Appendix A

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

MESOHABITAT TYPES

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

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

BAR COMPLEX VS. FLAT WATER

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

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

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

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

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

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

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

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

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

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

Appendix B

Photos of River2D Study Sites in the Stanislaus River

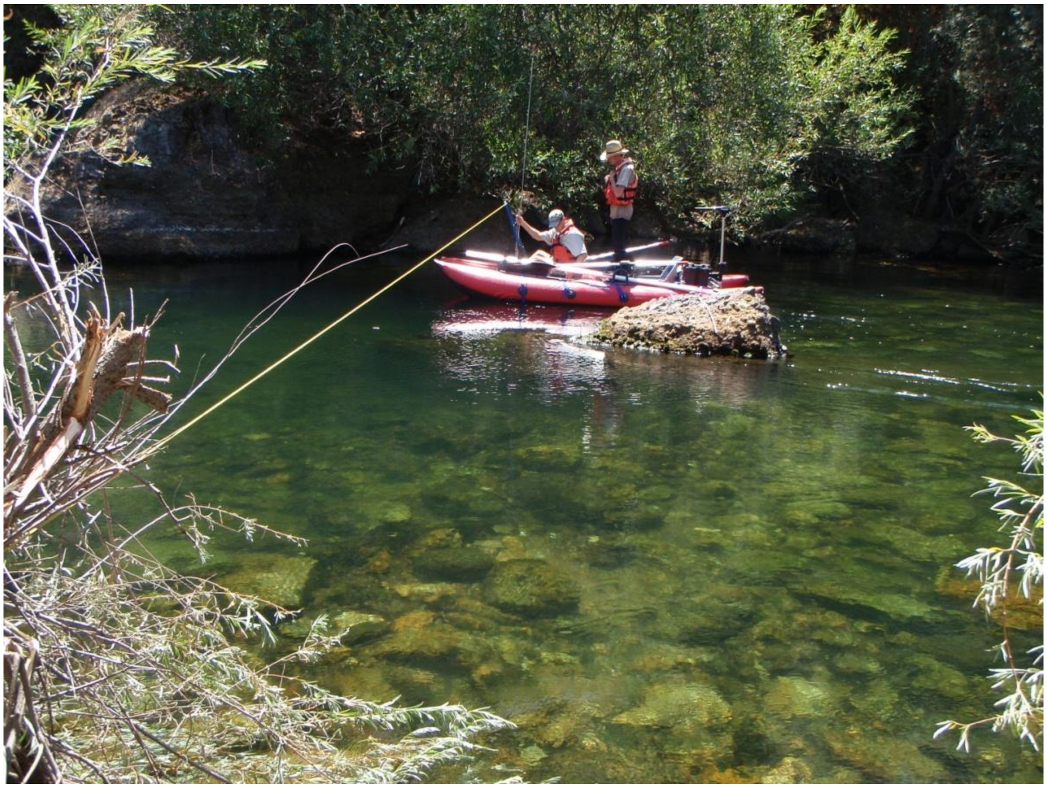

Photo B-1.—Study Site A – Two-mile Bar – lower boundary.

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

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

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

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

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

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

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

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

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

Appendix B

Photos of River2D Study Sites in the Stanislaus River

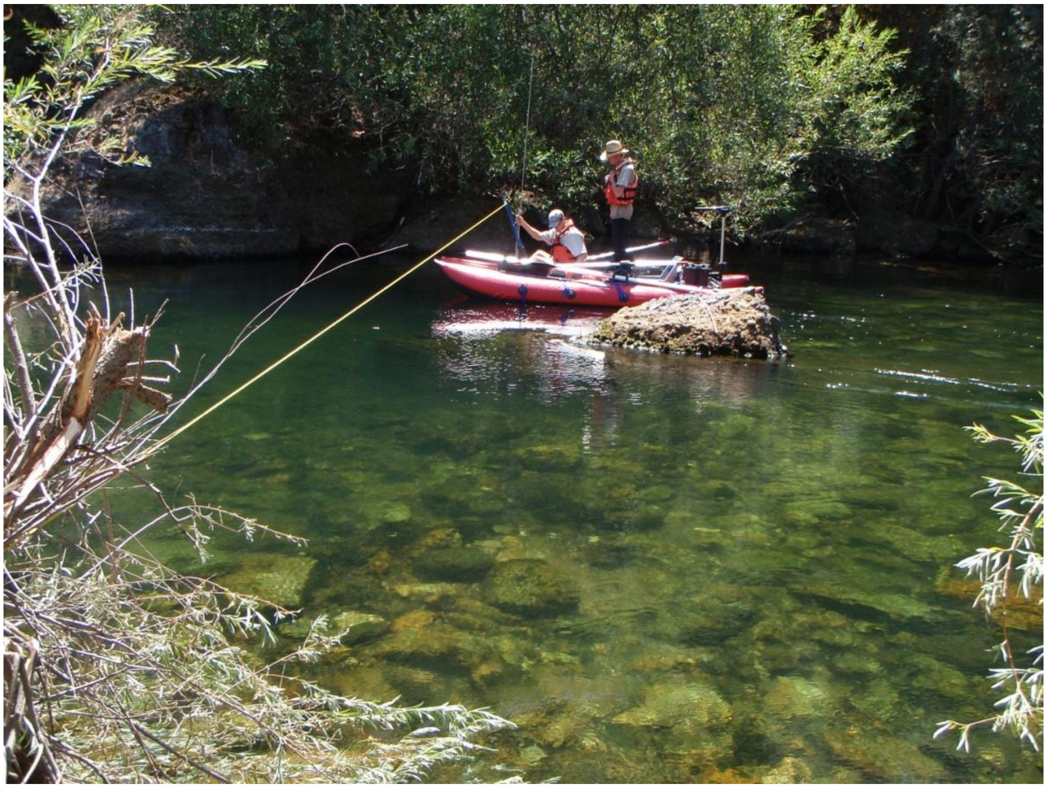

Photo B-1.—Study Site A – Two-mile Bar – lower boundary.

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

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

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

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

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

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

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

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

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

Appendix C

River2D Study Control Points

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

(Note: elevations not corrected)

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

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

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

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

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

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

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

Appendix D

Habitat Suitability Criteria

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

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

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

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

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

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

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

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

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

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

Appendix E

GIS Spatially Explicit Study Methodology

Prepared by Rob Hilldale, Bureau of Reclamation

CONTENTS

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HYDRAULIC MODELING FOR HABITAT SUITABILITY

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

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

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

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

Primary Objective

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

SRH-2D

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

Survey Data

Airborne LiDAR and Photogrammetry

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

Bathymetry Data Collection

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

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

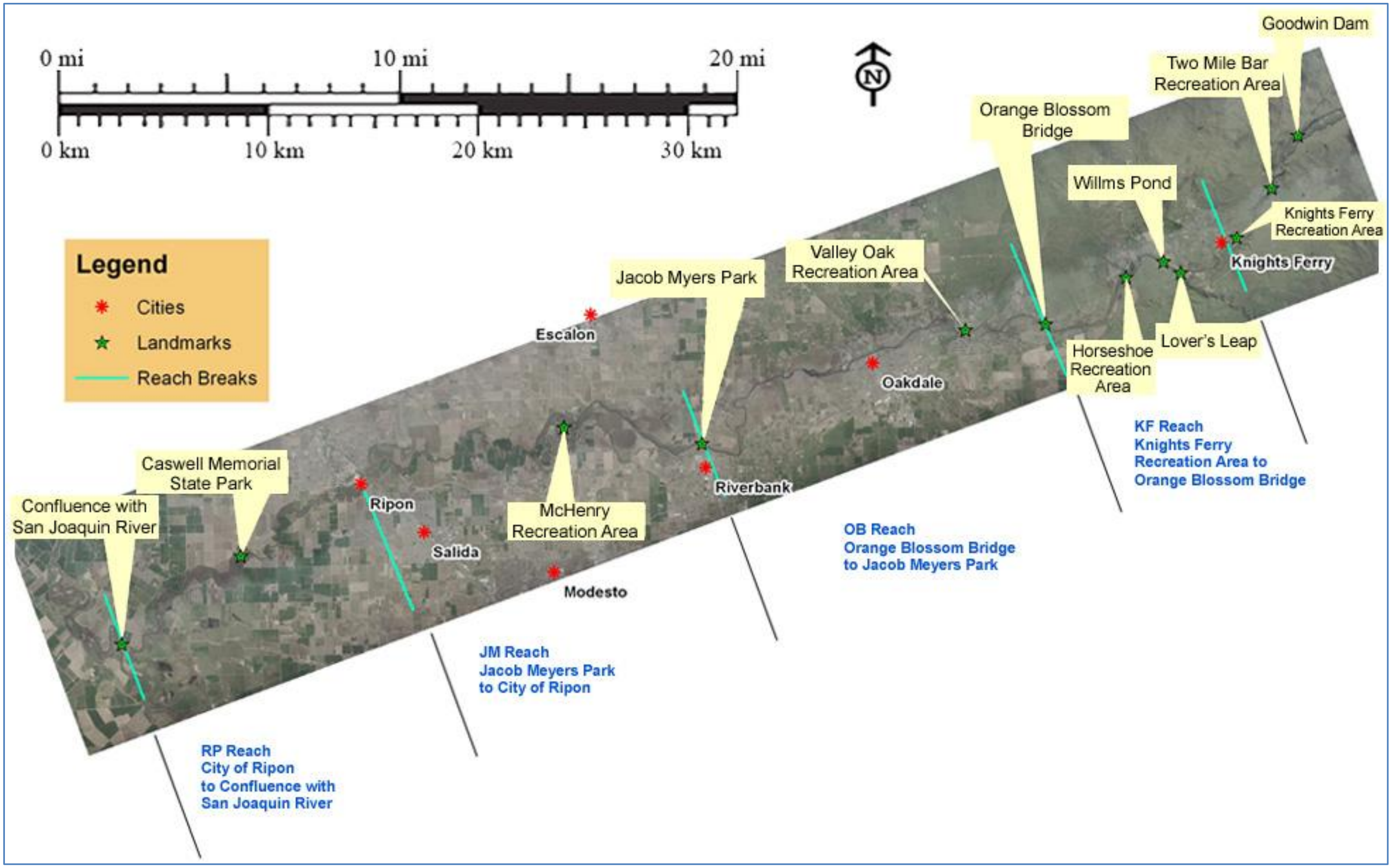

Figure E-1.—Overview of the lower Stanislaus River below Goodwin Dam. The study reach begins at Knights Ferry Recreation Area and ends at the San Joaquin River at Two Rivers Park.

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

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

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

Reclamation Hydrographic Surveys

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

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

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

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

Survey Control and Ground Truth Surveys

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

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

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

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

Supplemental Survey Data for Woody Debris

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

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

Bed Material Description

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

Modeling Methodology

Reach Delineations

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

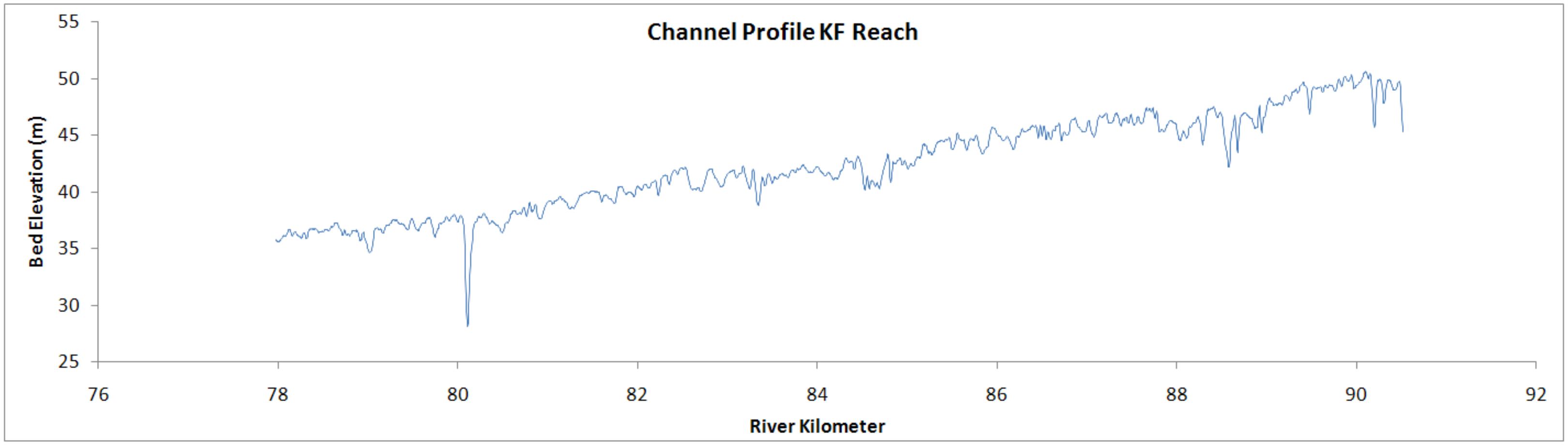

Figure E-5.—Longitudinal profile of the Knights Ferry reach. This is not a thalweg profile.

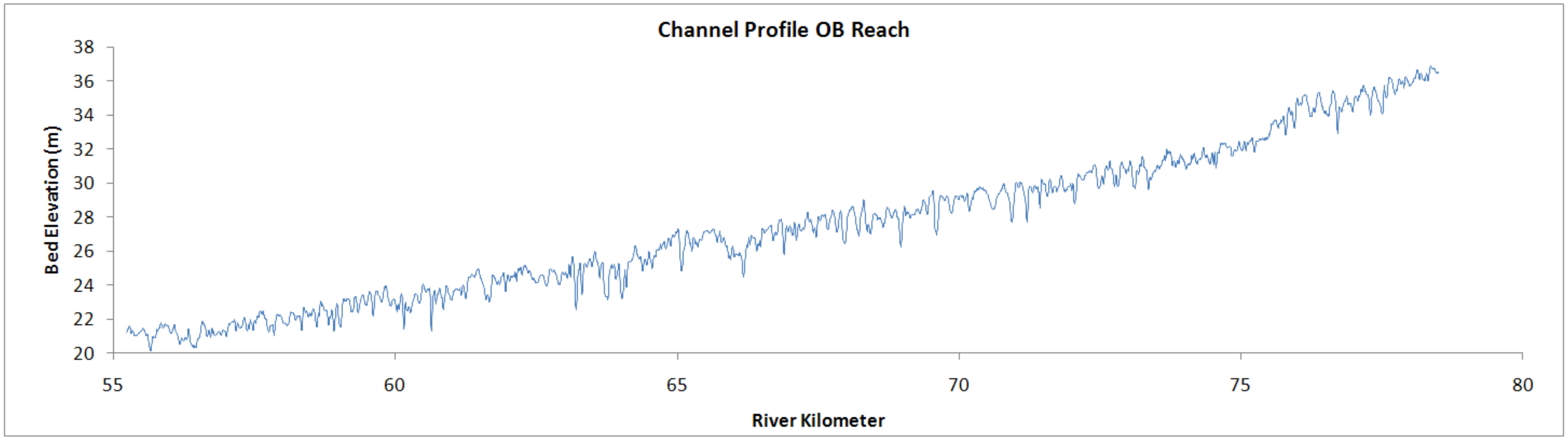

Figure E-6.—Longitudinal profile of the Orange Blossom reach. This is not a thalweg profile.

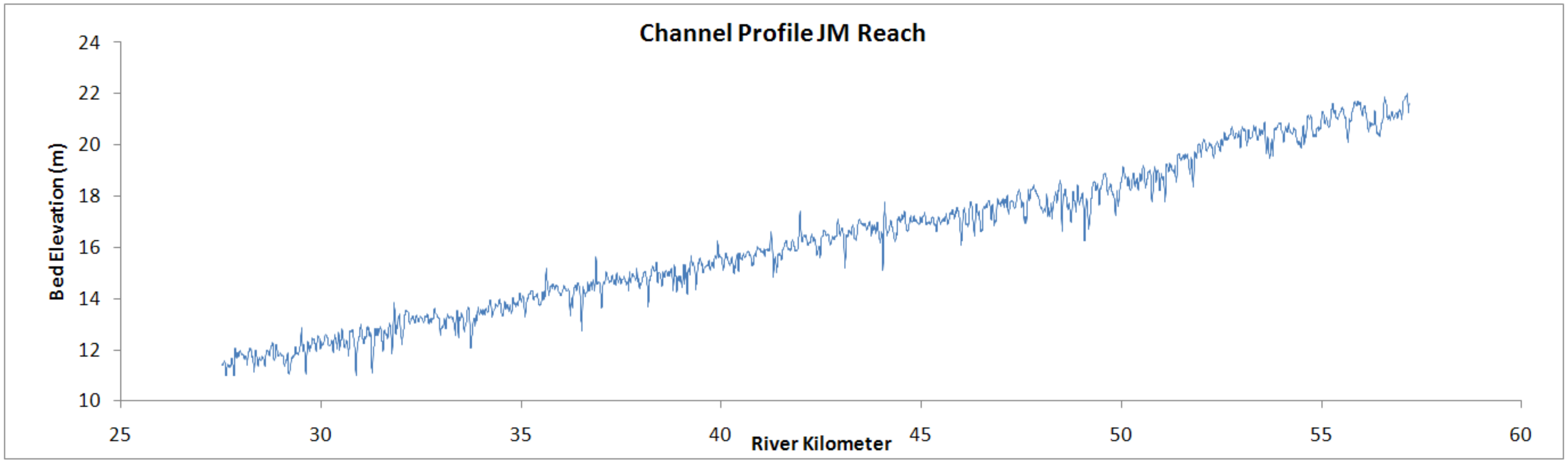

Figure E-7.—Longitudinal profile of the Jacob Meyers reach. This is not a thalweg profile.

