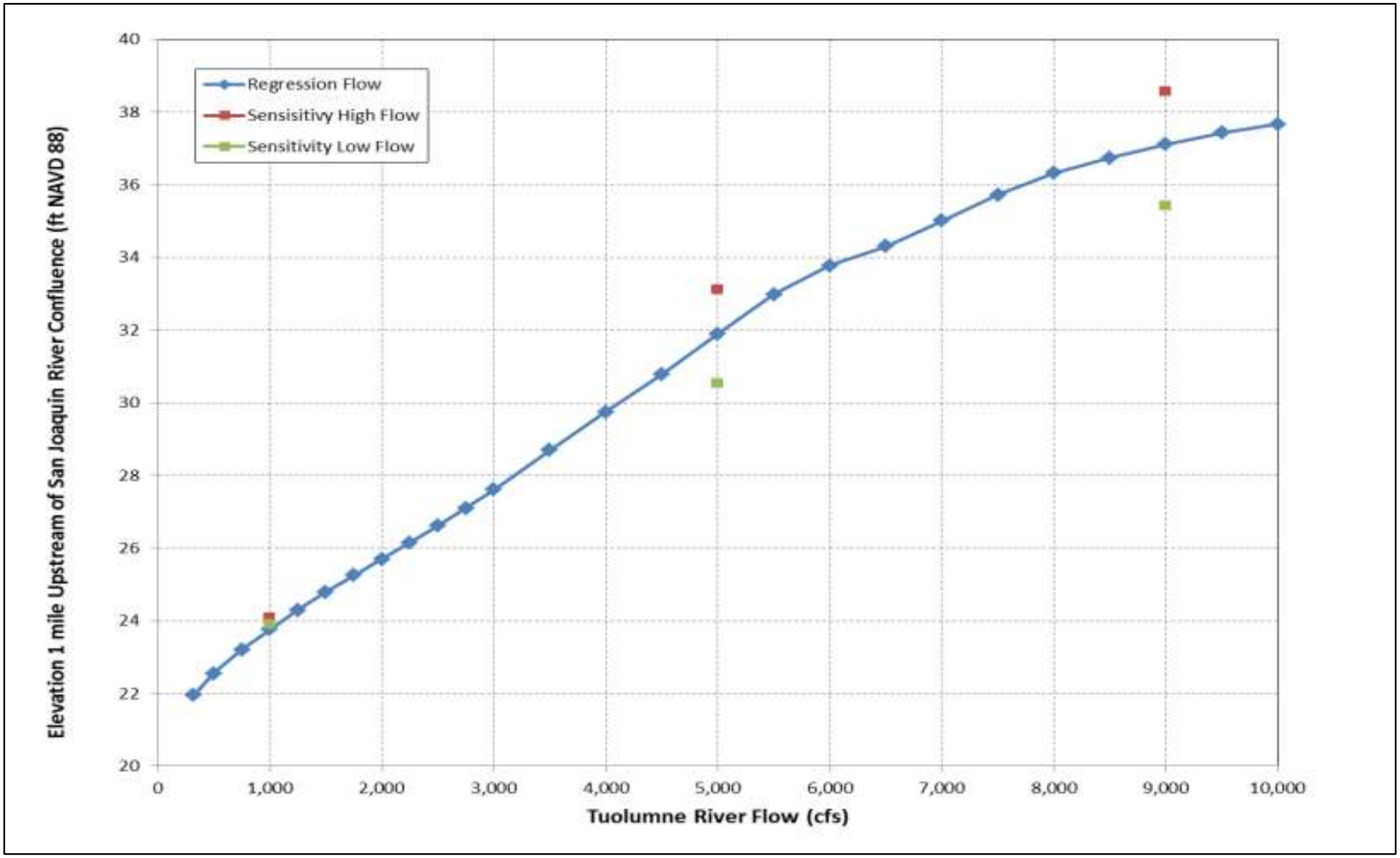

Figure 10. Model C boundary condition rating curve at RM 0.9.

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ATTACHMENT F

LOCATIONS OF SIGNIFICANT GEOMORPHOLOGICAL CHANGES

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1.0 LOCATIONS OF SIGNIFICANT GEOMORPHOLOGICAL CHANGES

Between 1993 and 2012, several locations in the study area underwent significant geomorphological changes. This attachment provides a description of model revisions undertaken during the calibration process and locations requiring further investigation due to changes in reach morphology which occurred subsequent to the aerial photo dates used for comparison of inundation extents and hydraulic behavior. This section presents areas that were identified as having undergone significant morphological changes potentially affecting hydraulic properties. The changes were carefully reviewed to ensure proper hydraulic simulation through verification of model results.

1.1 Model A

1.1.1 Artificial Dam Near RM 45.5.

The following figures show an artificial dam on the north side of the island at RM 45.5 (Cross section 45.54416). The dam was likely created during the construction of the artificial channel upstream on the north side of the river for the purpose of raising the water surface elevation to direct more flow through the engineered channel. The dam was added to the model to improve simulation of the hydraulic behavior in the region.

Figure 1. Artificial dam RM 45.5. Dam seems to be at floodplain stage or higher (2009 imagery, flow of 490 cfs) (Google 2013).

Figure 2. Artificial dam at RM 45.5. Dam seems to have been overtopped during preceding high flows but still can be seen through the water (2011 imagery, flow of 1,020 cfs) (Google 2013).

1.1.2 Bobcat Flat Near RM 43

The following figures show the floodplain restoration work that started in 2005 at Bobcat flat near RM 43. The purpose of the multi-phase project was to restore morphologic function and habitat for target species by lowering portions of the floodplain. Phase-I construction to restore riparian habitat, floodplain function and connectivity to the river, began in the summer of 2005 (McBain & Trush Inc. 2011). A previous hydraulic modeling study (Domenichelli & Associates 2010) showed inundation extents in the constructed floodplain at a flow of 5,000 cfs. Hydraulic behavior of the model was validated in this important region based on this documentation.

Bobcat Flat RM 43 Phase II
FINAL Technical Memorandum — McBain and Trush, Inc., 2011

Figure 6. Pre- (November 17, 2000) and post- (September 21, 2005) construction aerial photographs for Bobcat Flat RM 43 Phase I project area.

Figure 3. Before and after restoration work at Bobcat Flat (McBain & Trush 2011).

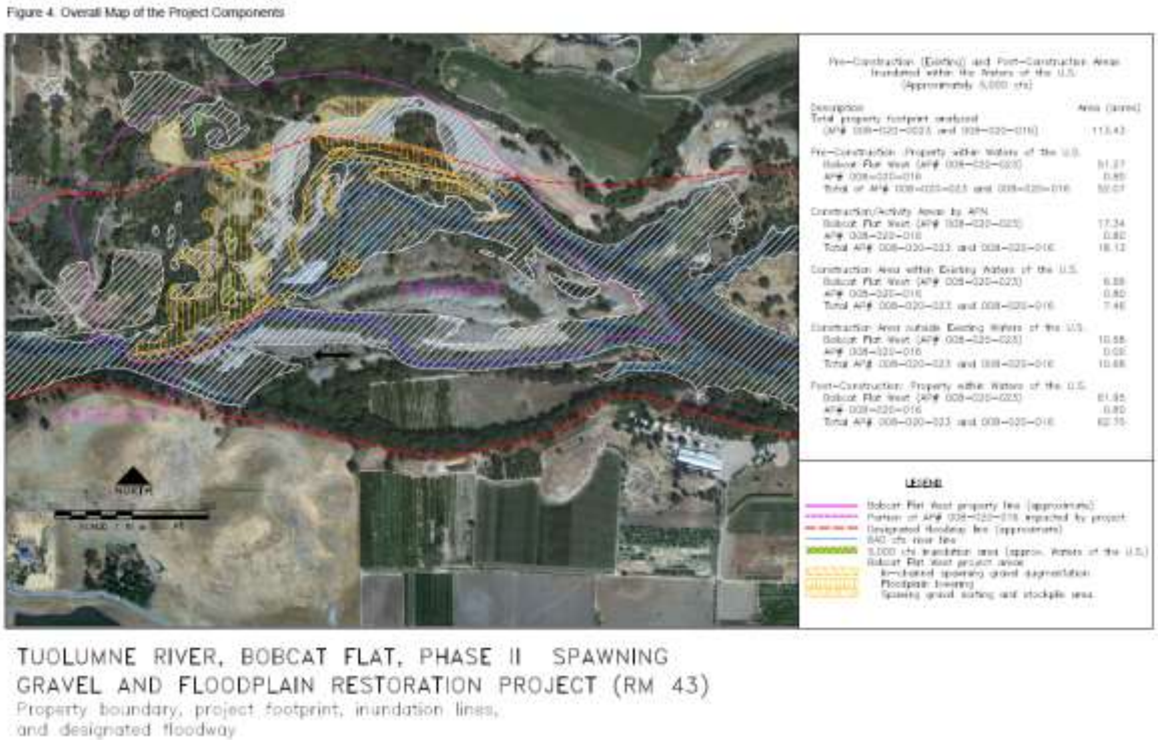

Figure 4. **Bobcat Flat (Domenichelli & Associates 2010).**

Figure 5. **Conditions prior to construction at Bobcat Flat (2005 imagery, flow of 4,030 cfs) (Google 2013).**

Figure 6. **The constructed floodplain at Bobcat Flat (2006 imagery, flow of 1,590 cfs) (Google 2013).**

Figure 7. **Flow in the constructed floodplain at Bobcat Flat (2010 imagery, flow between 5,400 and 6,000 cfs) (Google 2013).**

Figure 8. **Flow in the constructed floodplain at Bobcat Flat (2011 imagery, flow between 5,600 and 5,900 cfs) (Google 2013).**

1.1.3 Inundation Areas and Construction of Ponds Near RM 42

The photos show two new constructed ponds and visible changes in floodplain flow paths over time. Model hydraulic behavior was validated in this region based on the photographs.

Figure 9. **Inundated area near RM 42 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997).**

Figure 10. Two new constructed ponds and visible changes in floodplain flow paths near RM 42 (2011 imagery, flow of 1,020 cfs) (Google 2013).

1.1.4 Side Channel Near RM 50

The following locations experienced significant morphological changes in the river and/or floodplain since 1993, most likely due to sustained high flows during the 1997 flood event when peak flows exceeded 50,000 cfs at the USGS Gage below La Grange (Figure 11):

- Near RM 50 – Formation of side channel
- Near RM 48 – Erosion on overbank flow path leading to formation of side channel
- Near RM 48 – Aggradation on left overbank floodplain flow paths and floodplain
- Near RM 47 – Aggradation upstream of sand bar
- Near RM 46 – Aggradation on flow path connecting river to Zanker property

Figure 11. Flow hydrograph at USGS La Grange Gage during the 1997 flood event.

Below are images of a side channel near RM 50 on the south river bank that was created sometime between 1995 and 1998, likely due to the 1997 storm. The following figures show the evolution of the side channel development over time. The figures also show that once created, there is no flow in the side channel at 490 and 1,020 cfs, but flow is evident at 1,590 cfs and 2,689 cfs. Hydraulic behavior at these flows was verified during model validation.

Figure 12. No side channel exists at RM 50 prior to 1993 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 13. **No side channel exists at RM 50 prior to 1995 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997).**

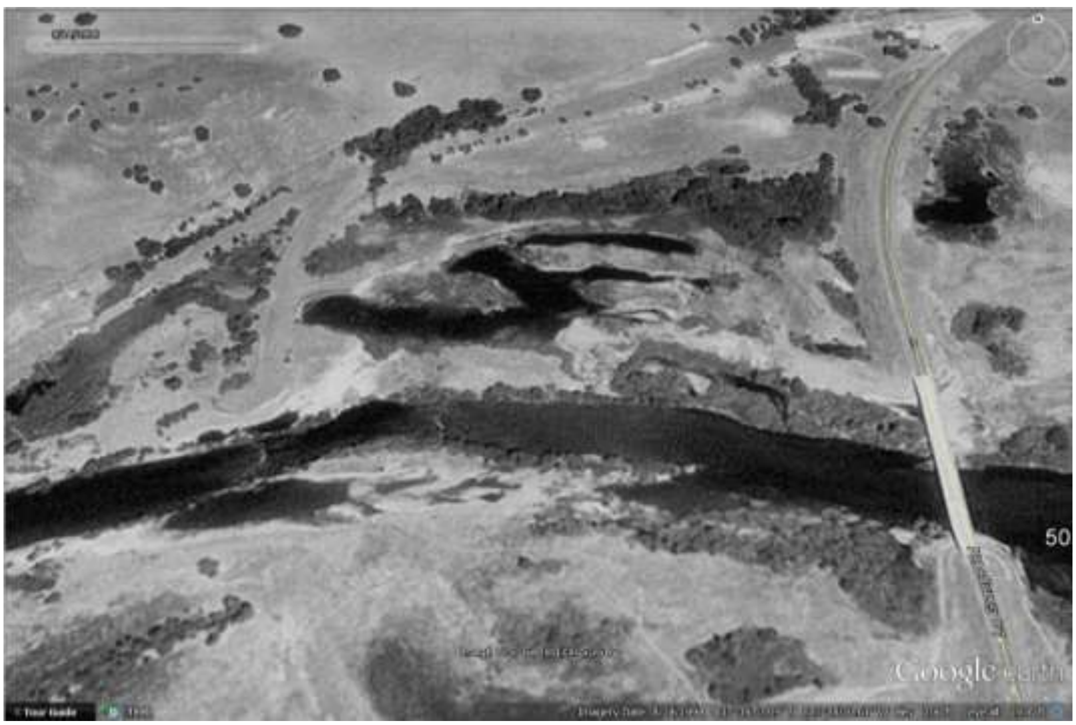

Figure 14. **1998 imagery shows a side channel at RM 50 (flow of 1,030 cfs) (Google 2013).**

Figure 15. 2009 imagery shows a side channel near RM 50 (flow of 490 cfs) (Google 2013).

Figure 16. 2011 imagery shows a side channel near RM 50 (flow of 1,020 cfs) (Google 2013).

Figure 17. **2006 imagery shows a side channel near RM 50 (flow of 1,590 cfs) (Google 2013).**

Figure 18. **2005 imagery shows flow in a side channel near RM 50 (flow of 2,680 cfs) (Google 2013)**

1.1.5 Basso Floodplain near RM 48

The figures below show changes in the Basso Floodplain at RM 48 between 1993 and 2005. The changes suggest aggradation on the floodplain altering the extent of flow paths and inundation. Flow leaves the channel into the floodplain and returns.

Figure 19. The Basso floodplain (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 20. The Basso floodplain (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.1.6 Aggradation Near RM 47.

Comparison of floodplains between 1993 and 2005 suggests aggradation upstream of the sand bar, altering flow paths and the extent of inundation.

Figure 21. Aggradation near RM 47 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 22. Aggradation near RM 47 (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.1.7 Zanker Property Near RM 46

The flow path connecting the river to the Zanker property at RM 46 has changed over time. In 1993 at flows of 3,100 cfs, flow appeared to leave the river and flow into the Zanker property (Figure 23). A 2005 aerial image of flow at 4,030 cfs shows that the flow paths and inundation extent have significantly changed (Figure 24). A comparison of these two figures suggests aggradation at the location, leading to formation of a sand bar, altering flow paths and the extent of inundation.

Figure 23. Zanker property near RM 46 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 24. Zanker property near RM 46 (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.2 Model B

No location of significant morphological changes encountered during calibration.

1.3 Model C

Two significant changes in the floodplain were noted.

1.3.1 TRRP Gateway Parcel Project Near RM 16

In 2009 as part of the TRRP (Tuolumne River Regional Park) Gateway Parcel Project by the City of Modesto (Tuolumne River Trust 2012), significant floodplain storage near RM 16 was added by recontouring and revegetating the land along this stretch of the river into a series of three floodplain terraces on both sides of the 9th Street Bridge (immediately adjacent to Dennett Dam). Figures 26 through 28 show the site in 2005, 2011 and 2012 terrain.

Figure 15. A 2005 image of the TRRP, prior to recontouring and revegetation (Google 2013).

Figure 26. A 2011 image of the TRRP, following recontouring and revegetation (Google 2013).

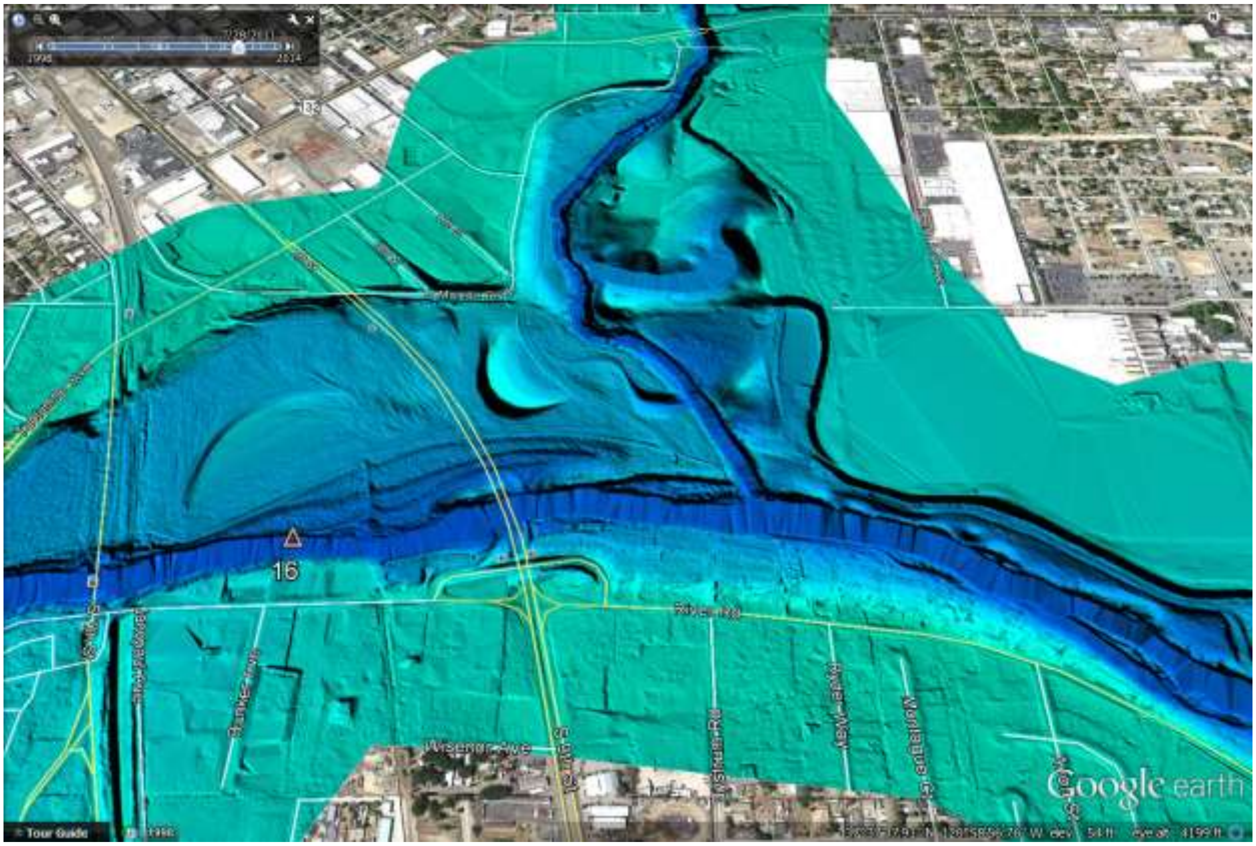

Figure 37. A 2012 image of the TRRP, after recontouring and revegetation.

1.3.2 Embankments Near RM 6.5

Near RM 6.5, some of the embankments appear to have either been breached in the 1997 flood or intentionally cut open to allow inflow. An aerial image from 1995 shows the extent of iundation at 8,322 cfs (Figure 28). In this image, there appear to be no cuts in the embankments and the adjacent fields appear dry. In contrast, the 2012 terrain shows cuts in the embankments (Figure 29). Therefore, the model was calibrated to allow water to flow into the adjacent fields connected by the embankment cuts for the calibration flow of 8,322 cfs.

Figure 48. **A 1995 image showing the embankments. There appear to be no cuts in the embankments (flow of 8,322 cfs) (TID/MID 1997).**

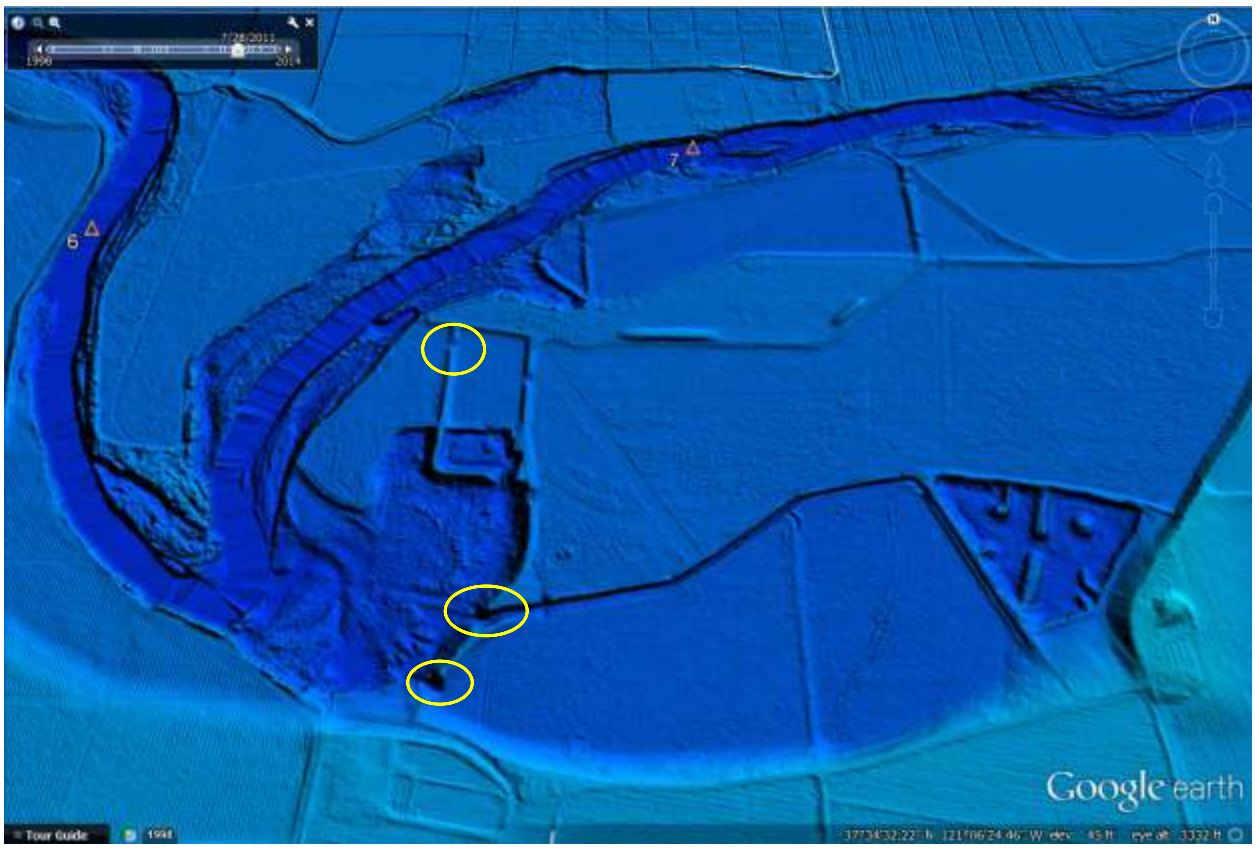

Figure 29. **A 2012 terrain image shows cuts in the embankments.**

2.0 REFERENCES

Dennett Dam Removal - Concept Level Basis of Design Report, Tuolumne River Trust, 2012.

Domenichelli & Associates. 2010. Hydraulic Modeling Results – Tuolumne River, Bobcat Flat RM 43. Prepared for McBain & Trush as part of the Bobcat Flat Restoration (McBain and Trush 2011).

Google Earth Pro, Google Inc, 2013.

McBain & Trush, Inc. 2011. Bobcat Flat River Mile (RM) 43 Phase II Restoration, Final Design Document. Prepared for the Friends of the Tuolumne River, Inc. May 24, 2011.

TID/MID 1997. Imageries from Tuolumne River GIS Database Report and Map. Report 1996-14 In 1996 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Prepared by EA Engineering, Science, and Technology, Lafayette, California.

STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT G

FLOODPLAIN INUNDATION EXTENT ANIMATIONS

Twenty animations which show the inundation extents for steady flows from 1,000 cfs to 9,000 cfs are available electronically. A CD with animations is available upon request to Jenna Borovansky (jenna.borovansky@hdrinc.com).

STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT H

COMPARISON OF USABLE HABITAT WITHIN IN-CHANNEL AND FLOODPLAIN AREAS

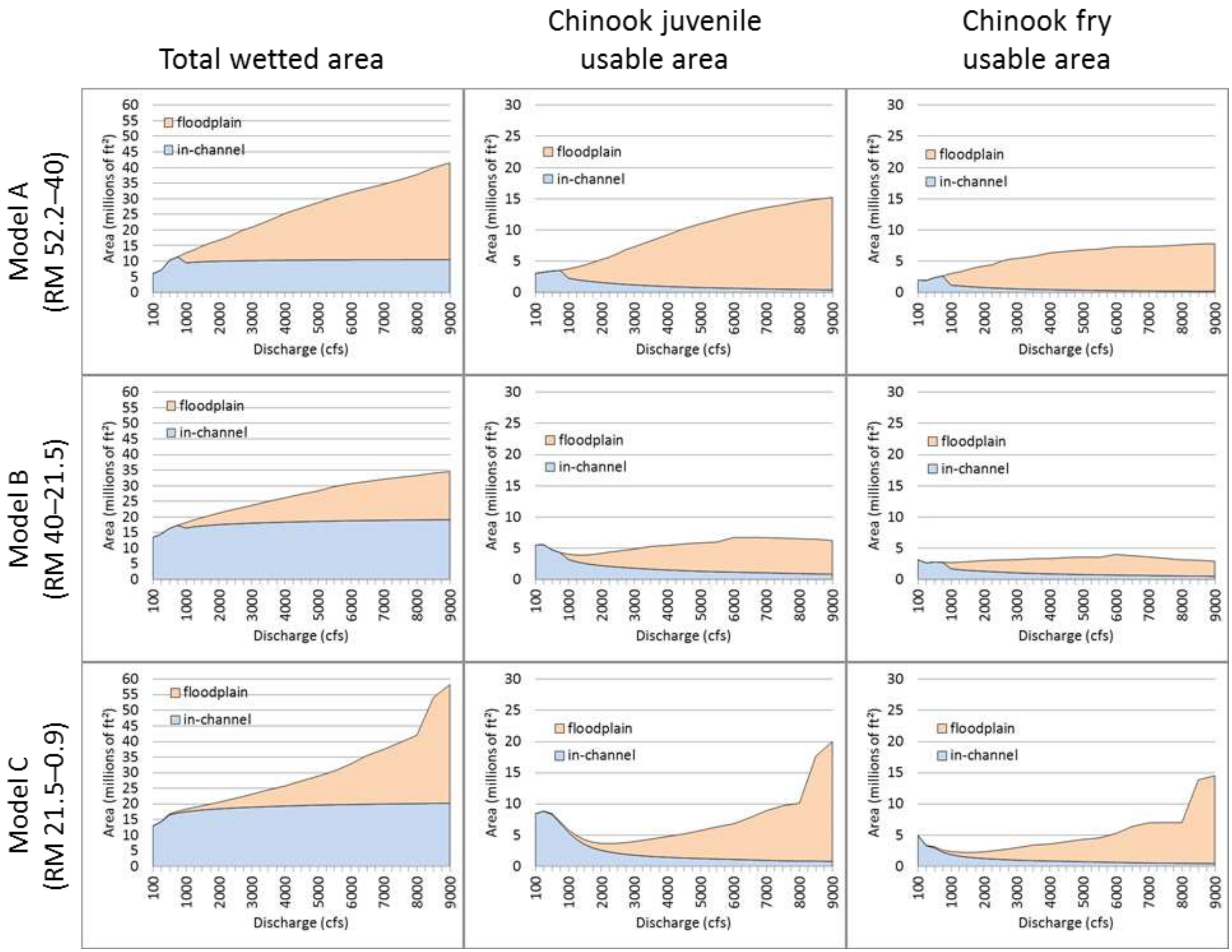

Figure 1. **Variations of total wetted area and usable habitat for Chinook salmon fry and juvenile life stages within in-channel and floodplain habitats within three sub-reaches of the lower Tuolumne River as a function of discharge.**

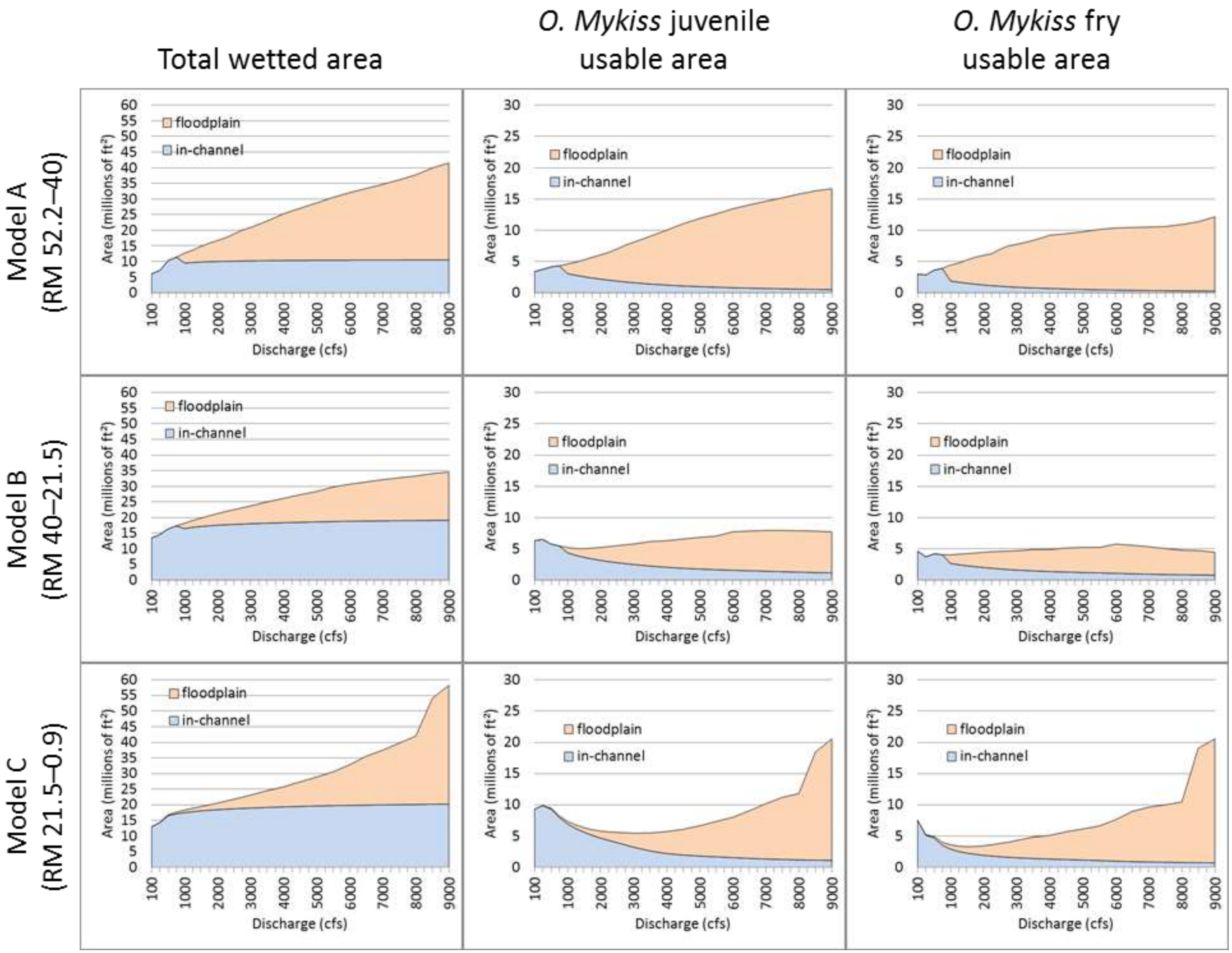

Figure 2. Variations of total wetted area and usable habitat for *O. mykiss* fry and juvenile life stages within in-channel and floodplain habitats within three sub-reaches of the lower Tuolumne River as a function of discharge.

STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT I

USEABLE HABITAT AREAS AT REPRESENTATIVE SITES

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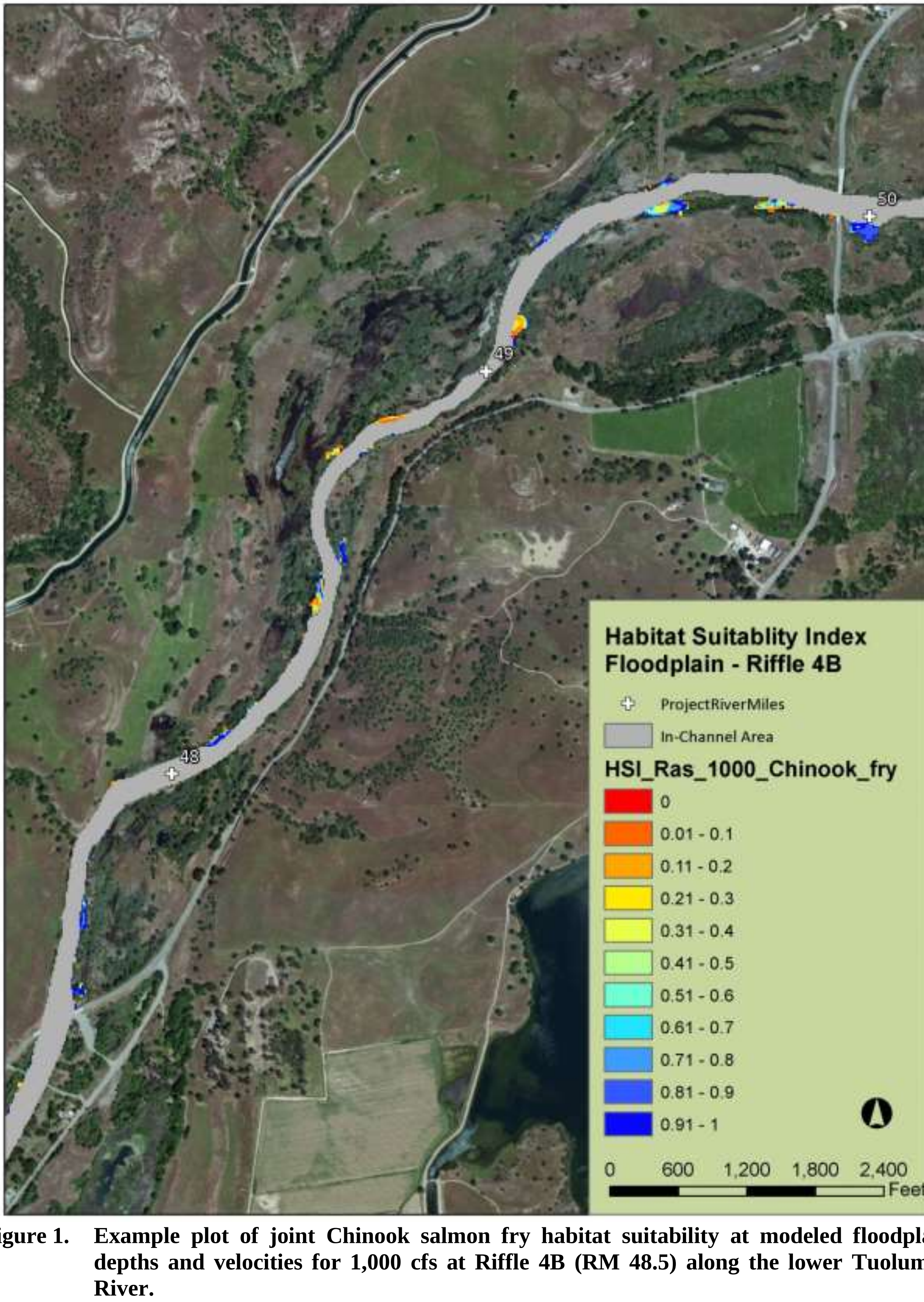

Figure 1. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

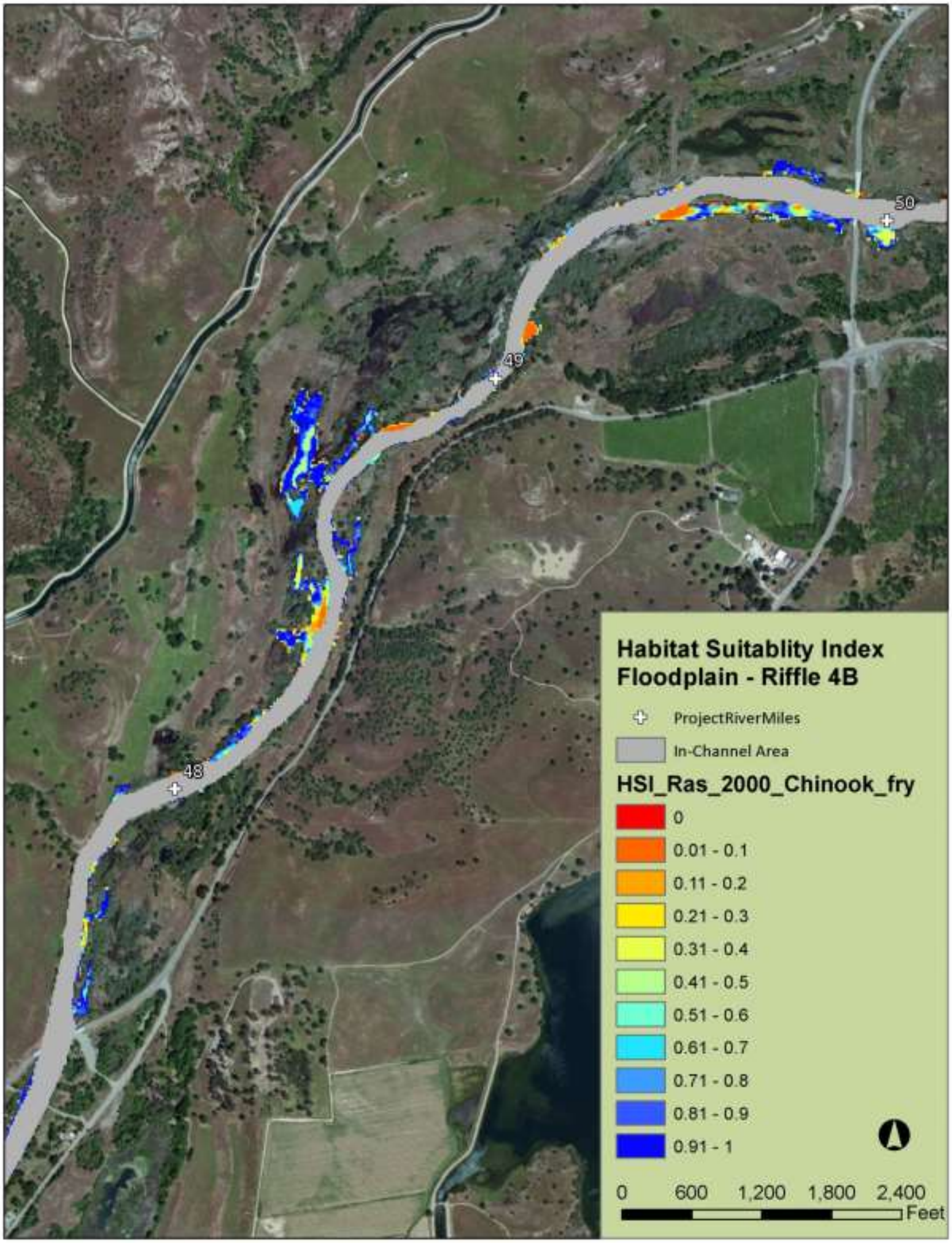

Figure 2. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

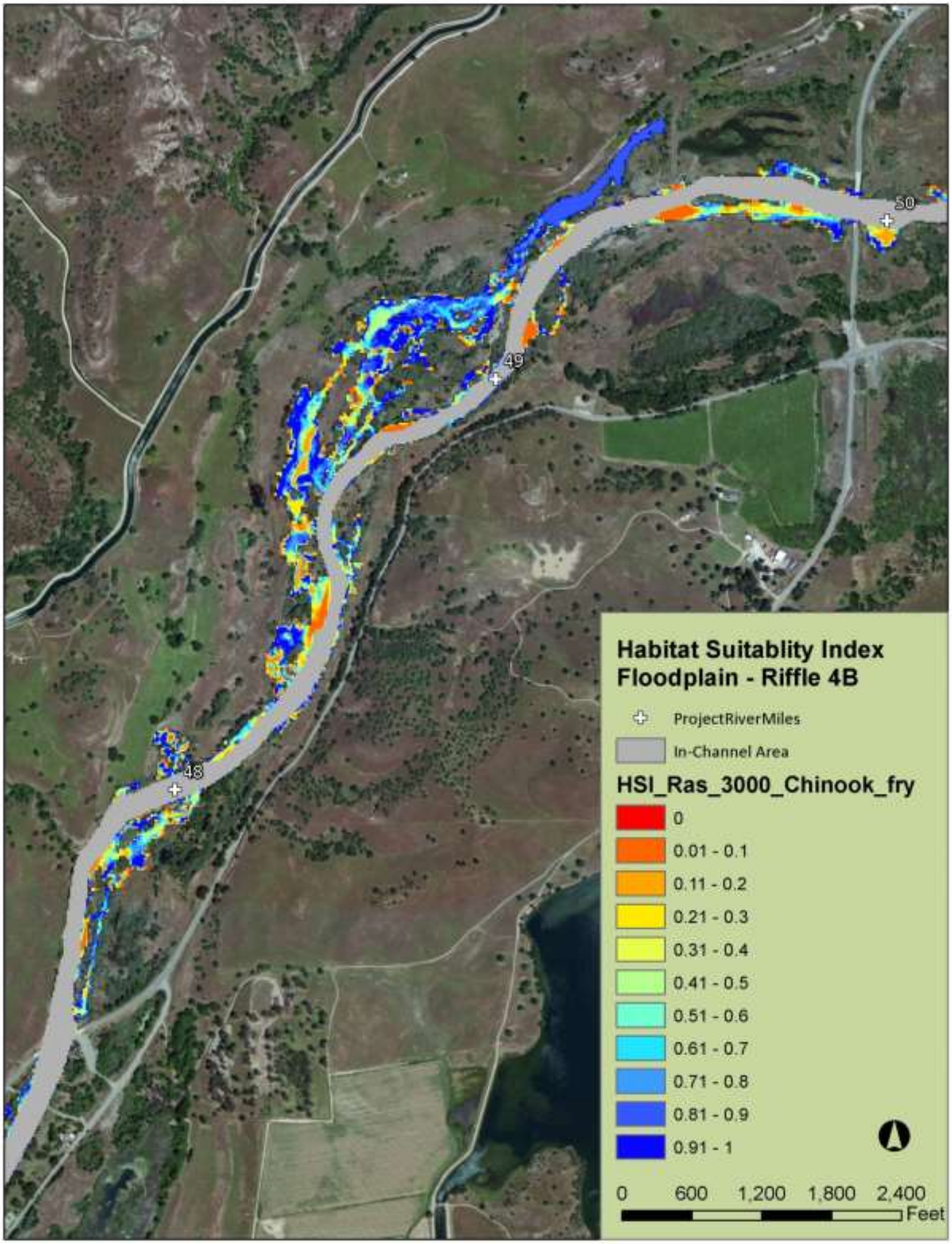

Figure 3. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

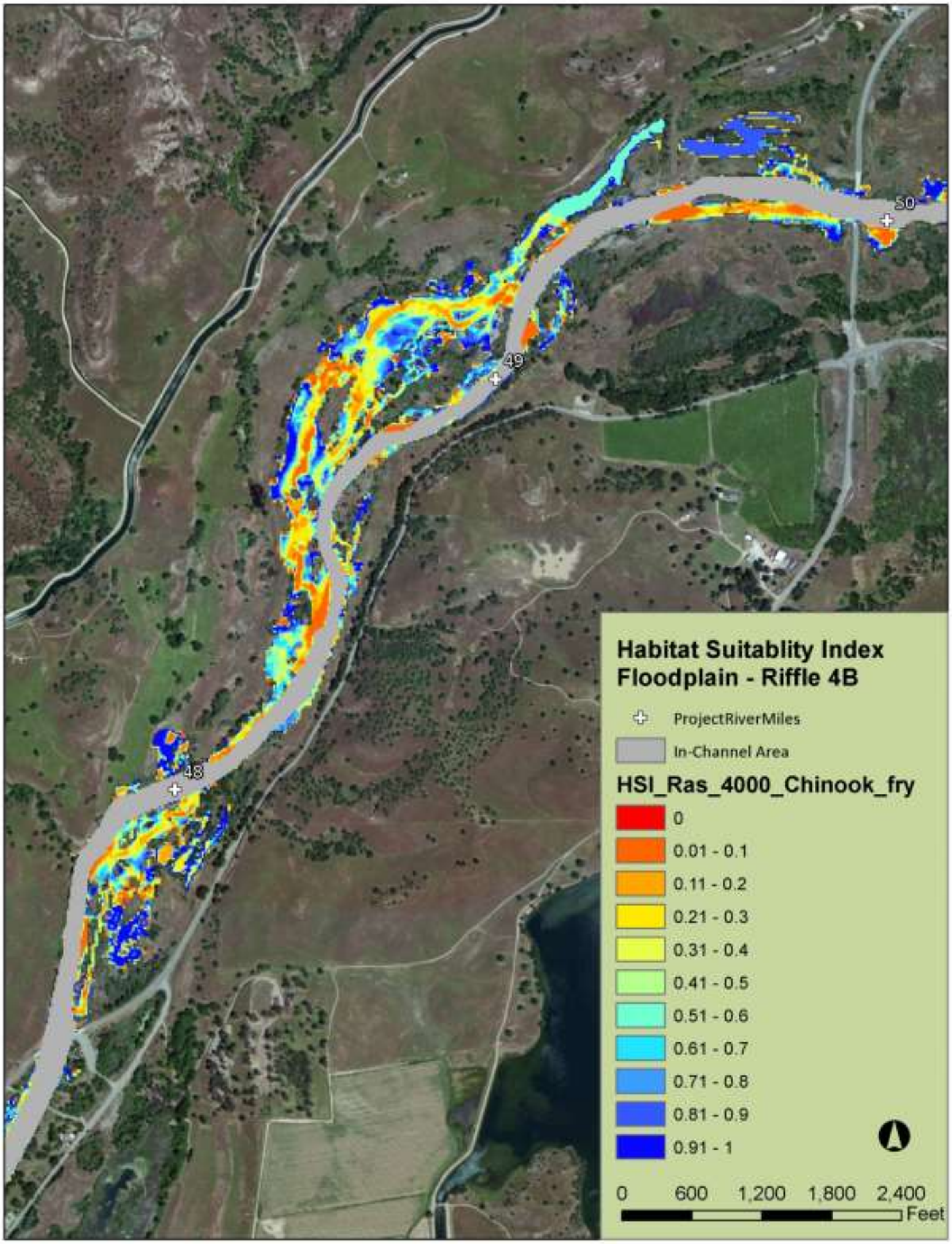

Figure 4. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

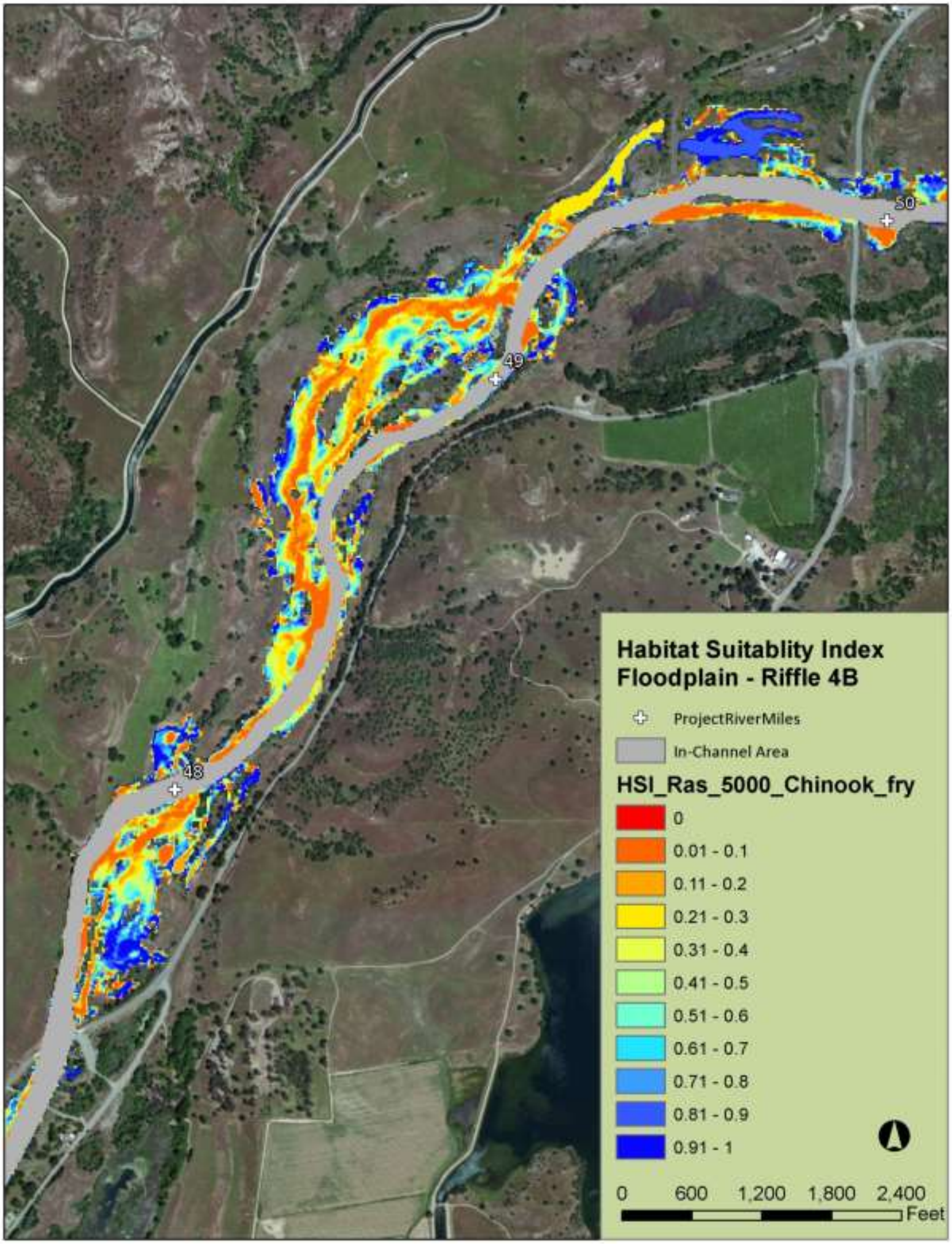

Figure 5. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for5,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