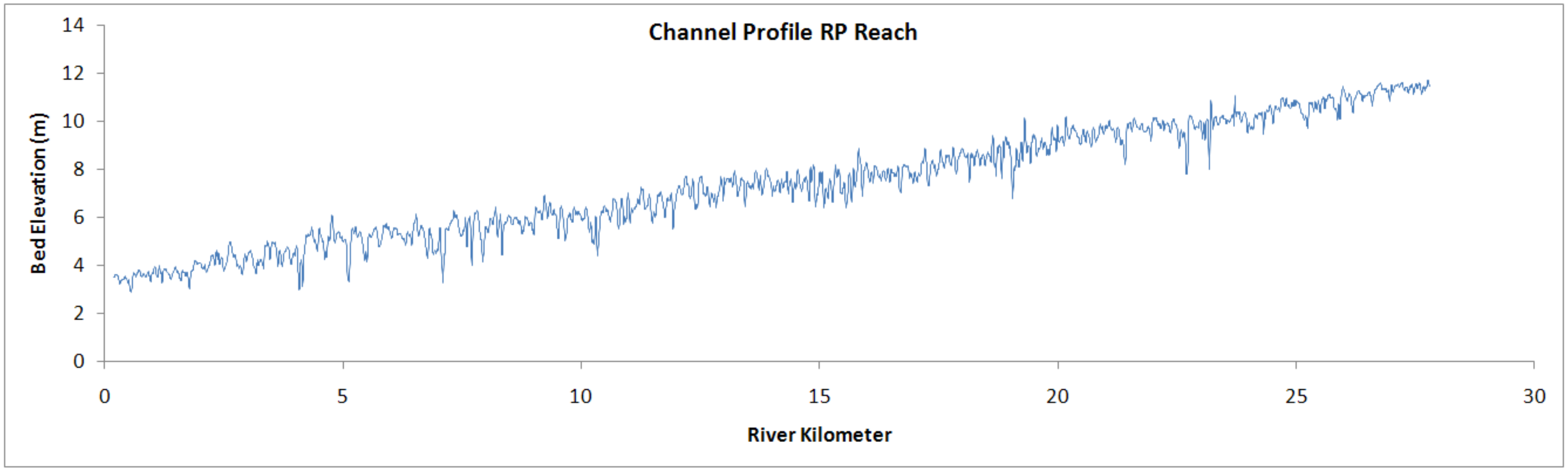

Figure E-8.—Longitudinal profile of the Ripon reach. This is not a thalweg profile.

Digital Elevation Model Development

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

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

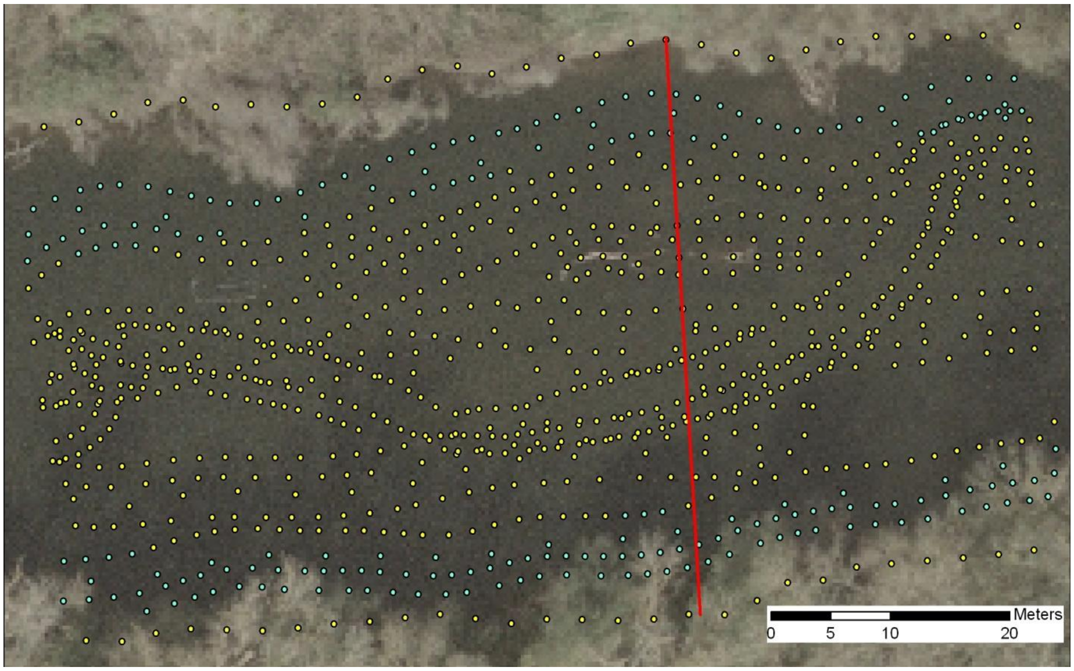

Figure E-9.—Example of the two data sets used for testing the interpolation scheme. The blue points near the channel margins were removed from the analysis and compared to an analysis using all the points. The red line marks the location of the cross section that was used to visually compare the results.

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

Generating the Computational Mesh

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

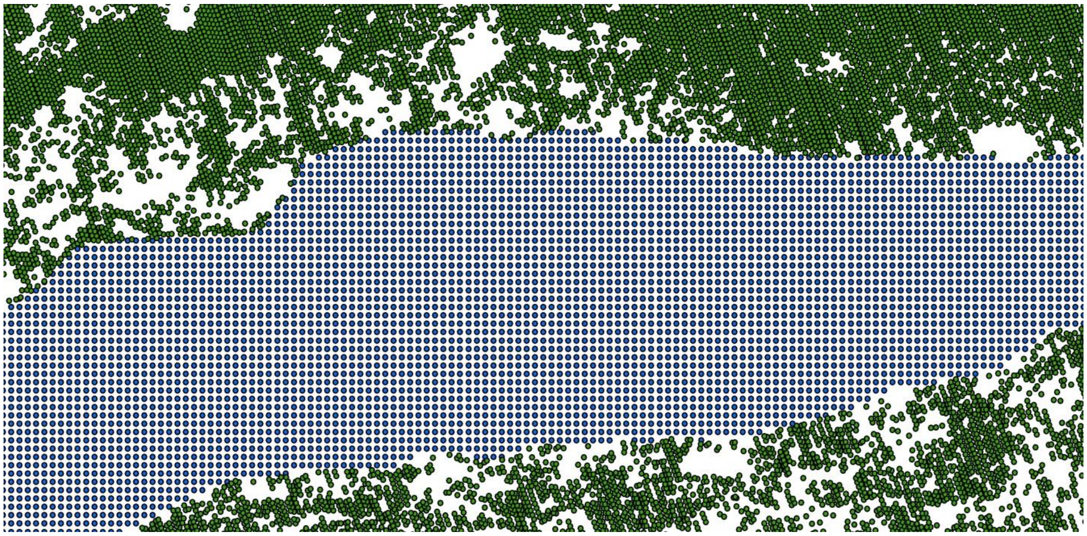

Figure E-10.—Example of the point data used to construct the terrain in Arc GIS. Green points are bare earth LiDAR and blue points are derived from the raster (1 m spacing) created with the SONAR survey data.

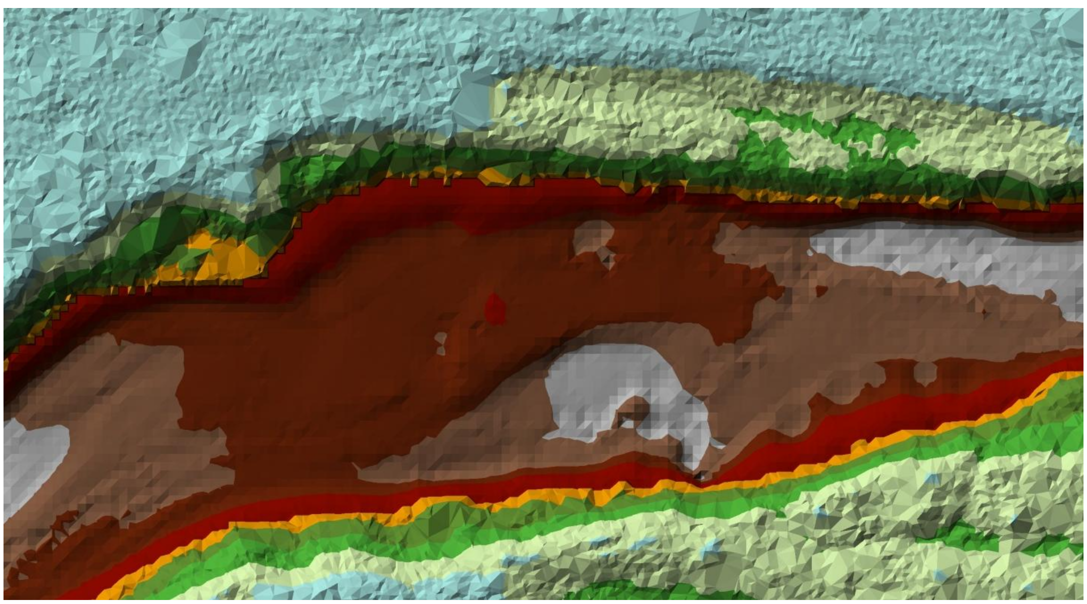

Figure E-11.—Example of the terrain resulting from the point data shown in figure E-10.

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

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

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

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

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

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

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

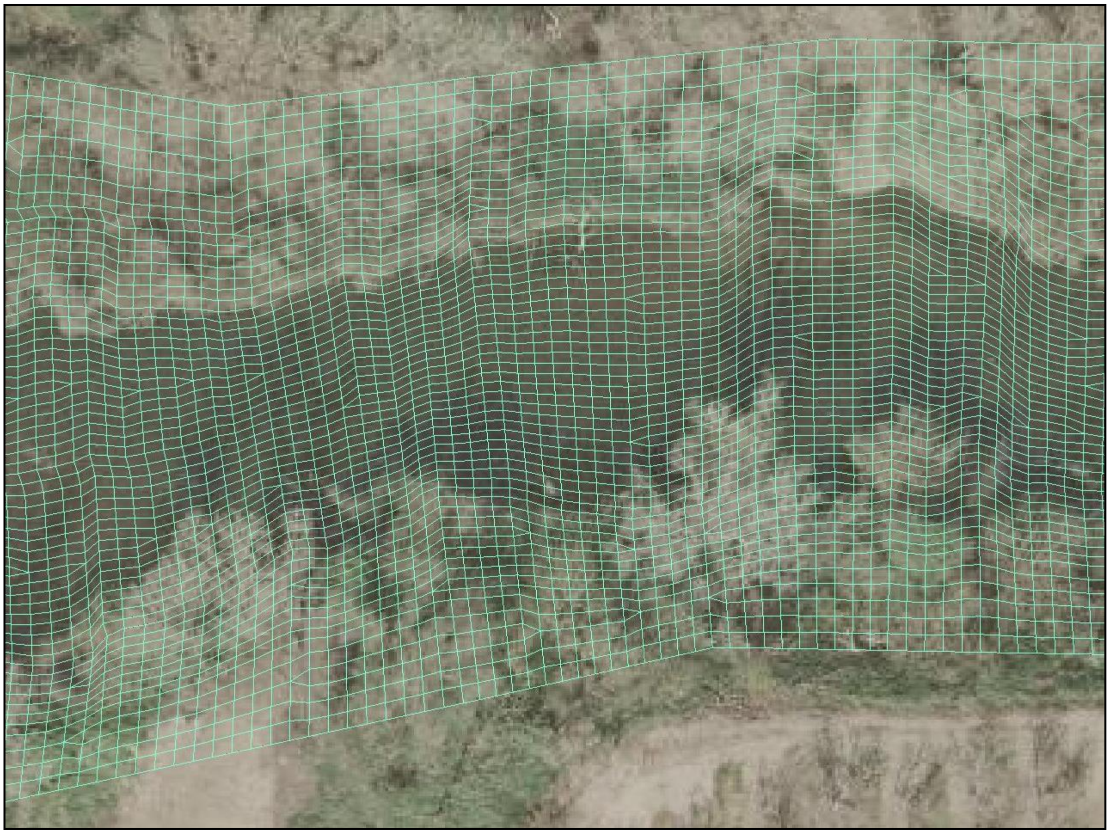

Figure E-12.—Example of the modeling mesh in the OB reach.

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

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

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

Modeling Details

Model Parameters and Boundary Conditions

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

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

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

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

Analysis of Potential Model Uncertainties

Sensitivity to Roughness

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

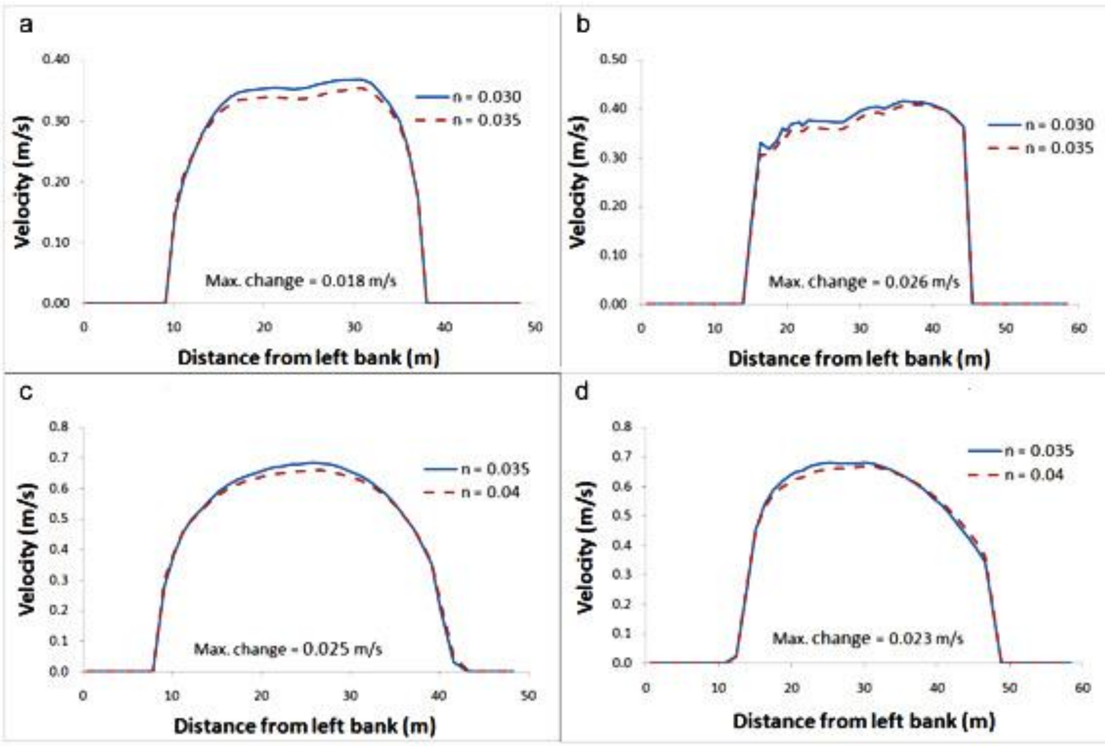

Figure E-14.—Velocity sensitivity to changes in Manning's *n* at two cross sections: (a) cross section 1 (RK 79.4), 7.8 m^3/sec (275 cfs); (b) cross section 2 (RK 80.0), 7.8 m^3/sec (275 cfs); (c) cross section 1 (RK 79.4), 37.9 m^3/sec (1,338 cfs); (d) cross section 2 (RK 80.0), 37.9 m^3/sec (1,338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

Mass Conservation Checks

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

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

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

Representation of Eddies

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

Model Calibration and Validation

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

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

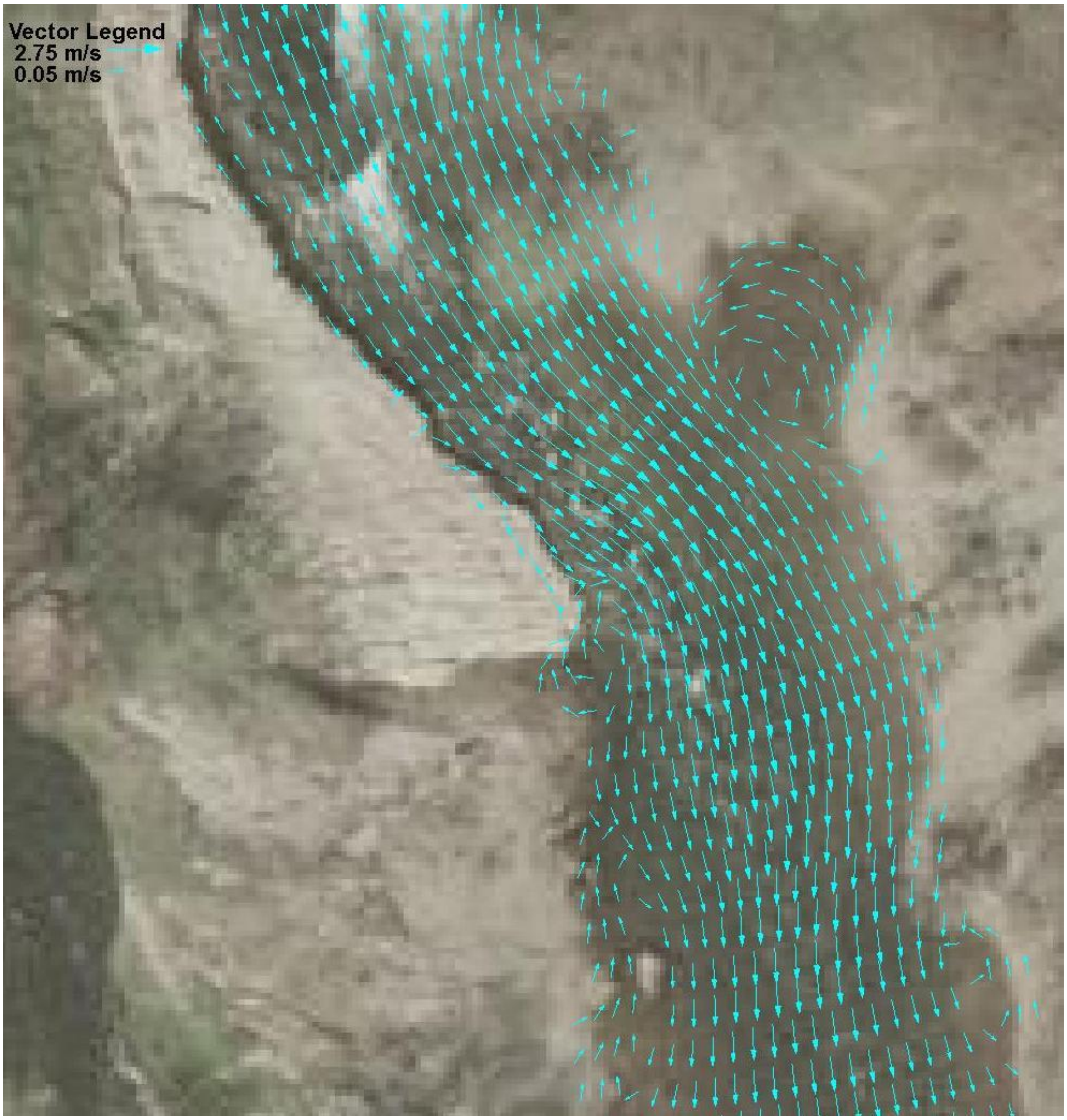

Figure E-15.—Figure displaying the vector representation of eddies in the vicinity of a bedrock outcrop. Discharge is 21.4 m^3/sec (756 cfs).

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

Water Surface Elevation

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

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

Model Validation Using Velocity

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

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

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

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

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

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

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

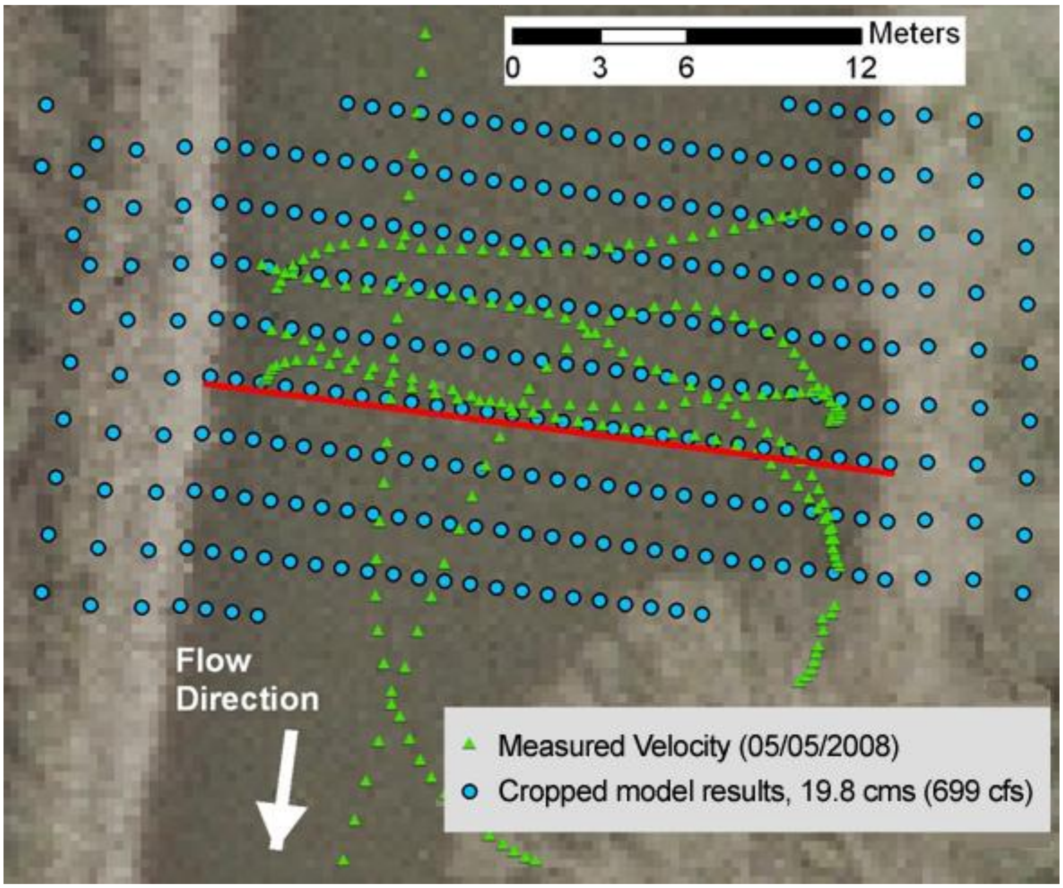

Figure E-16.—Example of velocity data comparison. The red line indicates the points used to obtain cross section data for the comparison.

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

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

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

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

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

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

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

Creating Habitat Value from Model Output

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

Constructing Depth and Velocity Rasters

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

Constructing a Distance to Edge Raster

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

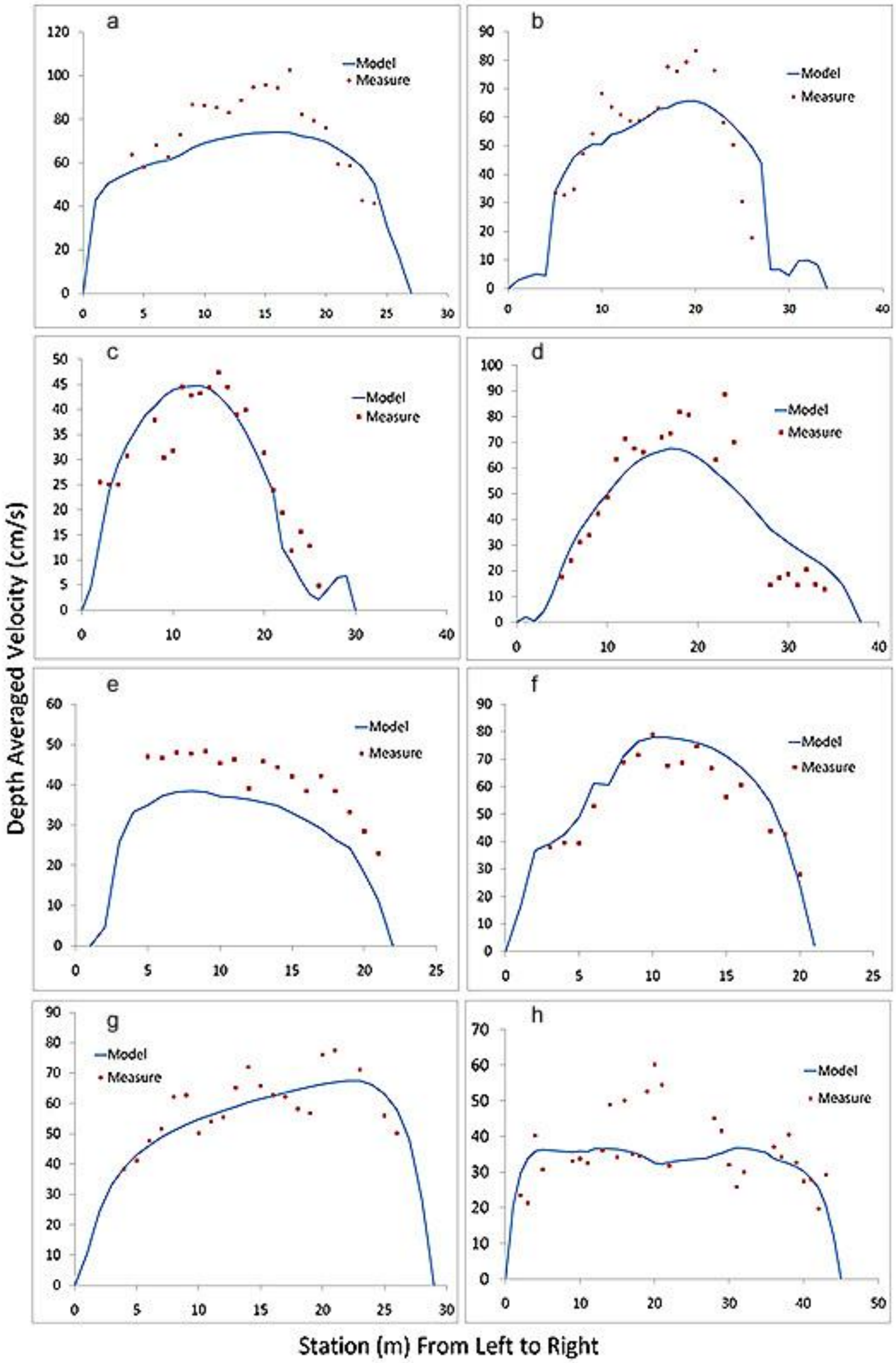

Figure E-17.—Charts of modeled and measured velocity. Values of the mean friction velocity over the measured portion of the cross section are shown: (a) KF segment (RK 89.0), 22.7 m^3/sec (800 cfs); (b) KF segment (RK 78.7), 22.7 m^3/sec (800 cfs); (c) OB segment (RK 77.6), 7.8 m^3/sec (275 cfs); (d)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

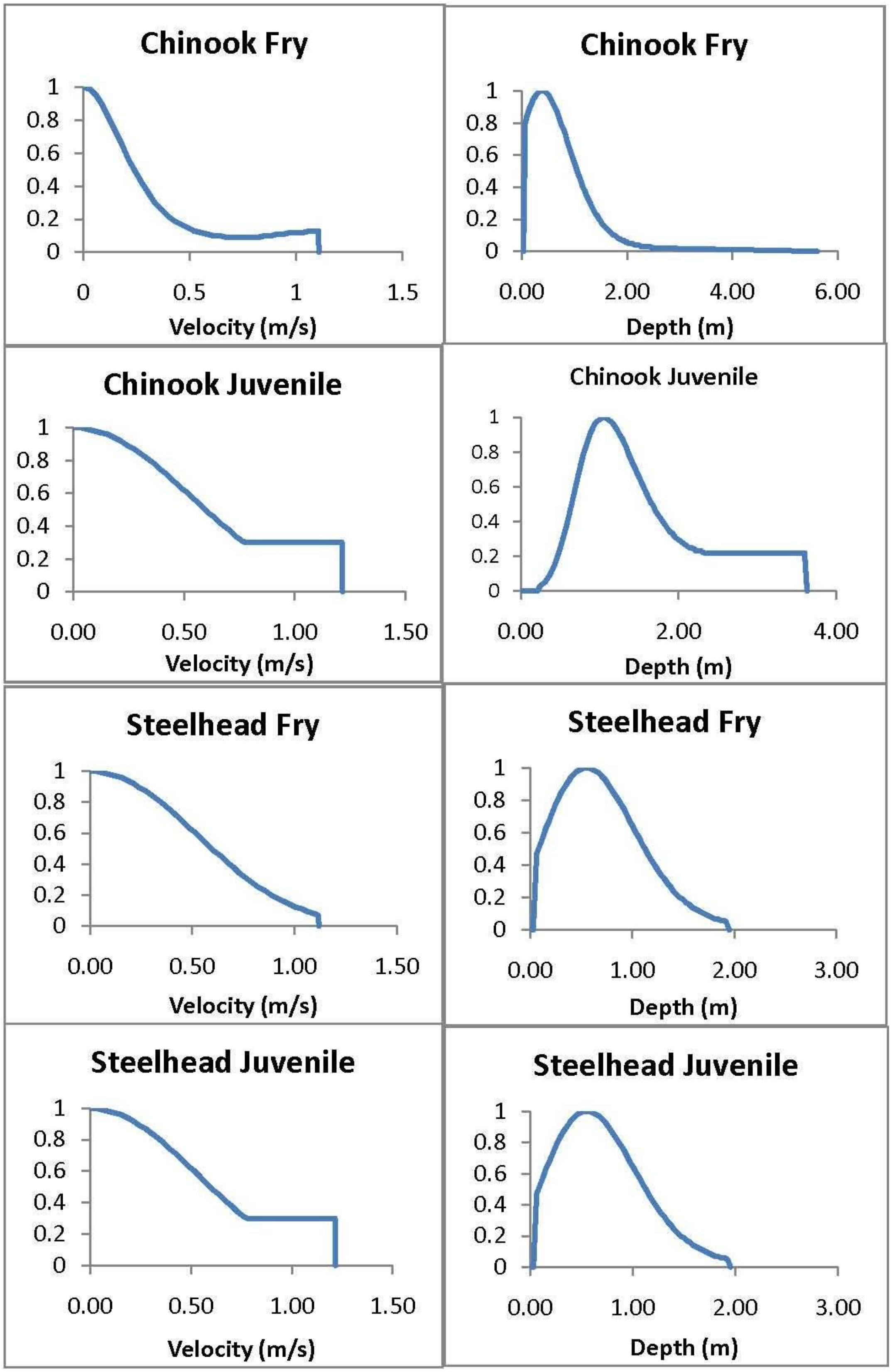

Figure E-18.—Habitat suitability criteria for the Yuba River. Constructed from data in Gard, 2008).

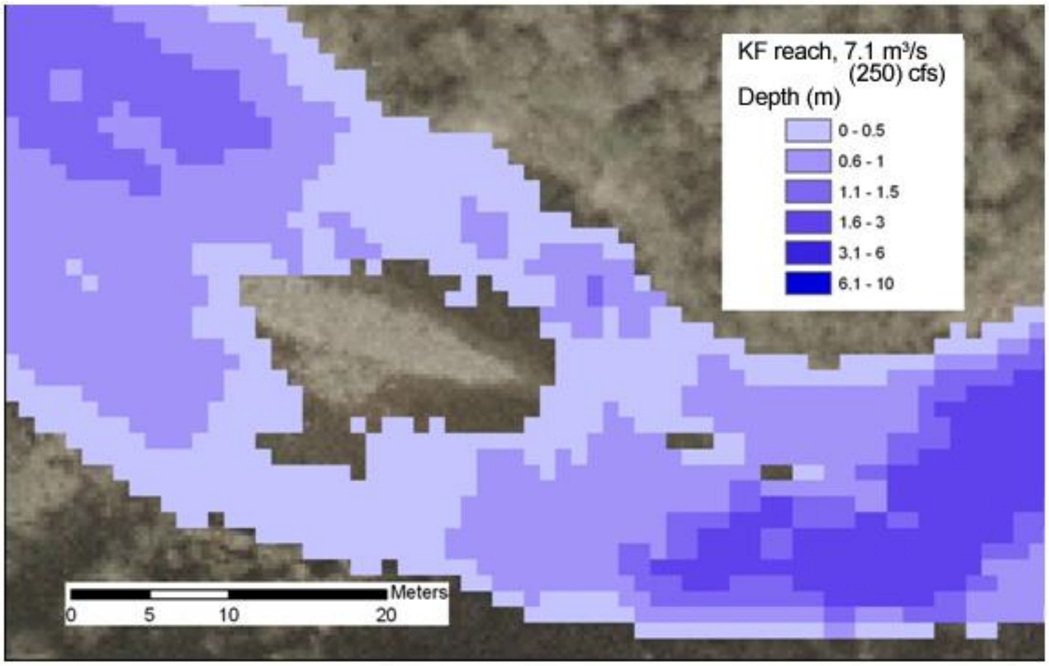

Figure E-19.—Example of a depth raster in the Knights Ferry reach.