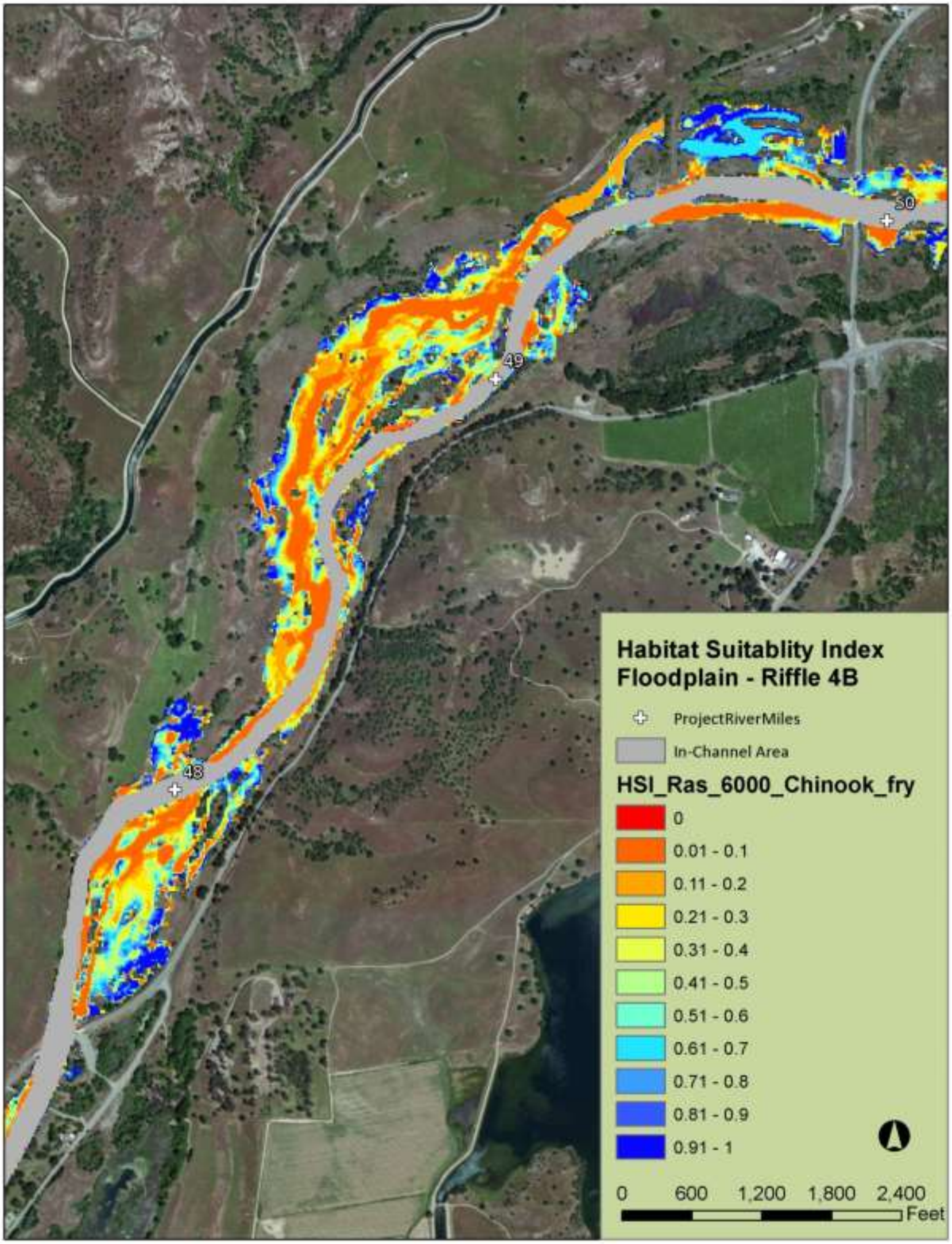

Figure 6. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

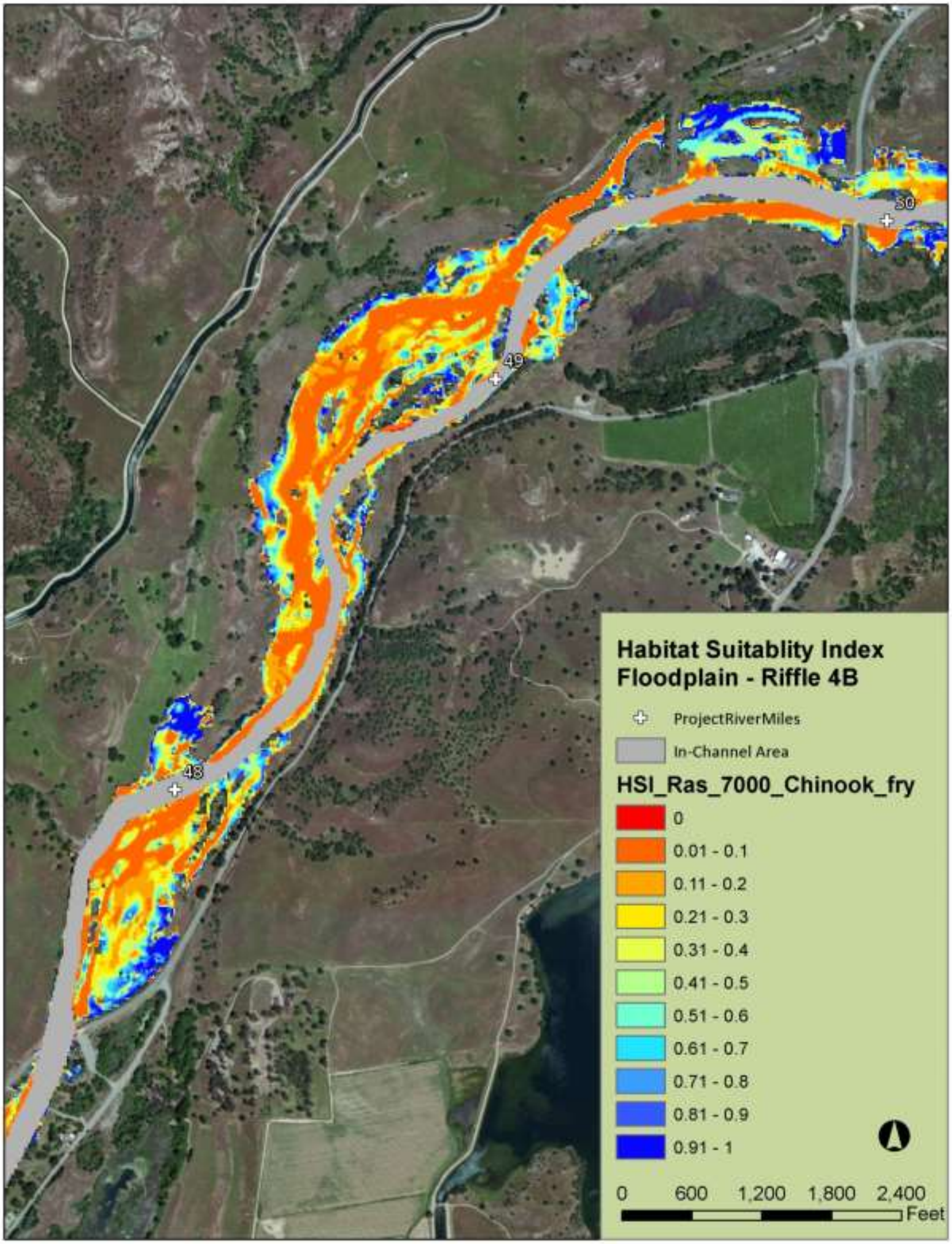

Figure 7. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

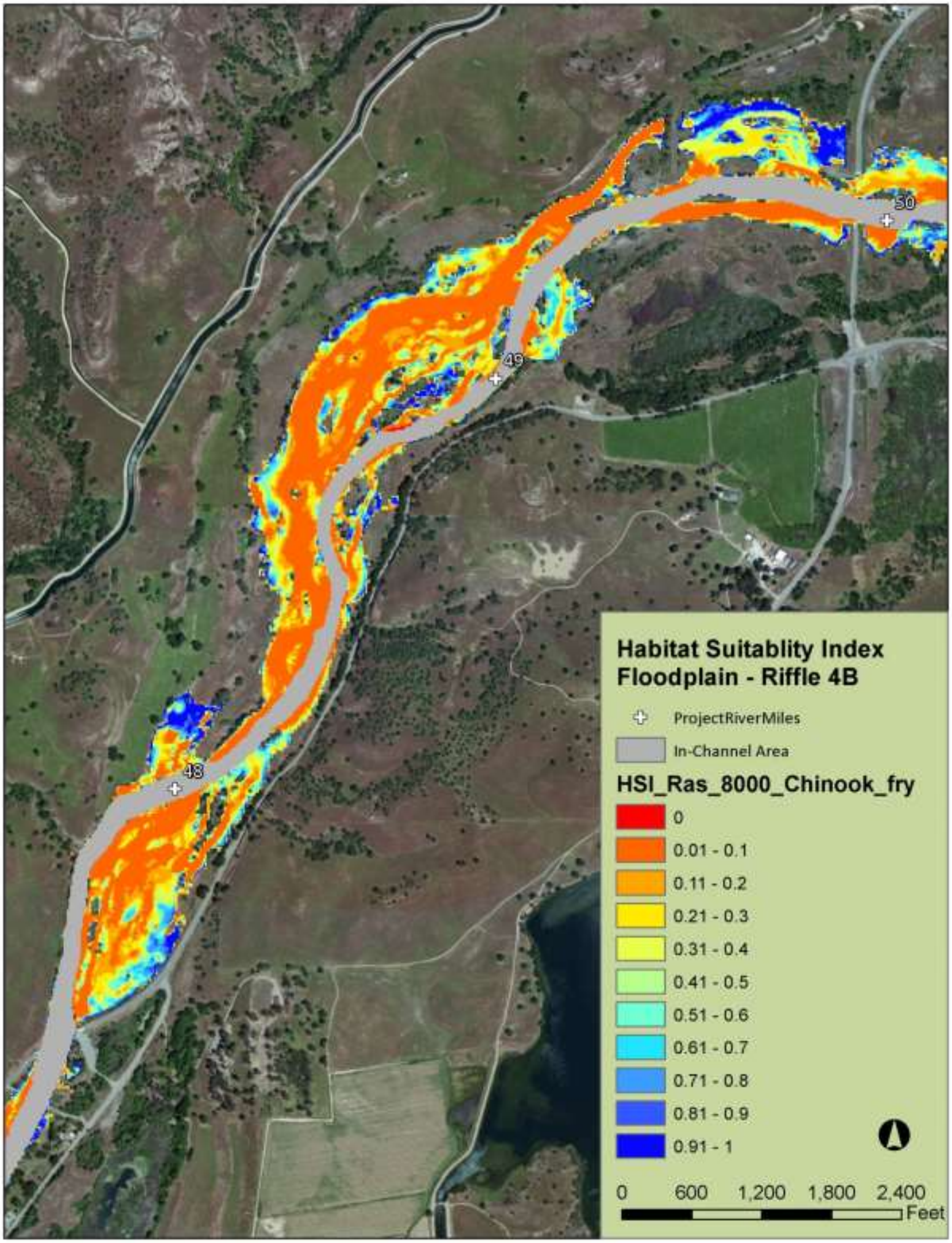

Figure 8. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

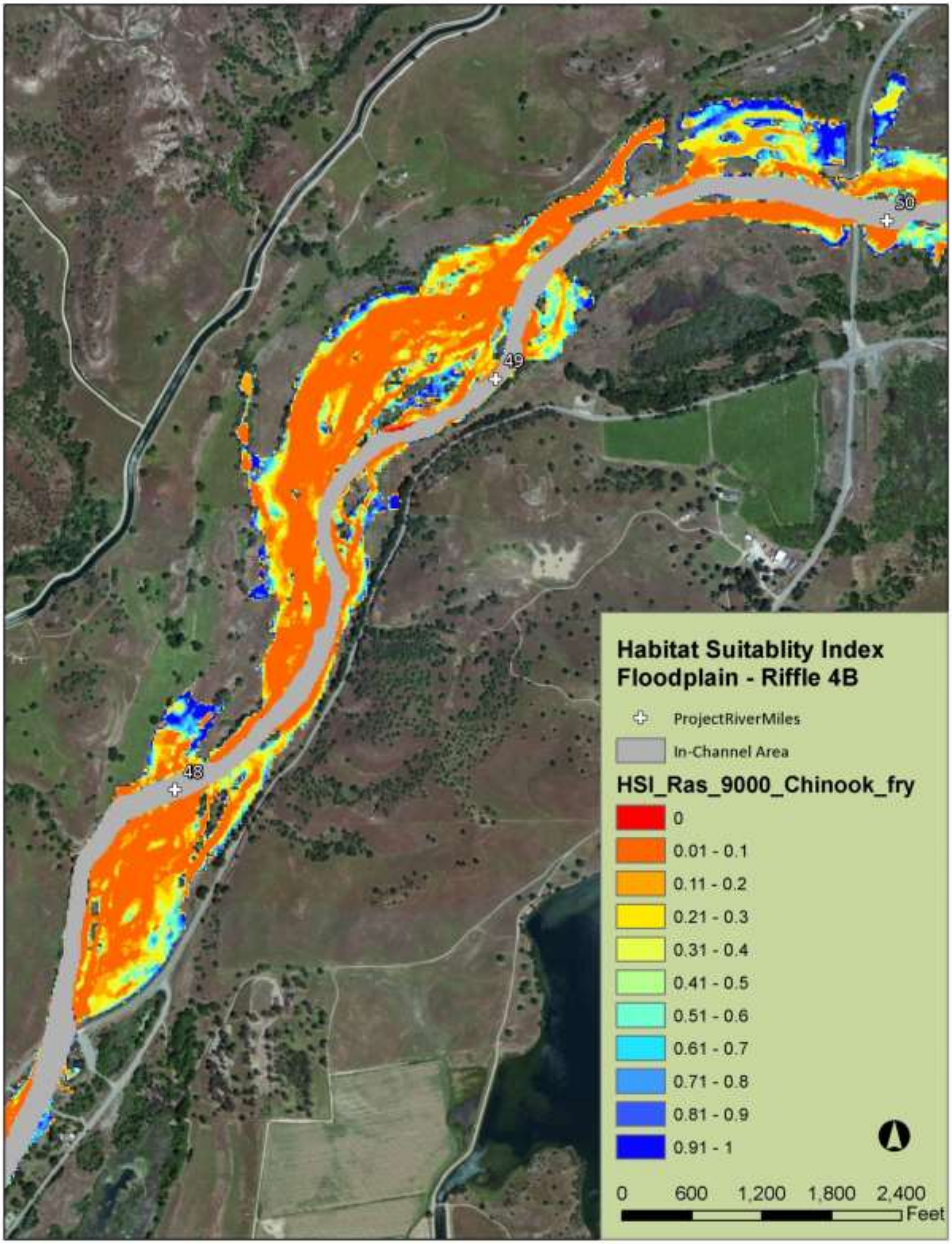

Figure 9. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

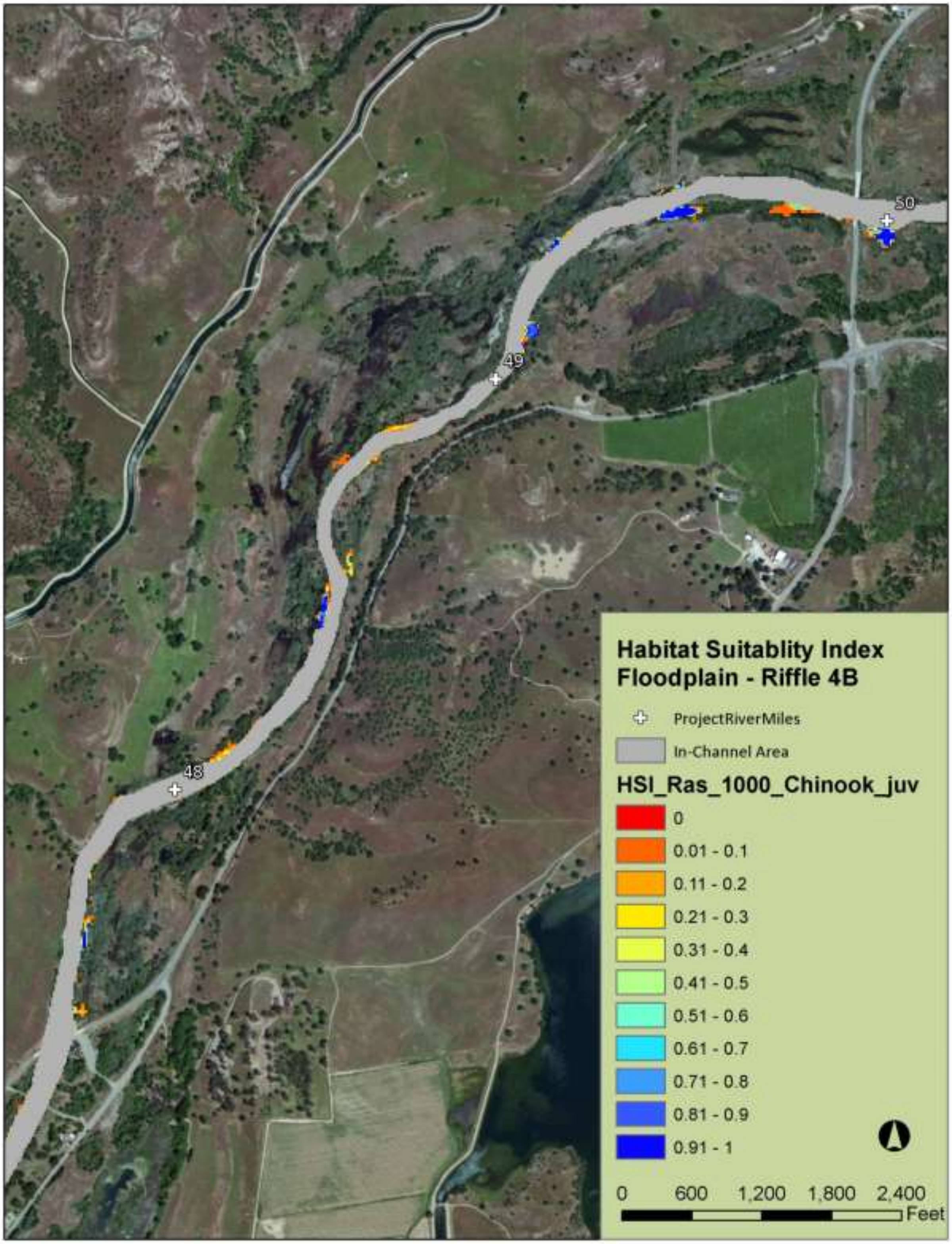

Figure 10. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

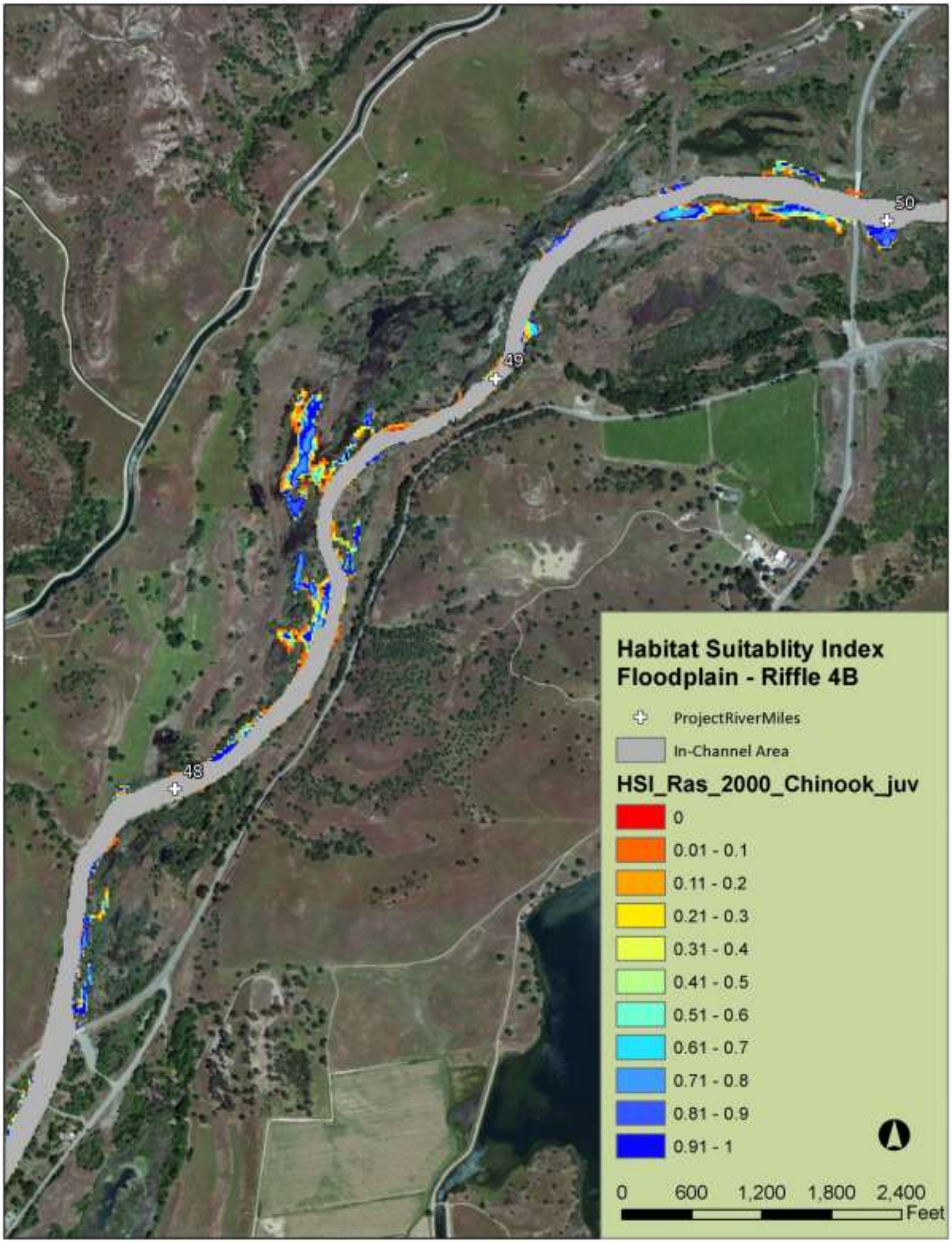

Figure 11. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

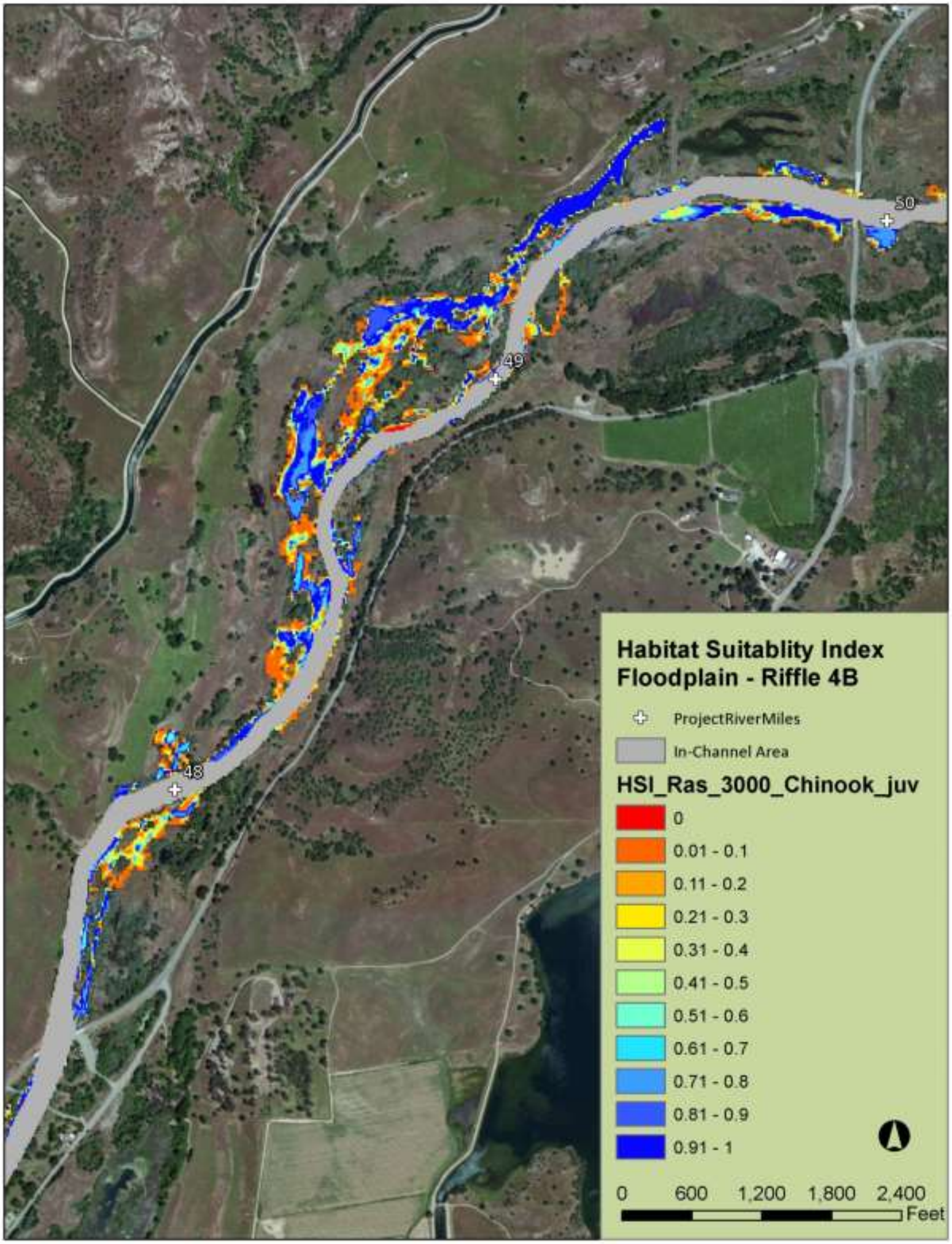

Figure 12. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

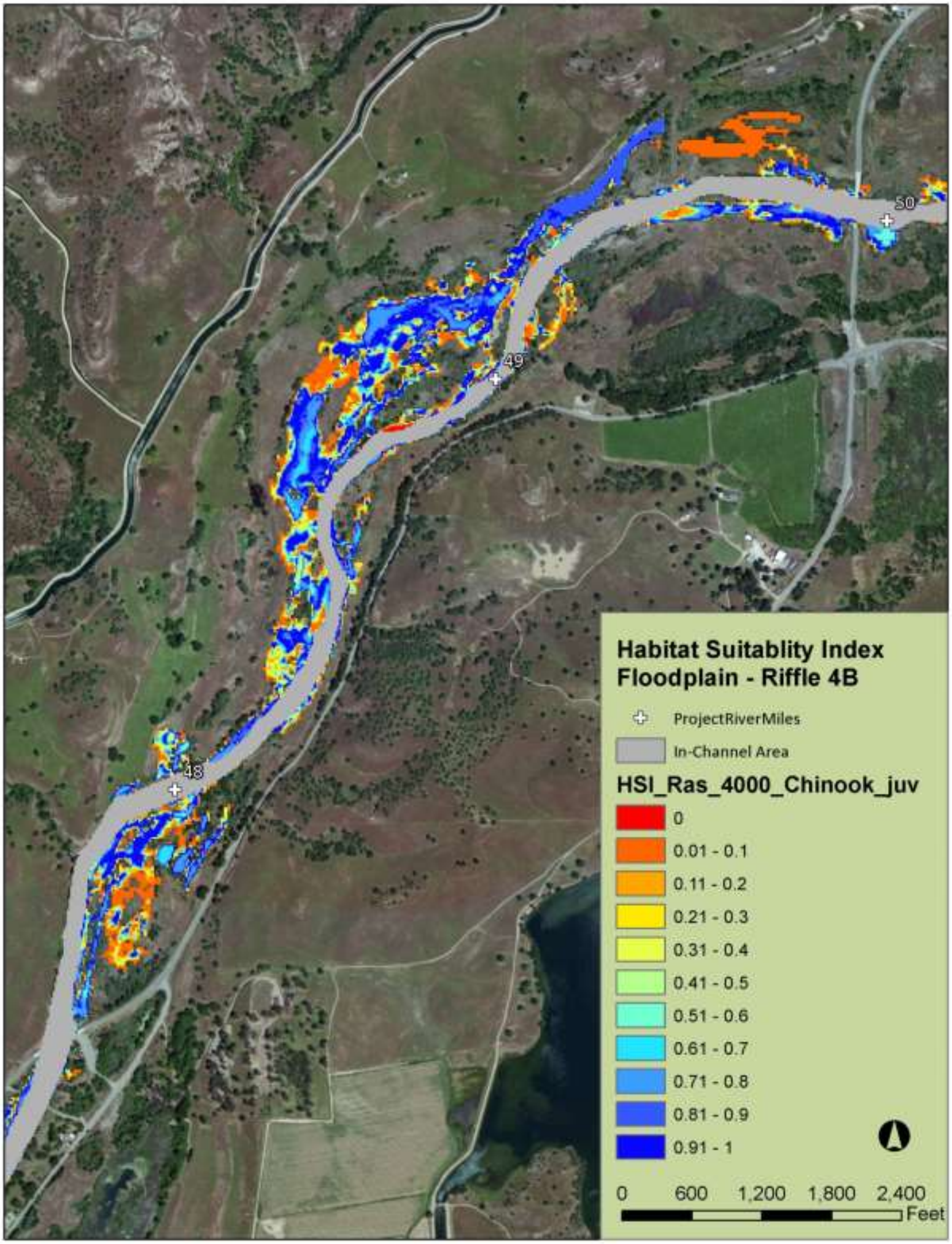

Figure 13. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

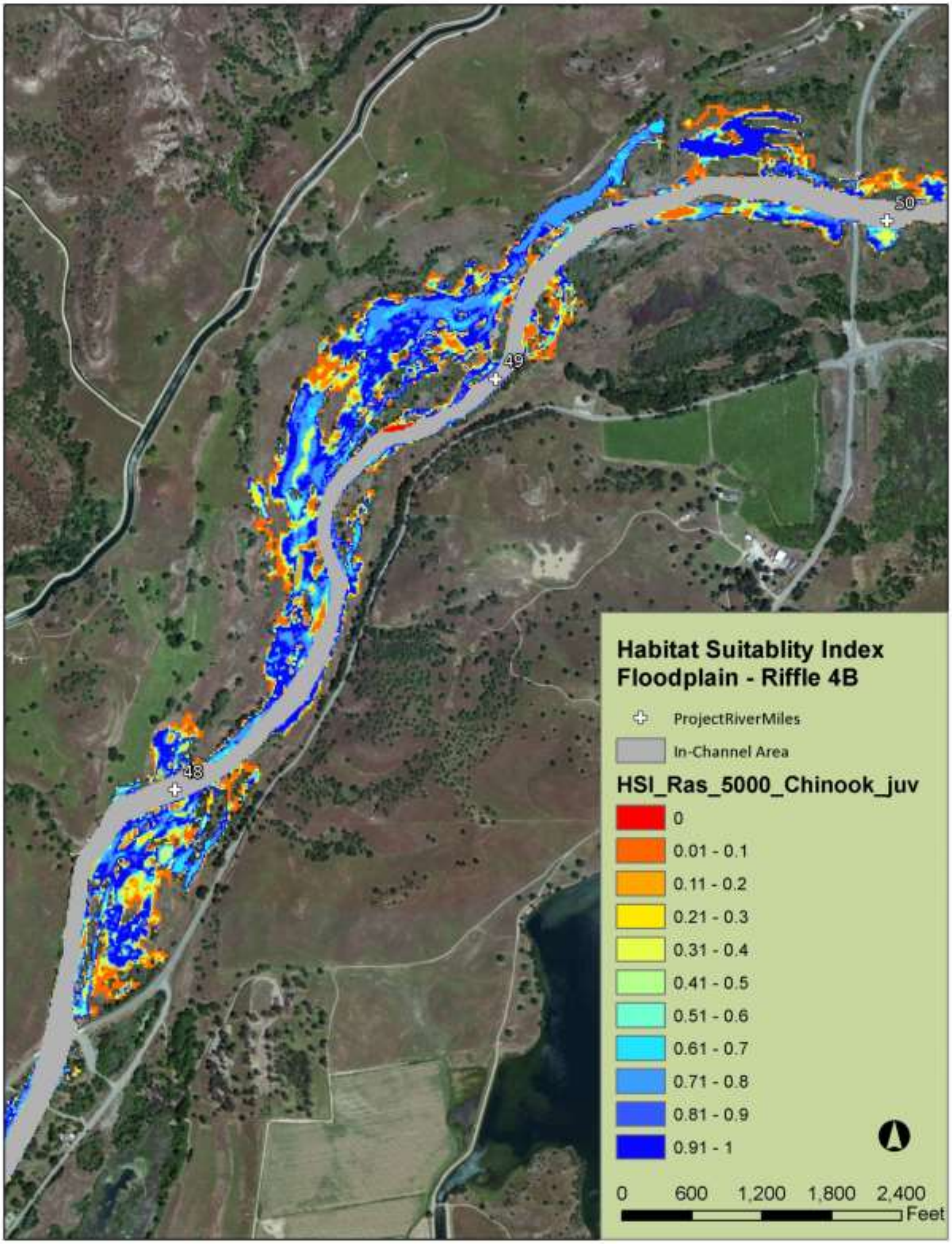

Figure 14. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

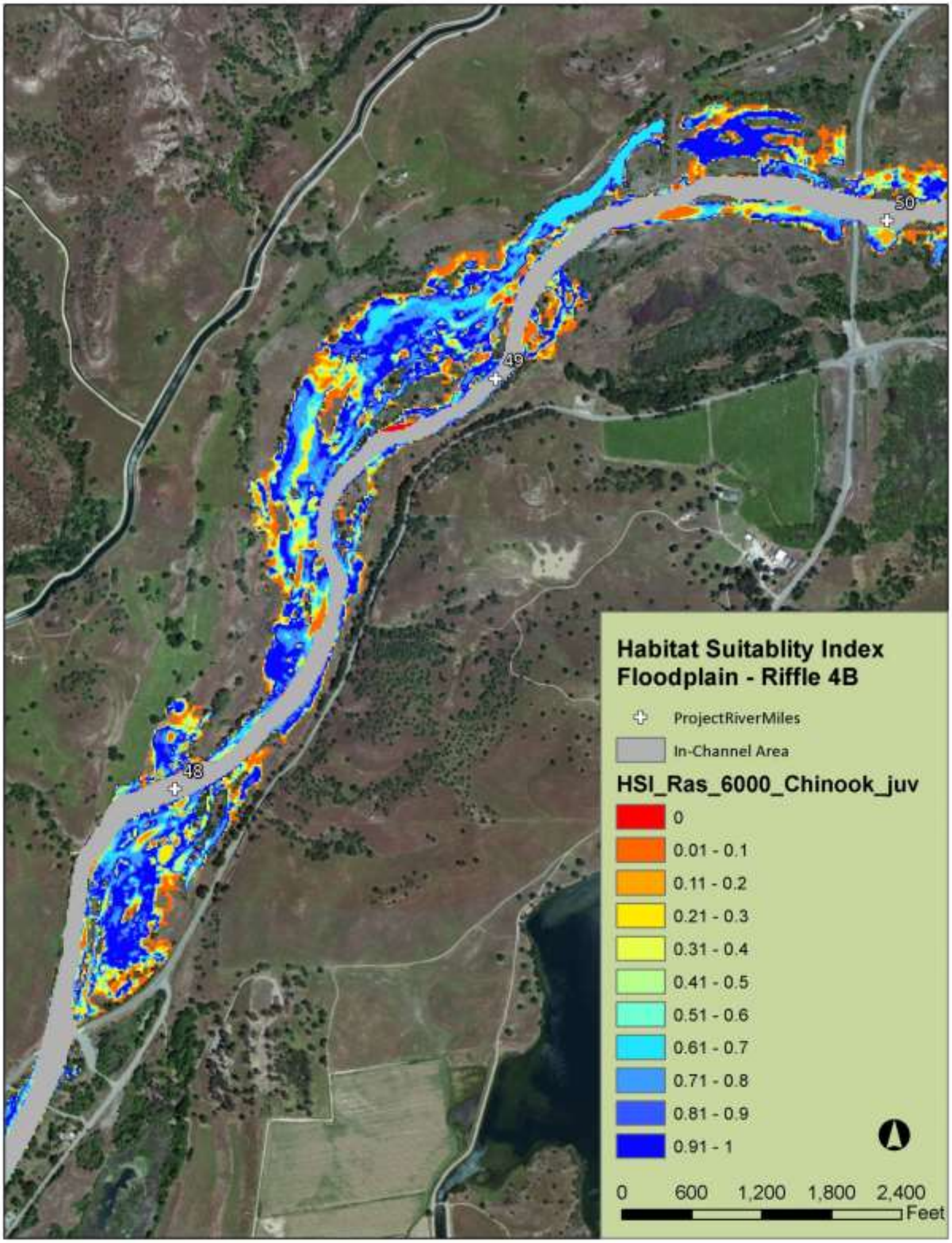

Figure 15. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

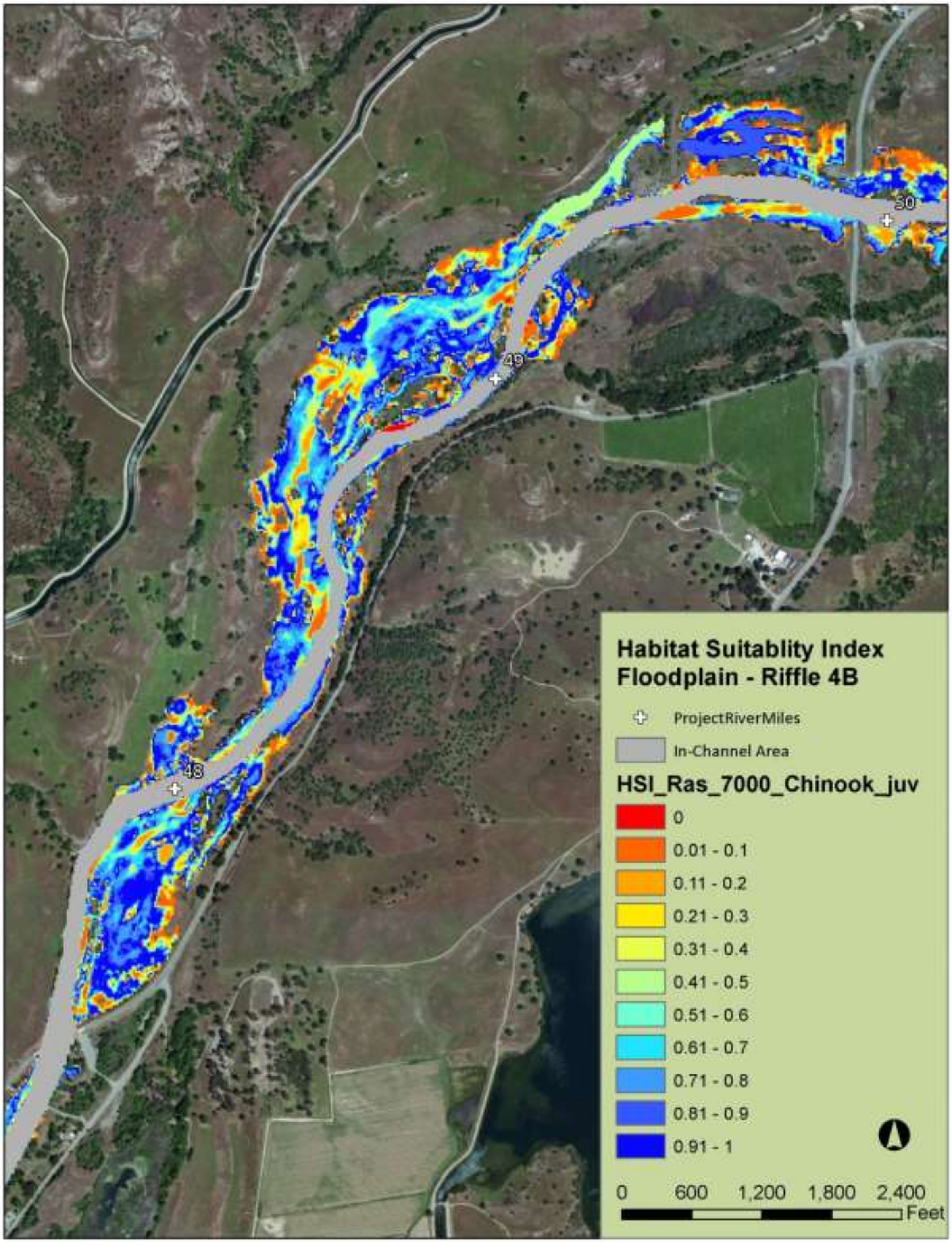