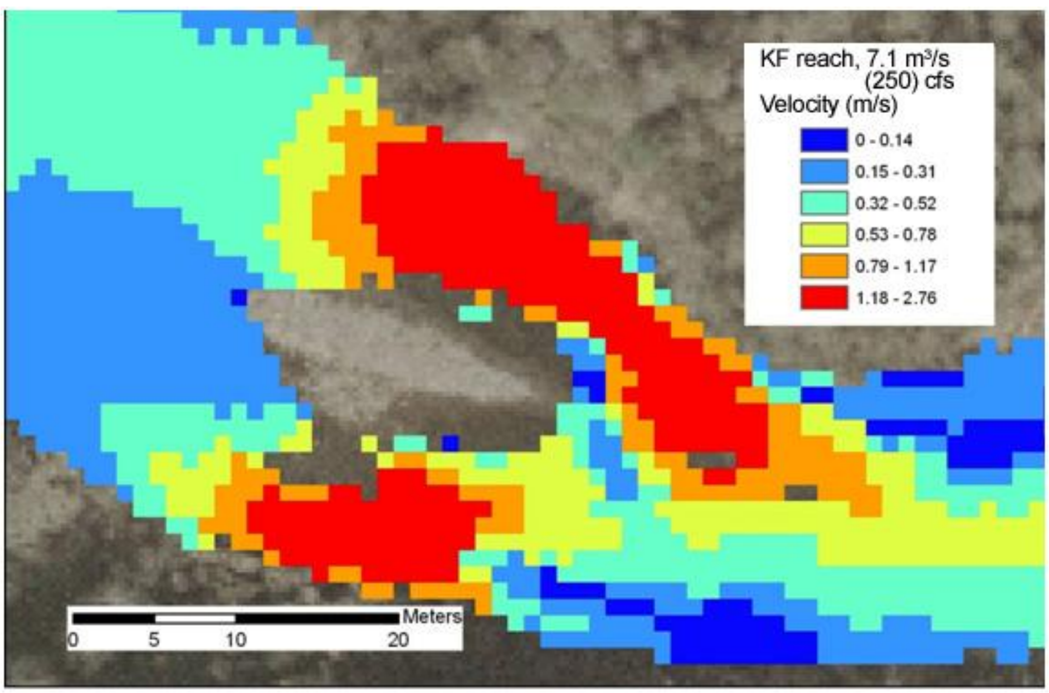

Figure E-20.—Example of a velocity raster in the Knights Ferry reach.

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

Constructing a Velocity Shear Raster

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

In this project the velocity shear is defined as:

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

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

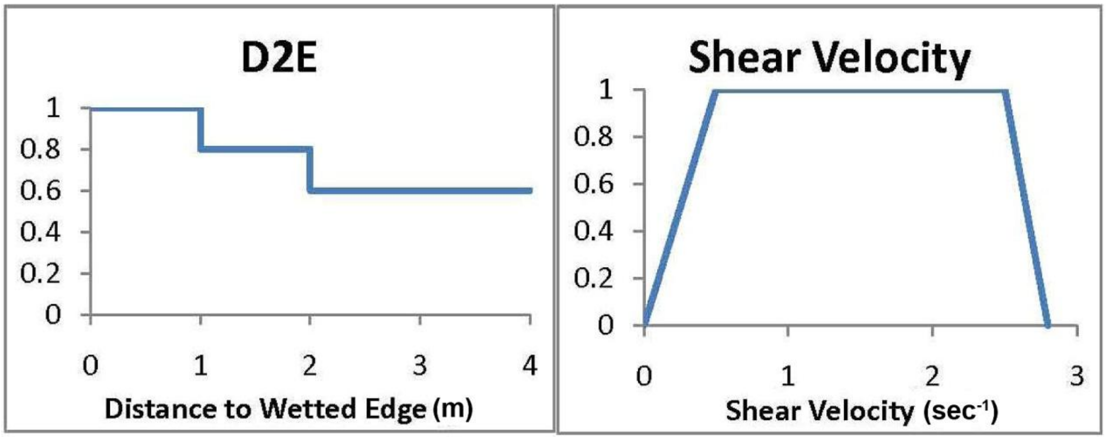

Figure E-21.—Habitat curves developed for this study for Distance to Edge (D2E) and Shear Velocity.

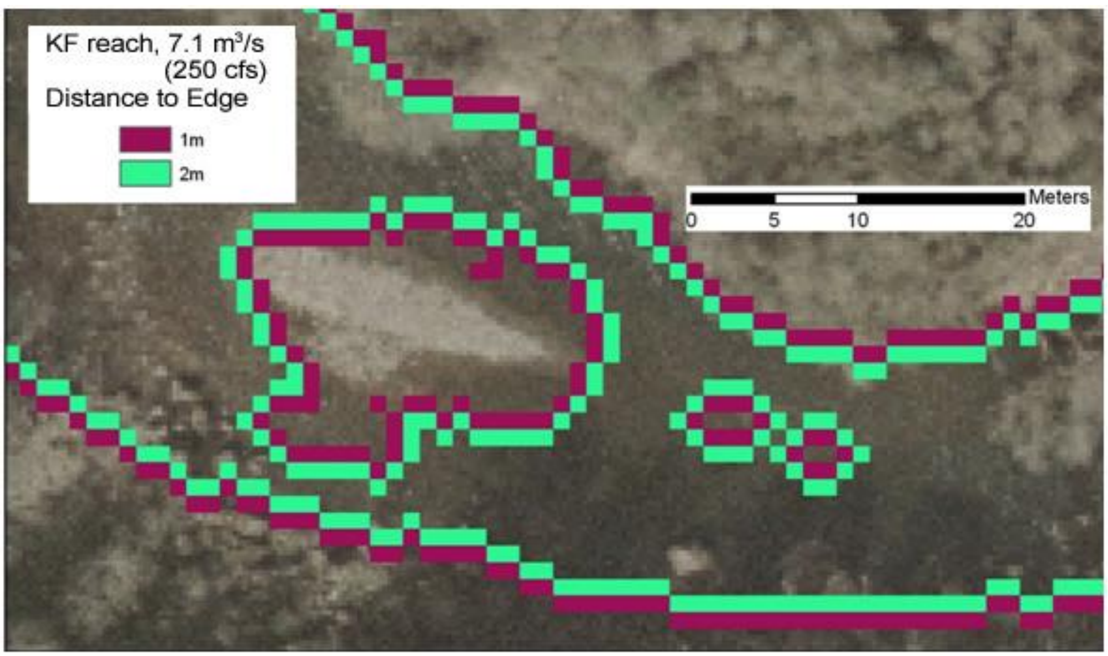

Figure E-22.—Example of a distance to edge raster in the Knights Ferry segment.

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

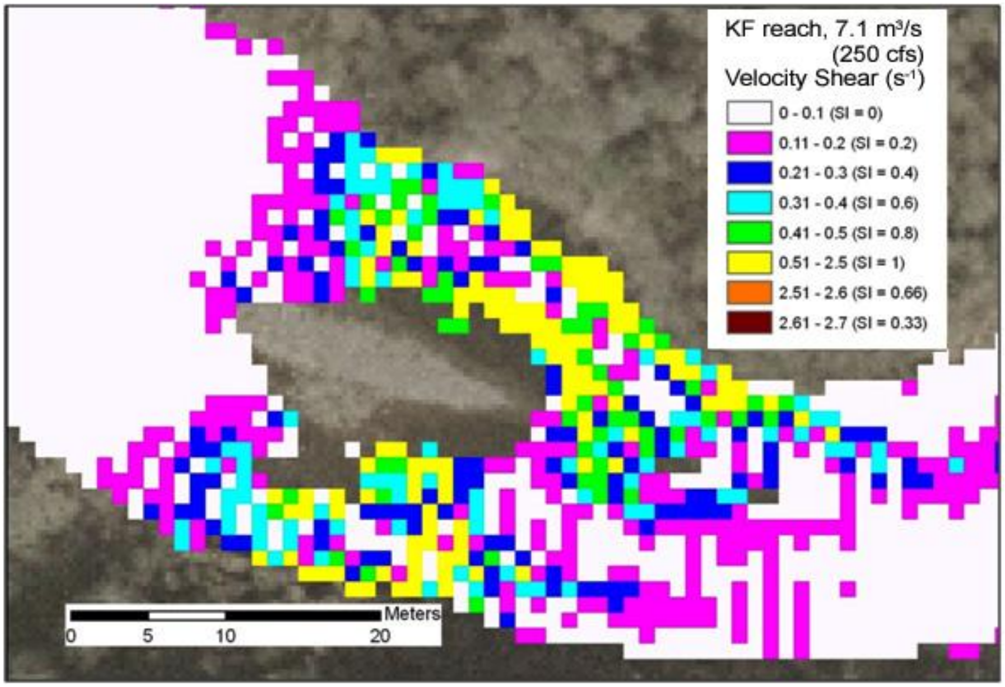

Figure E-23.—Example of a velocity shear raster in the Knights Ferry segment.

Constructing Habitat Suitability Index Rasters for Habitat Analysis

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

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

Discussion

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

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

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

ACKNOWLEDGEMENTS

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

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Appendix F

Bed Topography of River2D Study Sites on the Stanislaus River

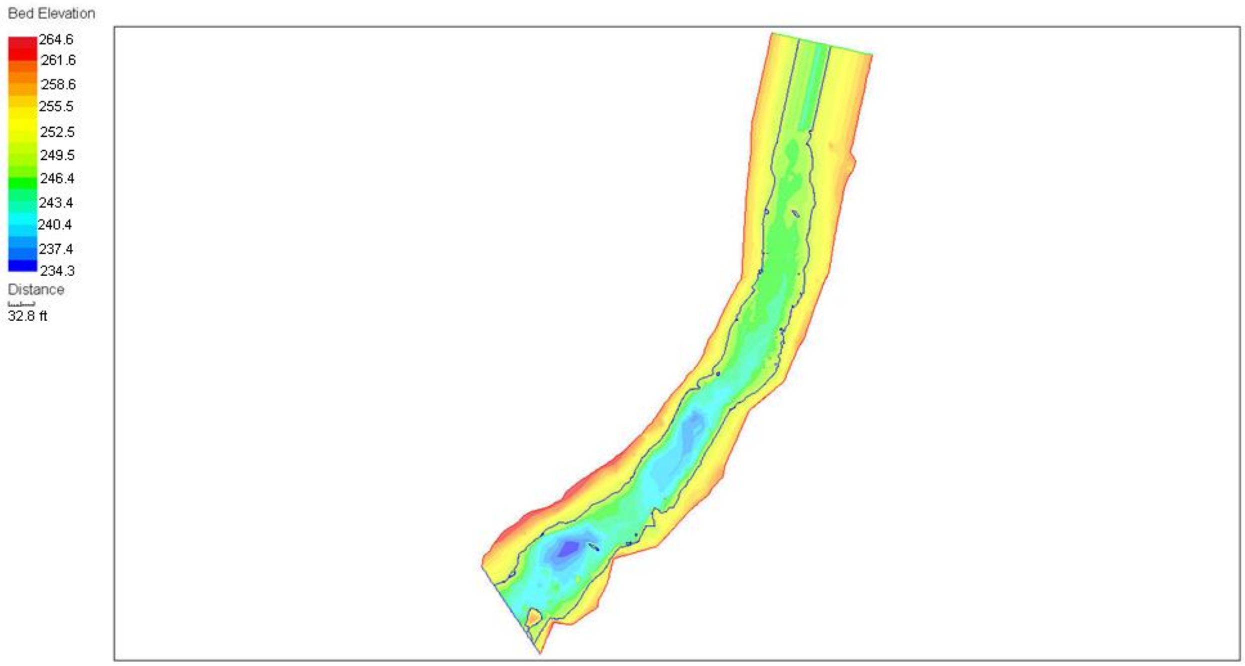


Figure F-1.—Bed topography of Two-mile Bar Recreation Area site.

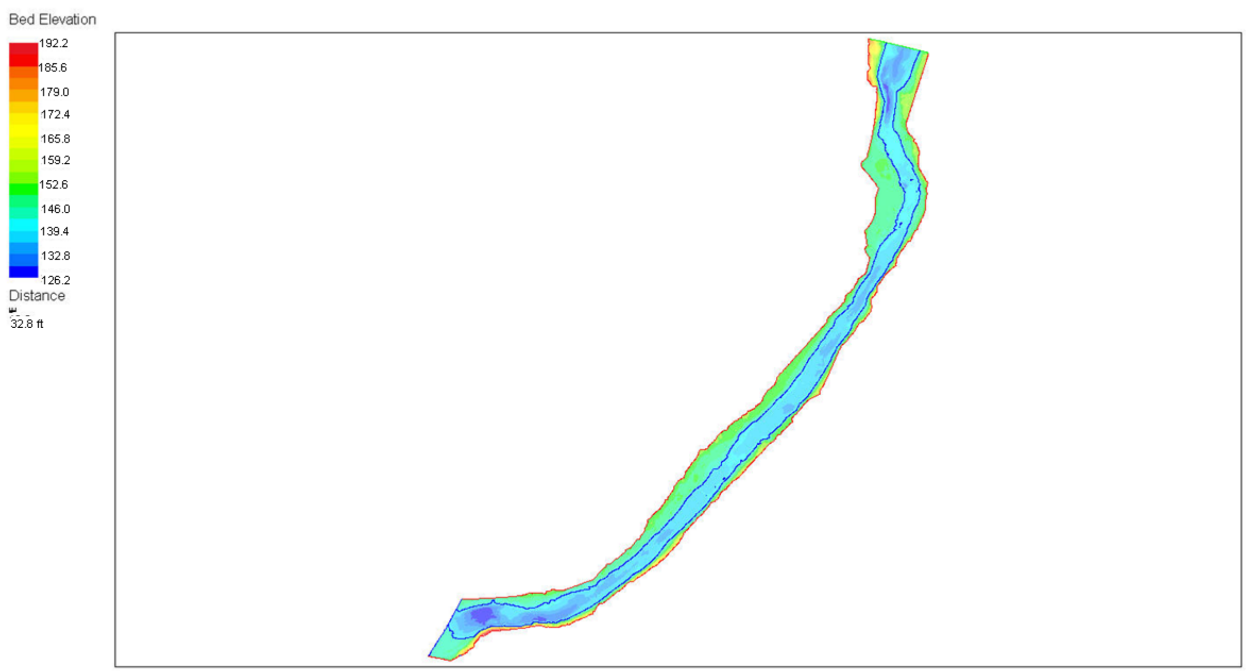


Figure F-2.—Bed topography of Horseshoe Recreation Area study site.

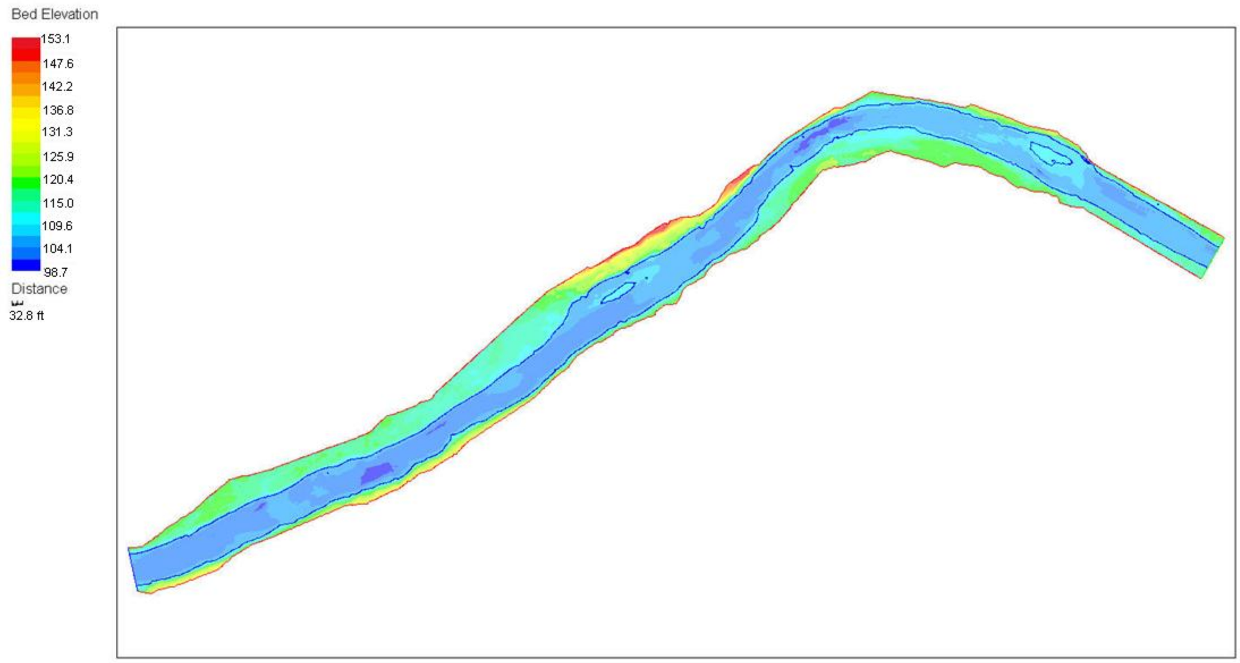


Figure F-3.—Bed topography of Valley Oak Recreation Area site.

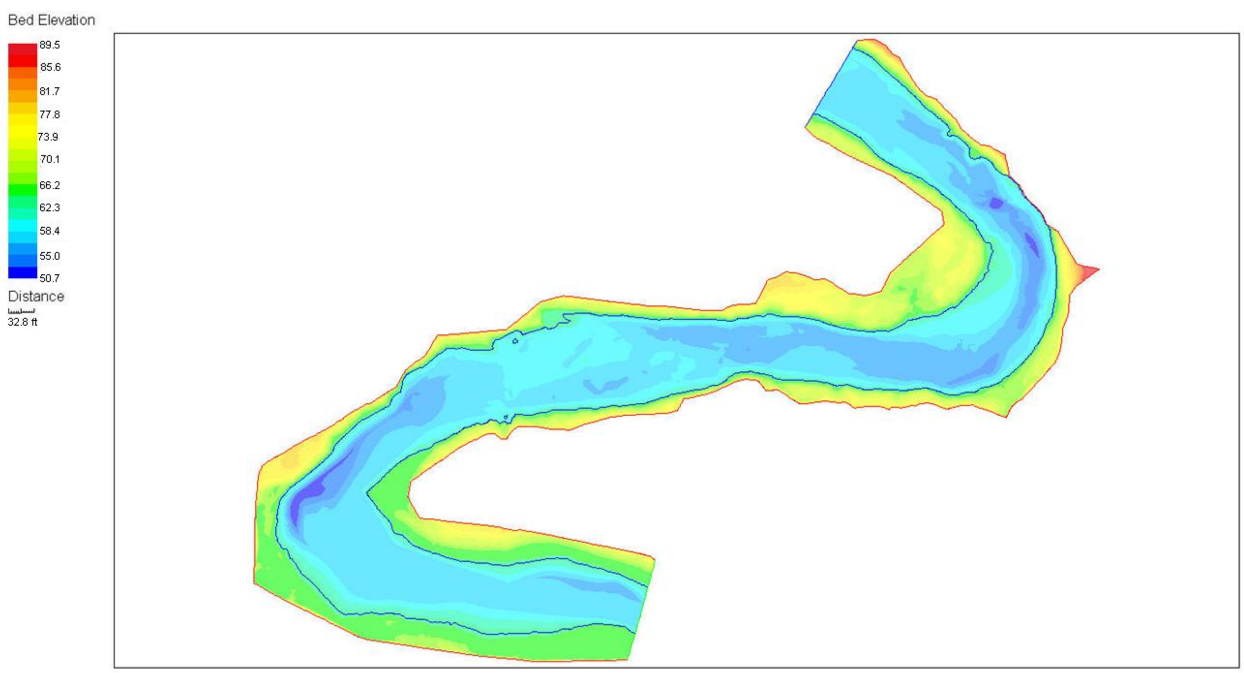


Figure F-4.—Bed topography of McHenry Recreation Area site.

Appendix G

Weighted Usable Area

River2D

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

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

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

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

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

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

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

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

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

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

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

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

Appendix H

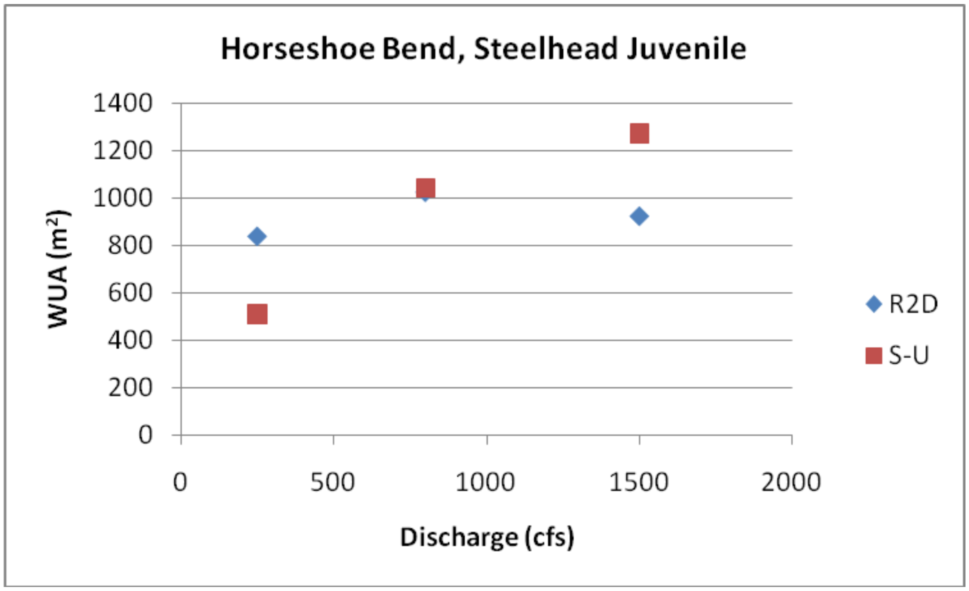
First Level Comparison of the River 2D and Scale-up Model Results

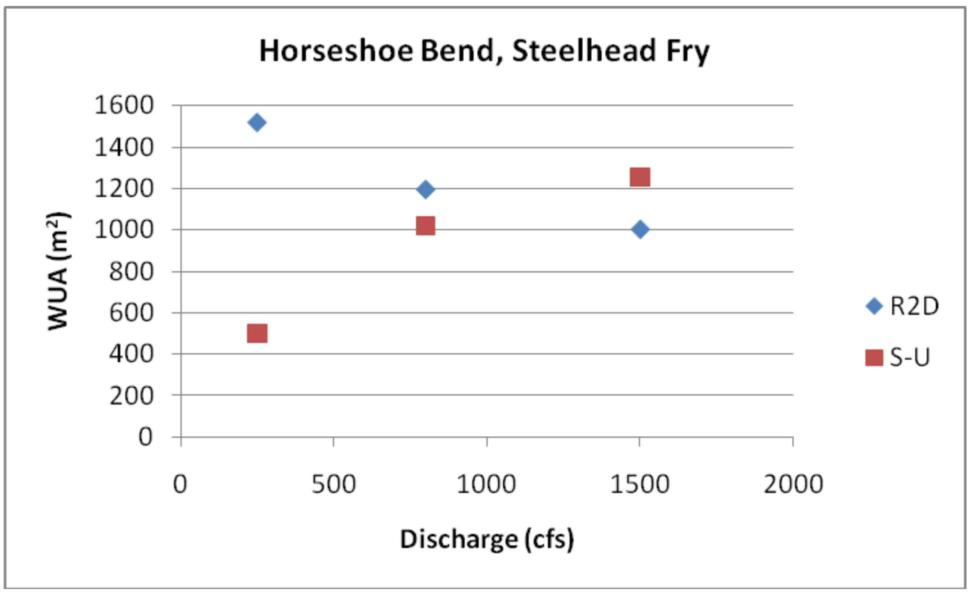
The first level comparison of the River 2D and the Scale-up model was to evaluate the same spatial area. The Scale-up results were trimmed to match the same spatial area that was modeled by River 2D. The idea was that, if the models match when the same spatial area (model footprint) is compared then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

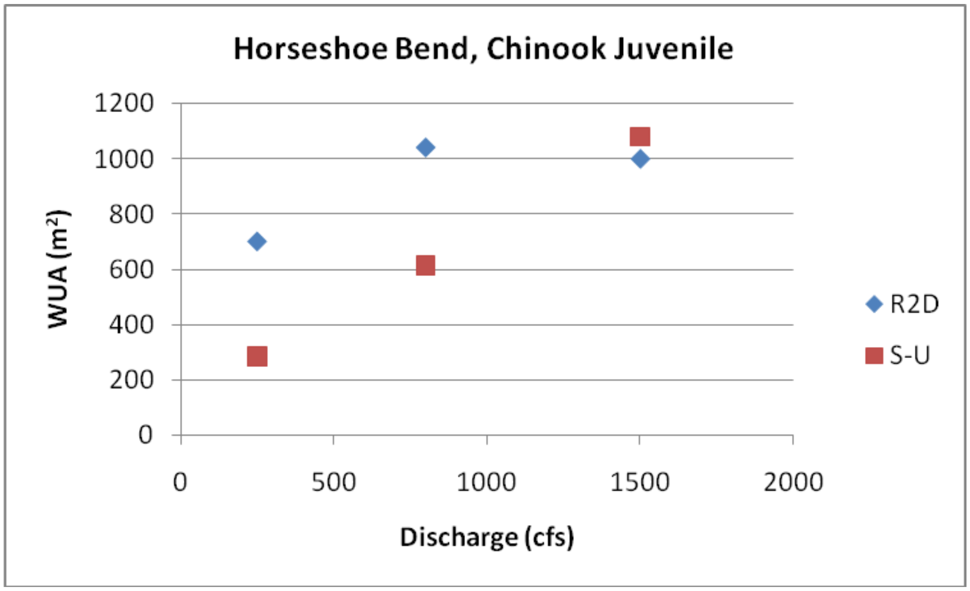
Habitat is defined as Weighted Useable Area (WUA), which is an equivalent calculation reported in the Area of Suitable Habitat (ASH) in Scale-up. Approximately 56 river miles were modeled for the Scale-up study. Approximately 1.6 river miles were modeled using the River 2D study. Results were then extrapolated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

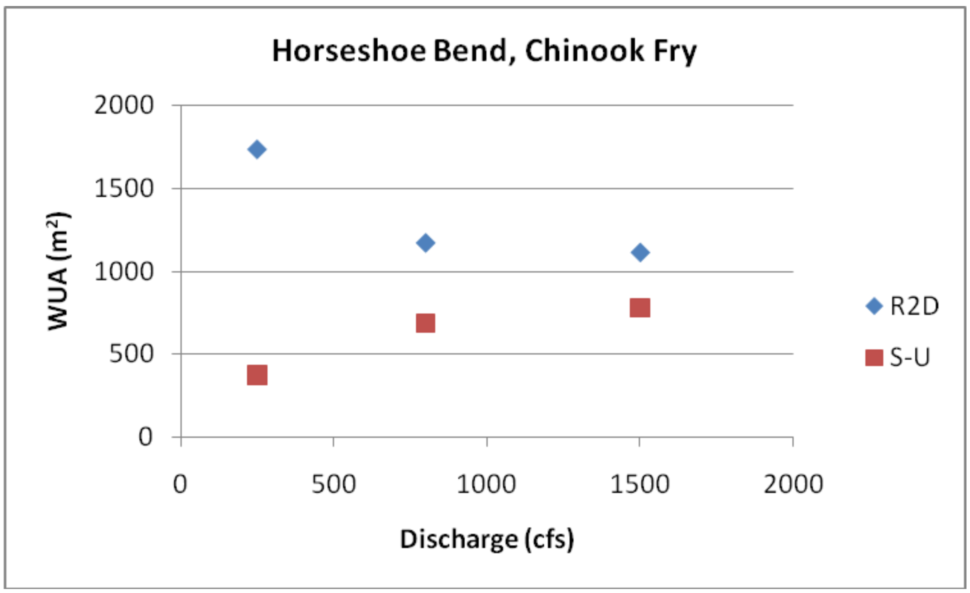
The results of the comparison were inconclusive (see tables below).

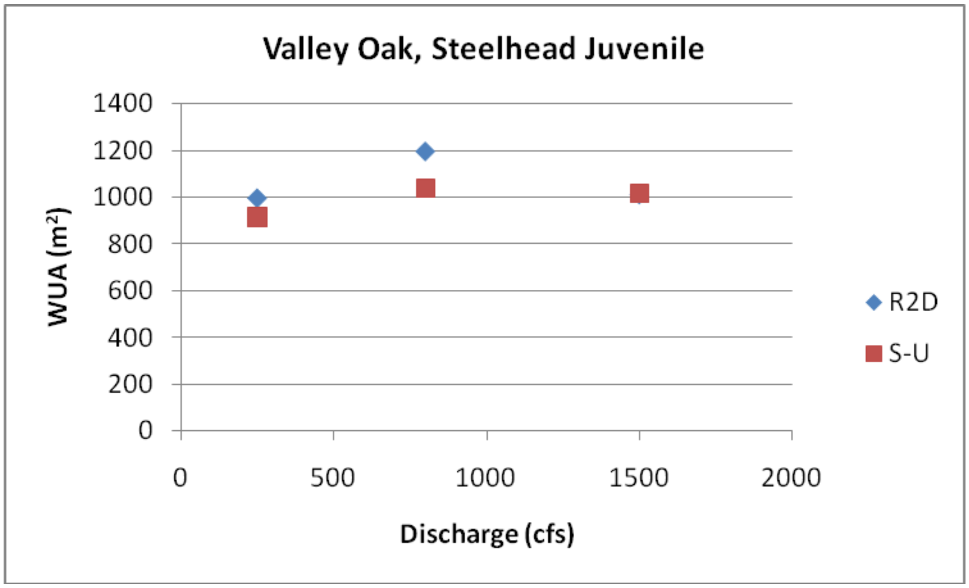
	River 2D results			Scale_up results			
Q (cfs)	Horseshoe Bend	Valley Oak	McHenry	Horseshoe Bend	Valley Oak	McHenry	
250	1737.1	1418.2	415.1	372.5	548.6	107.2	Chinook fry (m^2)
800	1171.7	1078.1	285.4	687.2	606.7	182.3	
1,500	1113.6	1113.6	279.2	779.6	625.1	156.9	
250	702.1	800.8	267.2	285.3	412.8	77.4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

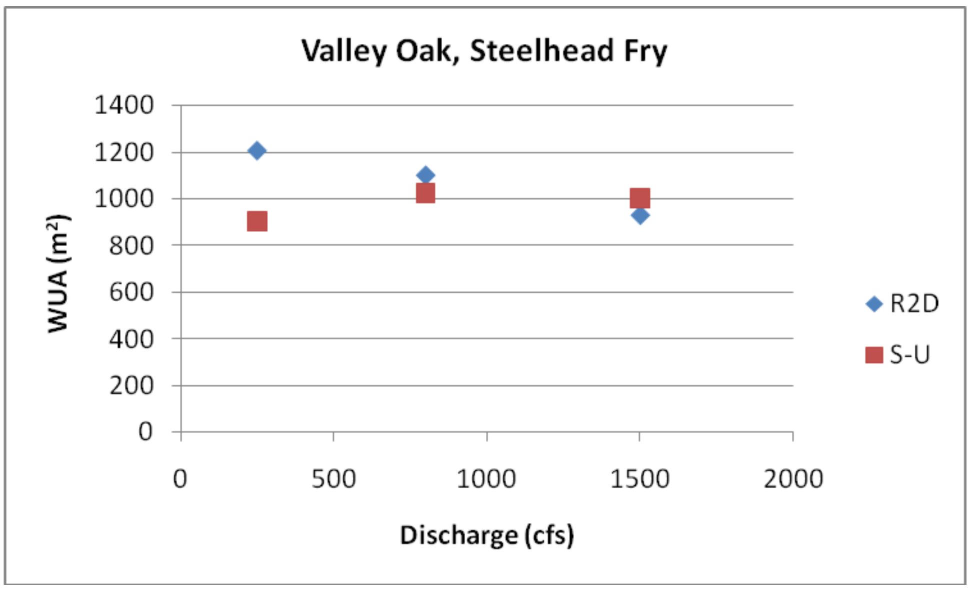

Horseshoe Bend, Steelhead Juvenile
1400
1200
1000
800
600
400
200
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

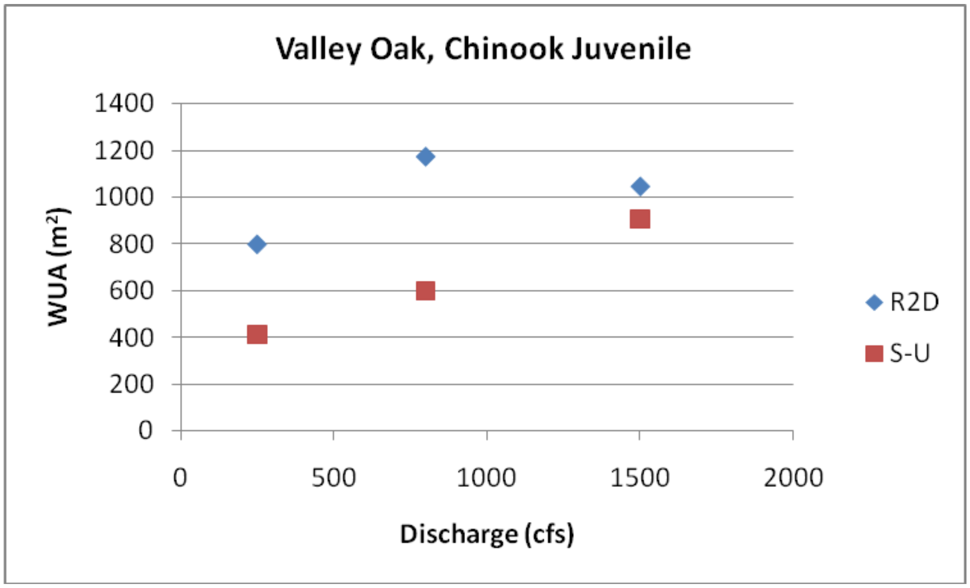

Horseshoe Bend, Steelhead Fry
1600
1400
1200
1000
800
600
400
200
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