Figure 16. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

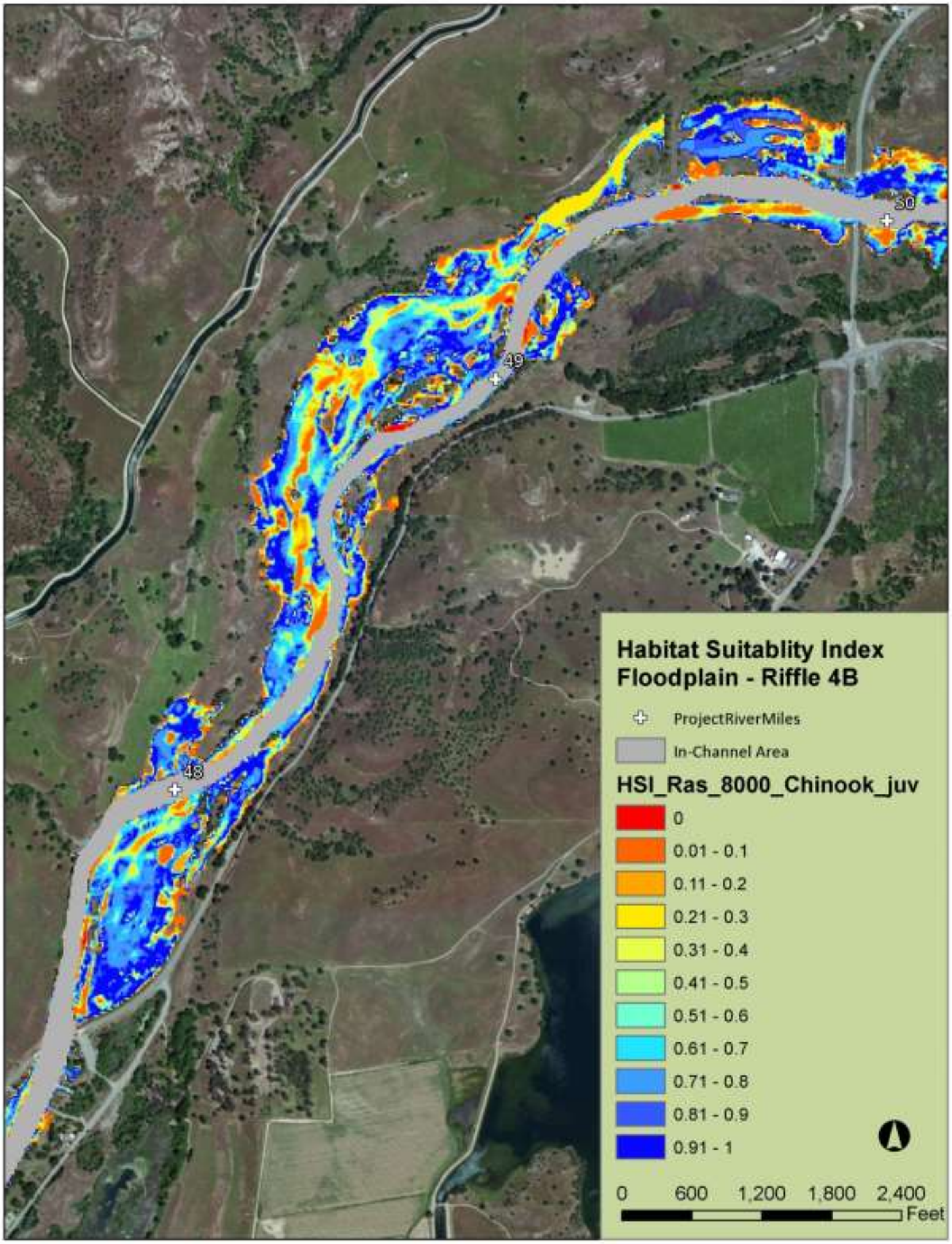

Figure 17. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

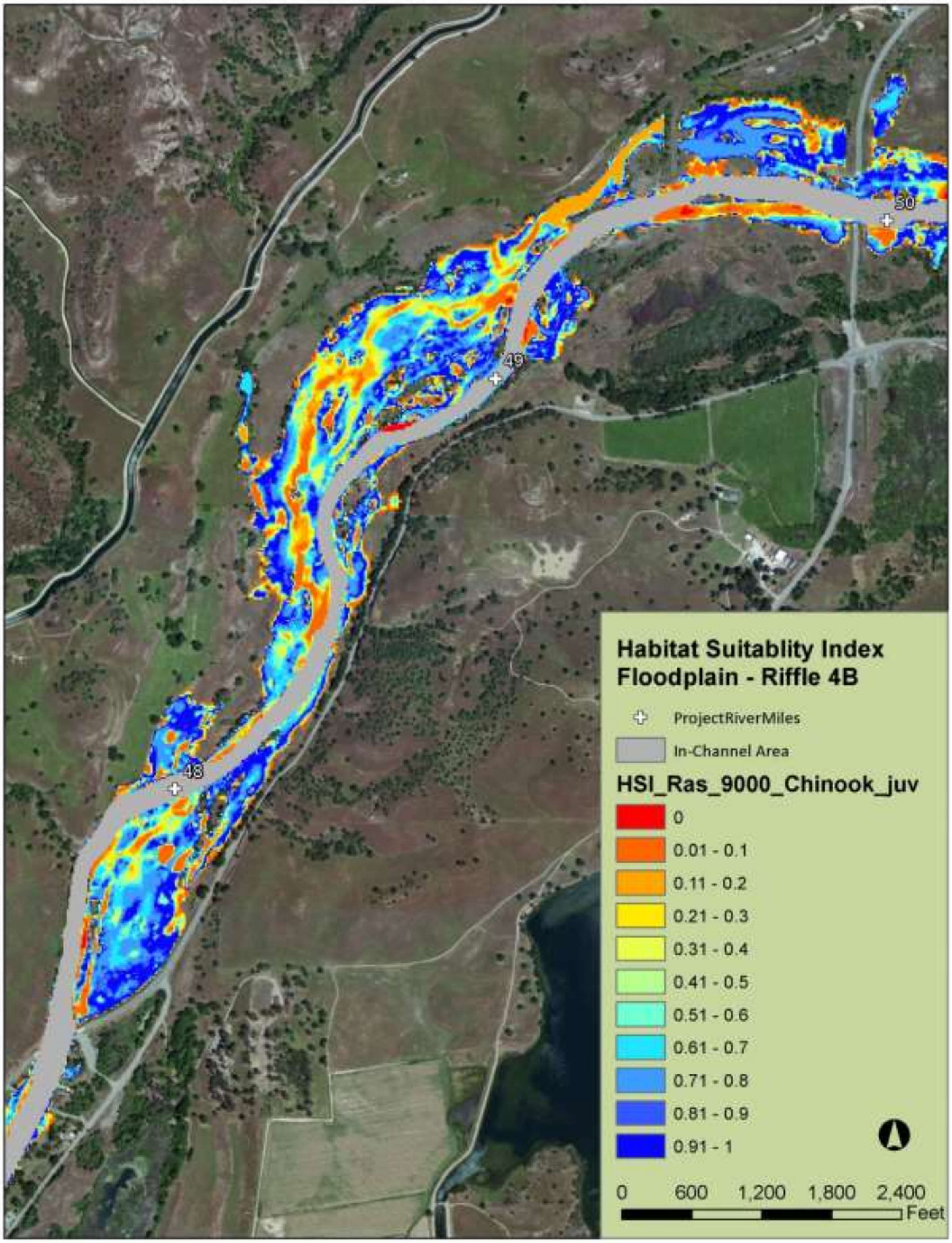

Figure 18. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

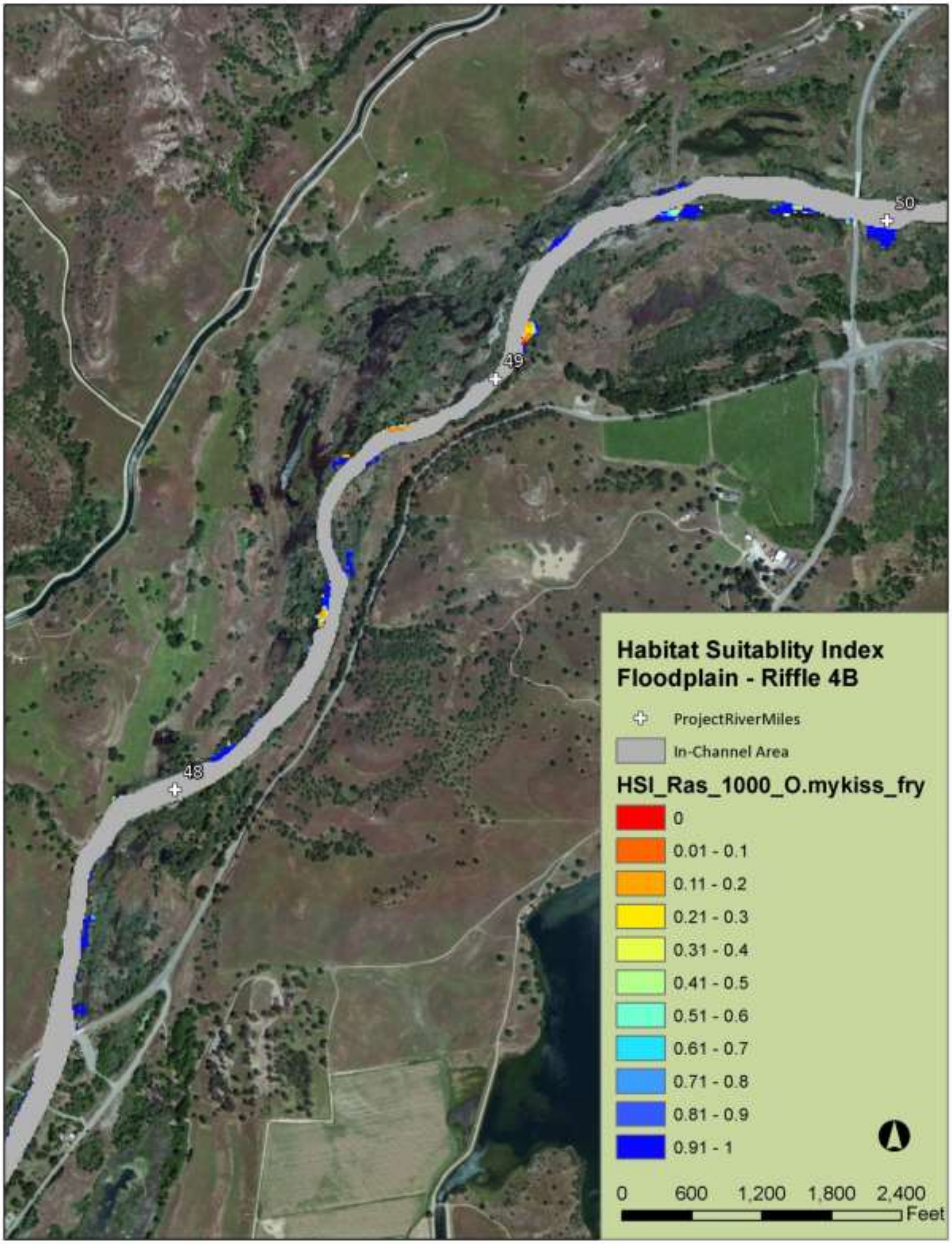

Figure 19. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

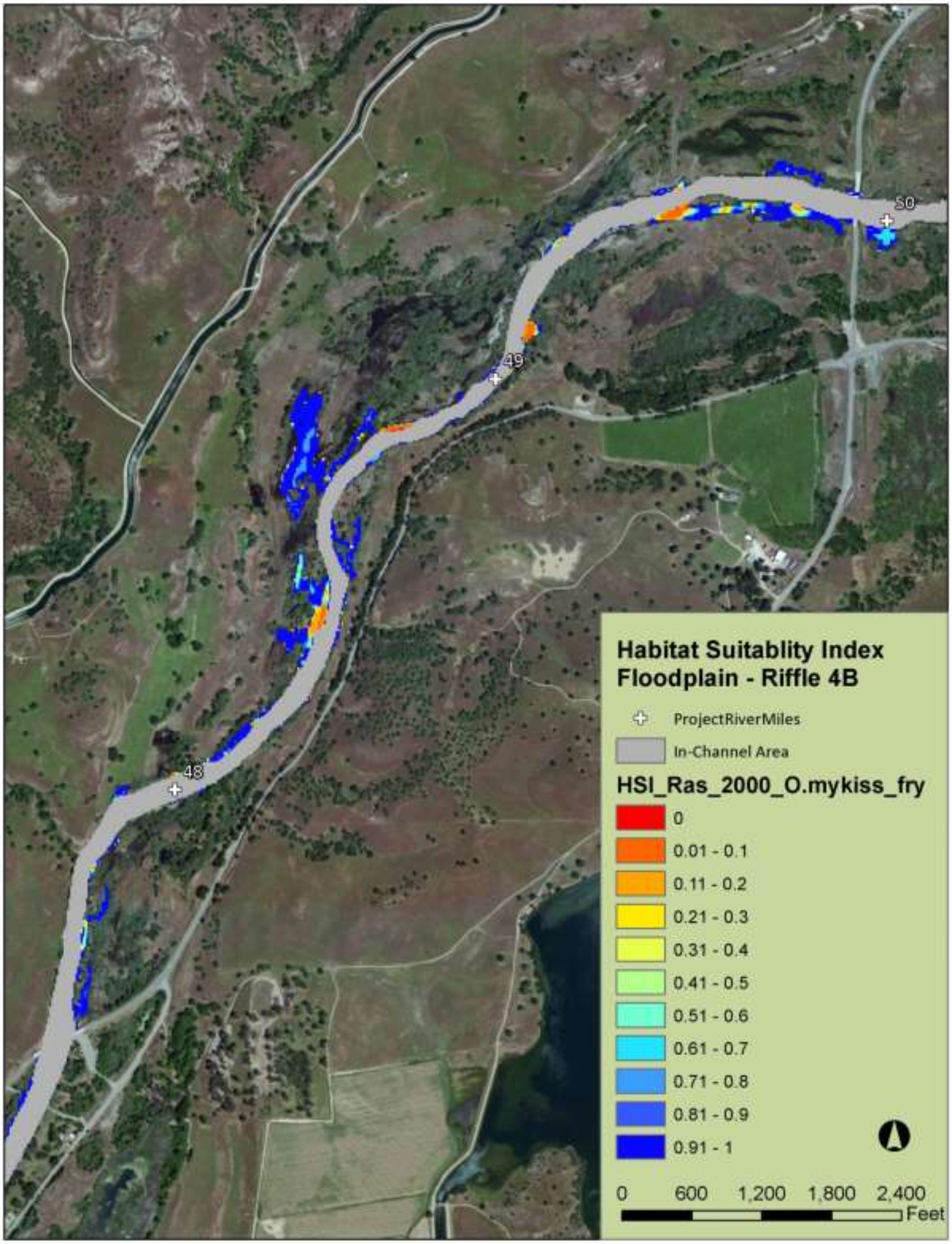

Figure 20. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

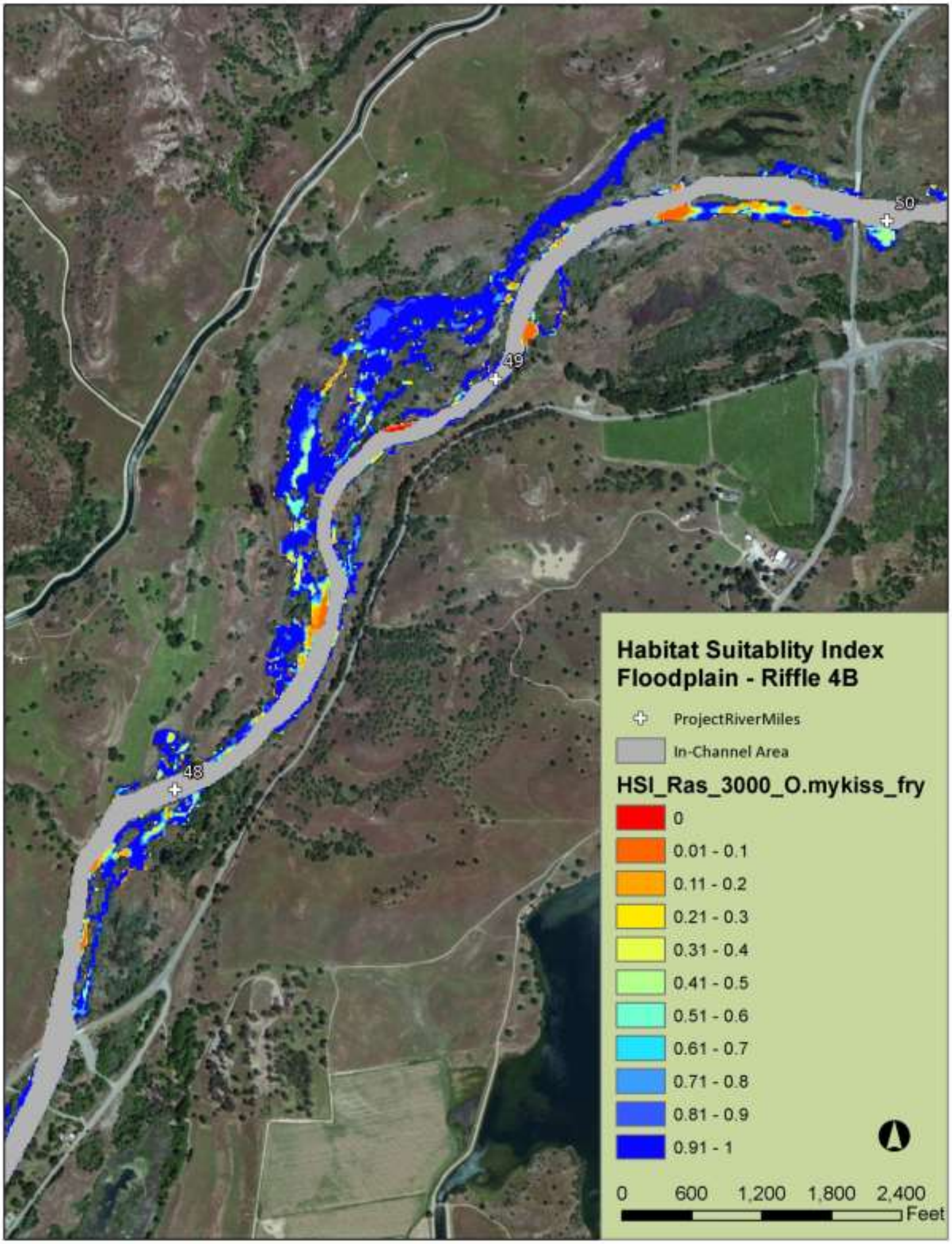

Figure 21. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

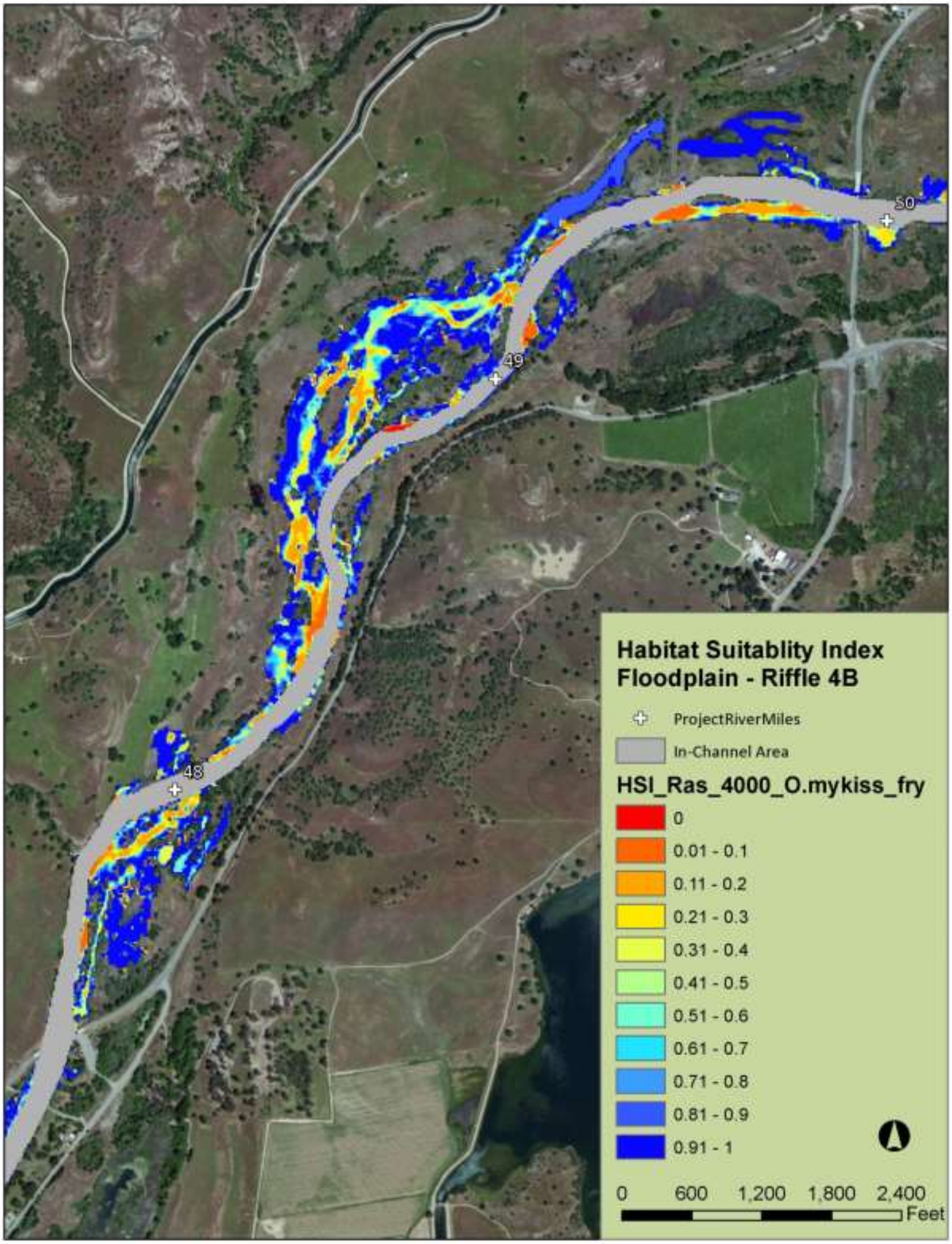

Figure 22. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

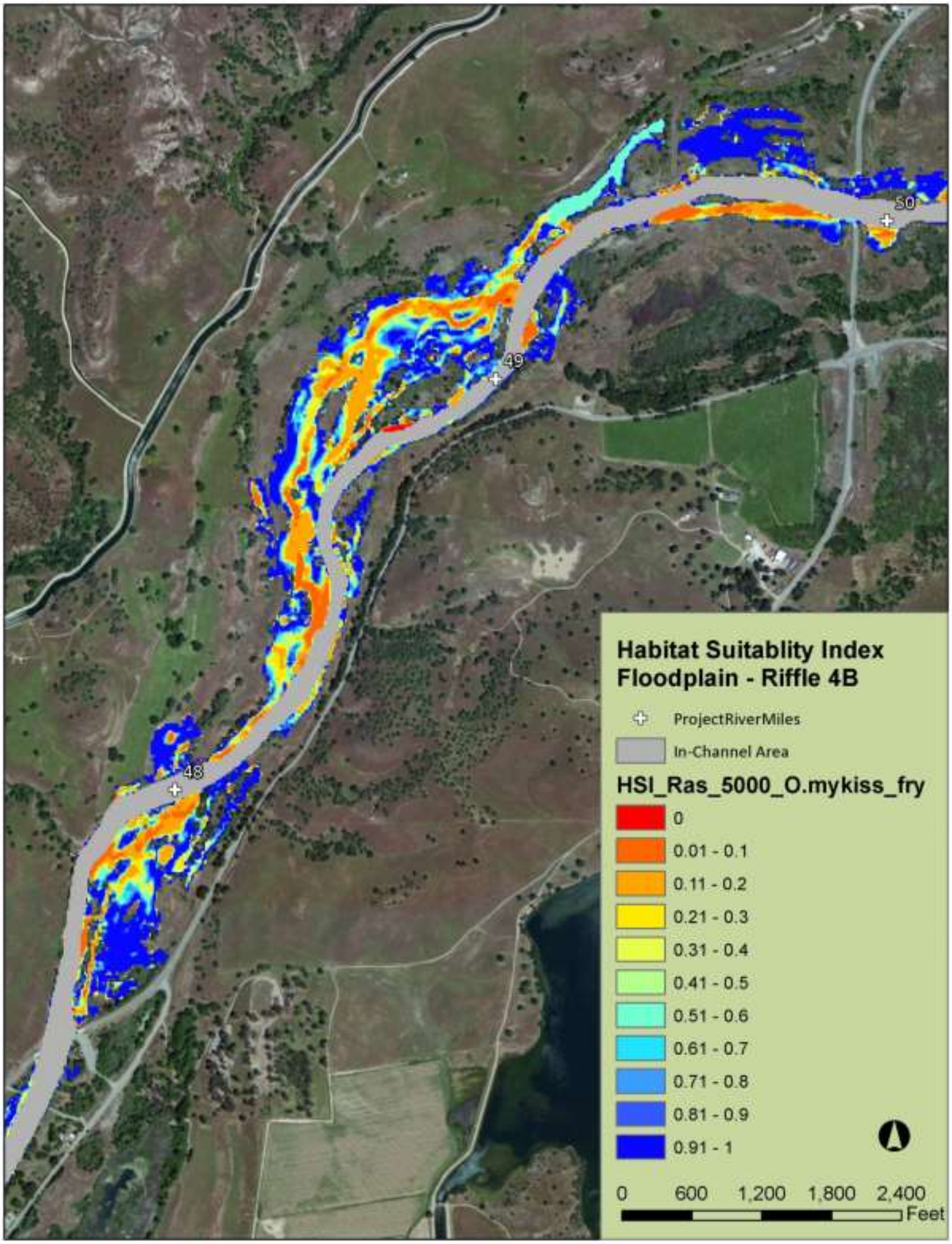

Figure 23. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

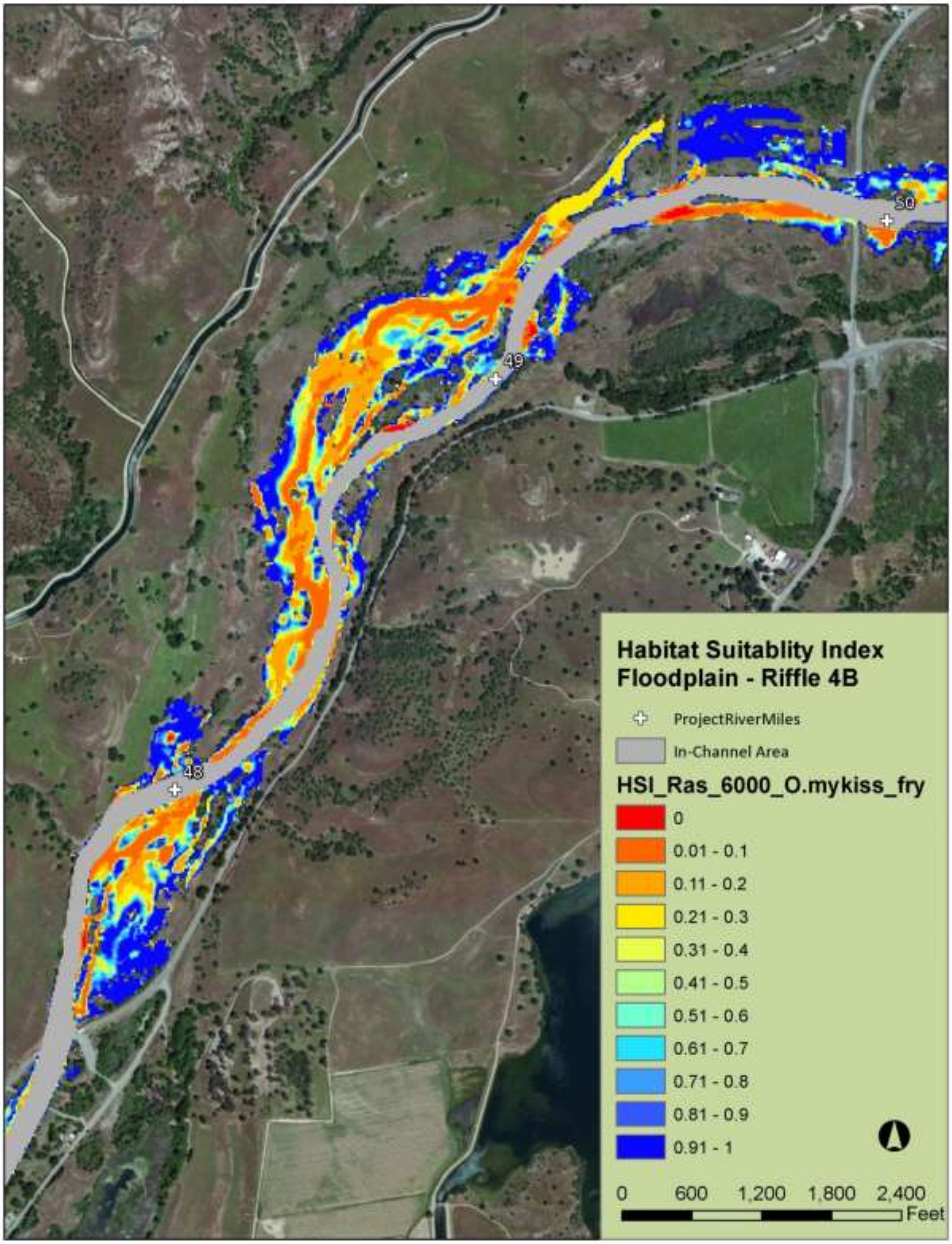

Figure 24. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

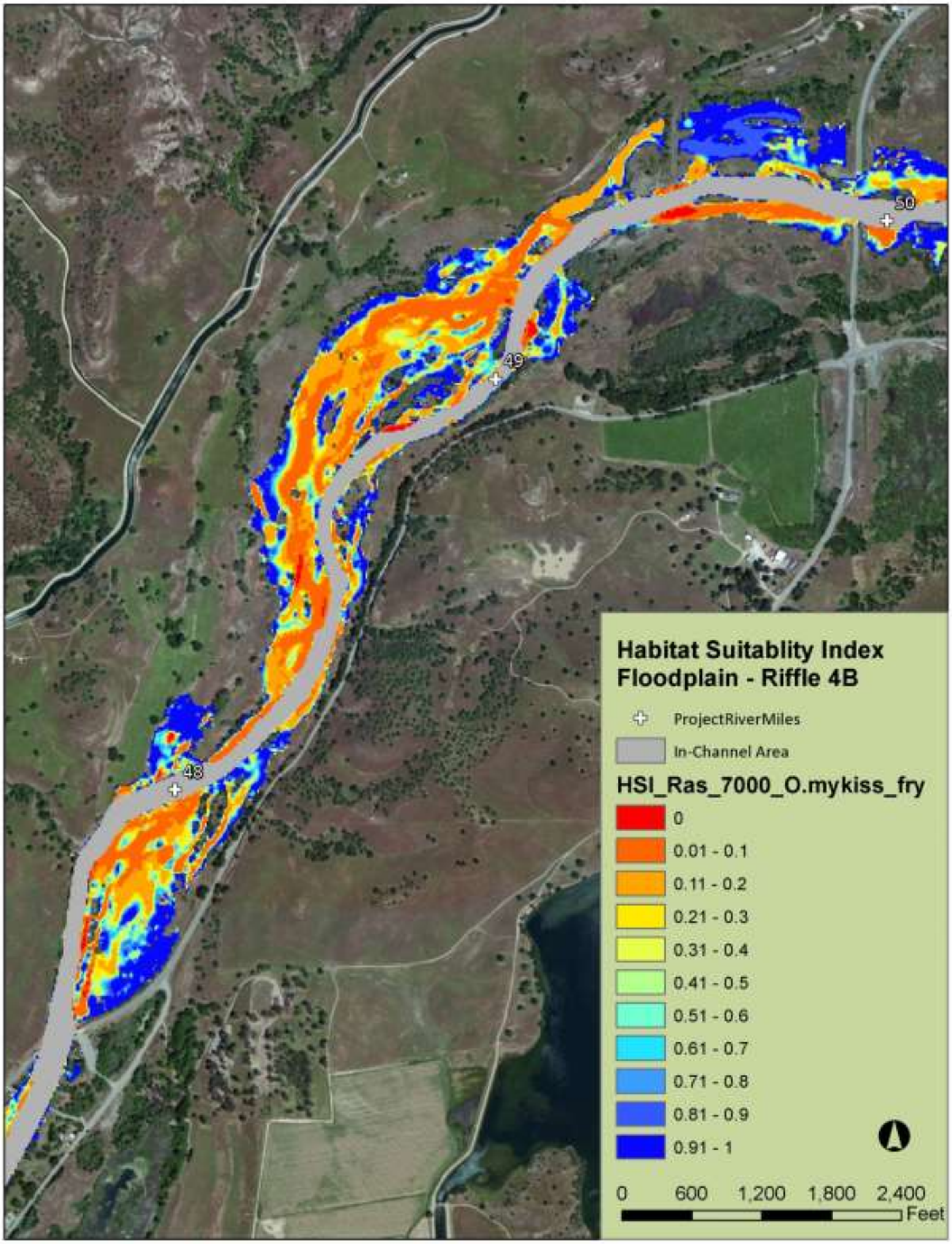

Figure 25. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

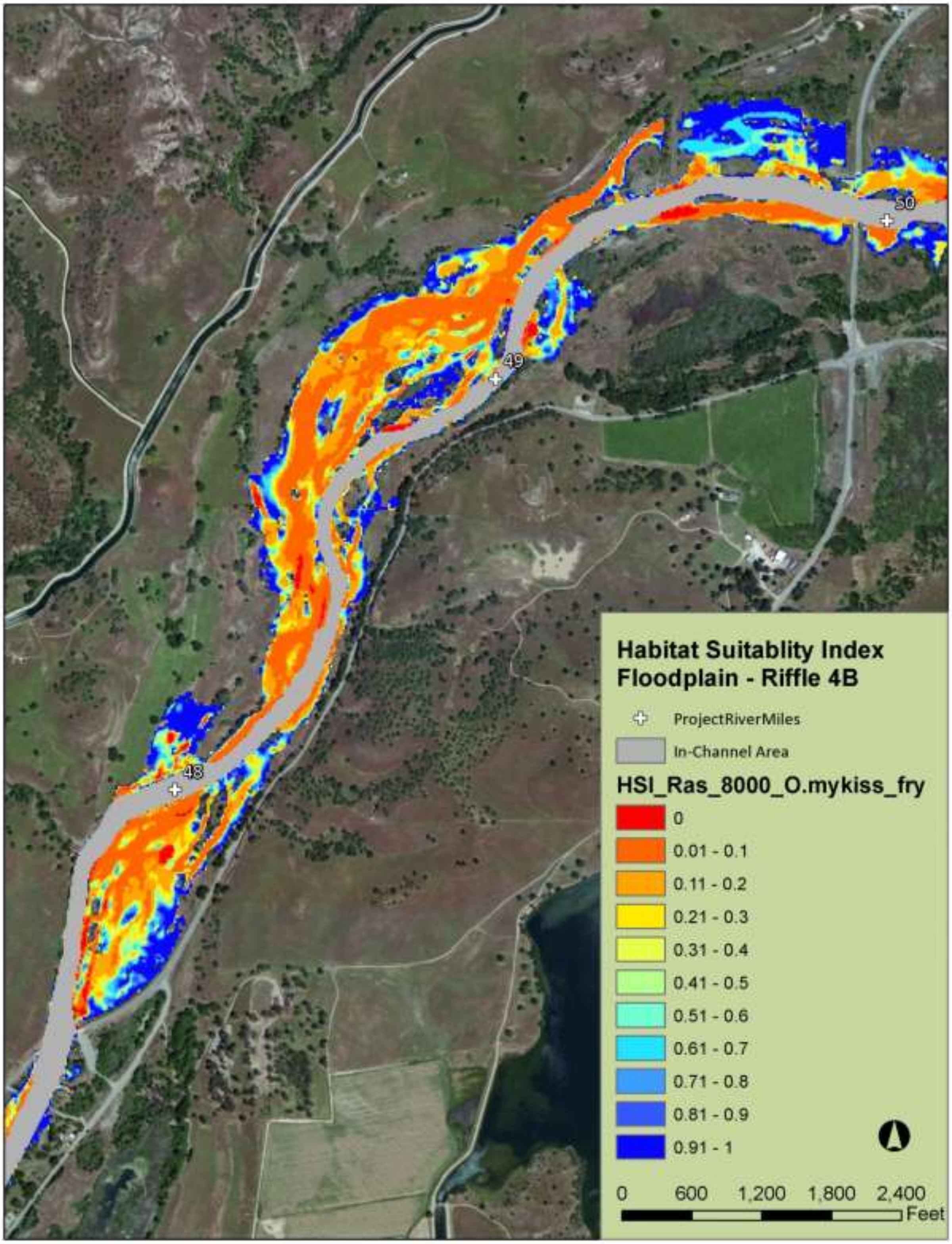

Figure 26. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

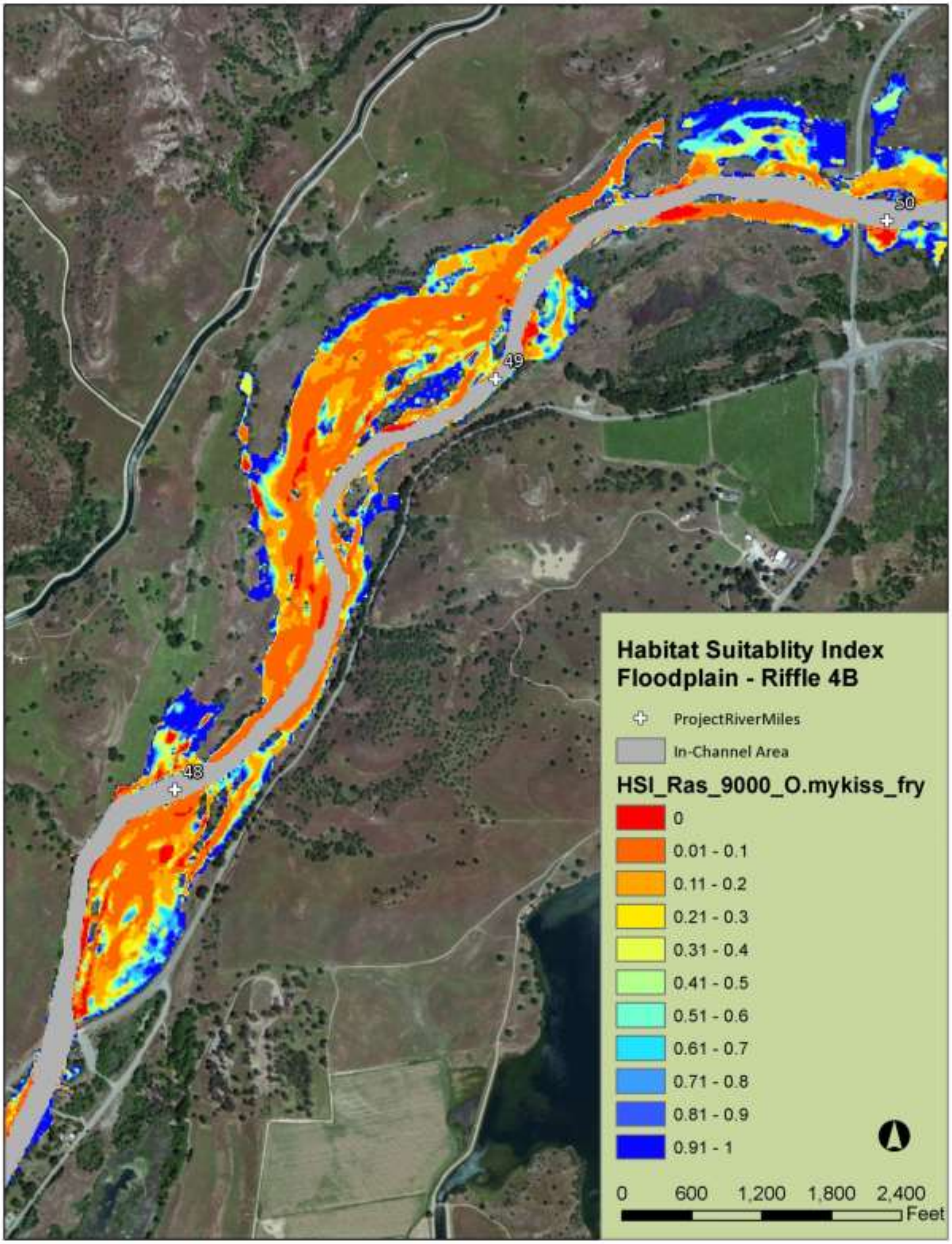

Figure 27. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

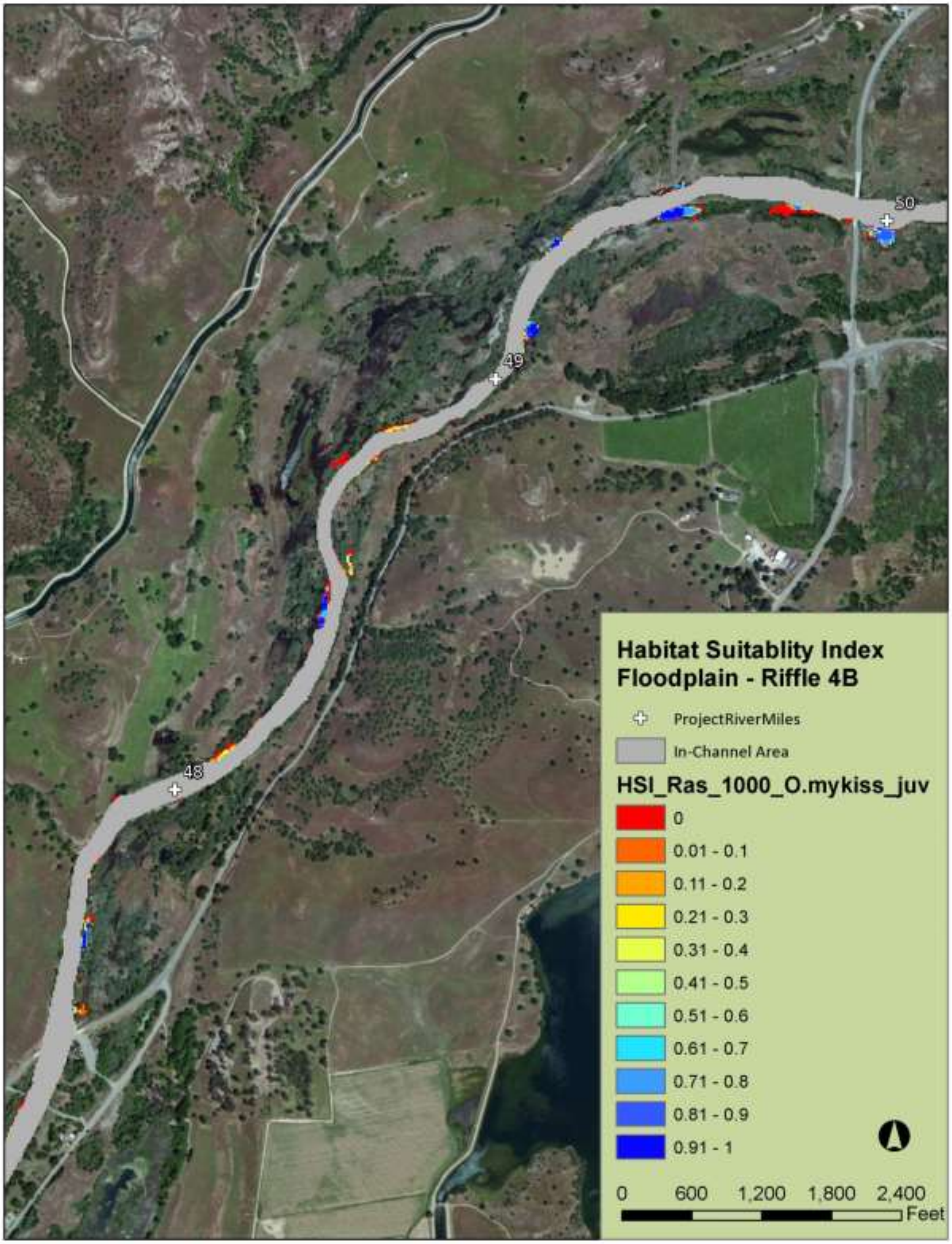

Figure 28. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

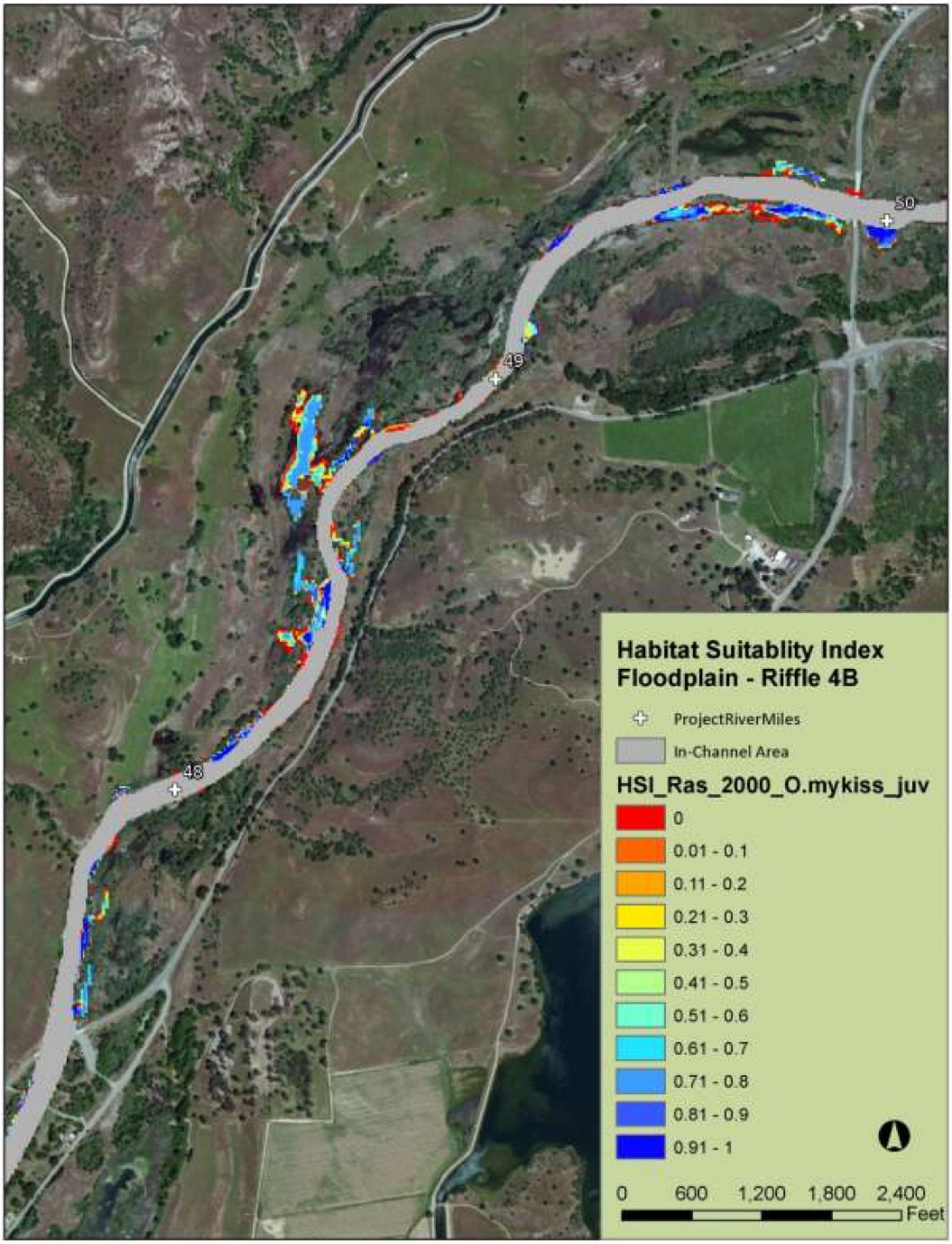

Figure 29. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

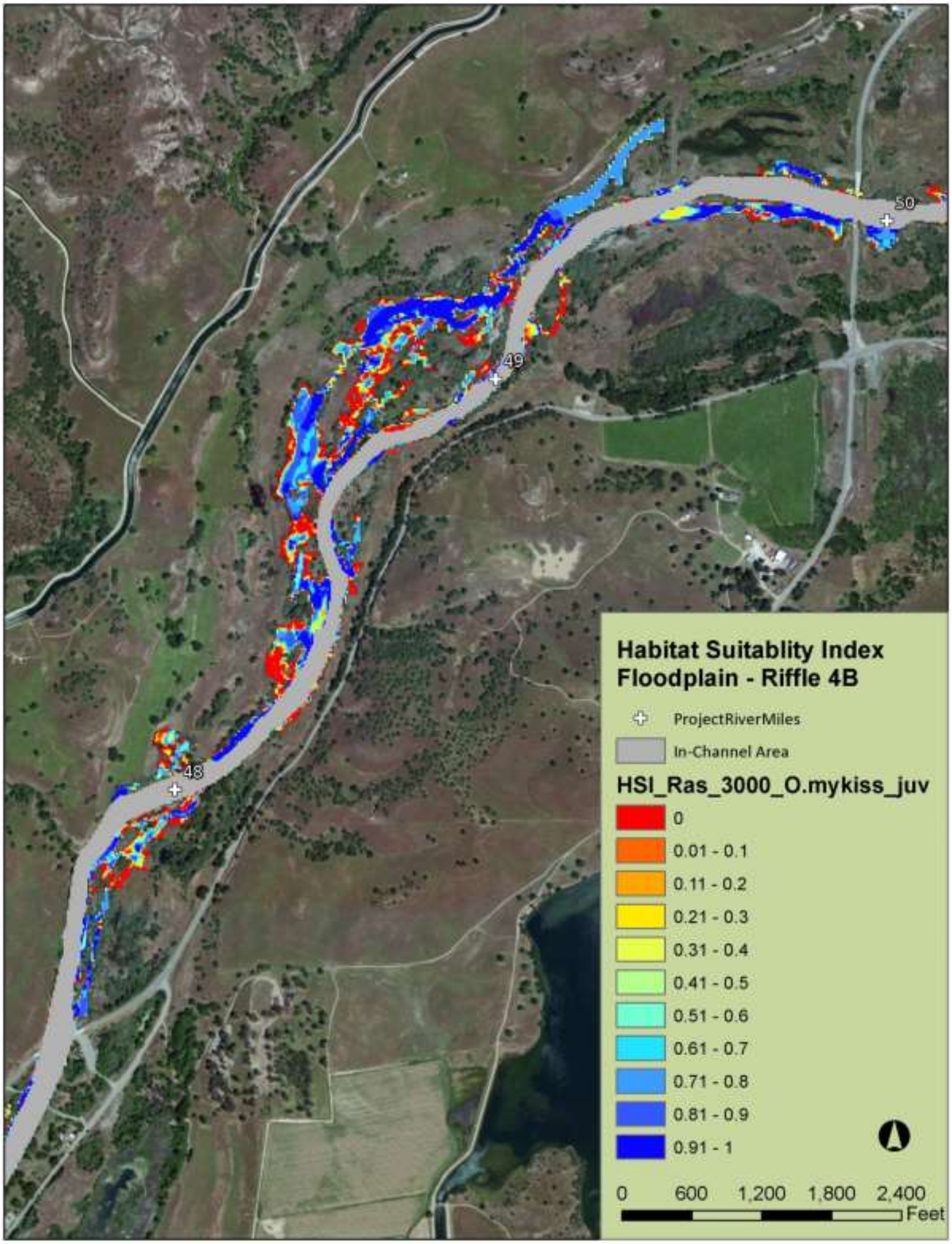

Figure 30. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

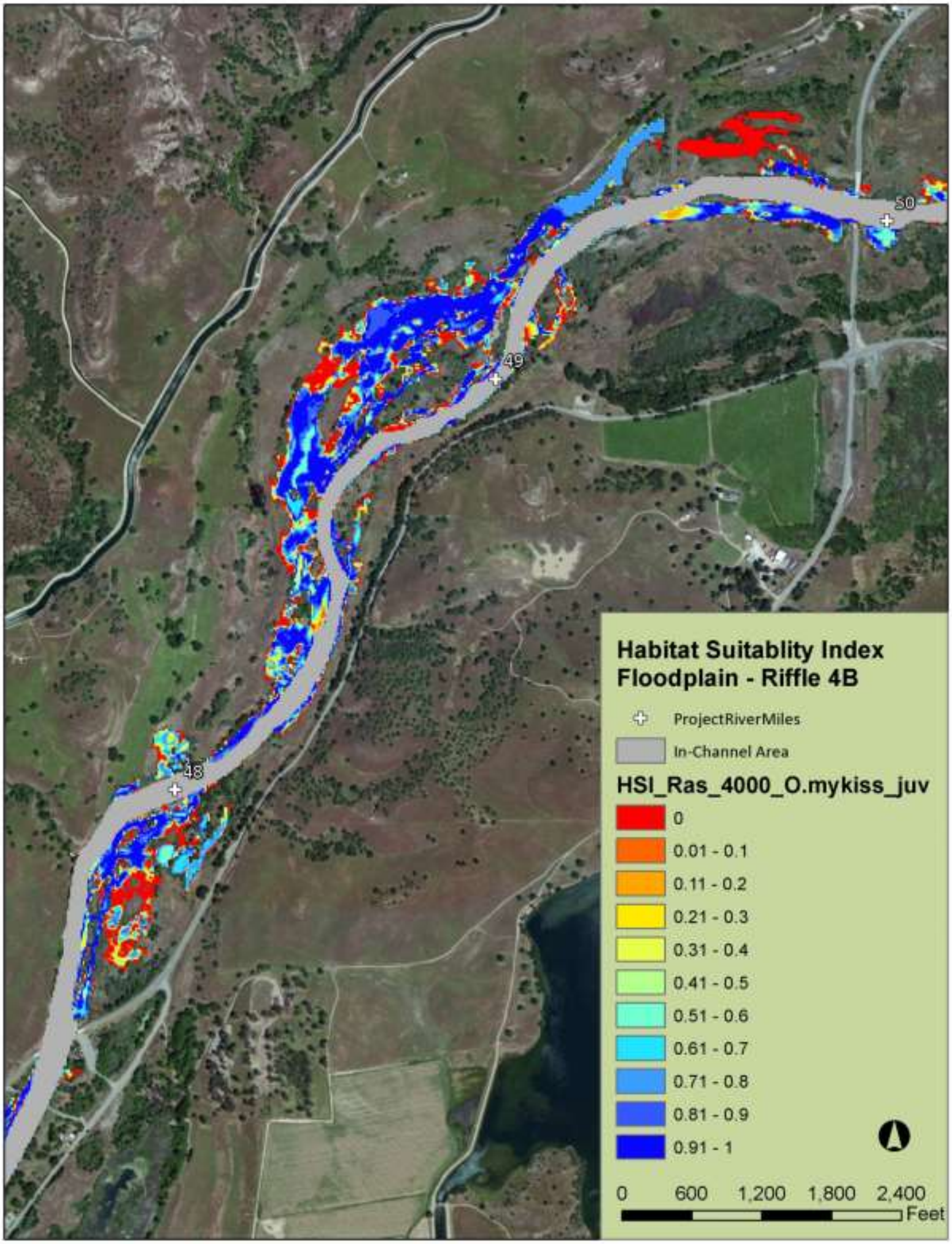

Figure 31. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

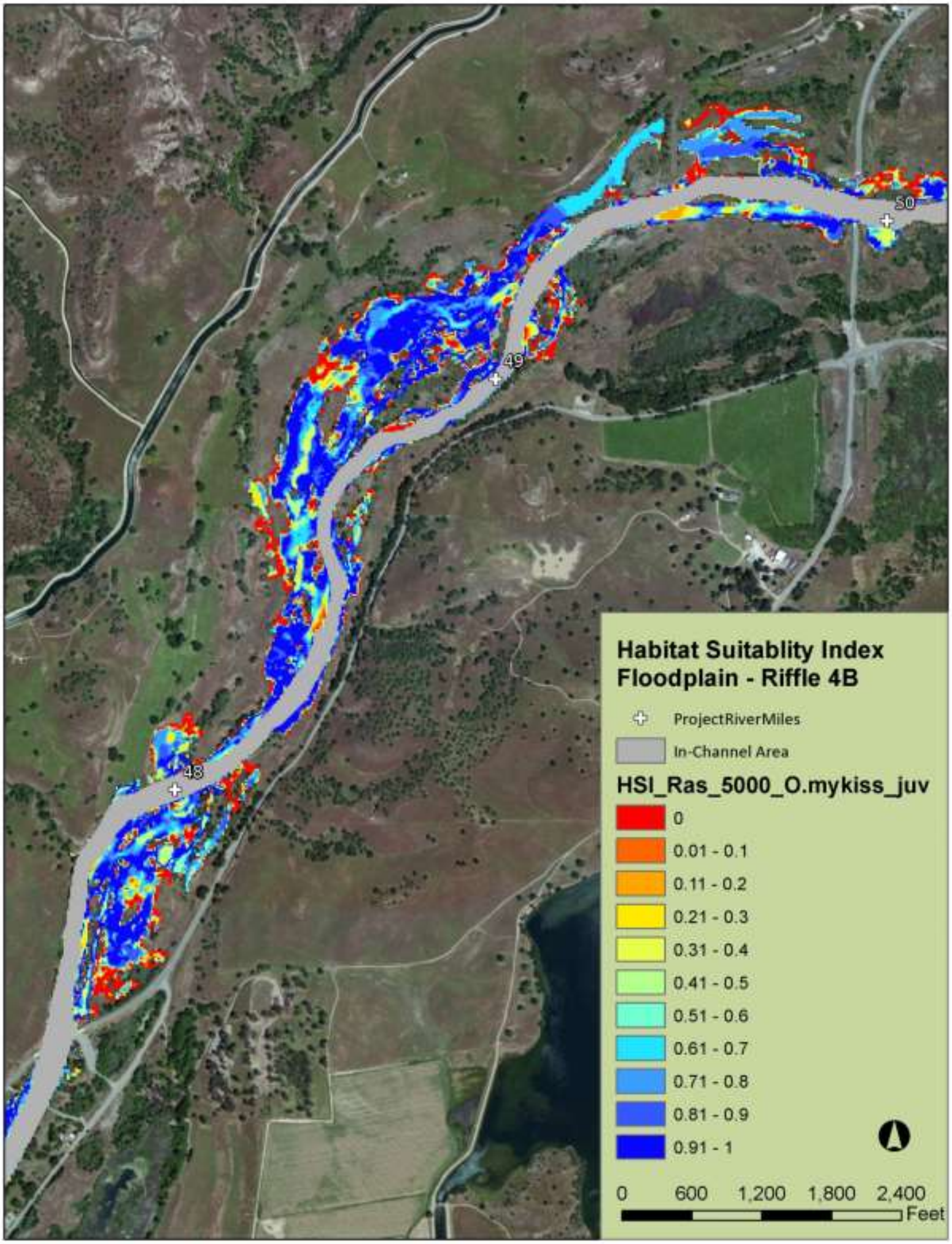

Figure 32. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

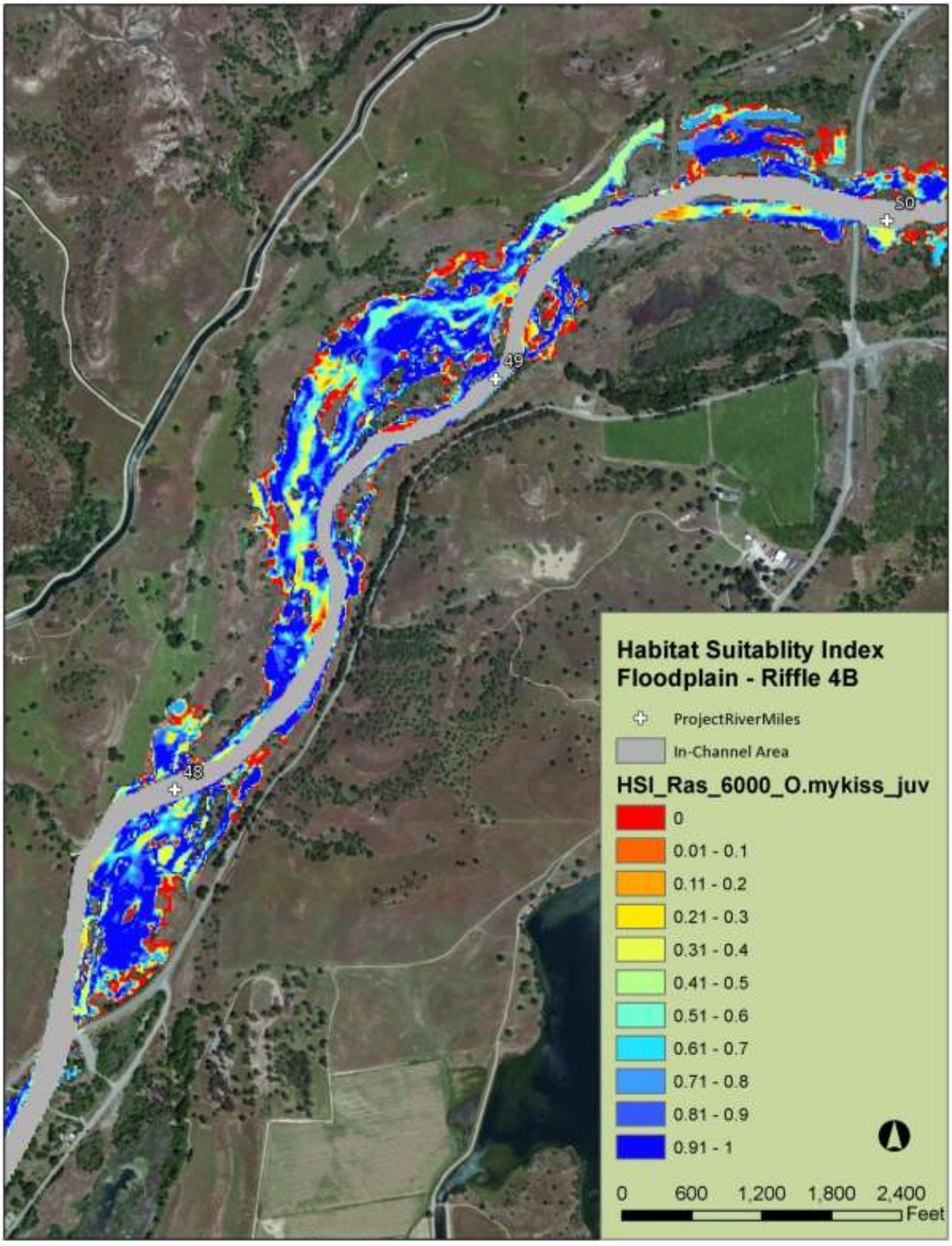

Figure 33. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

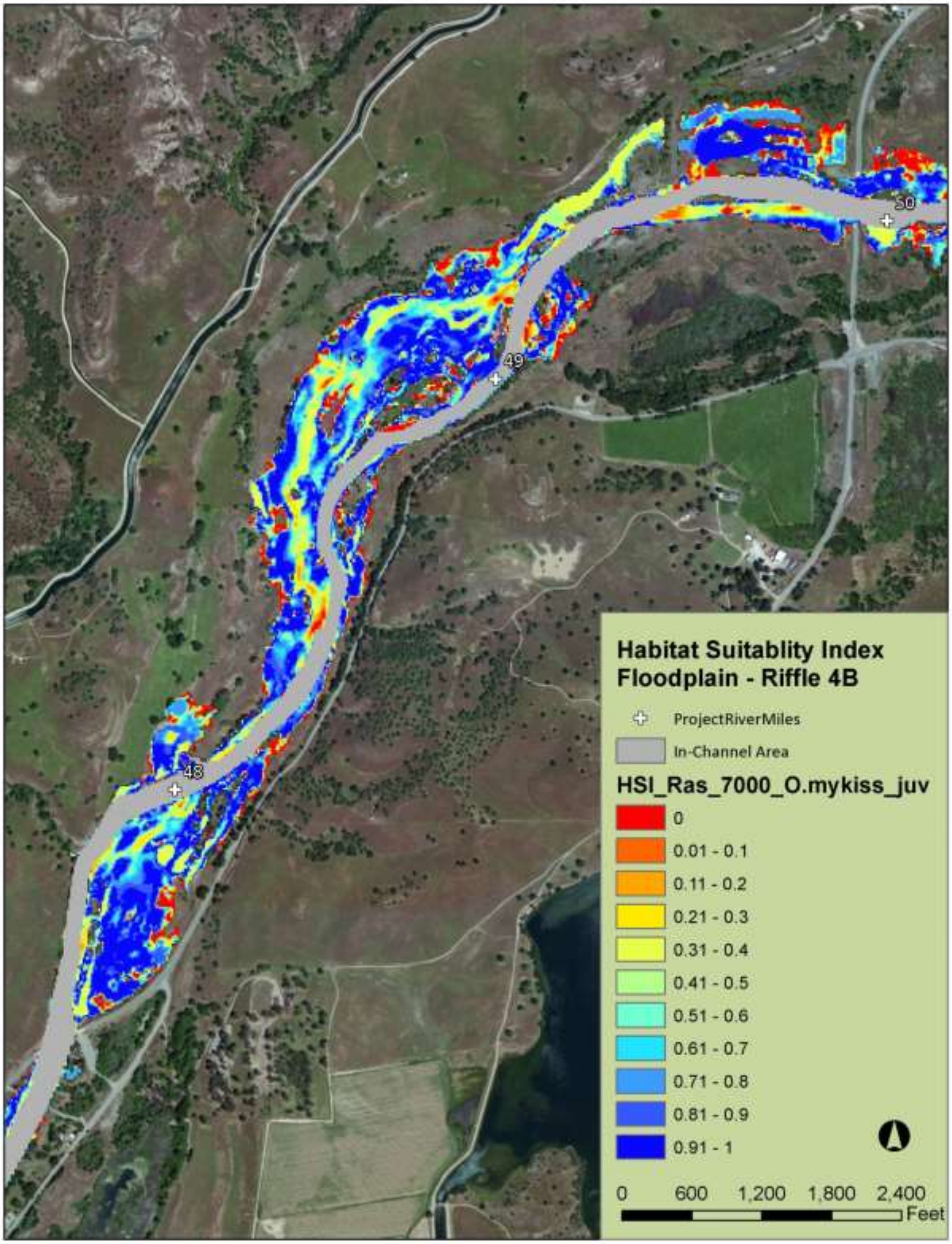

Figure 34. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

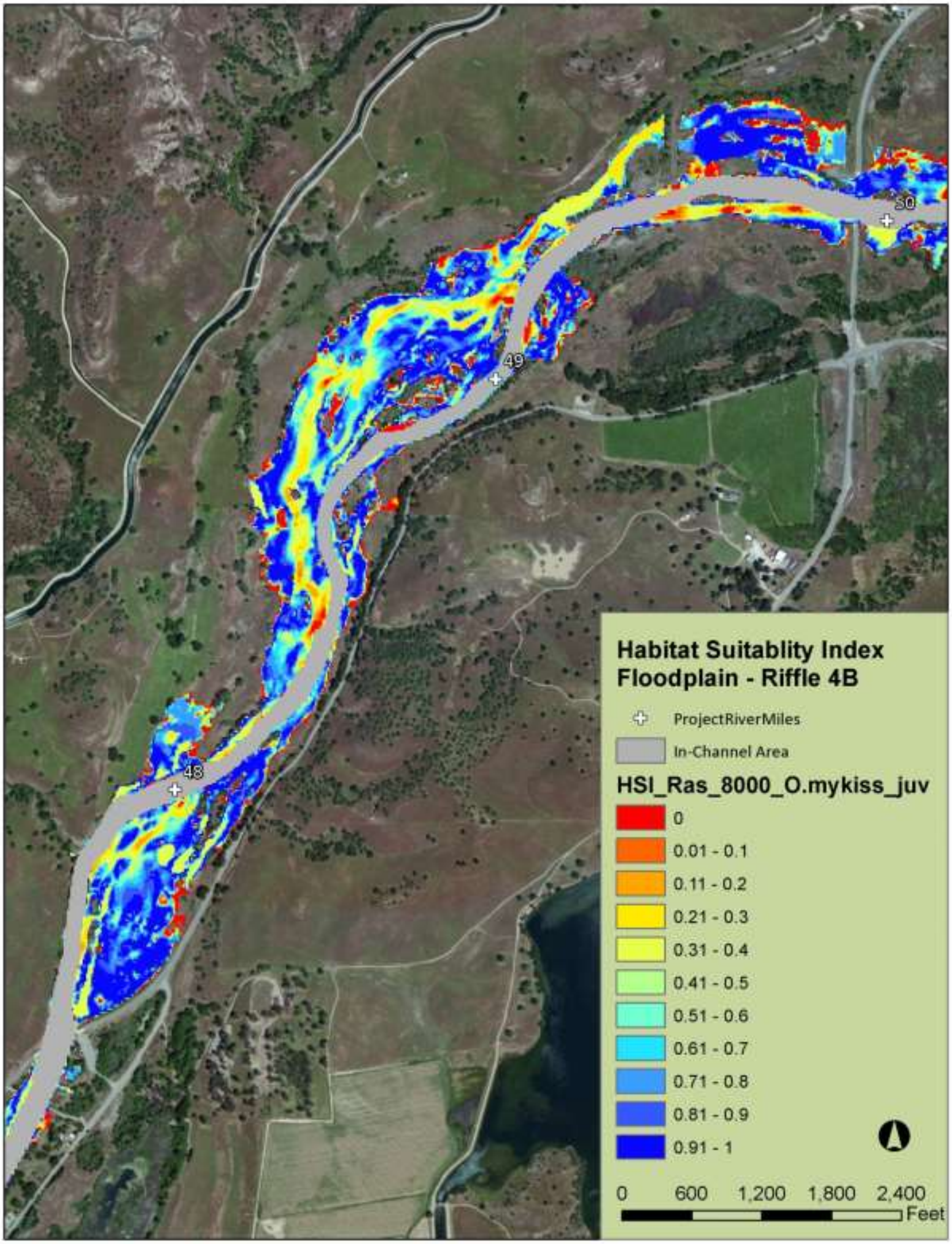

Figure 35. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

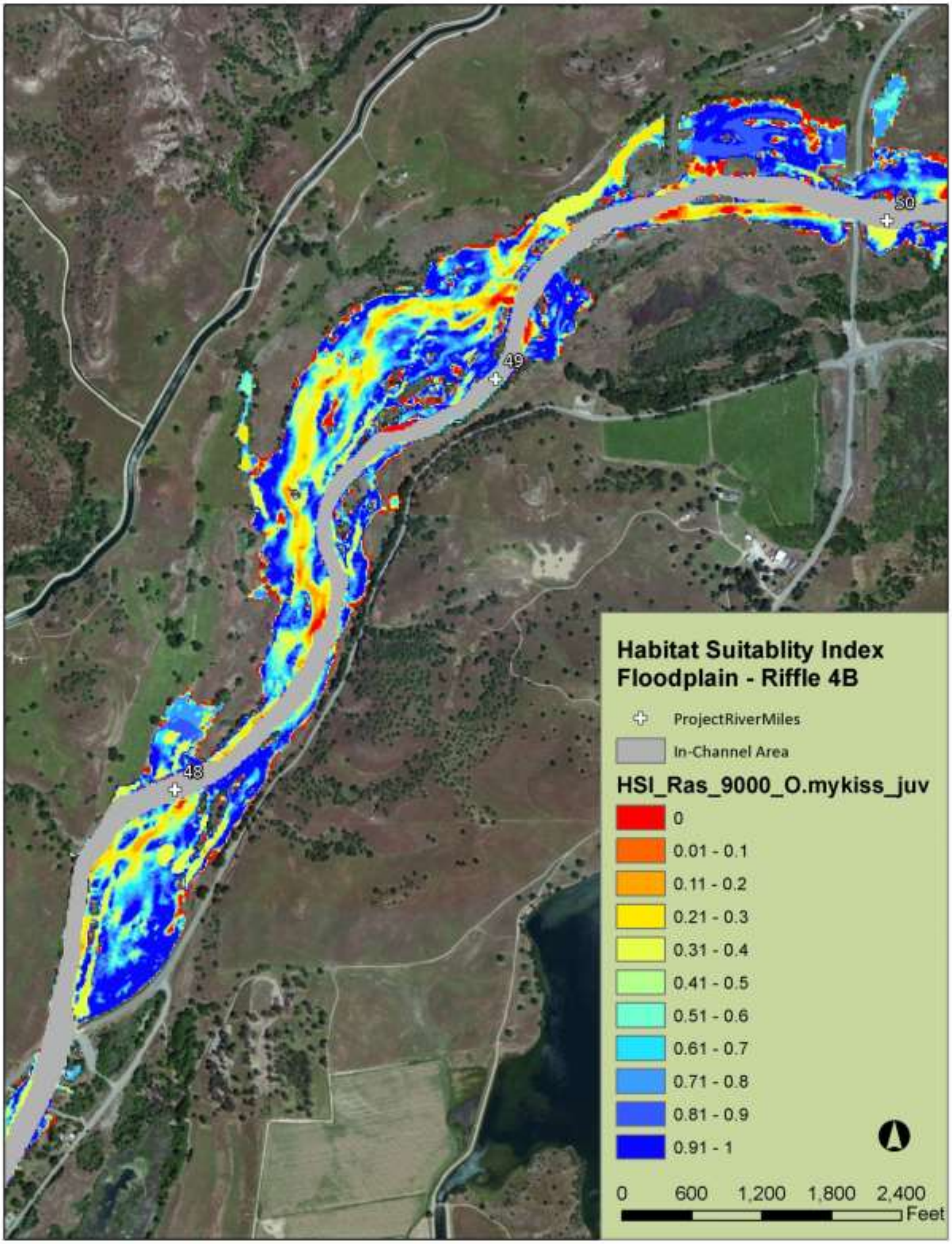

Figure 36. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Riffle 4B (RM 48.5) along the lower Tuolumne River.