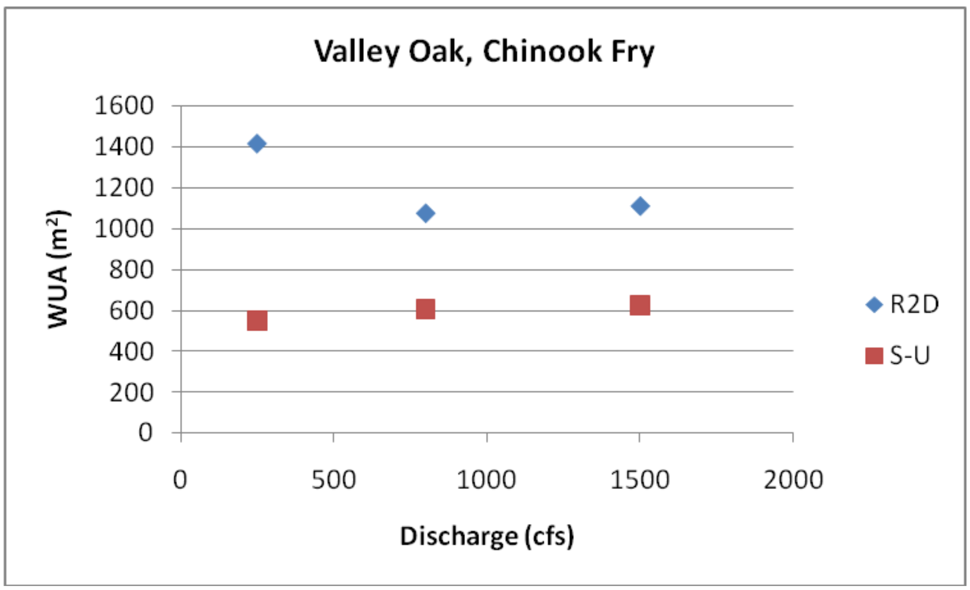

Horseshoe Bend, Chinook Juvenile
1200
1000
800
600
400
200
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

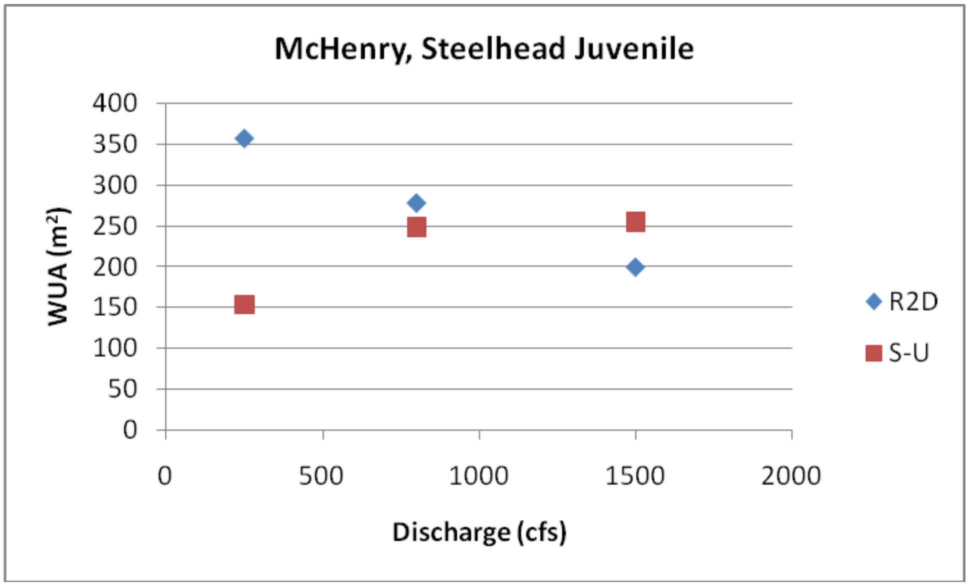

Horseshoe Bend, Chinook Fry
2000
1500
1000
500
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U

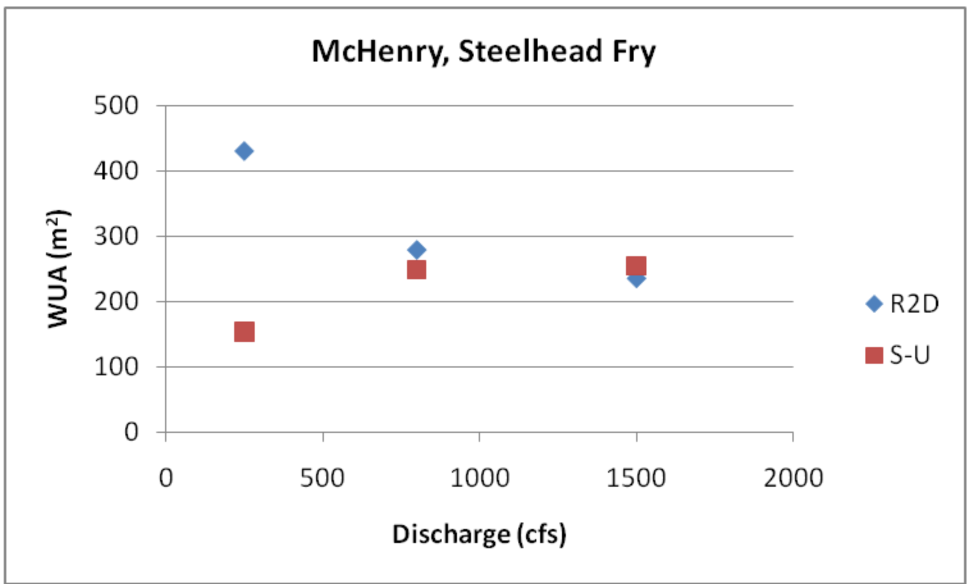

Valley Oak, Steelhead Juvenile
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
WUA (m²)
R2D
S-U

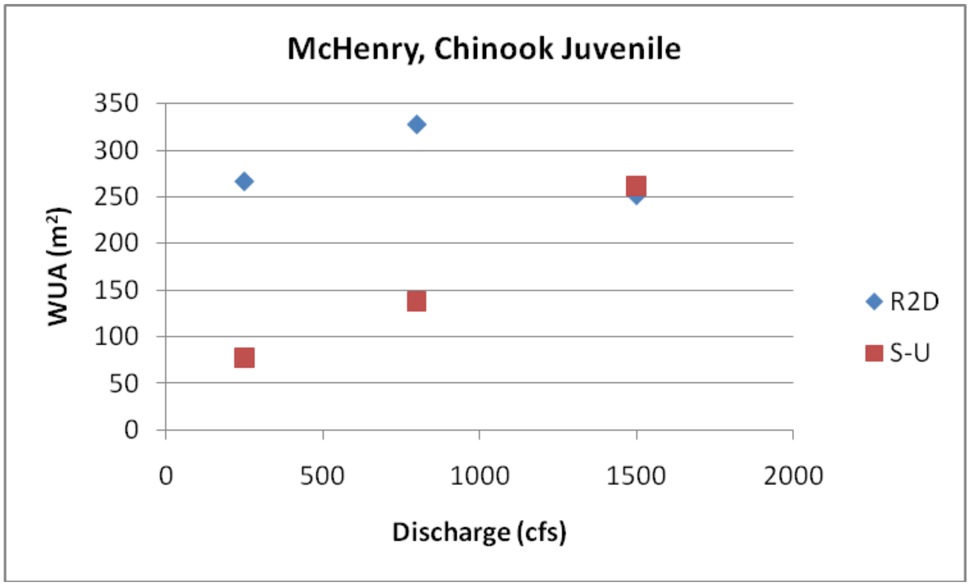

Valley Oak, Steelhead Fry
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Discharge (cfs)
WUA (m²)
R2D
S-U

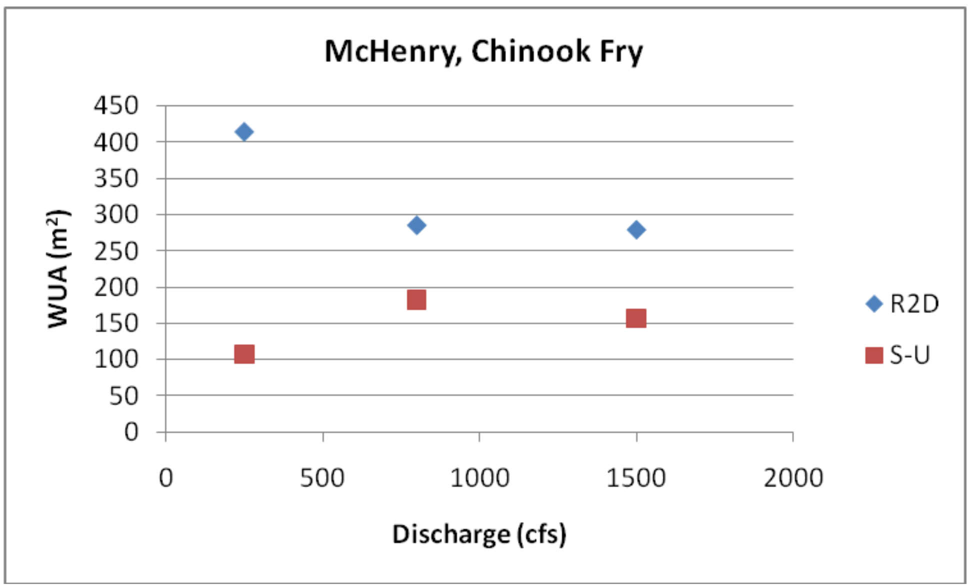

Valley Oak, Chinook Juvenile
1400
1200
1000
800
600
400
200
0
WUA (m²)
0
500
1000
1500
2000
Discharge (cfs)
R2D
S-U


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


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


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


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


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

APPENDIX I

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

Date: July 10, 2012

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

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

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

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

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

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

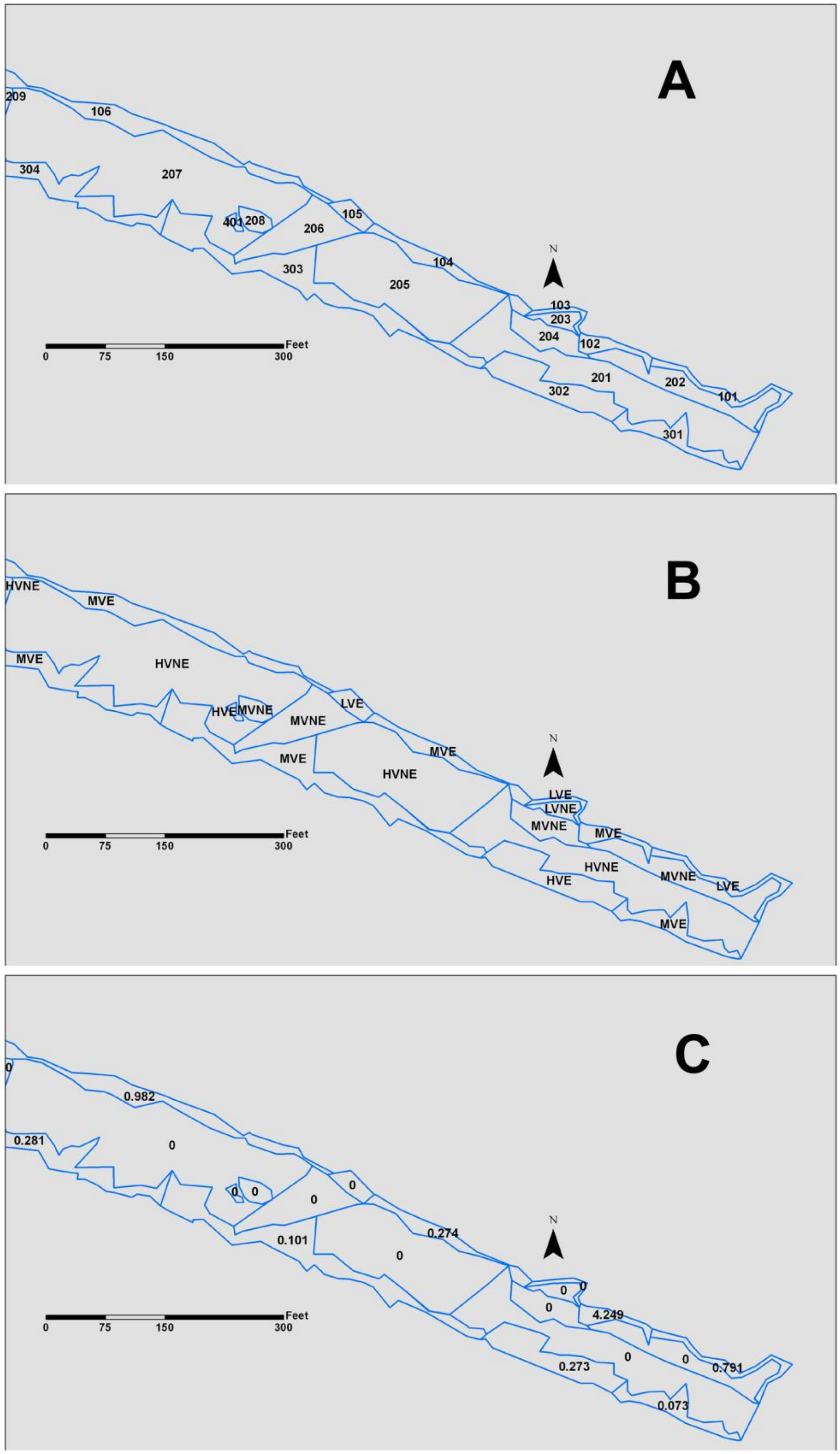


Figure 1: Example of a mesohabitat polygon mapped at Lovers Leap at 800 cfs. A – Mesohabitat ID number, B. – Mesohabitat type, C. – Density of Chinook juveniles.

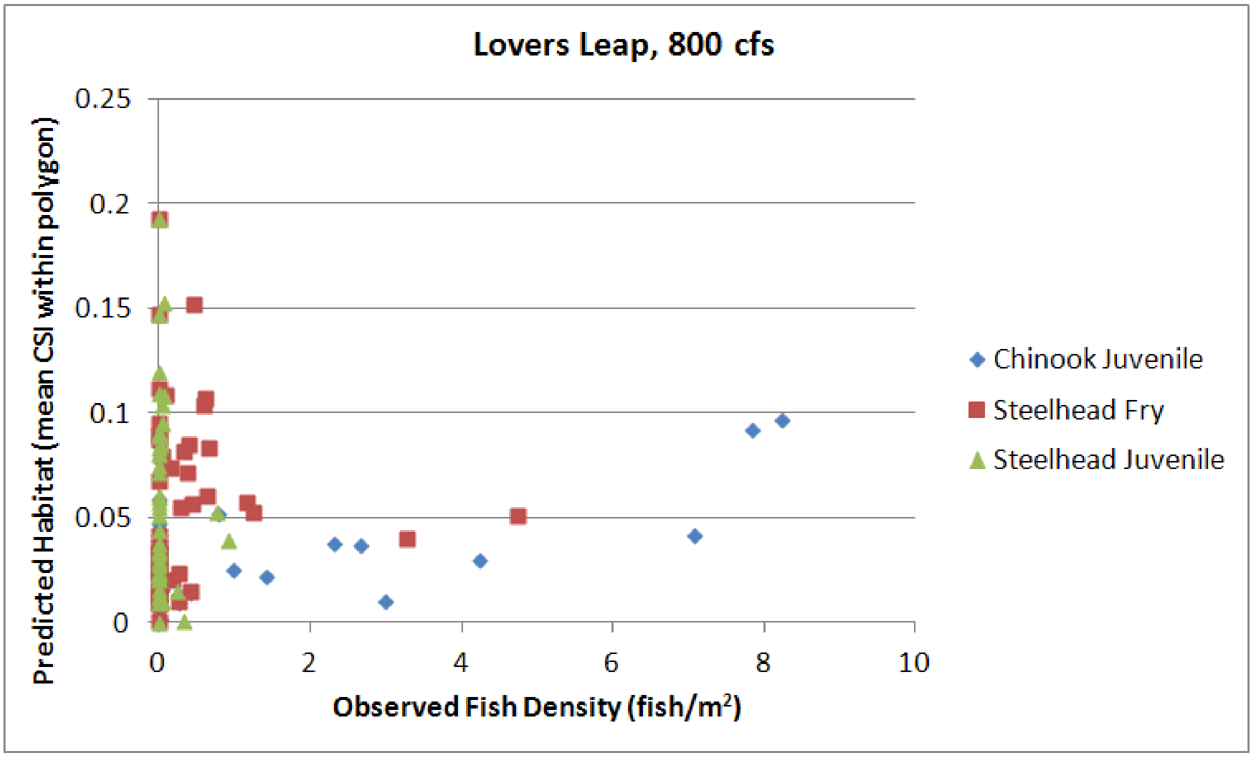


Figure 2: Plot of observed fish density vs. mean CSI value in each polygon.