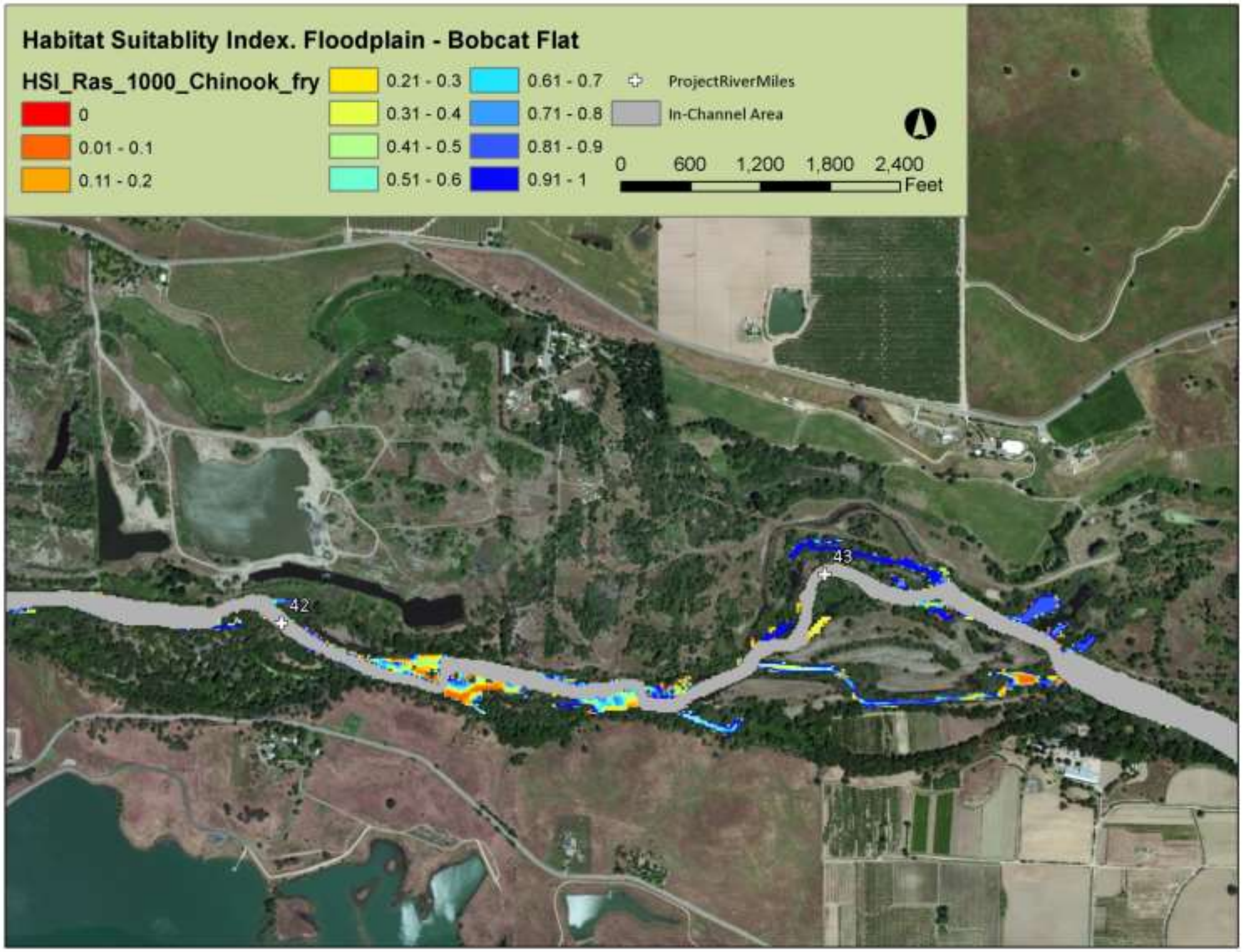

Figure 37. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

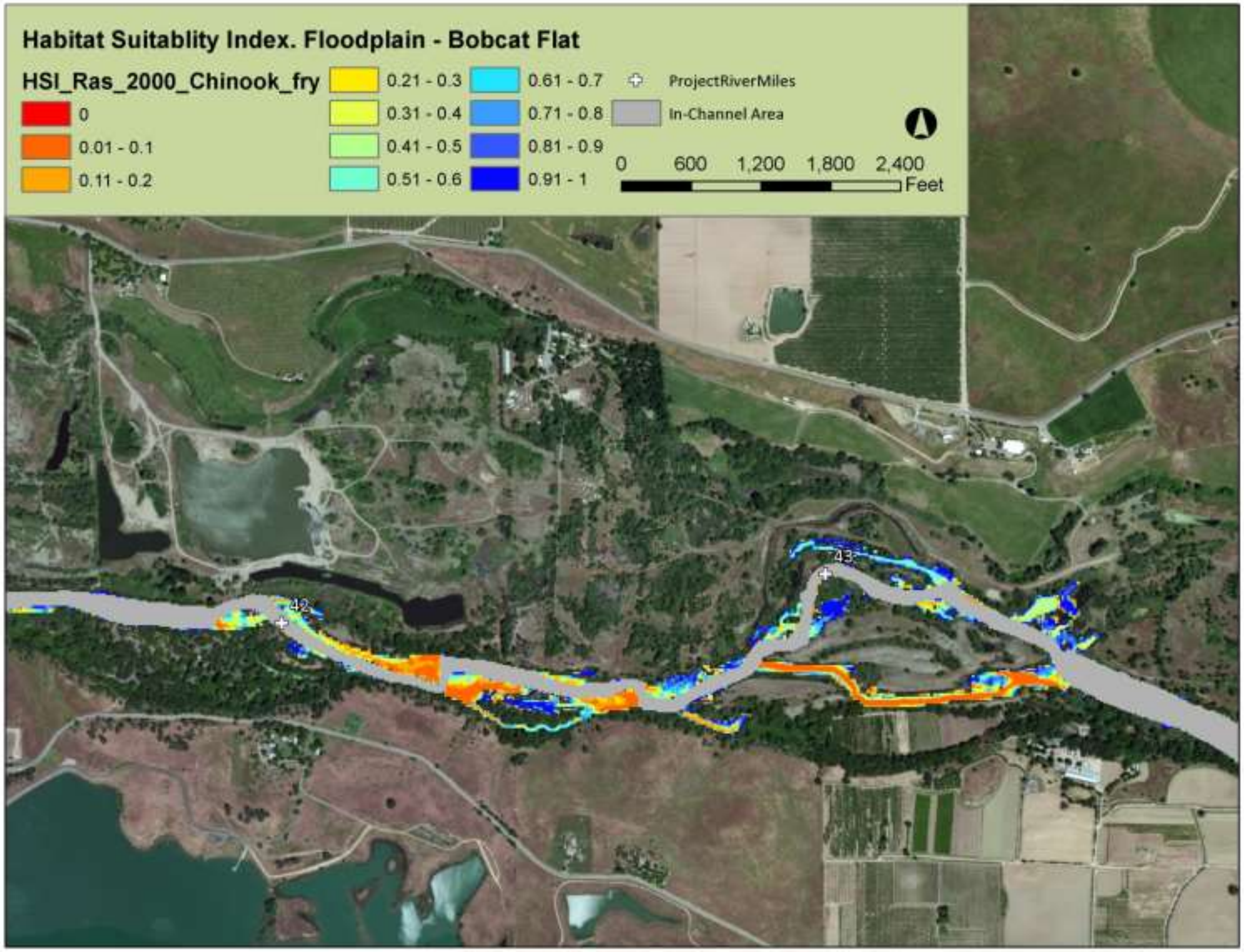

Figure 38. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

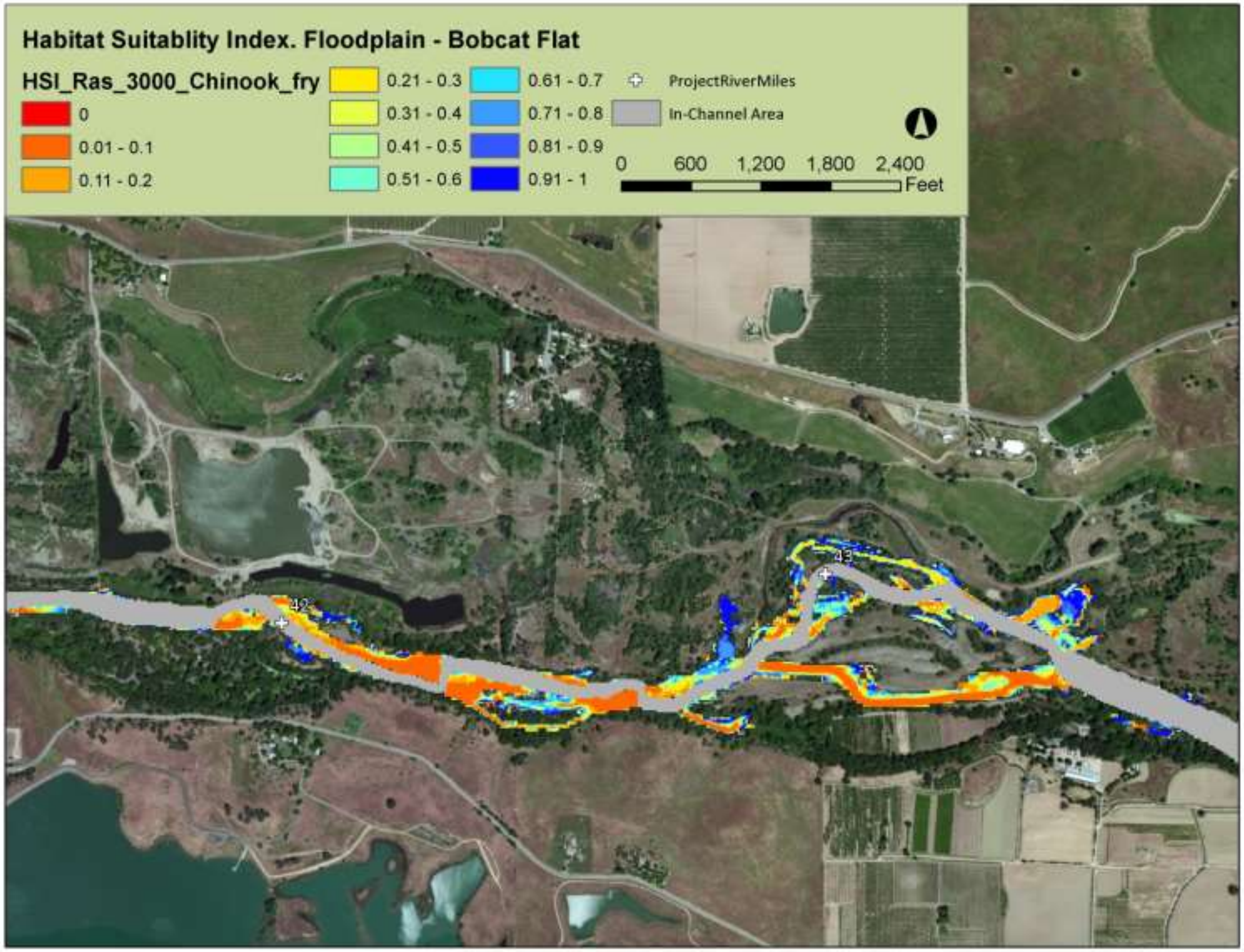

Figure 39. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

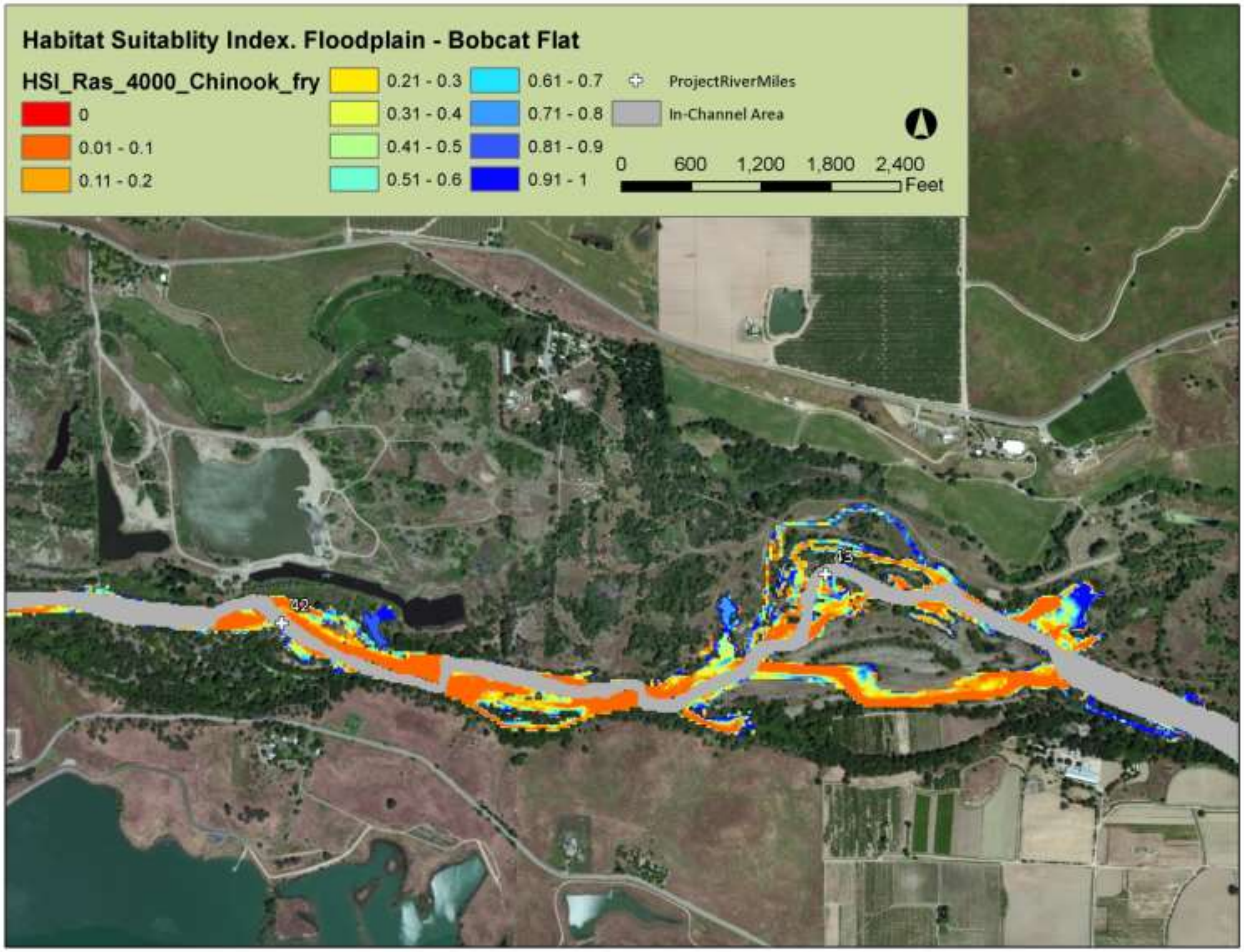

Figure 40. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

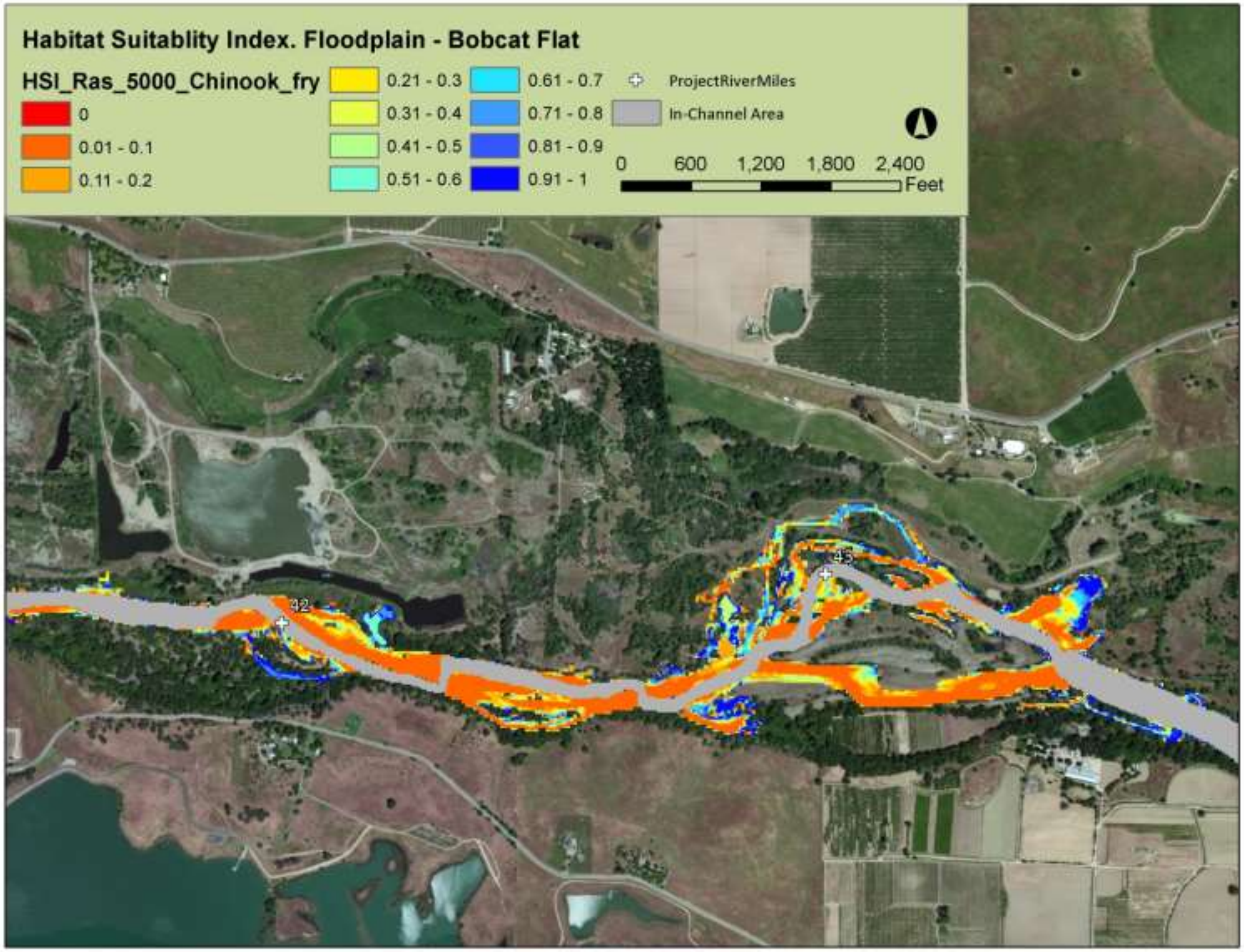

Figure 41. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

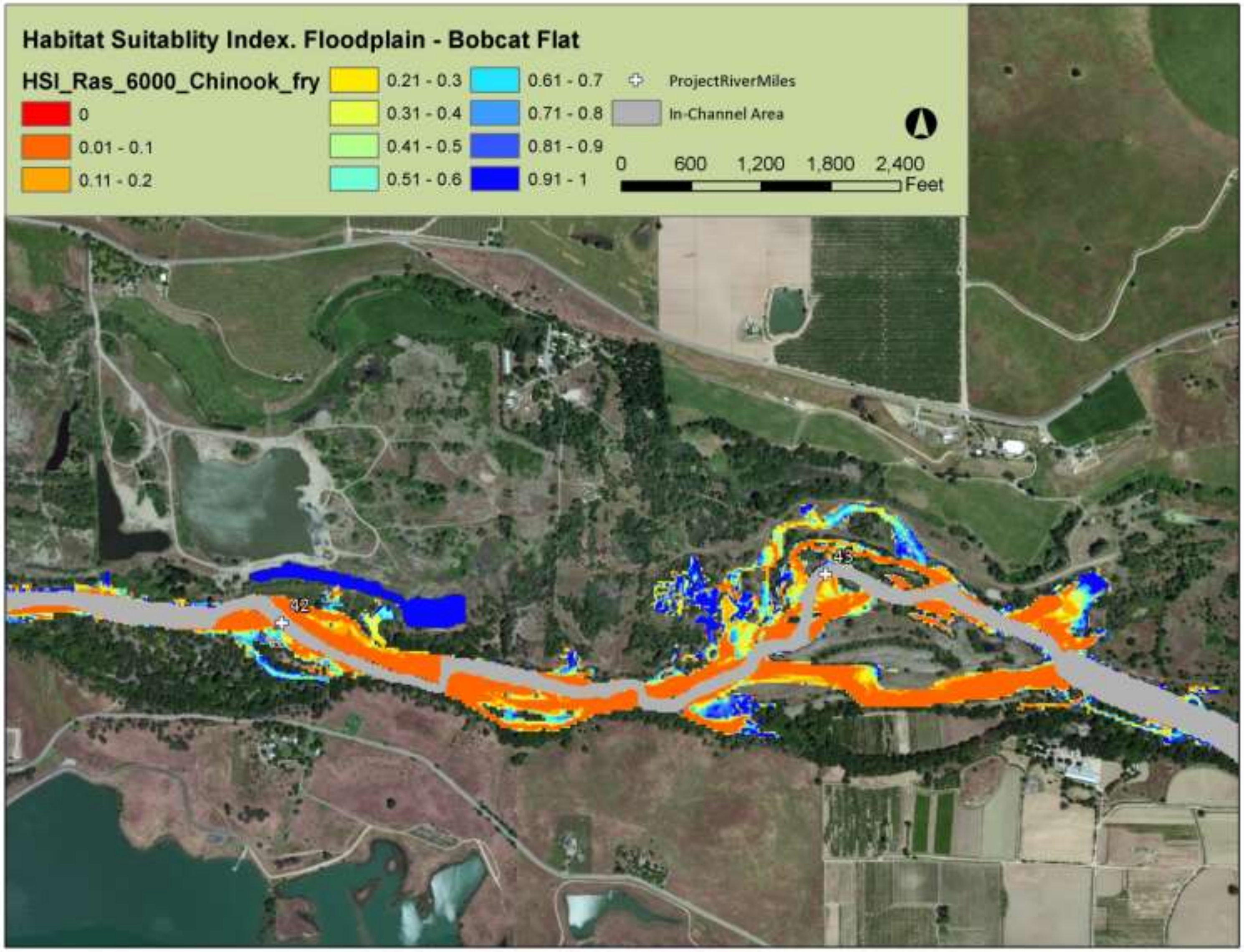

Figure 42. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

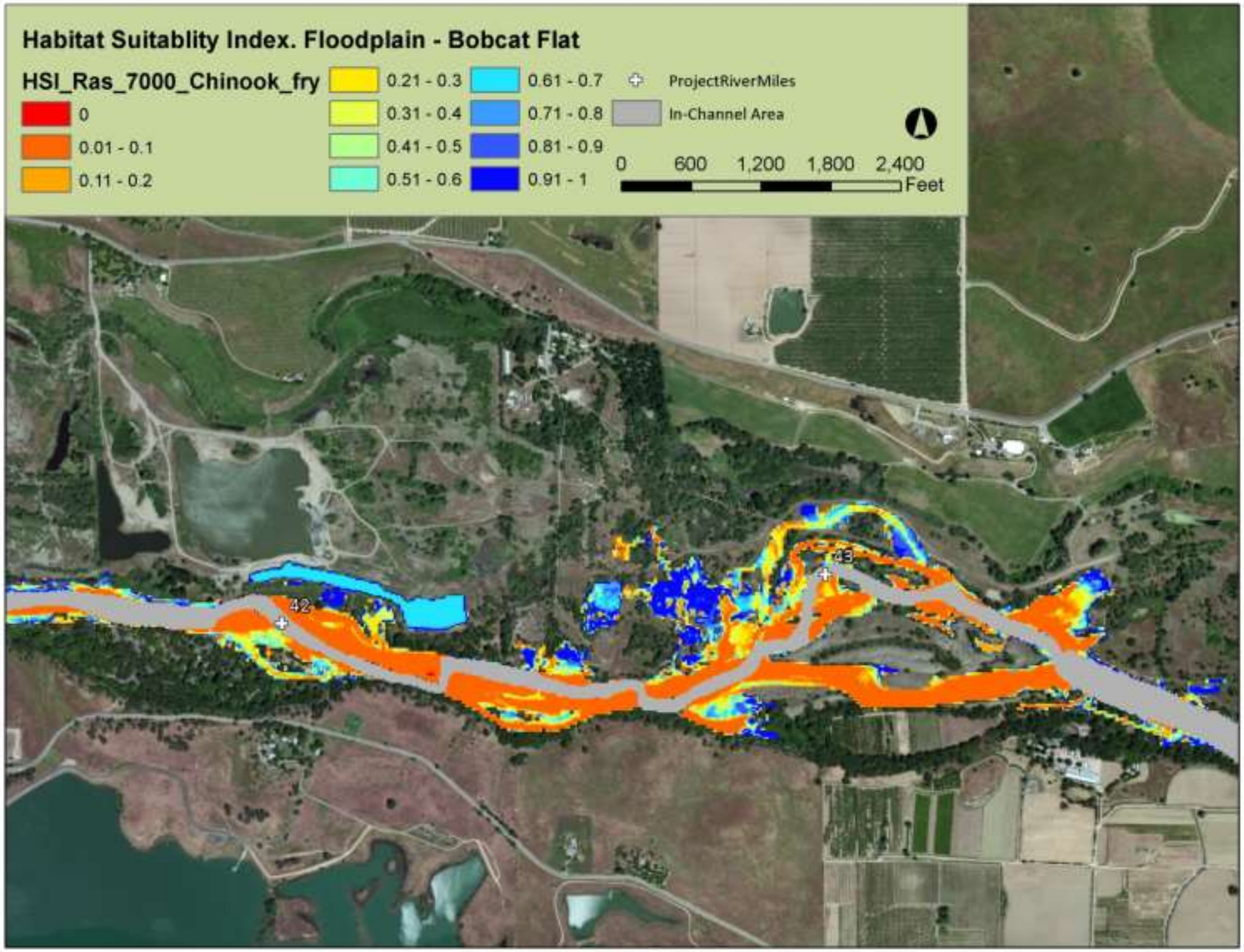

Figure 43. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

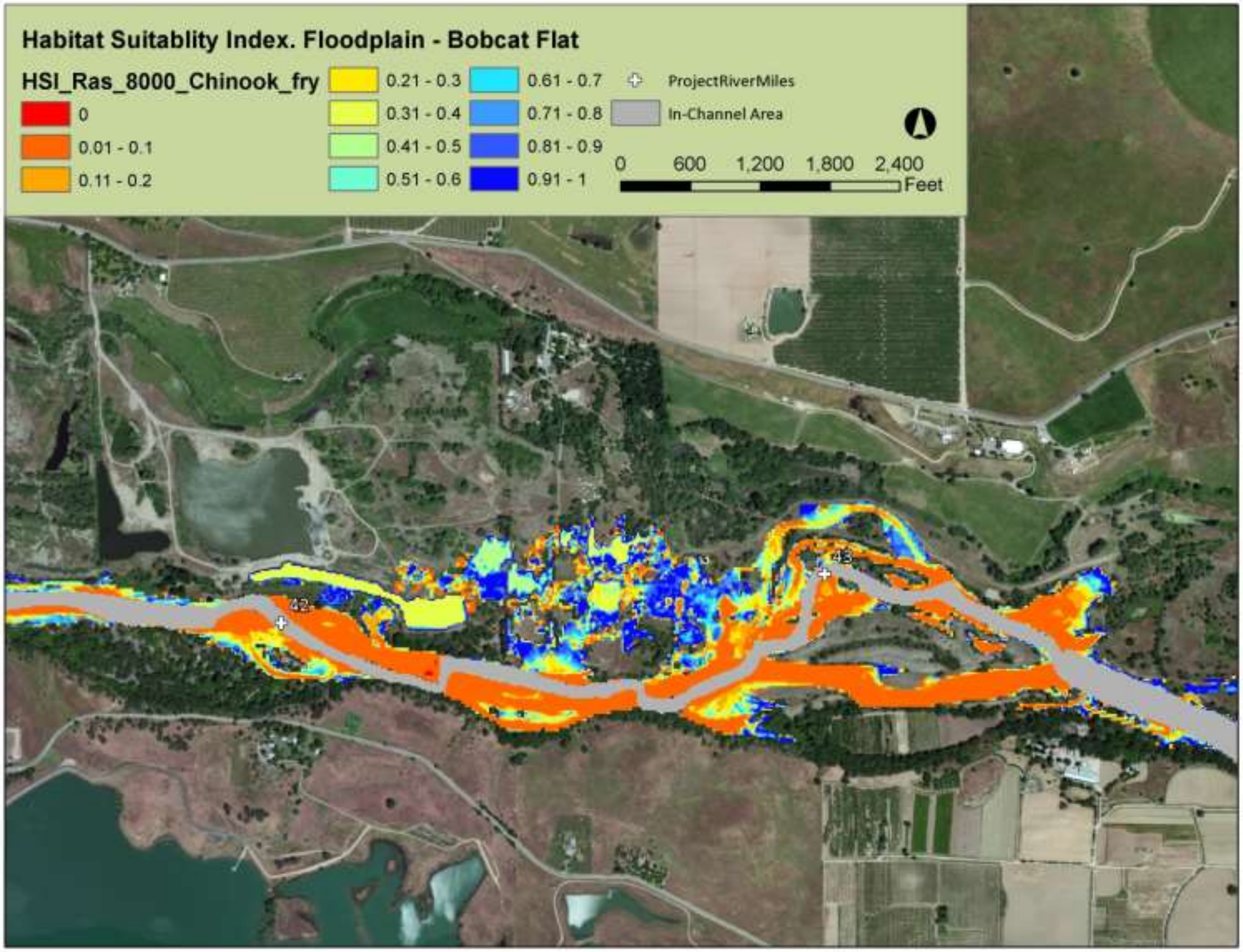

Figure 44. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

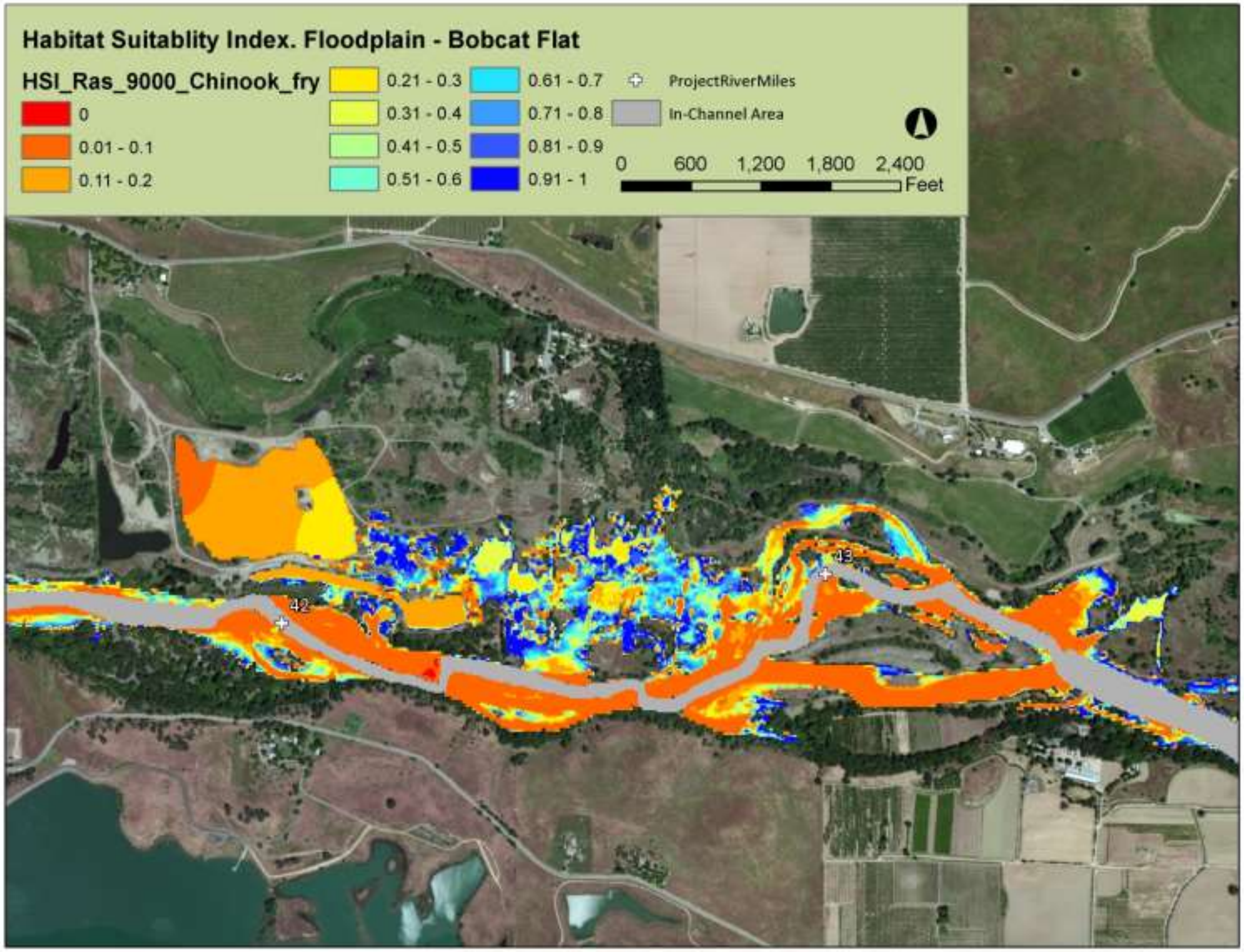

Figure 45. Example plot of joint Chinook salmon fry habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

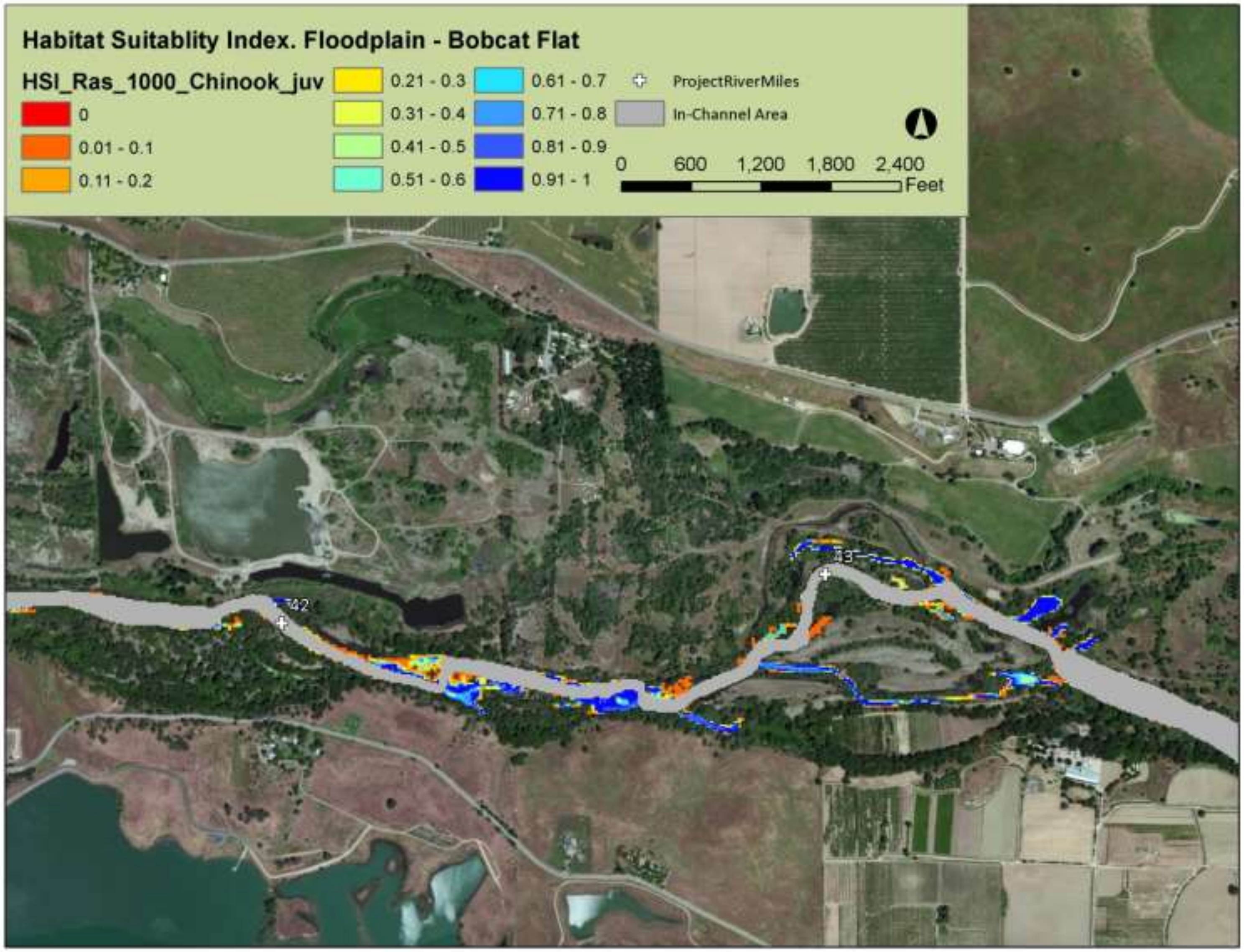

Figure 46. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

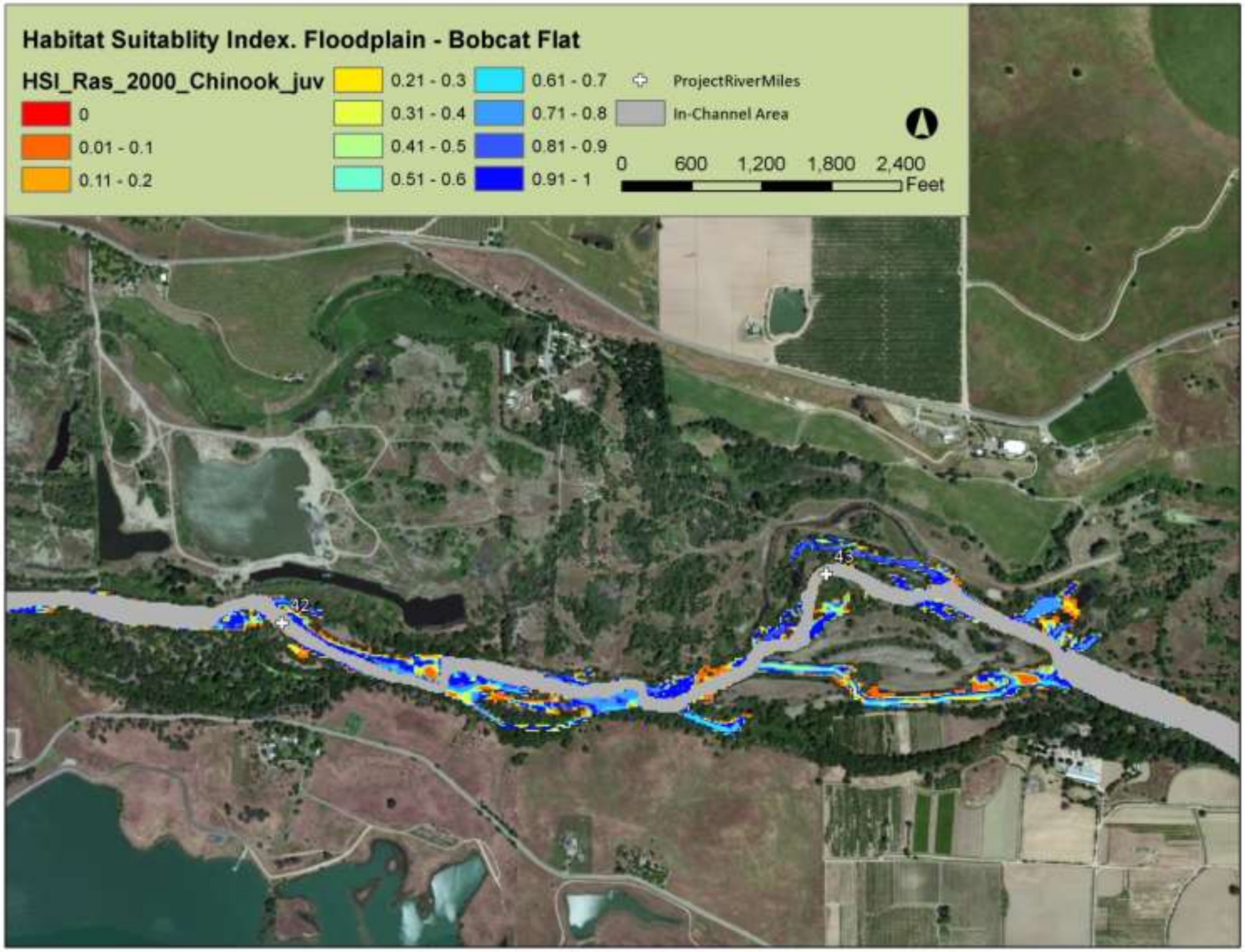

Figure 47. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

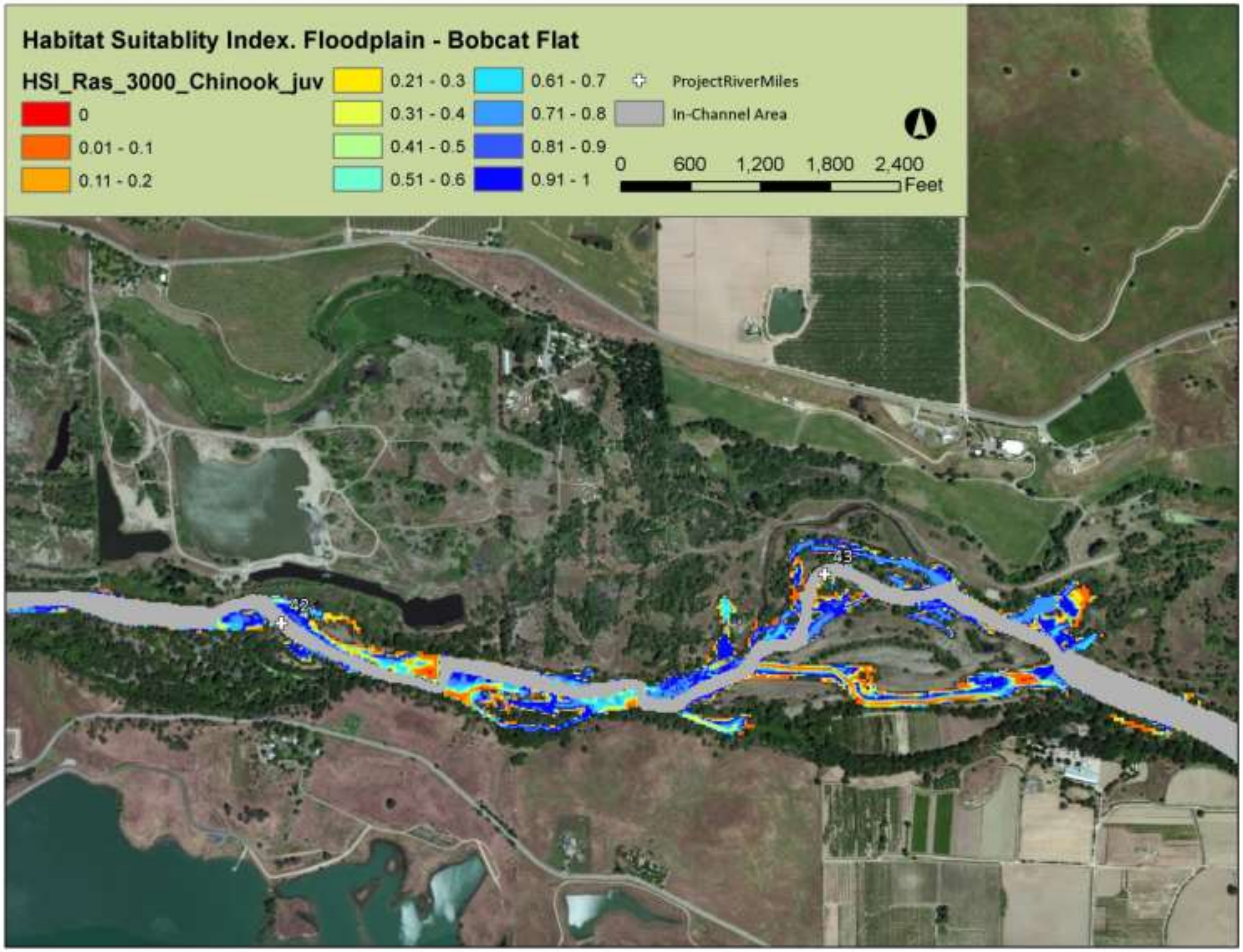

Figure 48. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

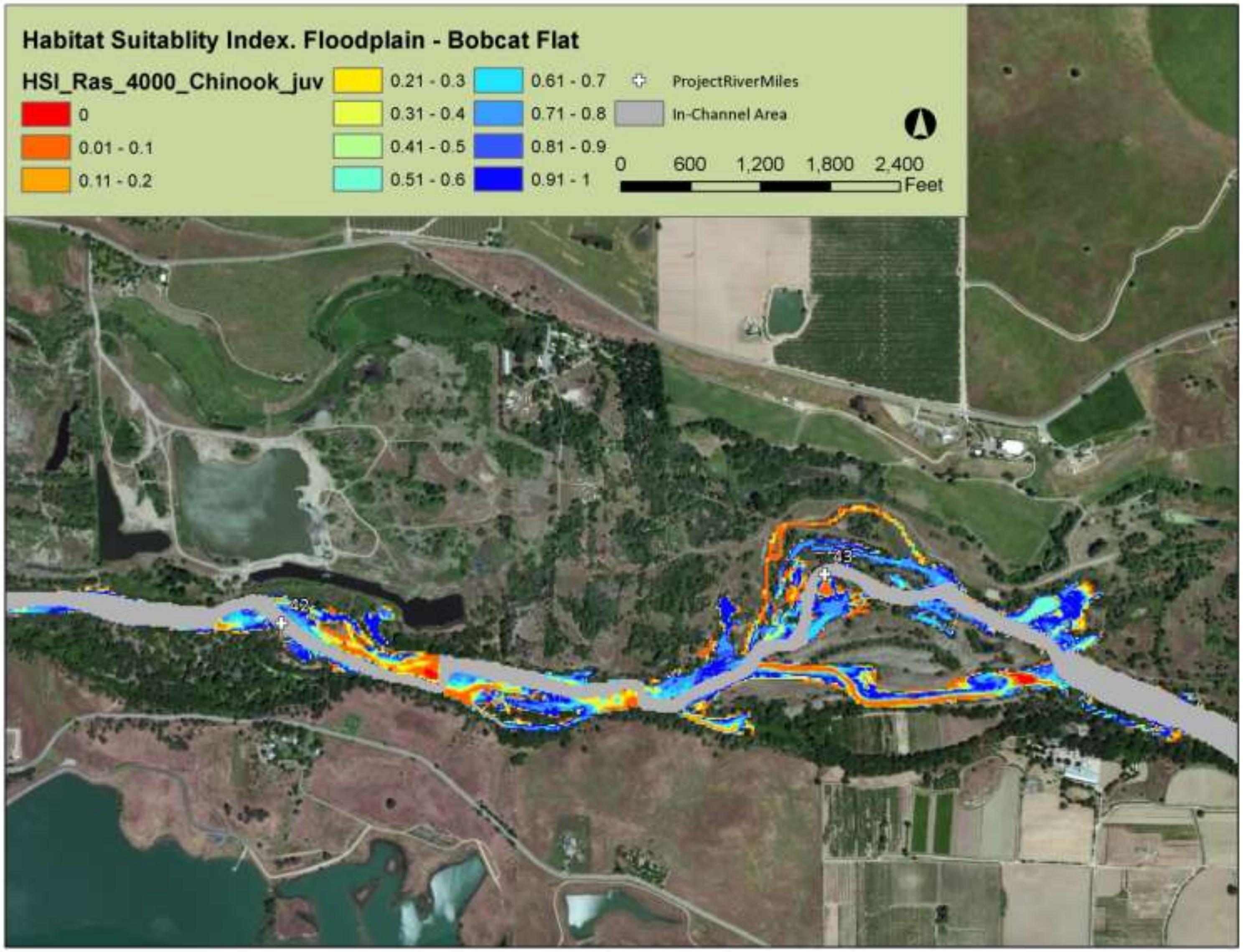

Figure 49. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

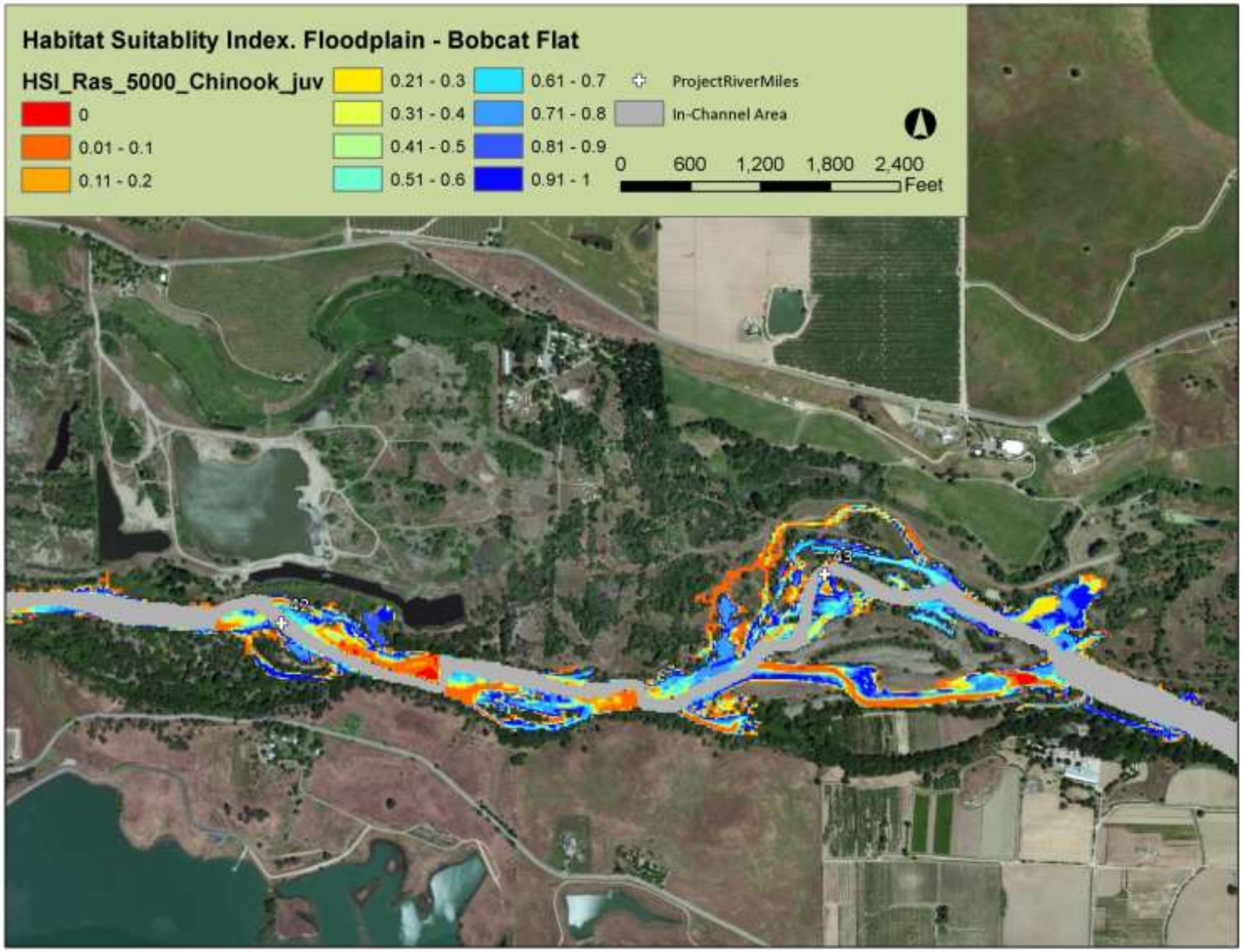

Figure 50. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

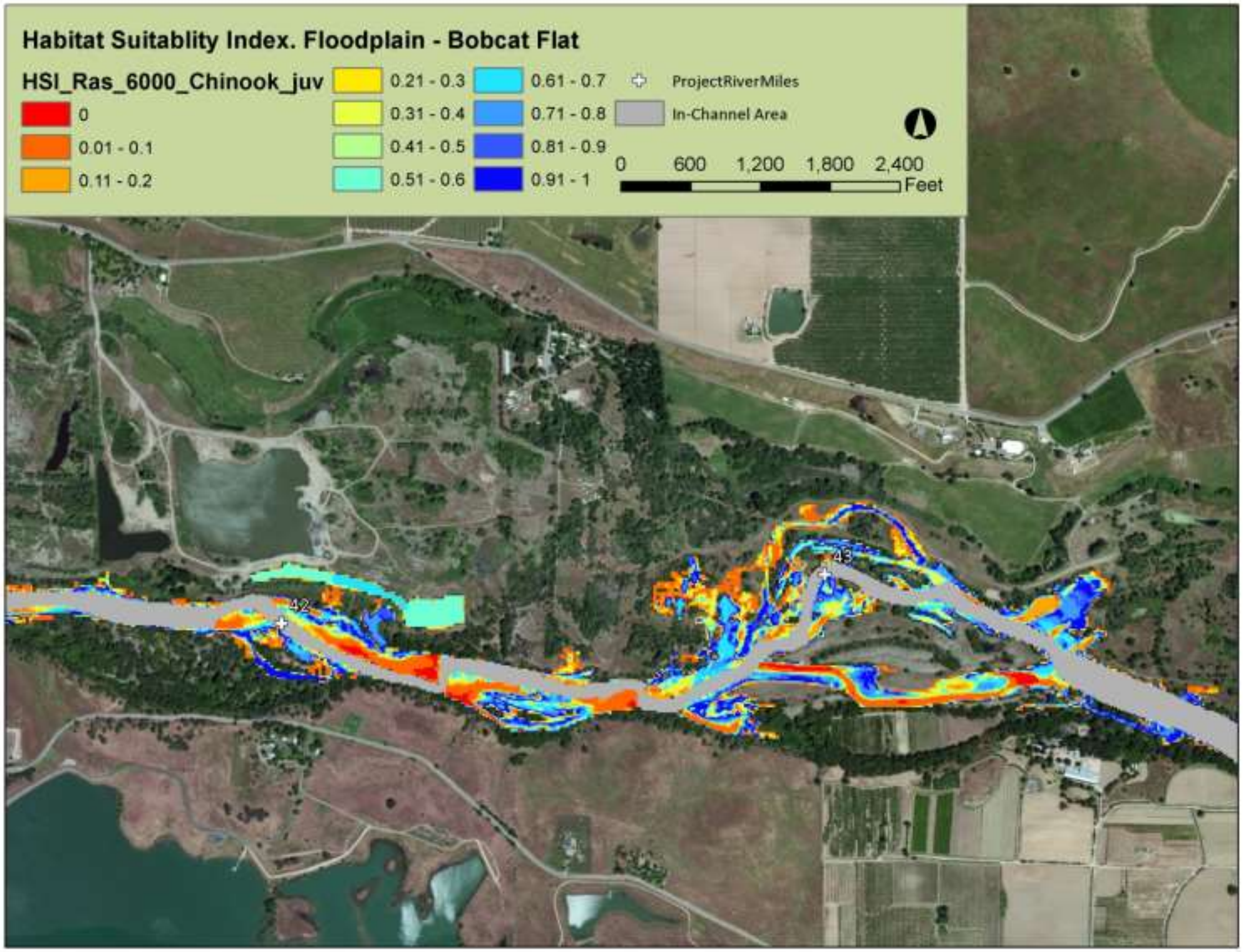

Figure 51. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

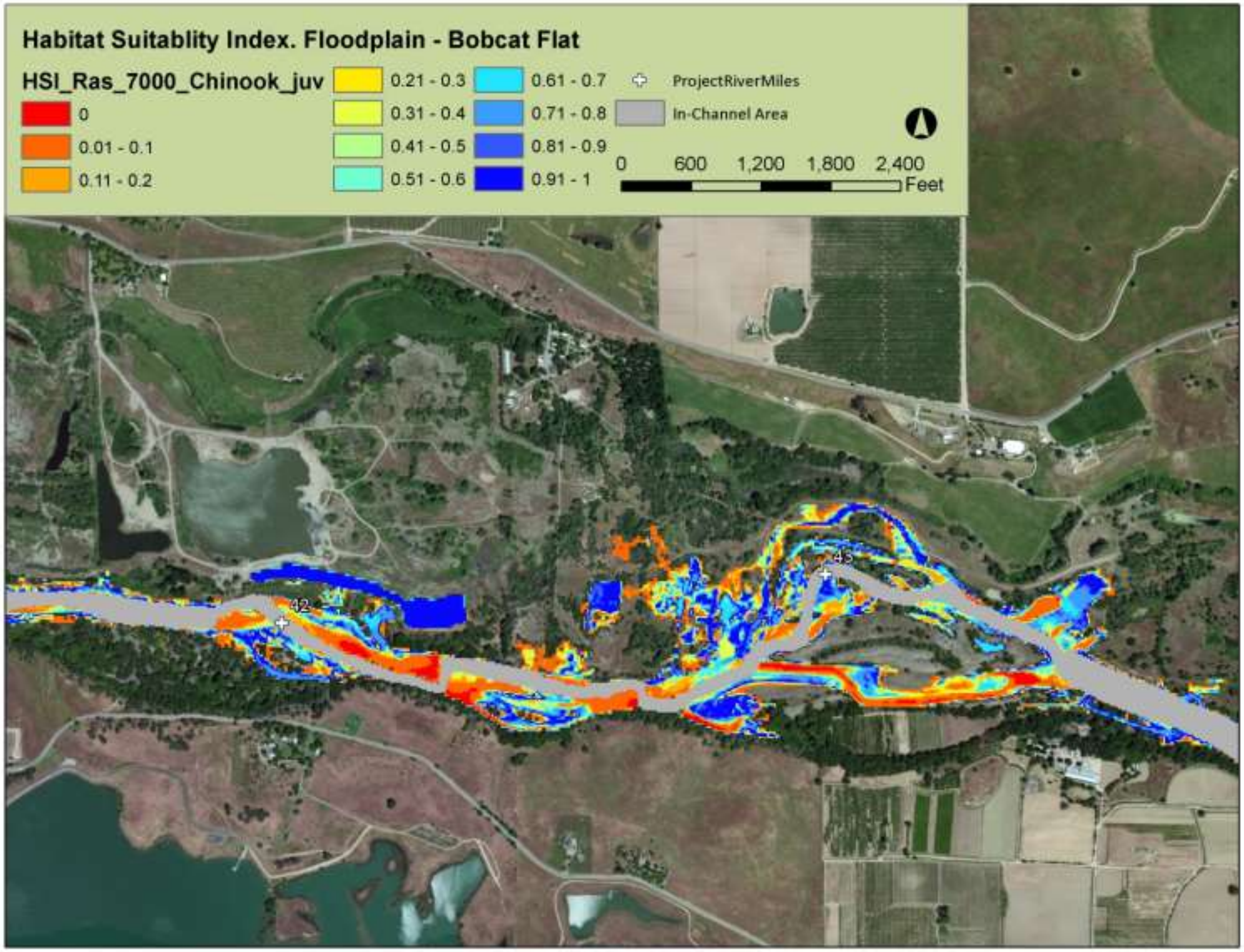

Figure 52. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

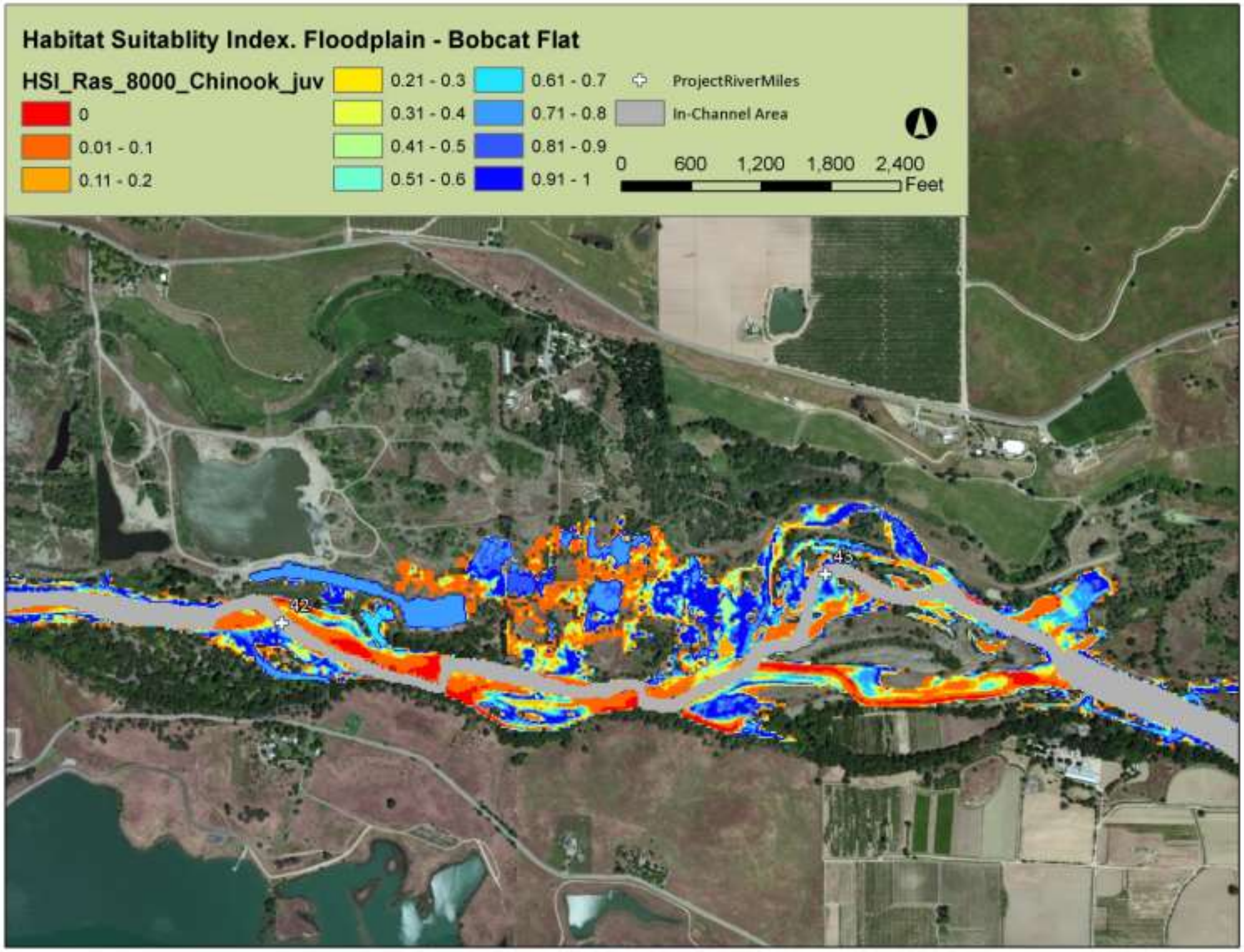

Figure 53. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

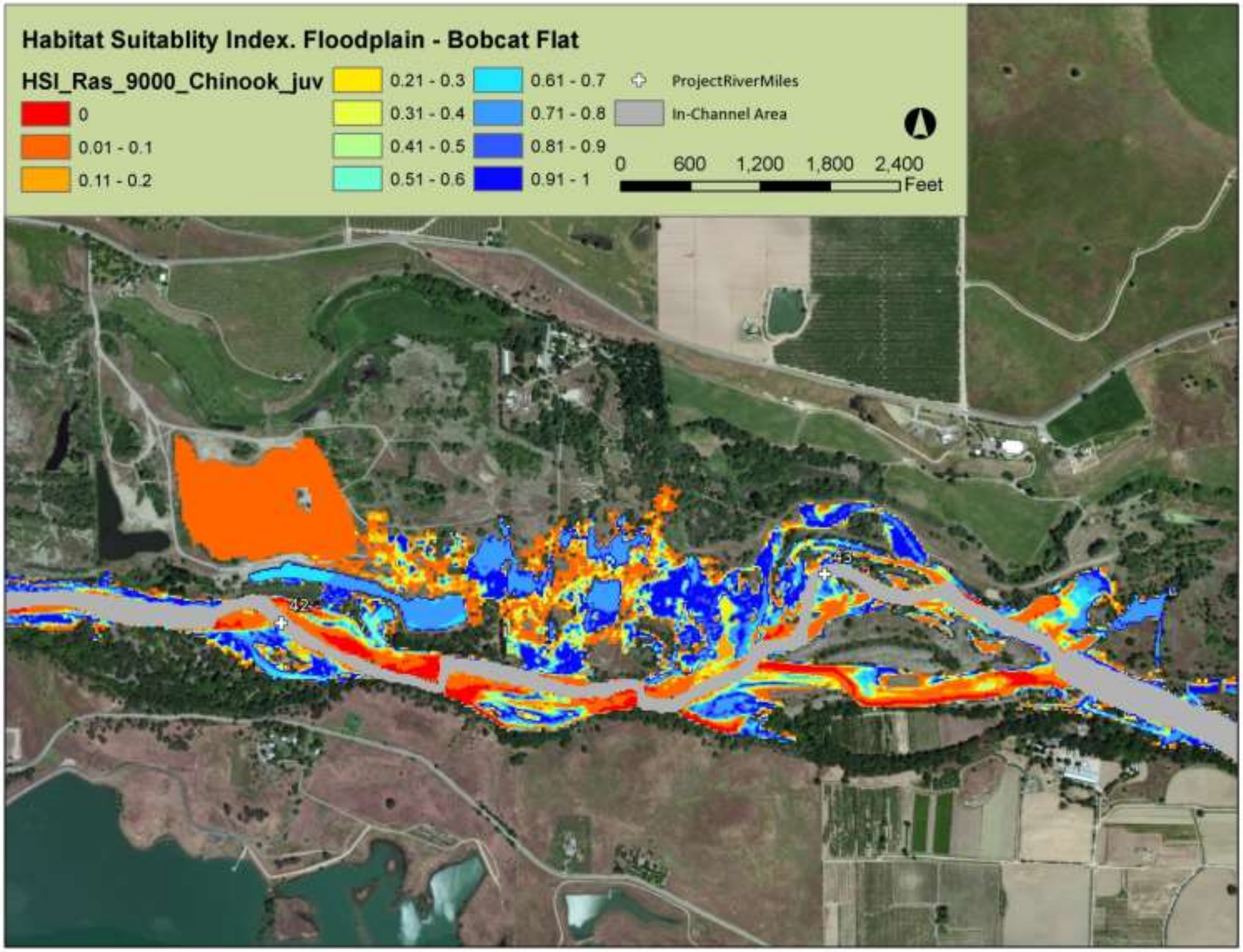

Figure 54. Example plot of joint Chinook salmon juvenile habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

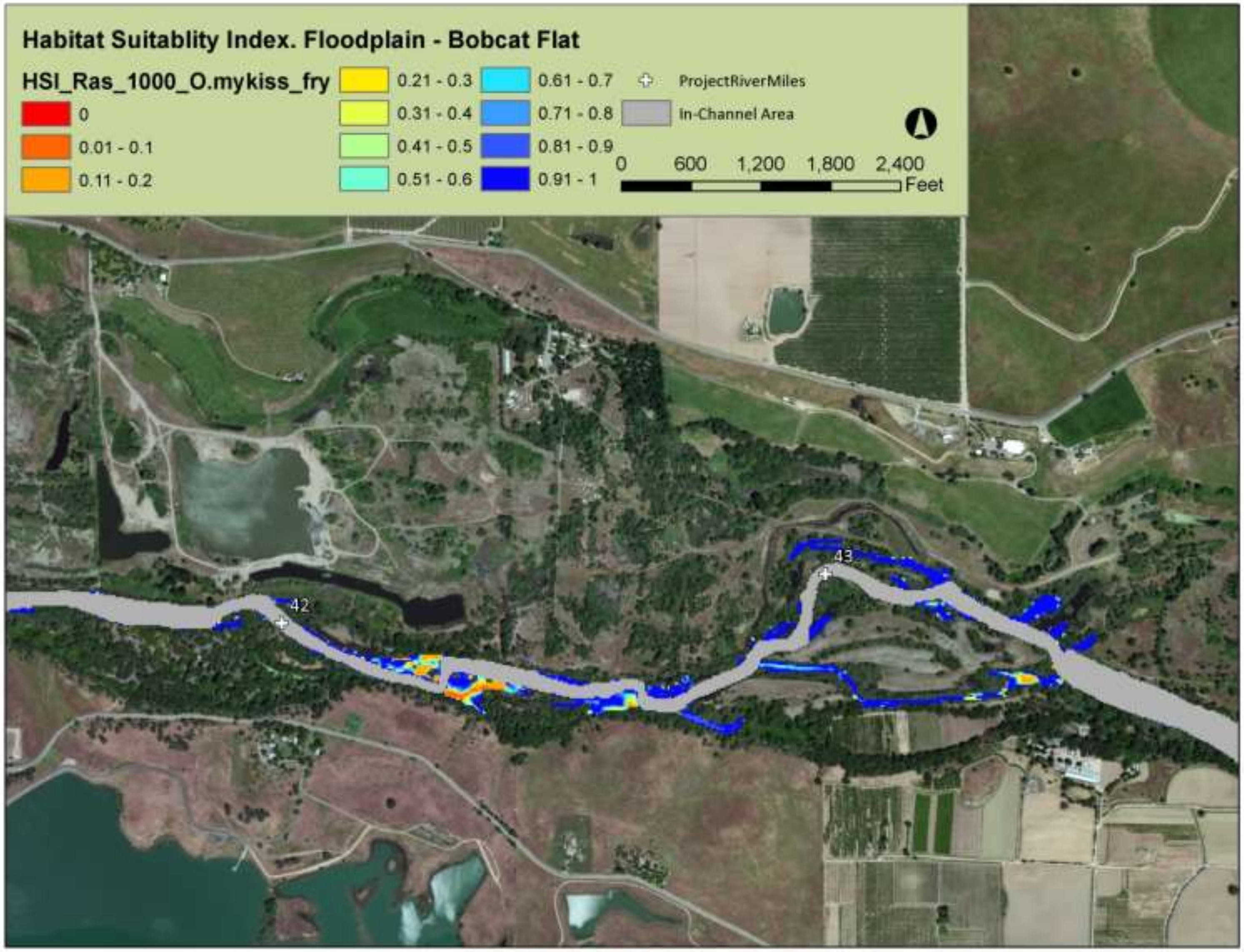

Figure 55. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

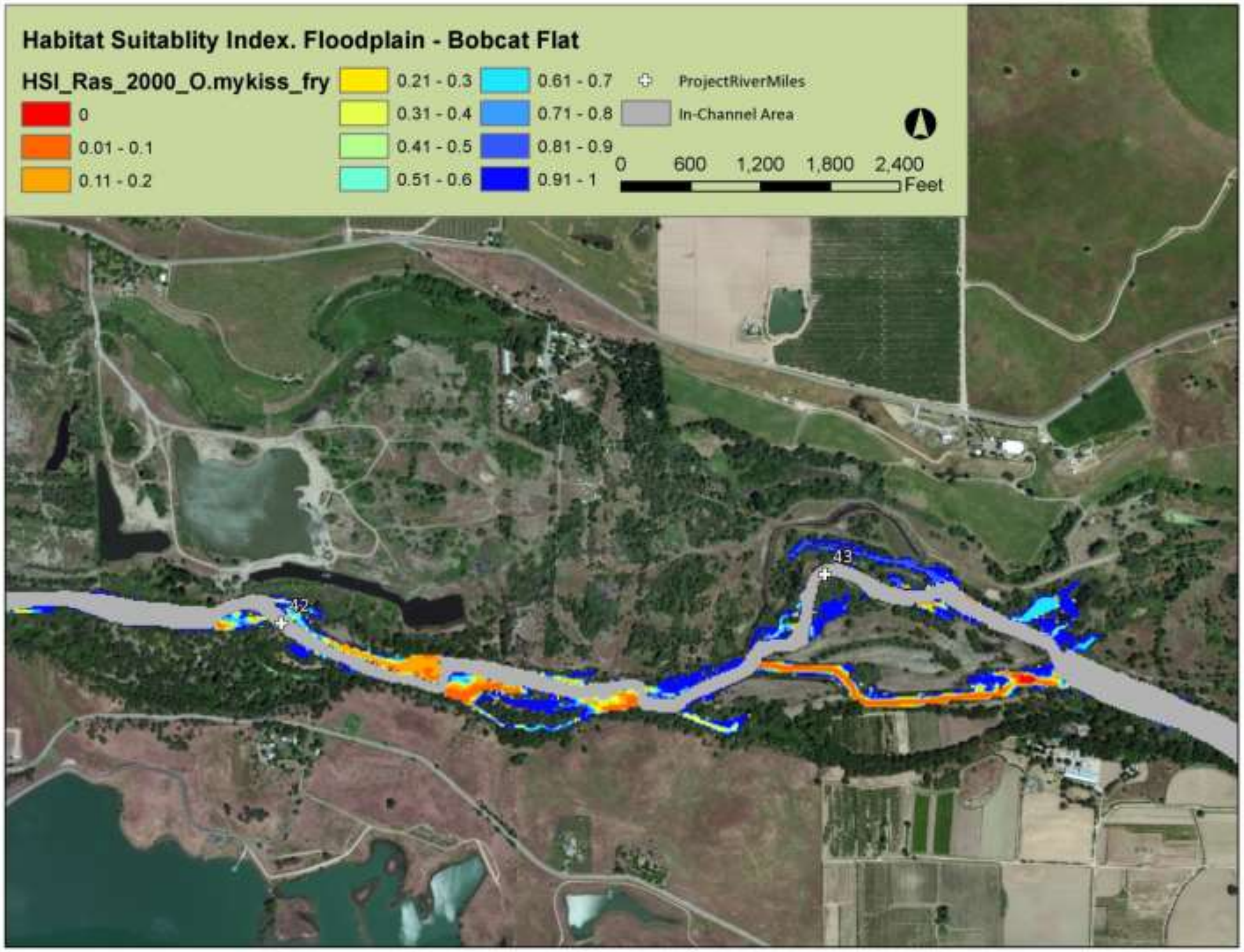

Figure 56. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

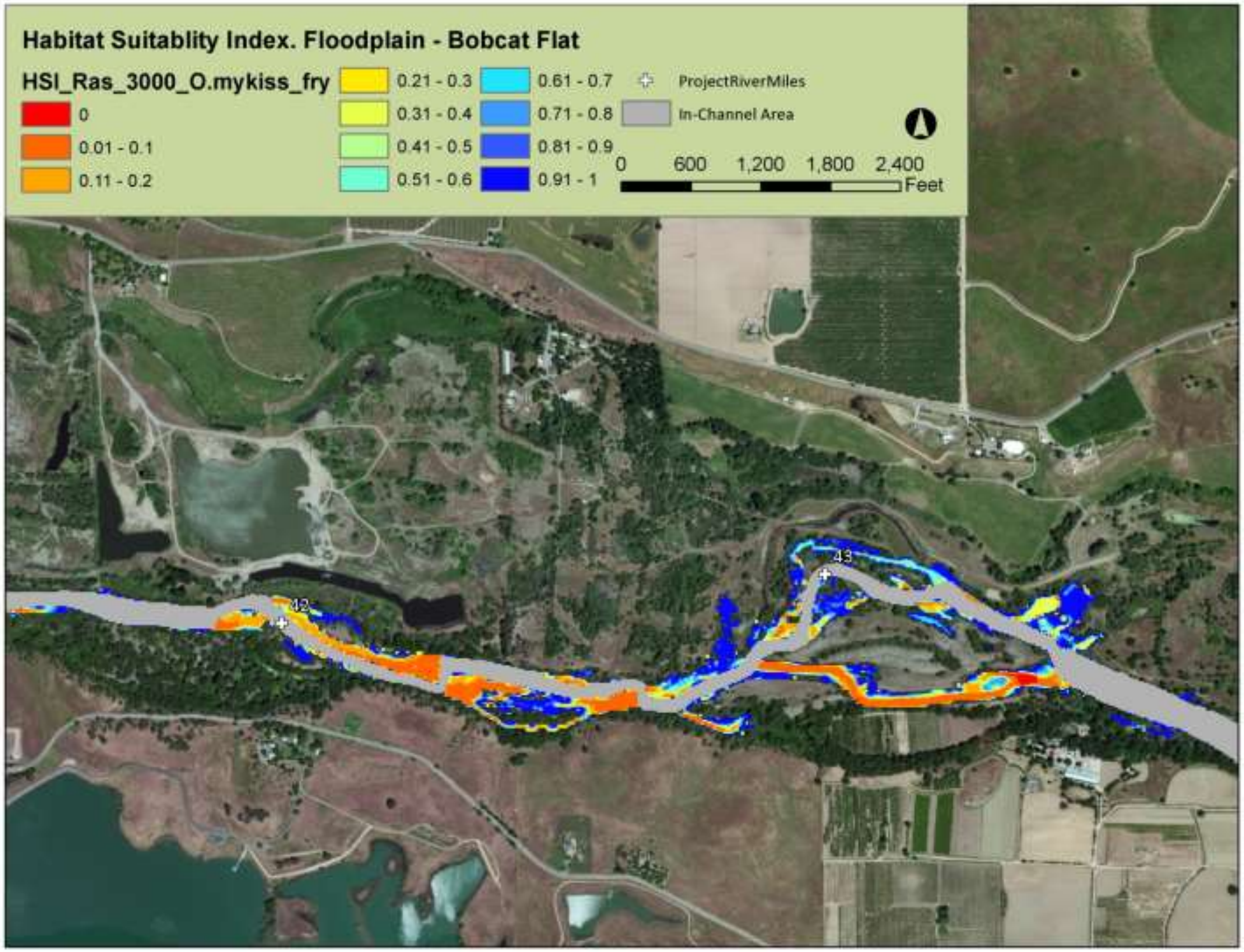

Figure 57. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

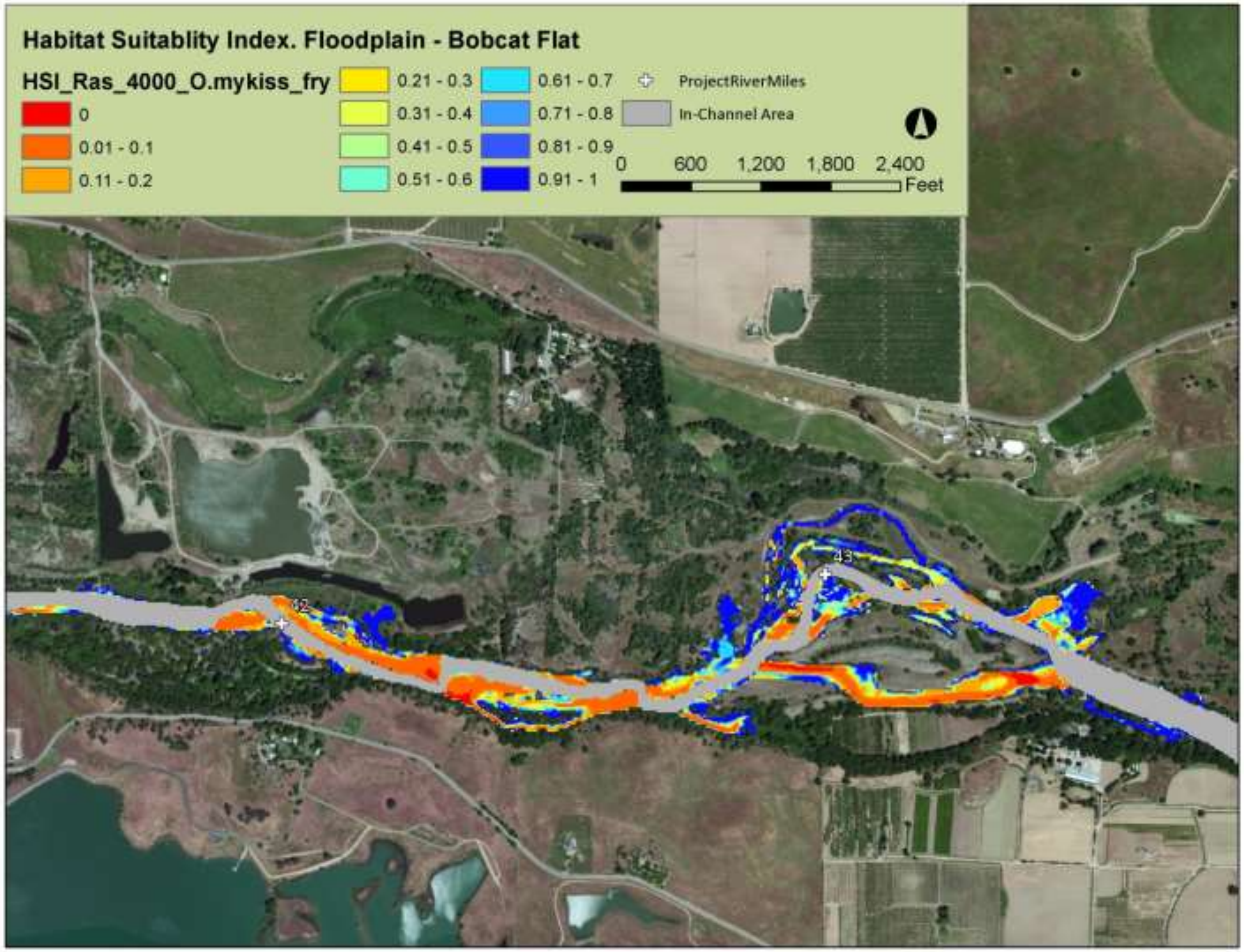

Figure 58. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

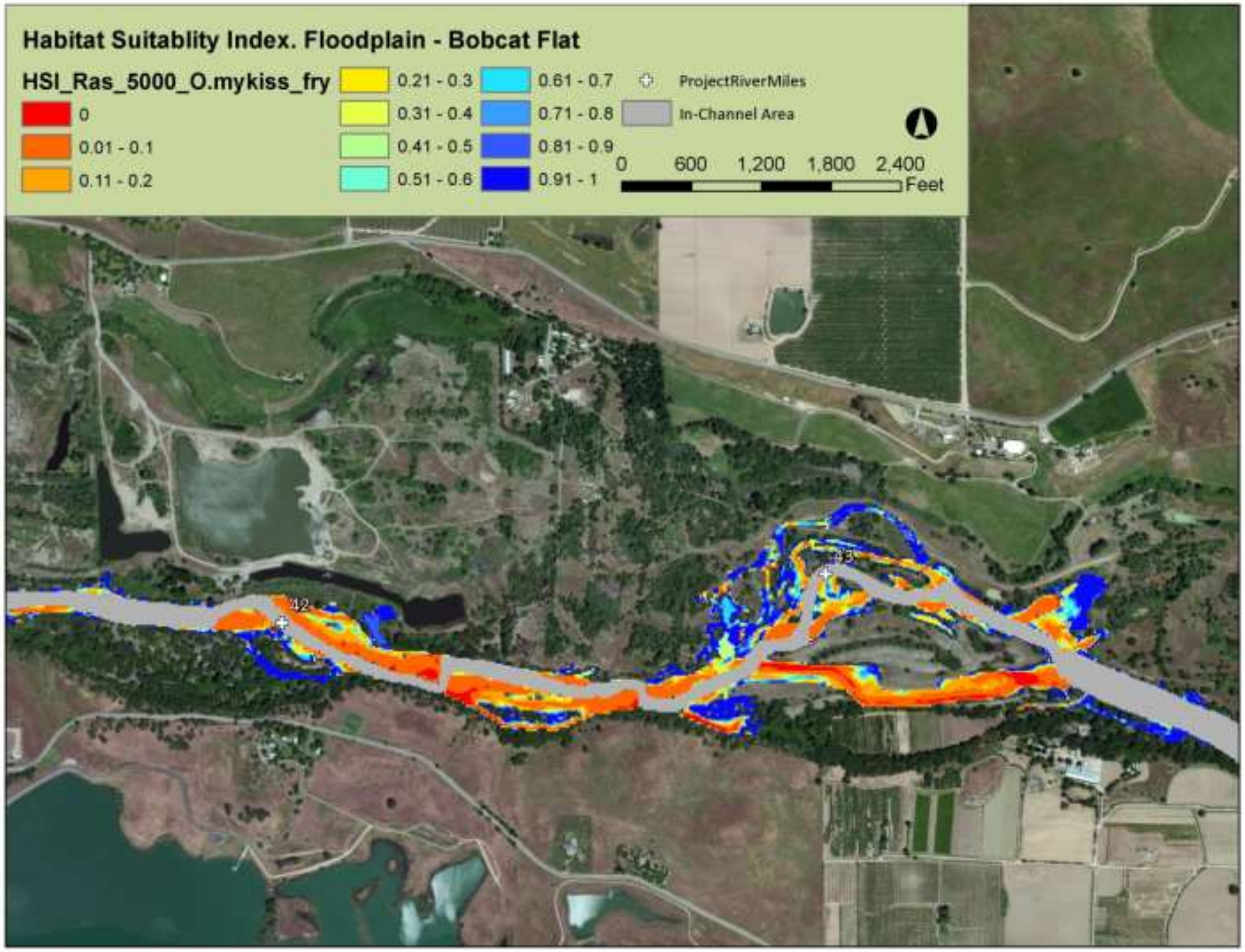

Figure 59. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

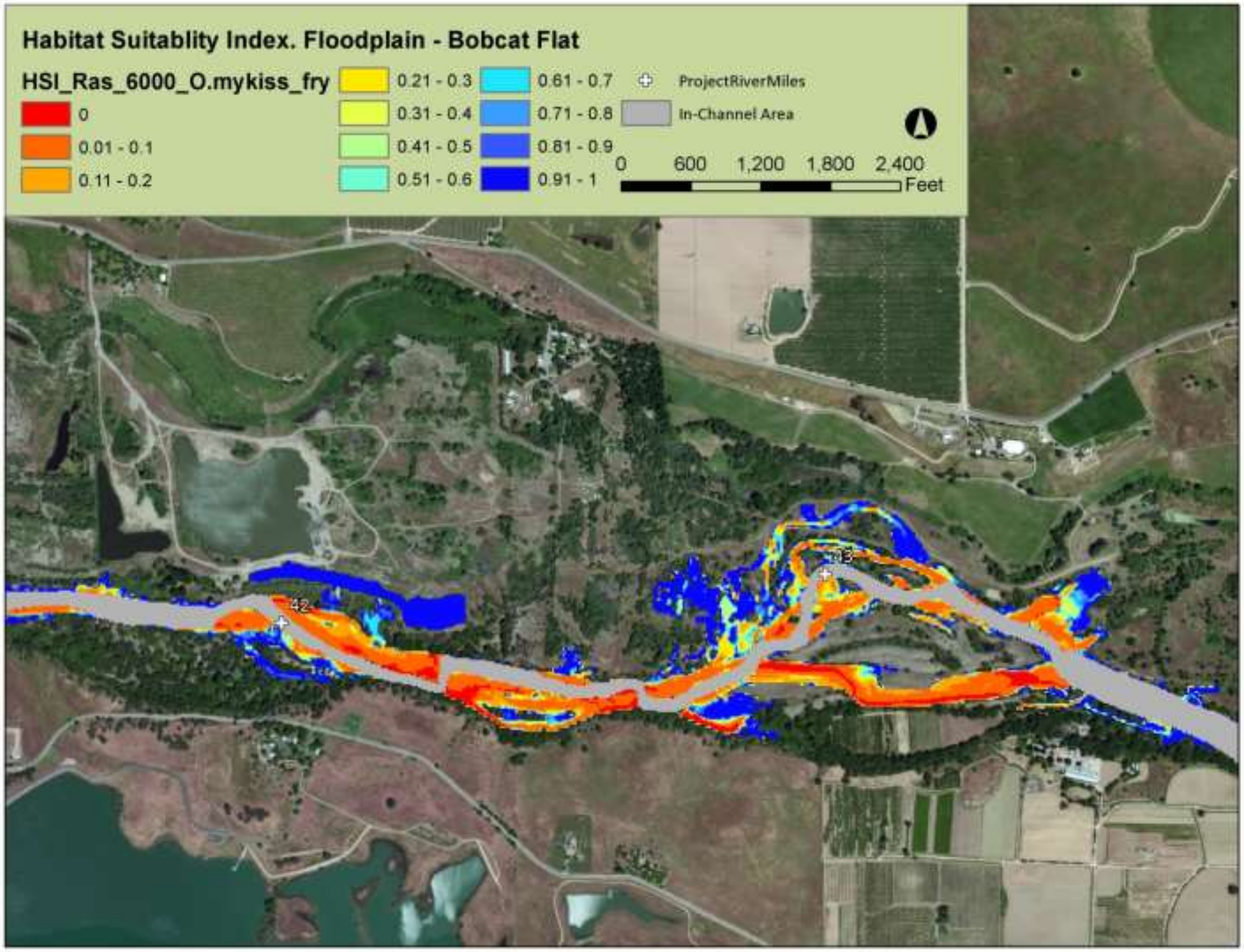

Figure 60. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

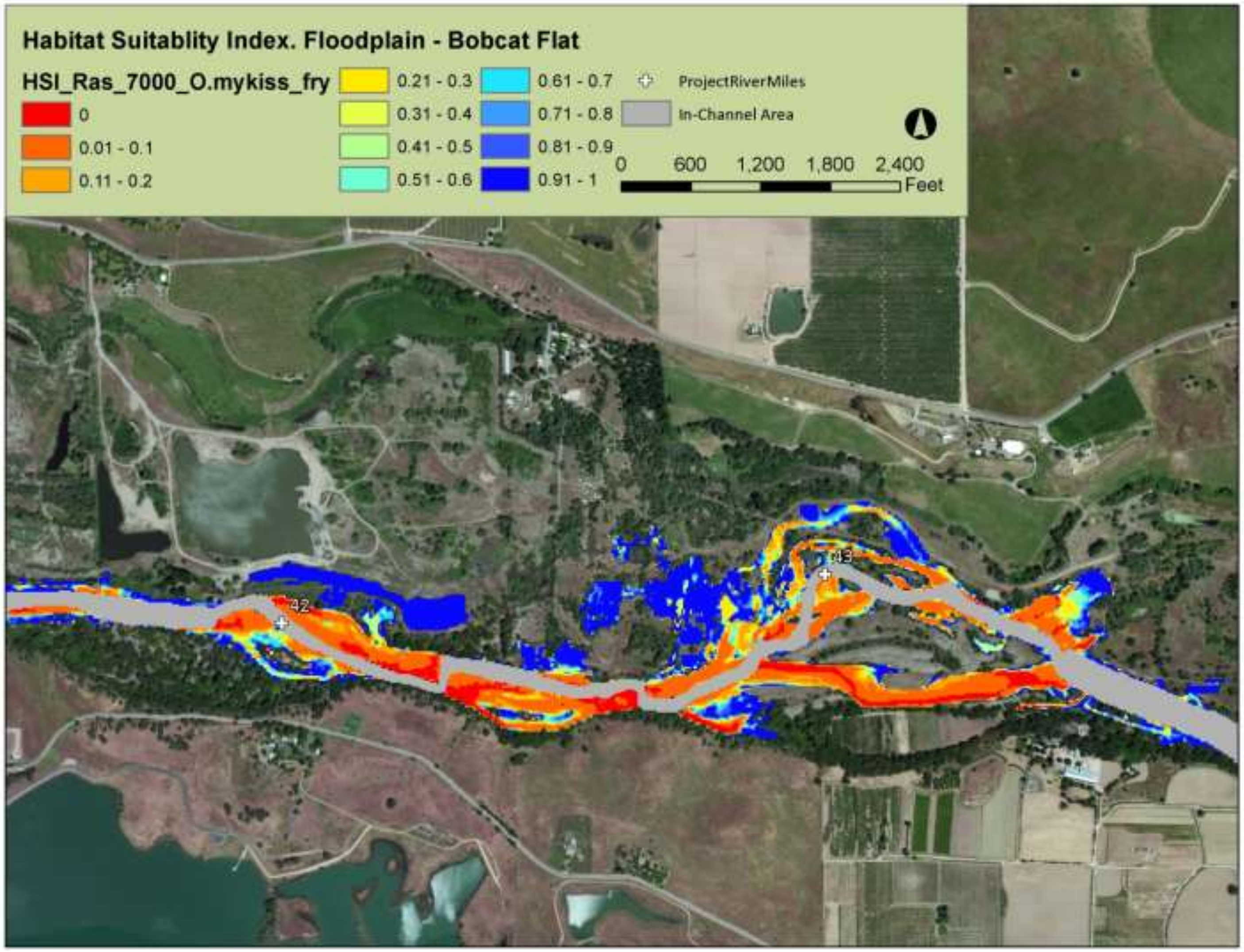

Figure 61. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

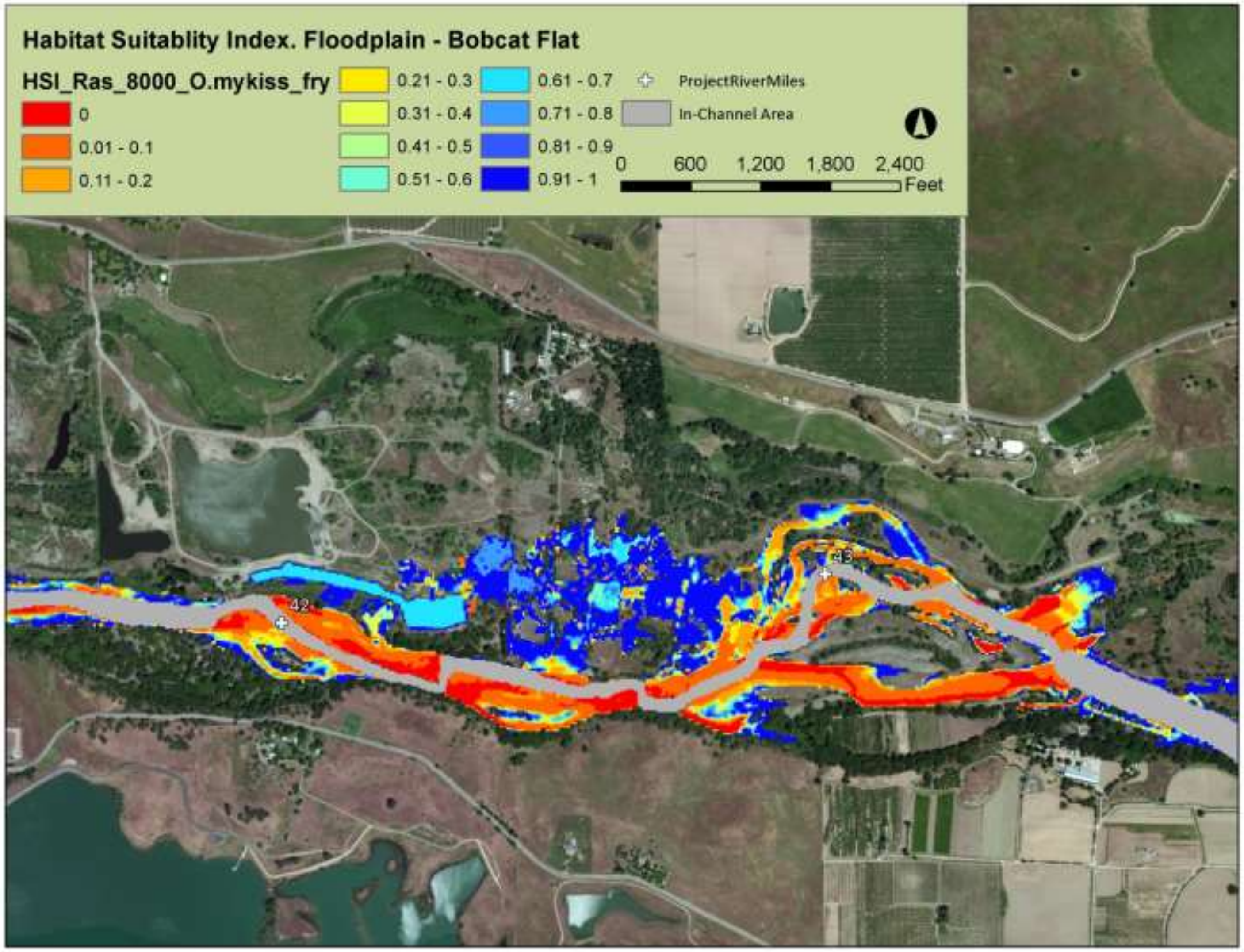

Figure 62. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

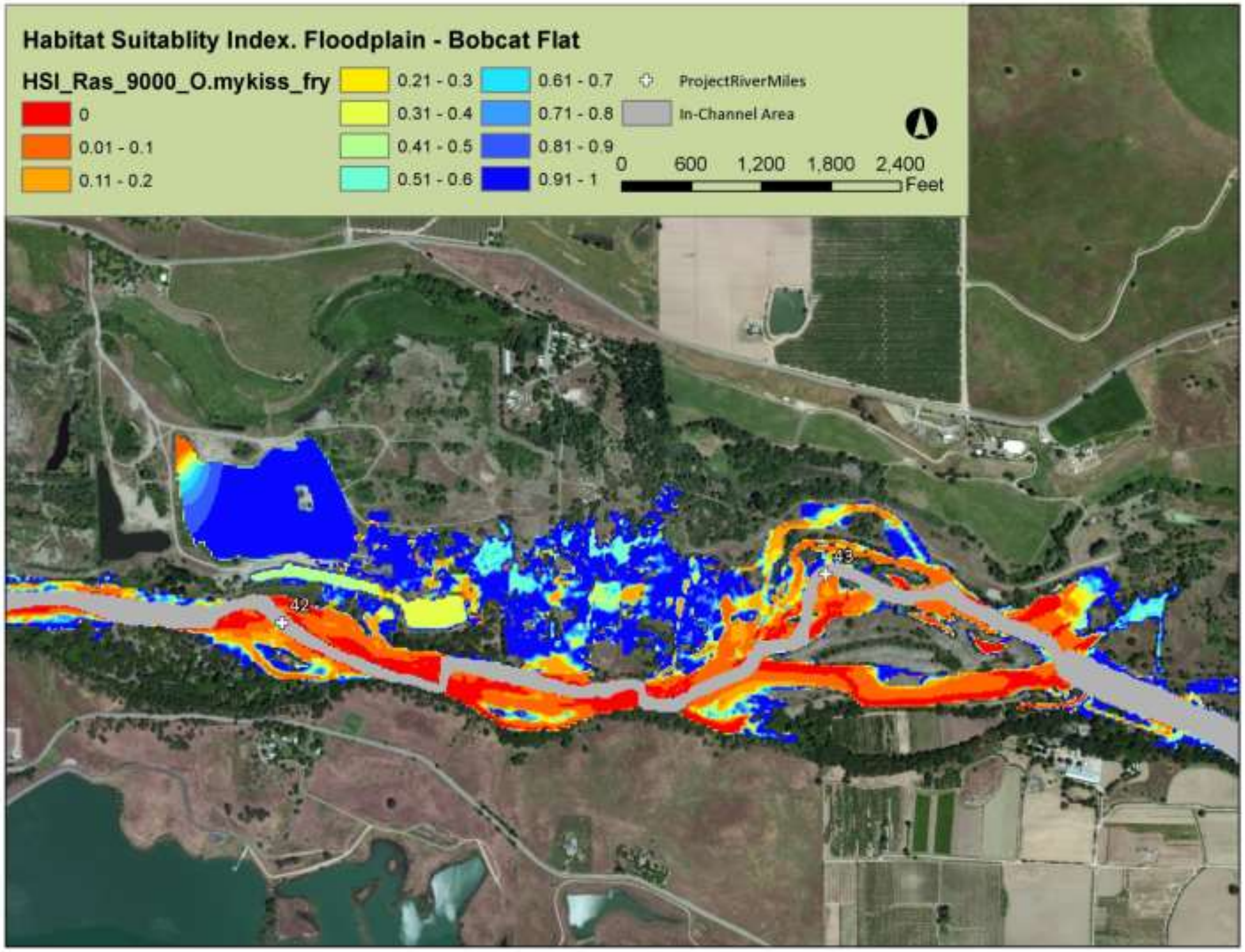

Figure 63. Example plot of joint *O. mykiss* fry habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