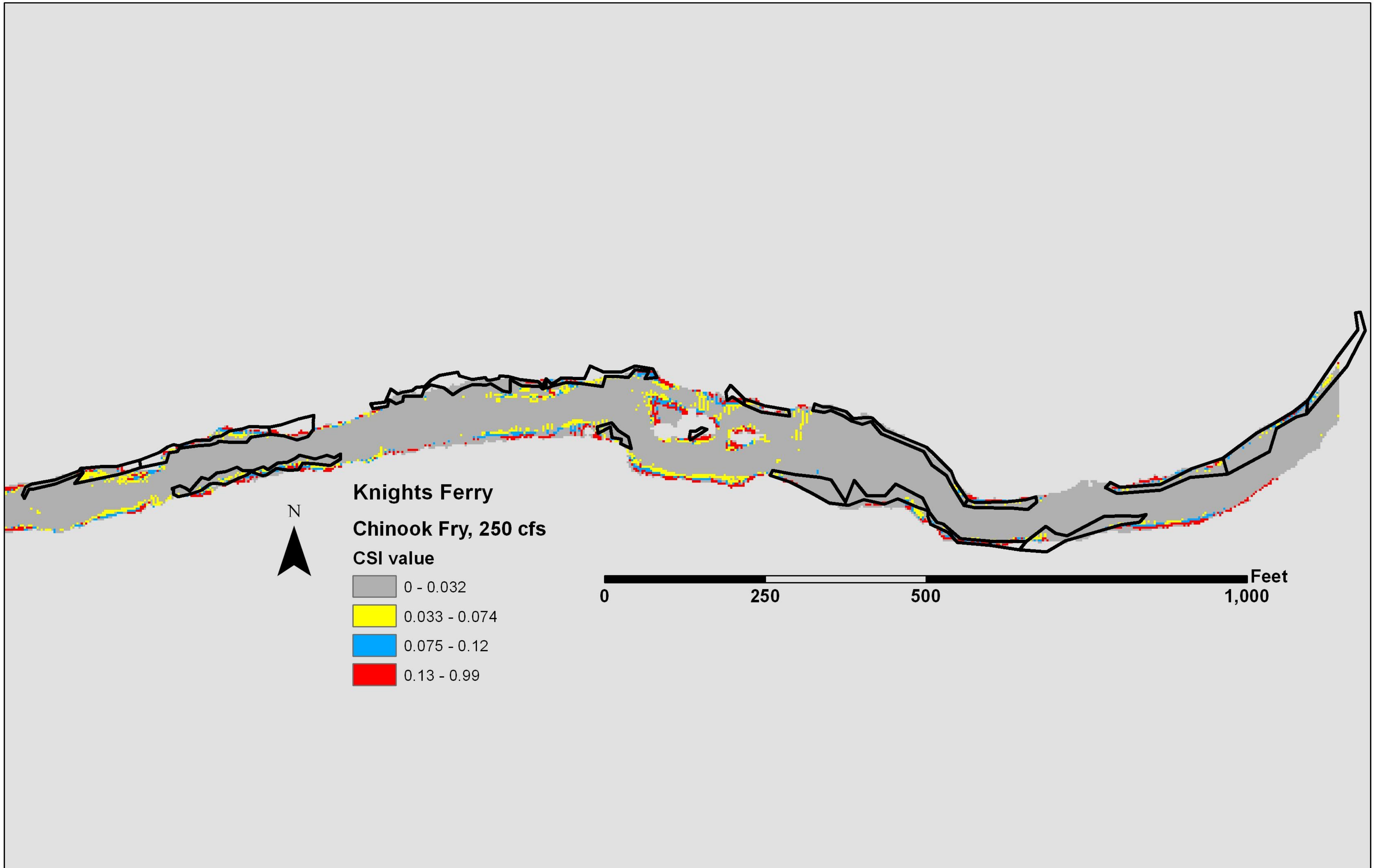


Figure 3: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

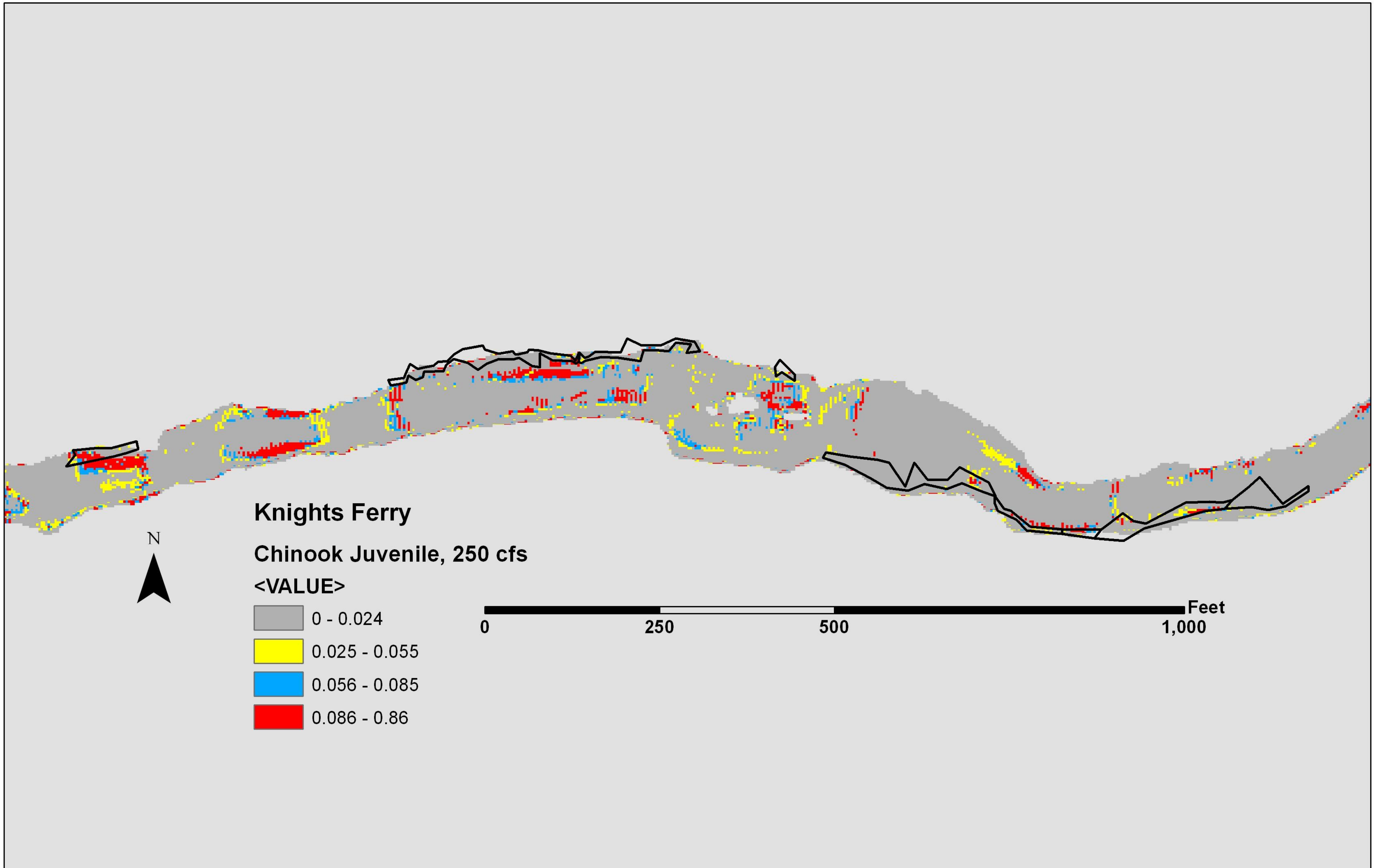


Figure 4: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

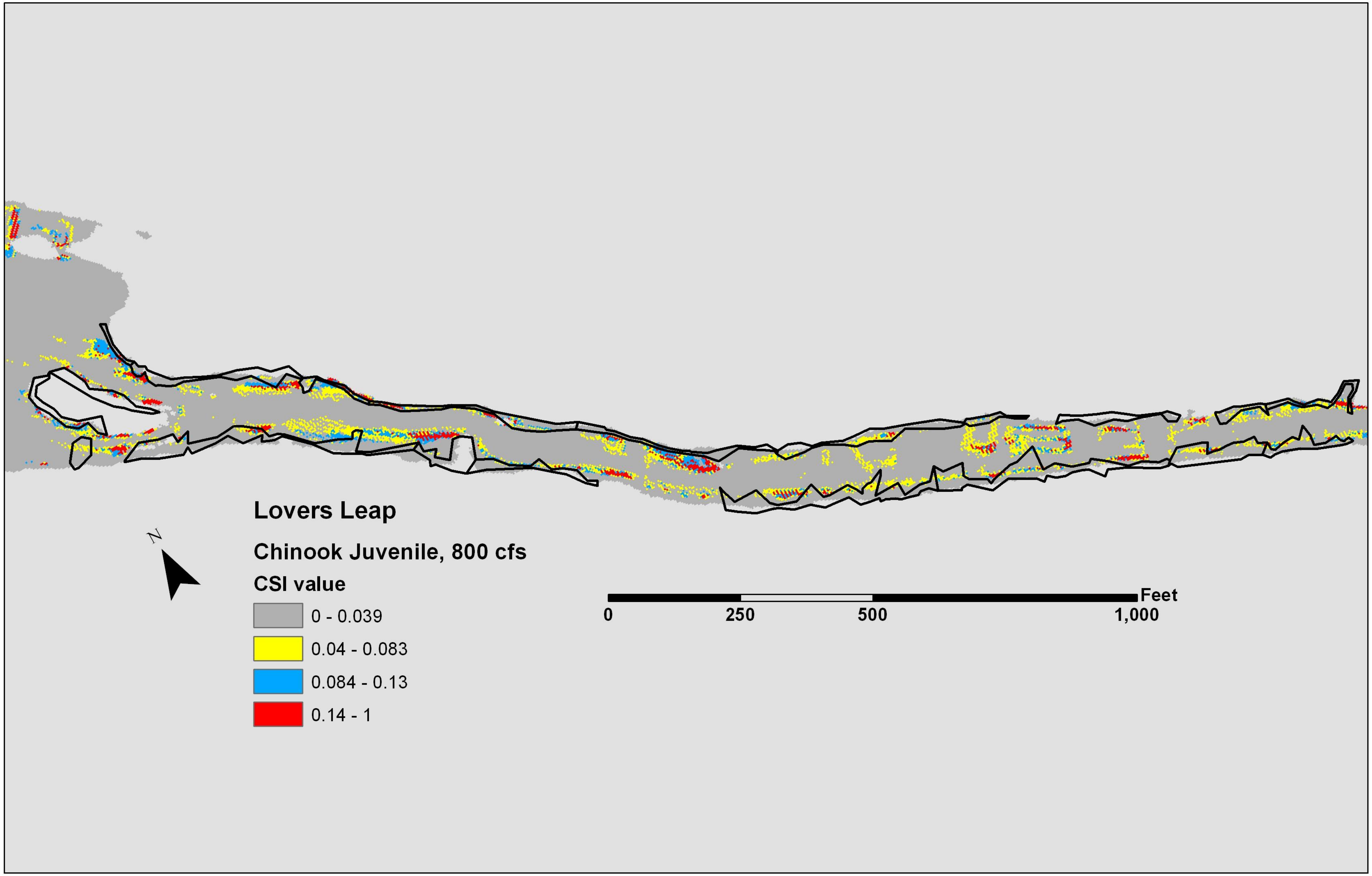


Figure 5: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

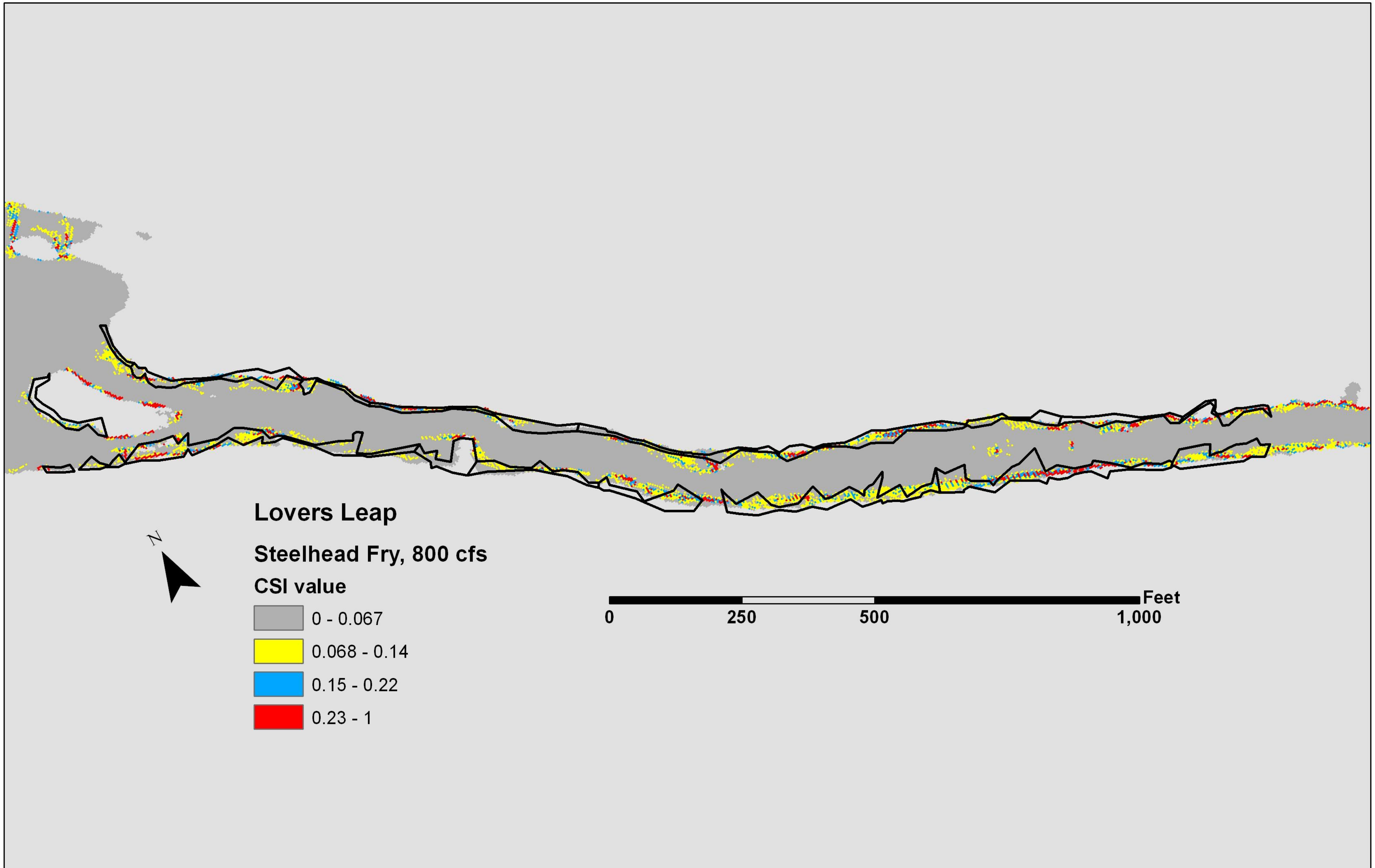


Figure 6: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

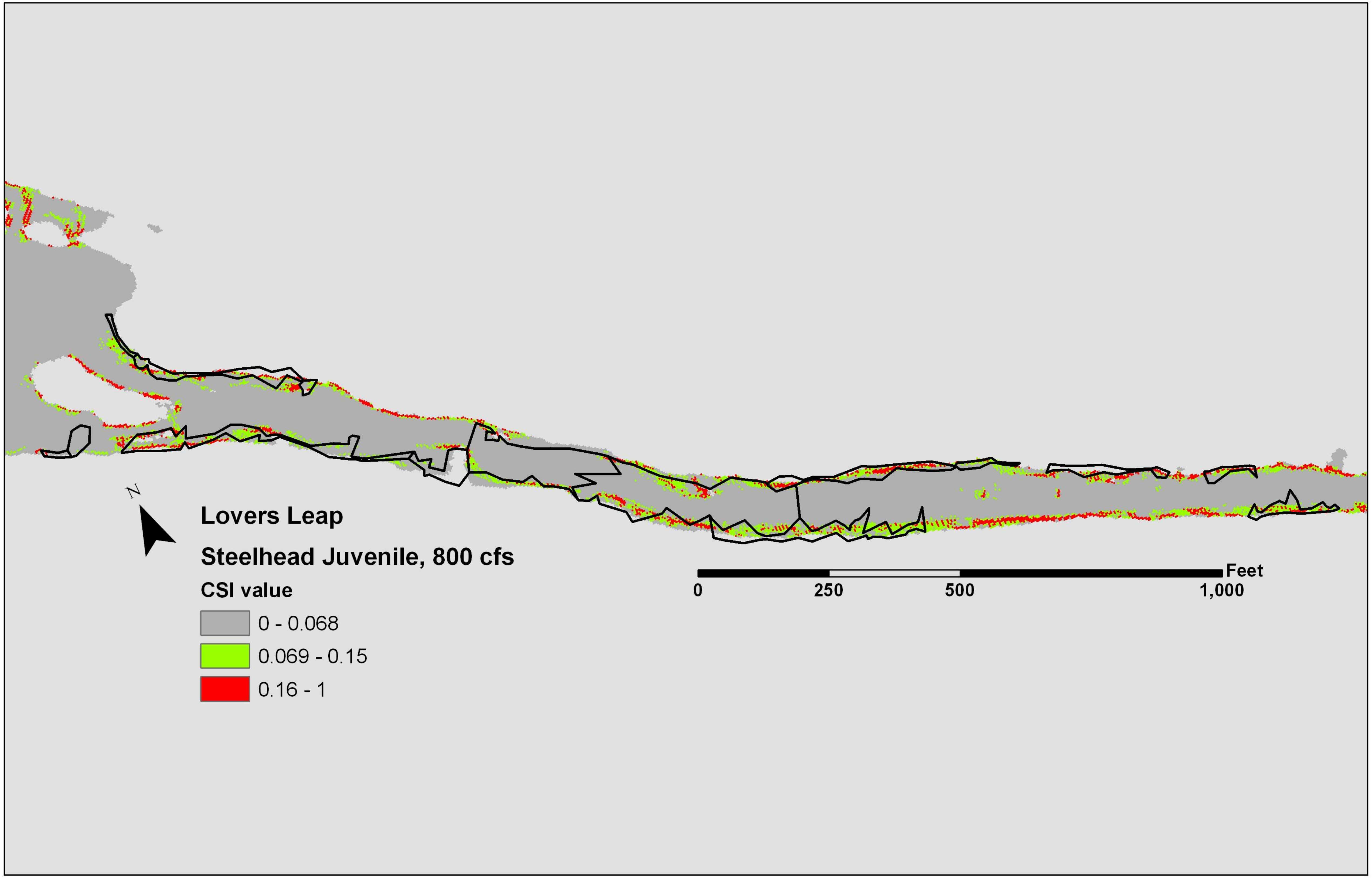


Figure 7: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

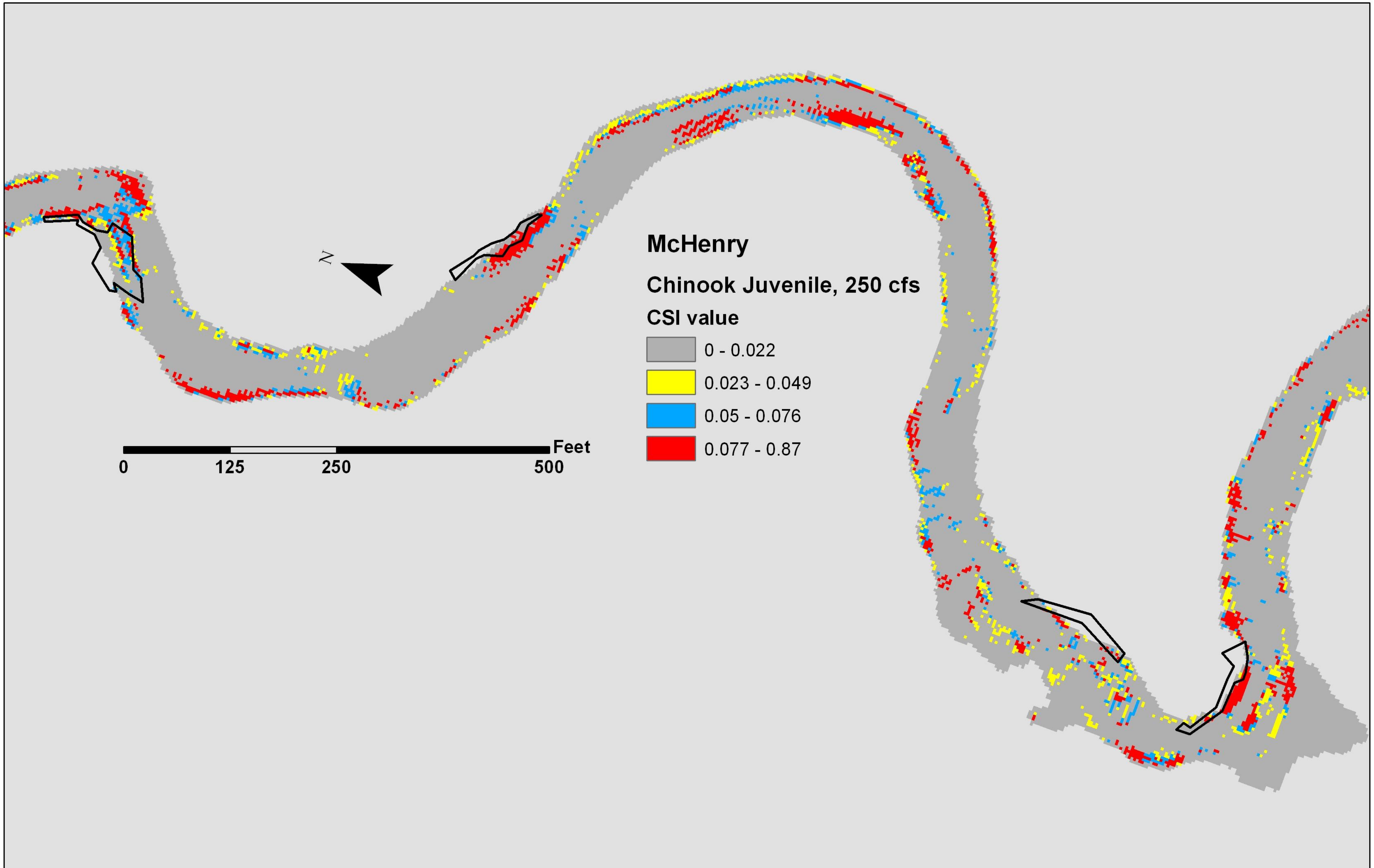


Figure 8: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

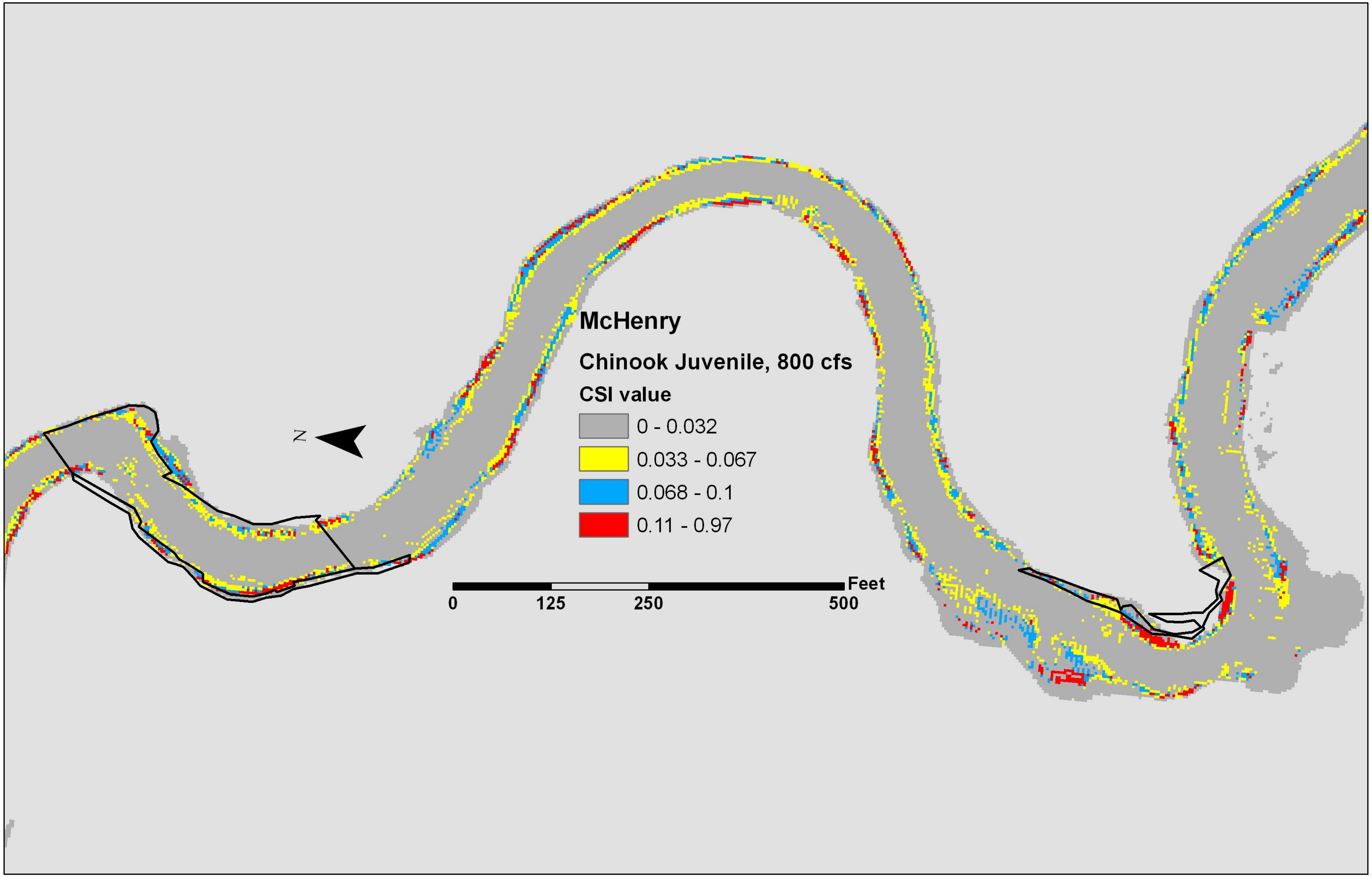


Figure 9: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

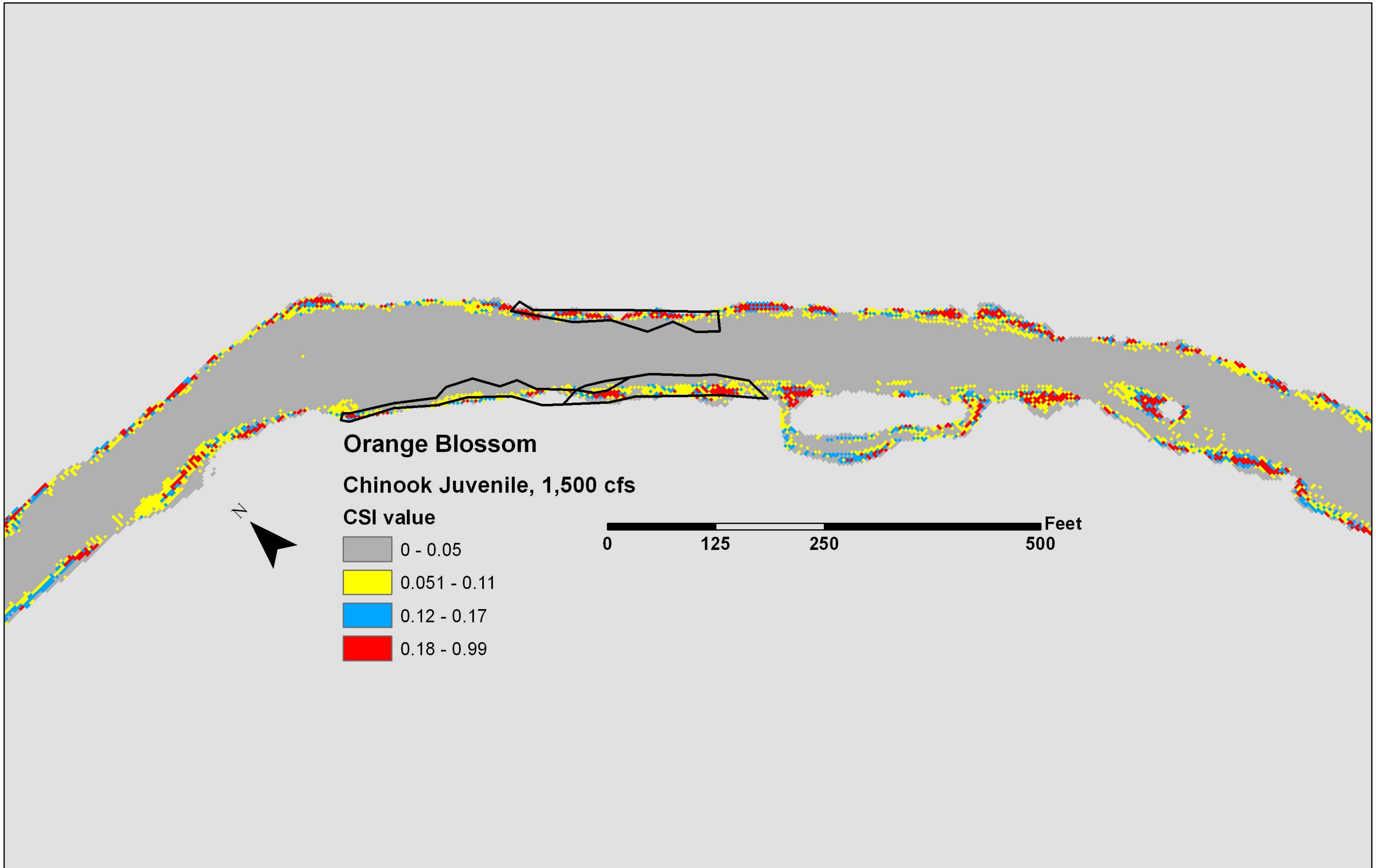


Figure 10: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

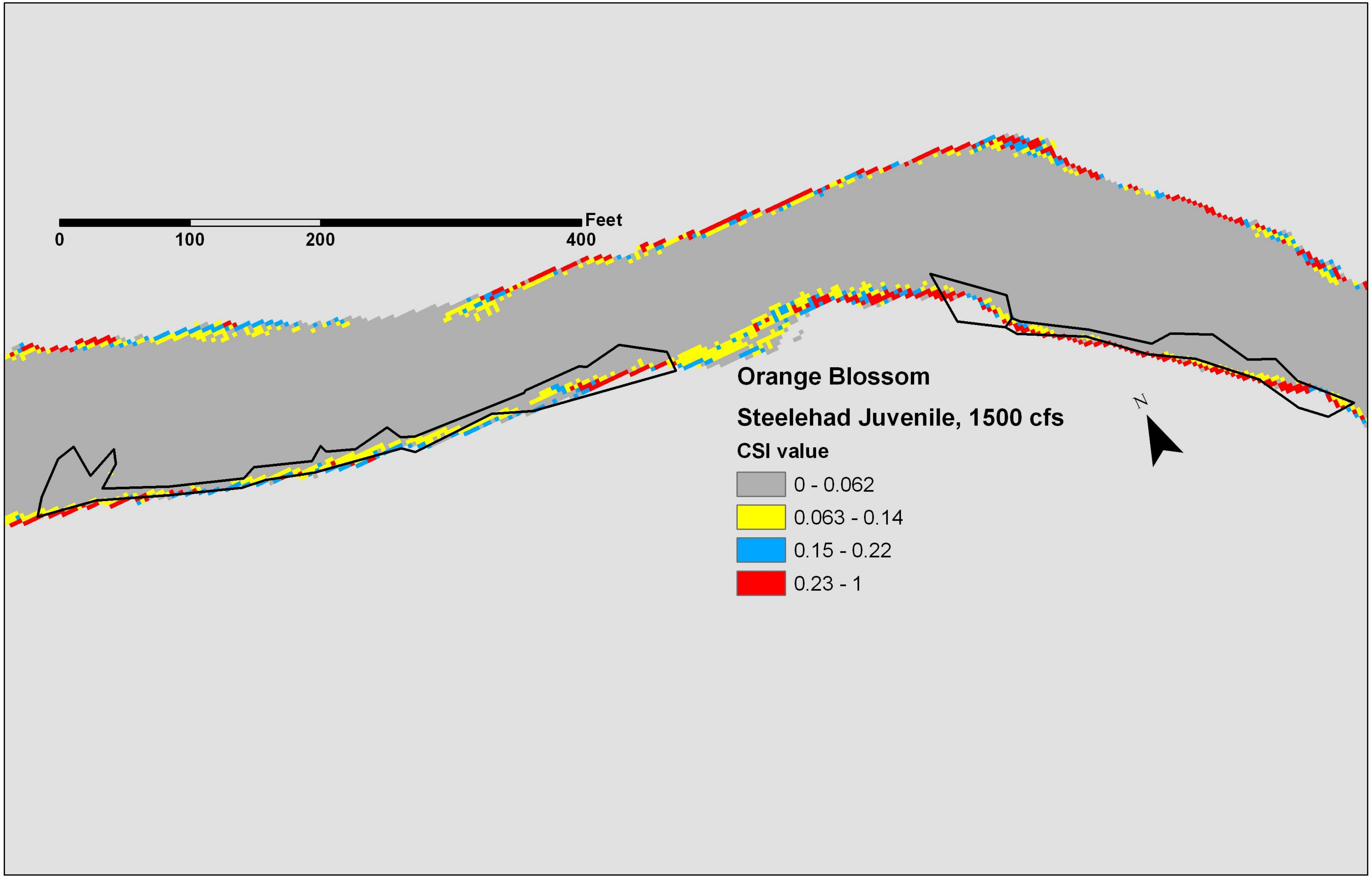


Figure 11: Populated polygons resulting from FFC data are shown over predicted habitat from the Scale-Up study.

APPENDIX J

STANISLAUS RIVER DISCHARGE-HABITAT RELATIONSHIPS FOR REARING SALMOIDS

Response to Reviewer Comments

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

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

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

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

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

modeling. To evaluate these:

a. Calculate habitat at 250, 800 and 1,500 cfs in both models just for footprint of River2D sites - if result same for the 2 models, difference between models because River2D sites were not representative of entire river.
b. Calculate habitat at 250, 800 and 1,500 cfs in both models just for footprint of River2D sites and just using depth and velocity criteria - if get different results for two models, differences are due to hydraulic modeling.

If get different results for a) but same results for b), differences are due to cover and adjacent velocity versus distance to edge and shear.

These analyses are in addition to the comments listed above - the first addresses the second bullet point under comment #2, the second addresses the first bullet point under comment #4.

2a tested by clipping out the footprint of the River 2D sites from the scale-up model and examining results from both models for the same river reaches. The results of both models were different, suggesting that the next analysis step should be to evaluate 2b. If results for both models are the same for 2b, that suggests that the differences between the two models are due to the differences in using cover vs. distance to edge and adjacent velocity vs. shear. If results for both models are different for 2b, that suggests that the differences are due to hydraulic modeling.

A completed bioverification analyses using available fish data was done, but sample size was not sufficient and results were

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

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

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

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

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