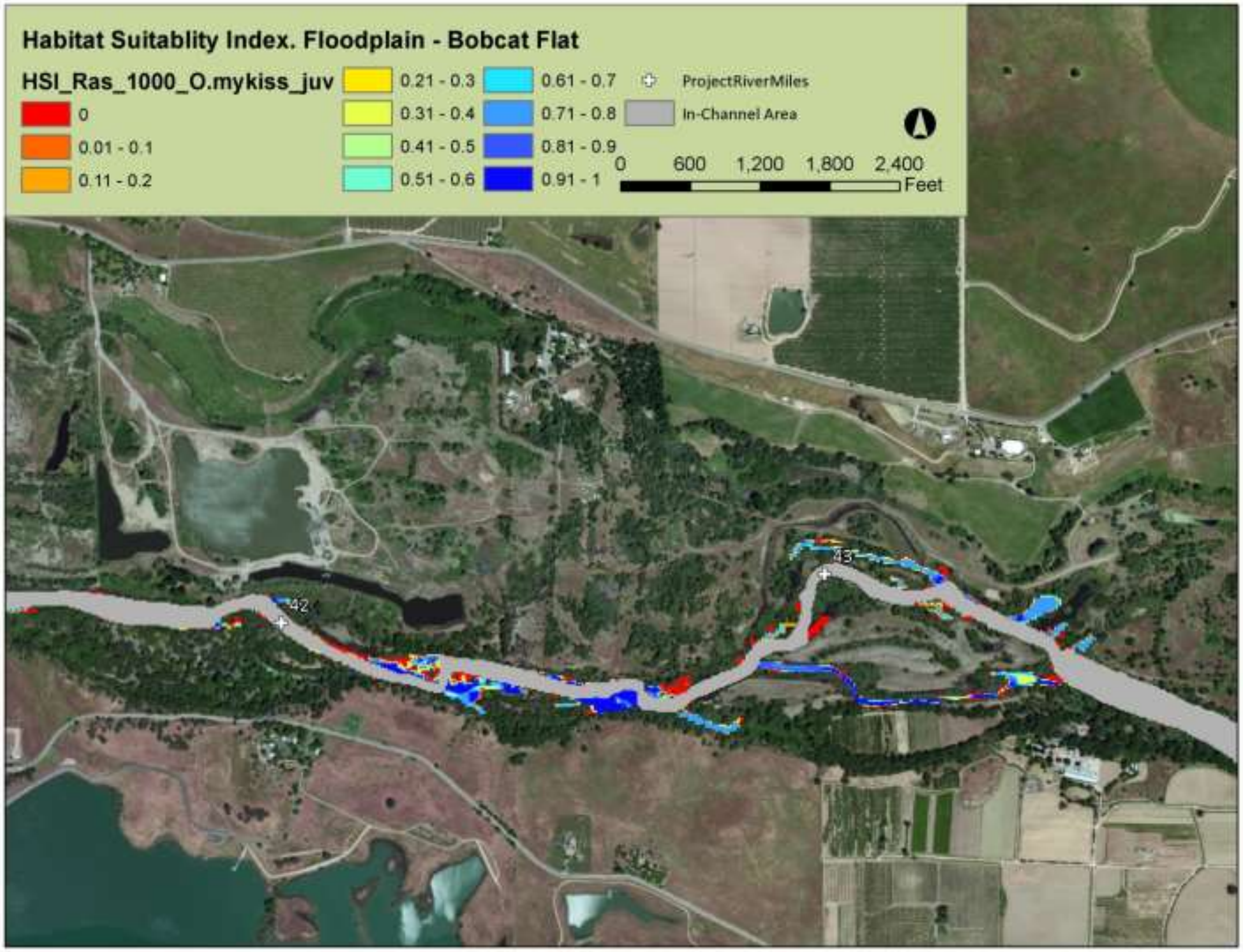

Figure 64. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 1,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

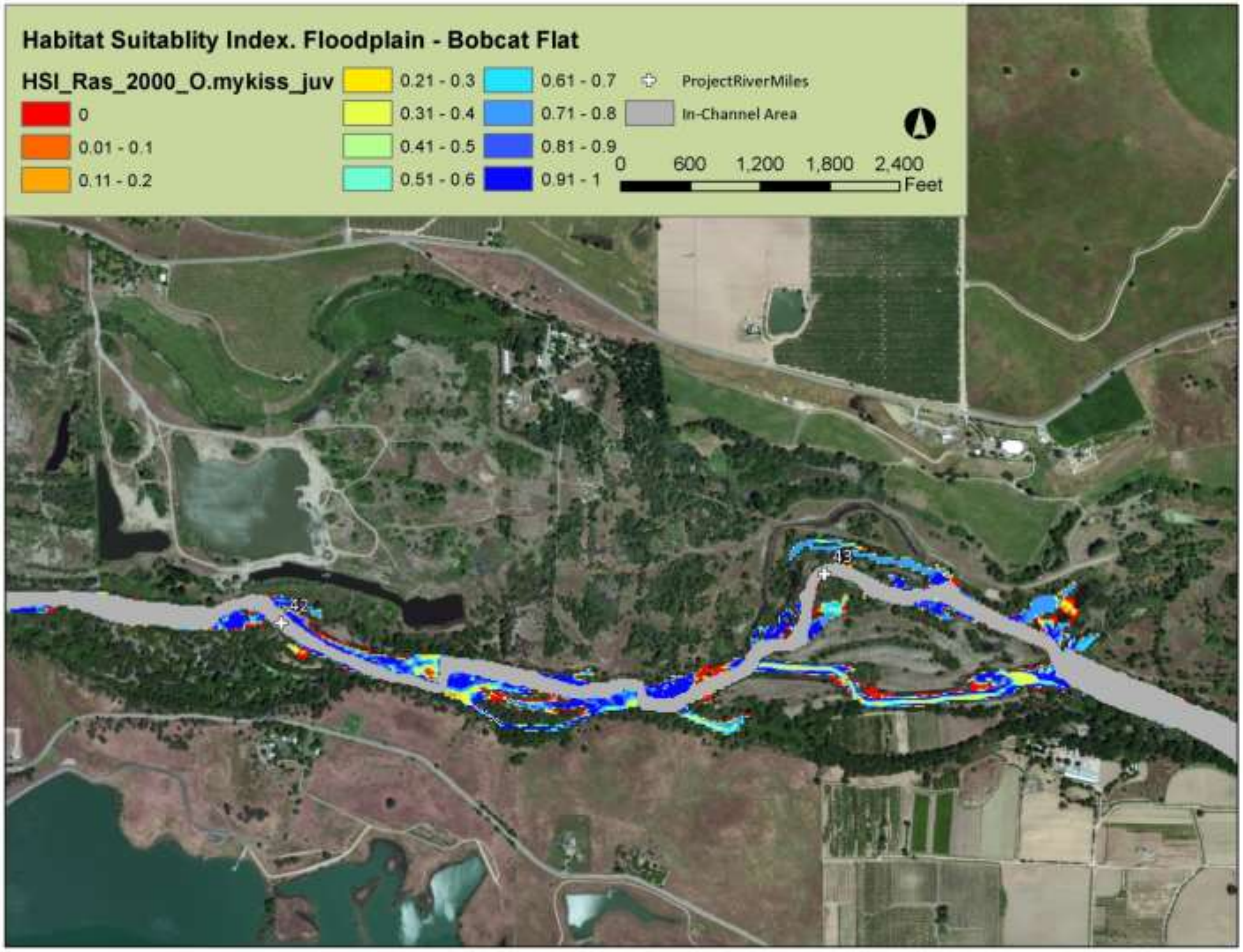

Figure 65. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 2,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

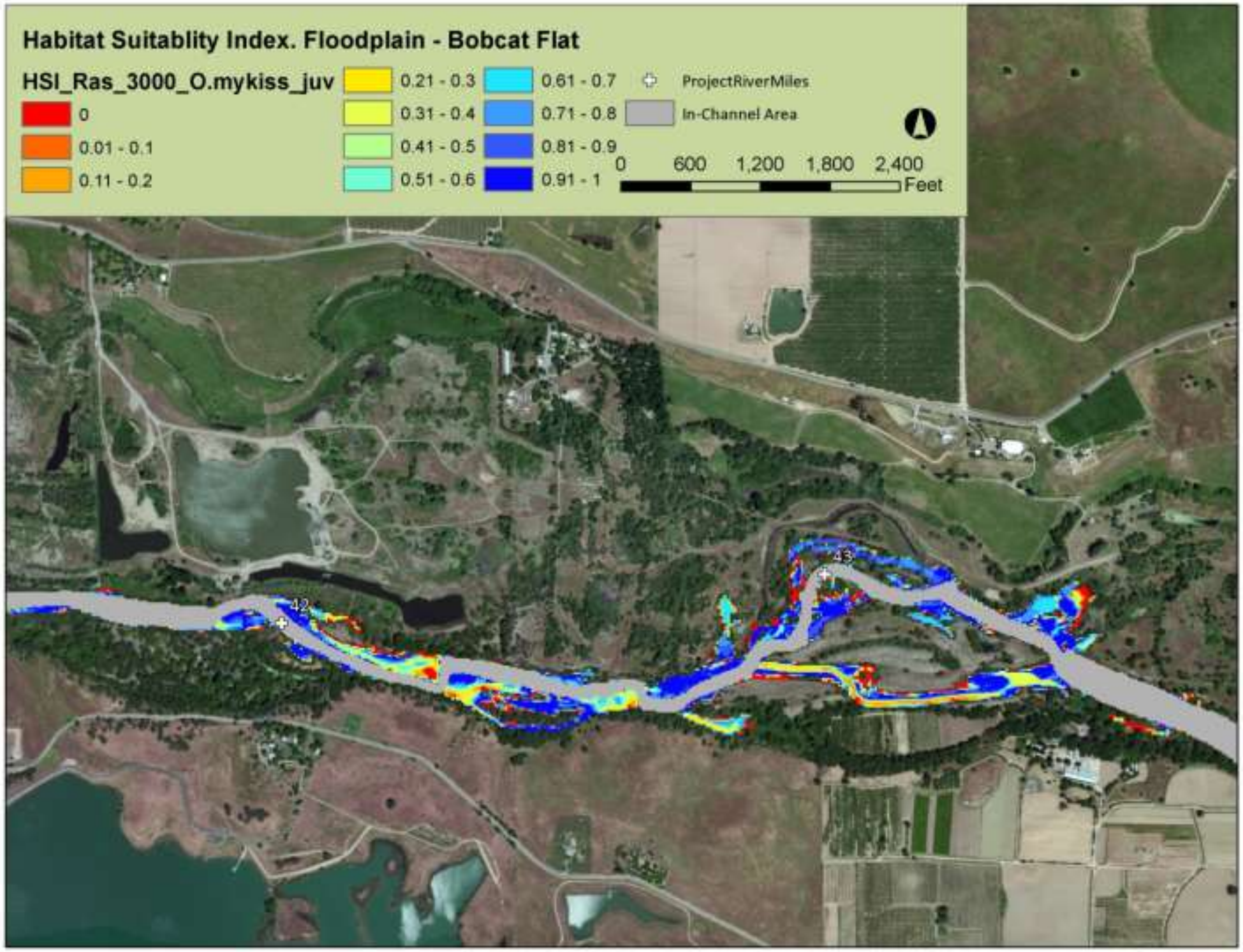

Figure 66. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 3,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

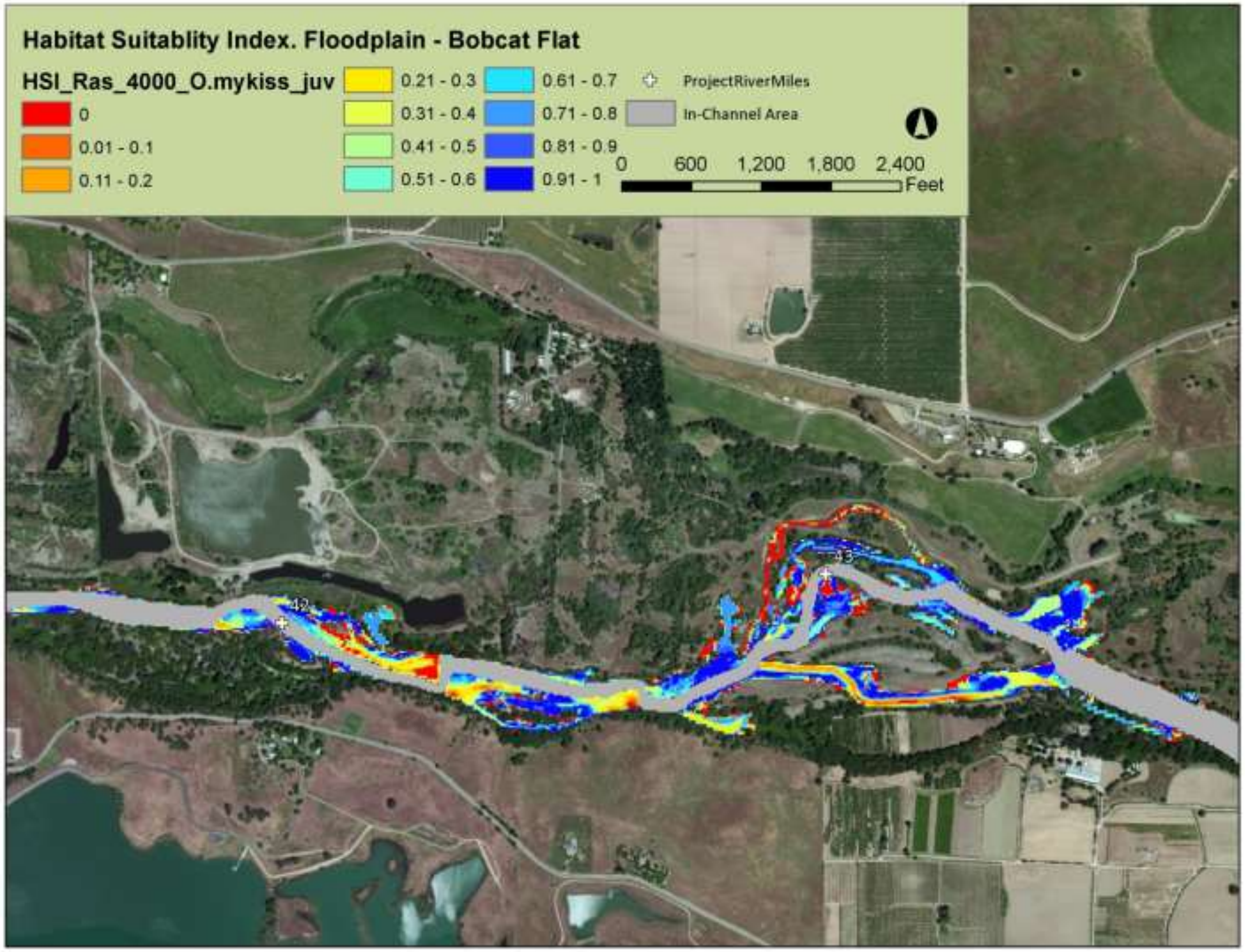

Figure 67. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 4,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

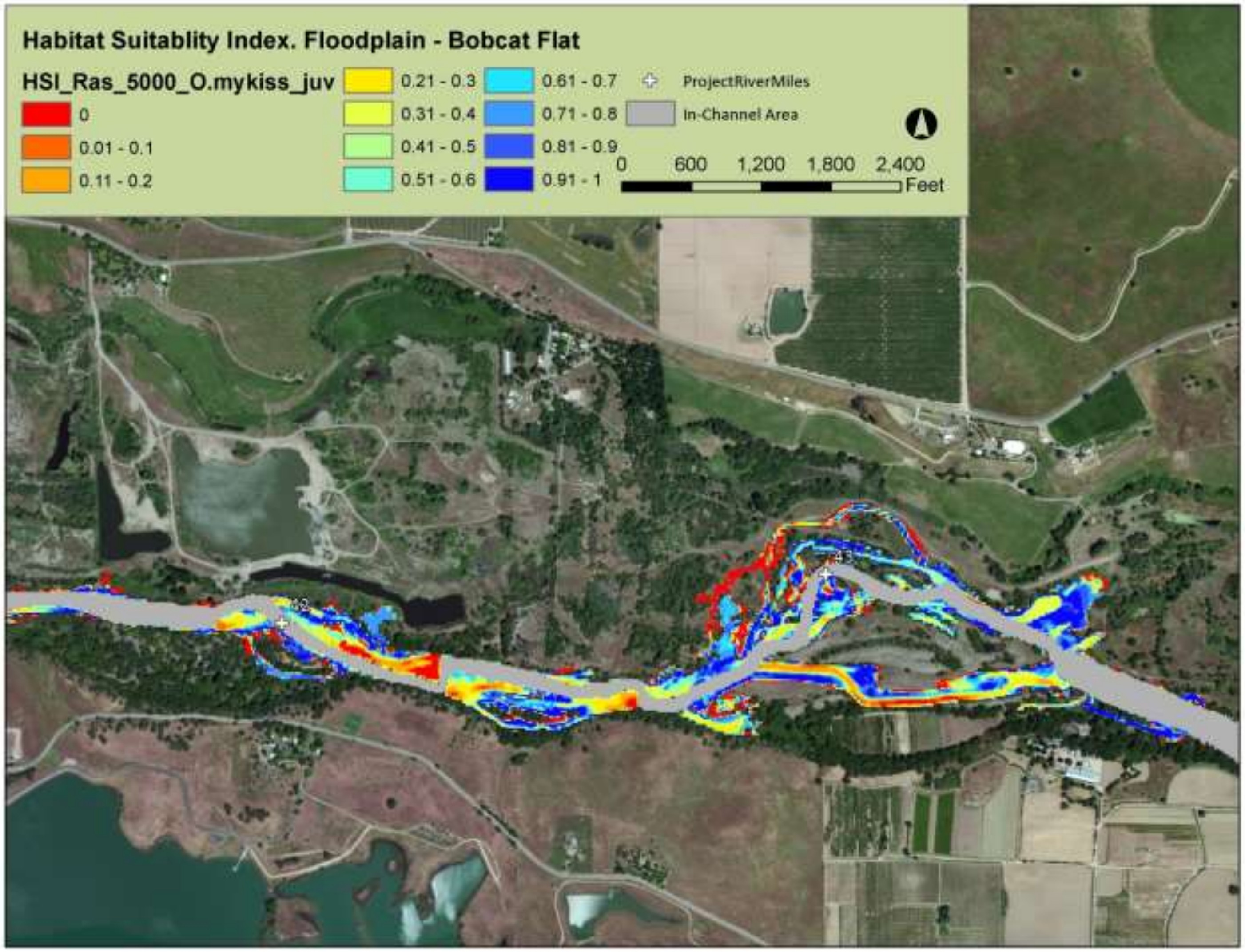

Figure 68. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 5,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

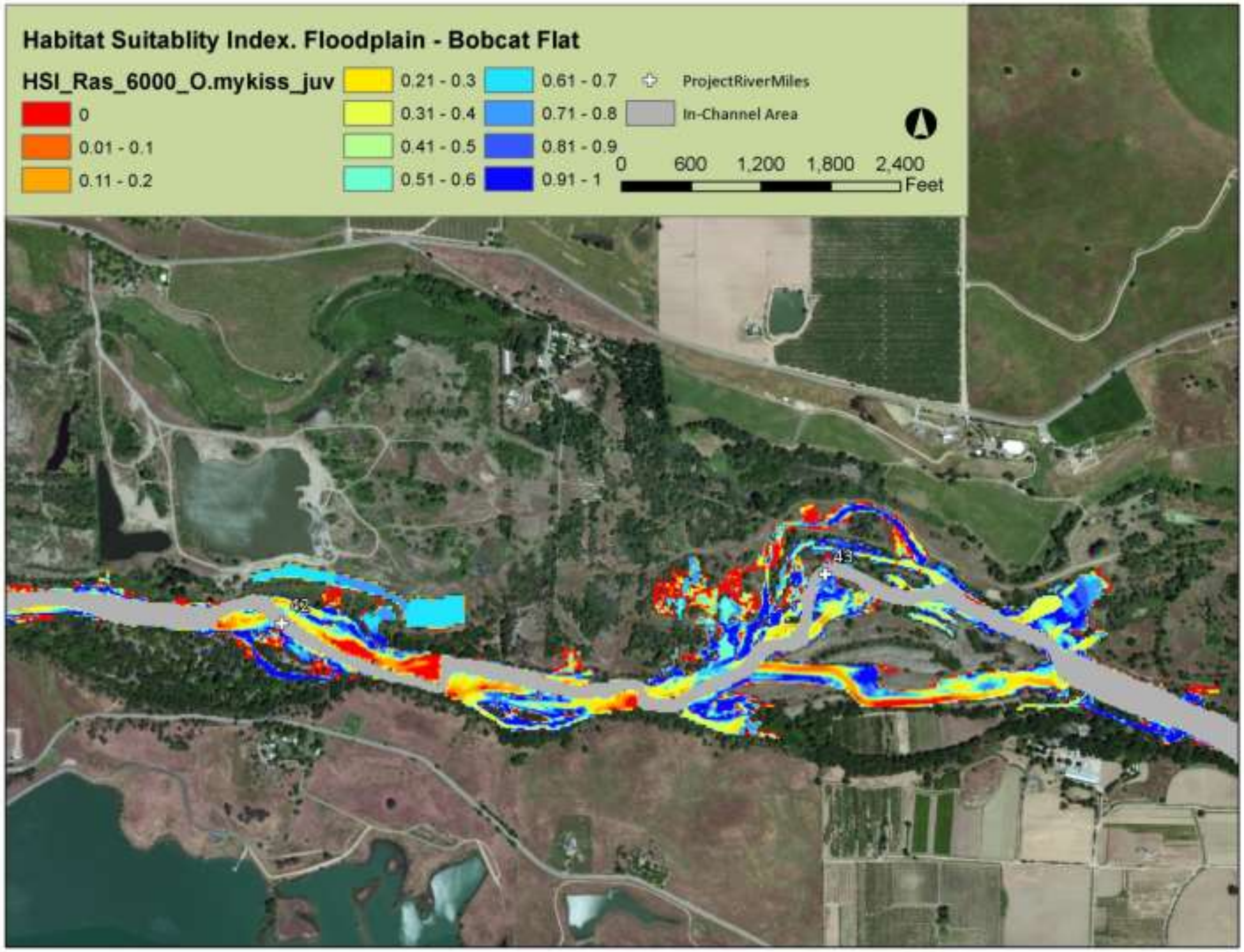

Figure 69. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 6,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

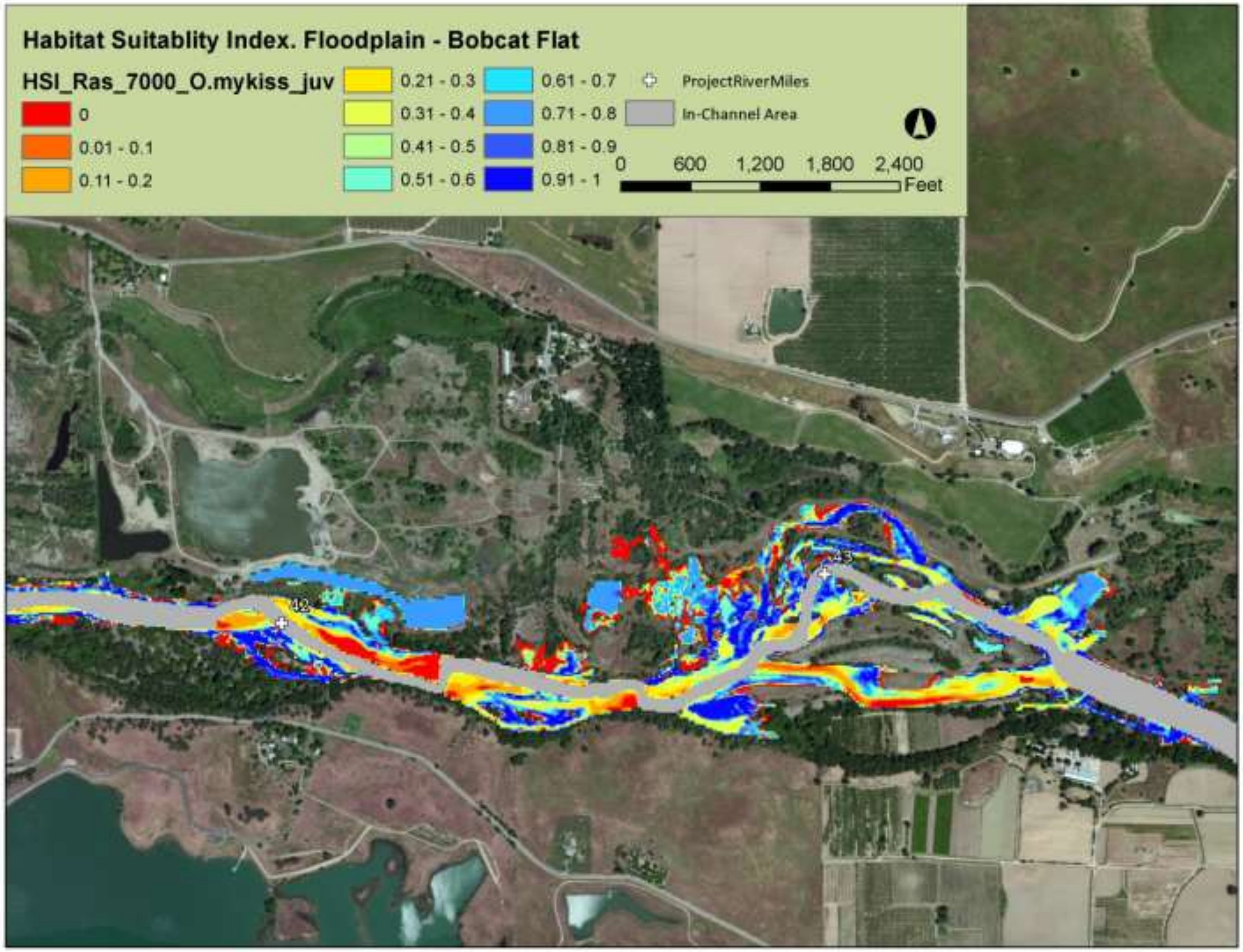

Figure 70. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 7,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

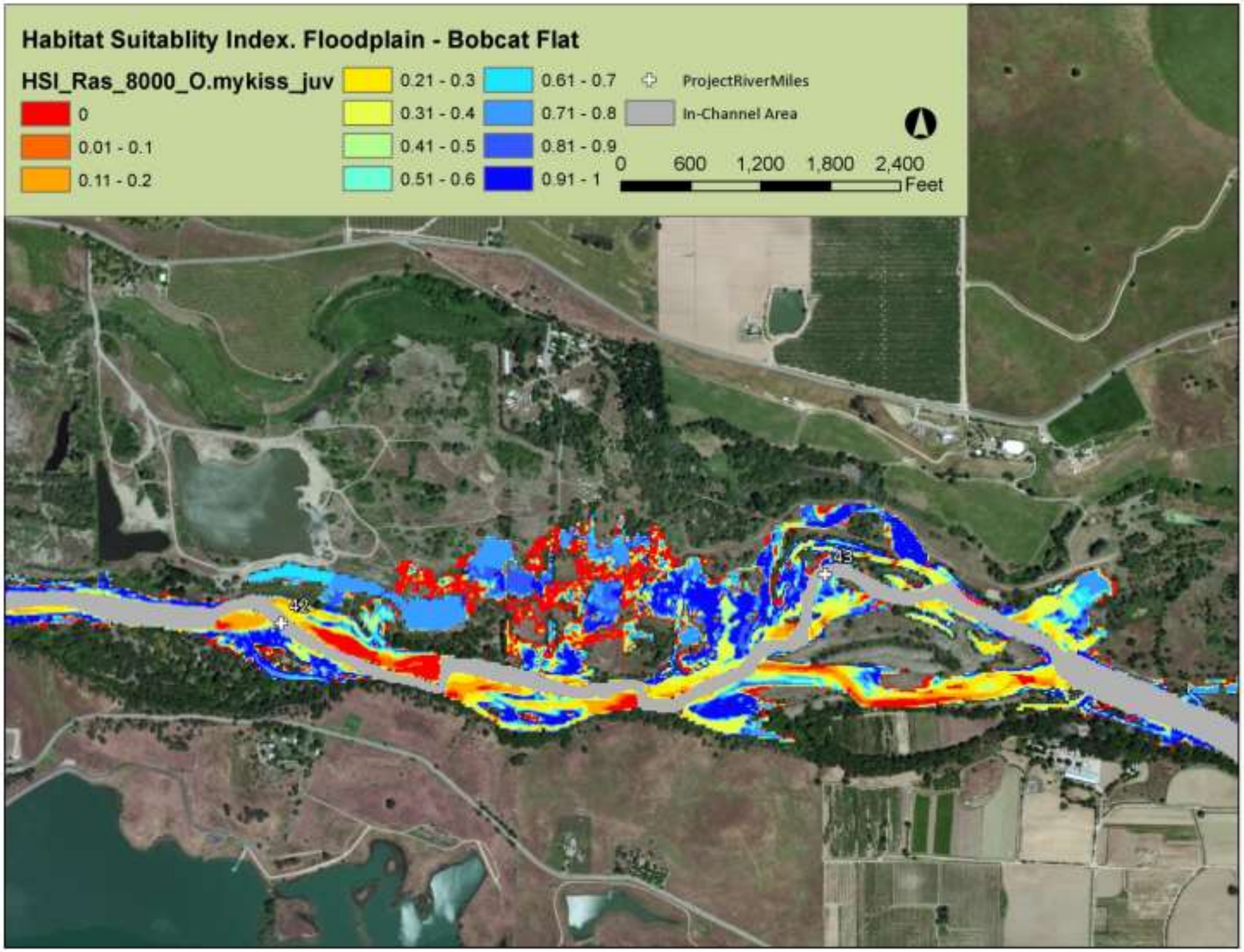

Figure 71. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 8,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.

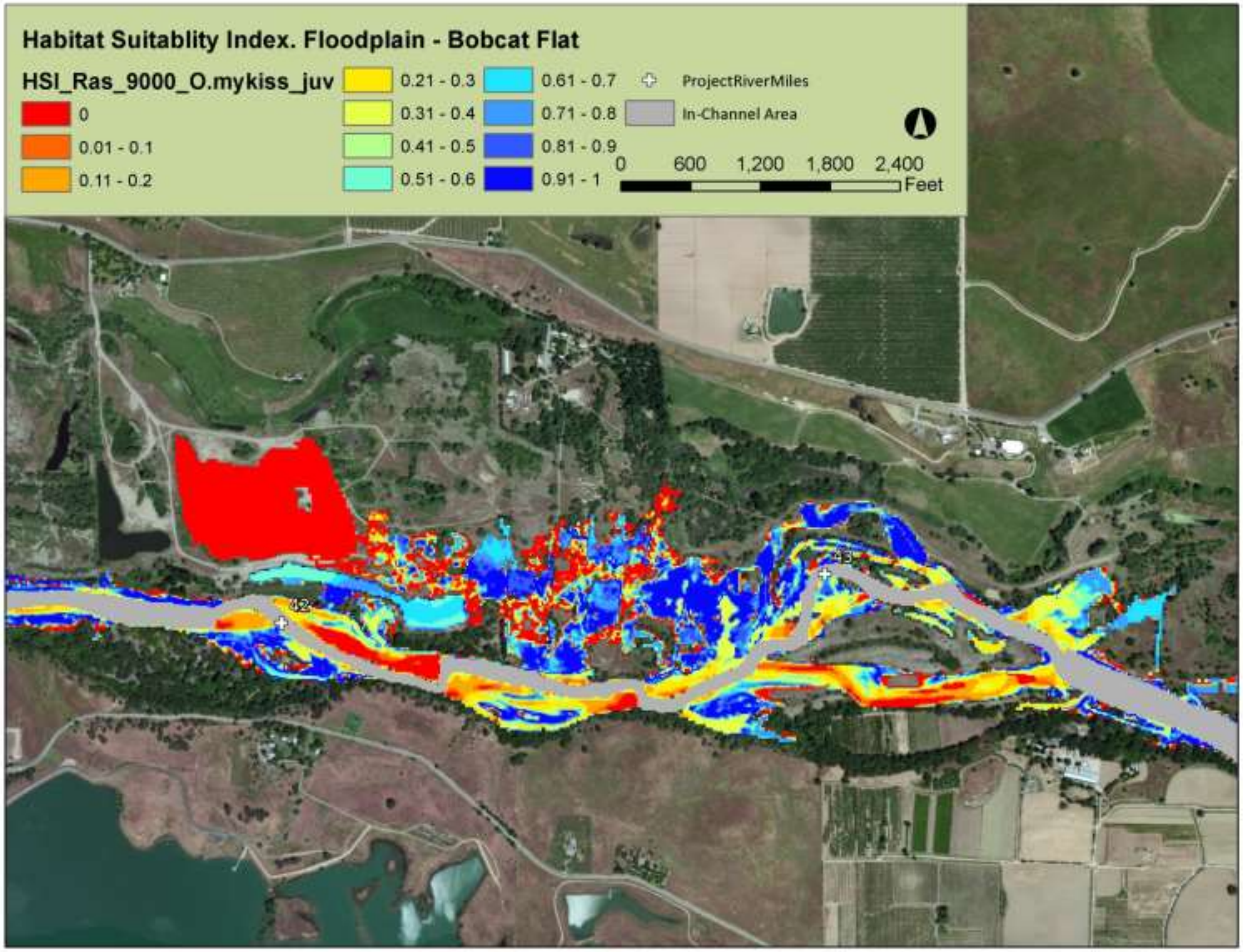

Figure 72. Example plot of joint *O. mykiss* juvenile habitat suitability at modeled floodplain depths and velocities for 9,000 cfs at Bobcat Flat (RM 43) along the lower Tuolumne River.