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Lower Tuolumne River Instream Flow Study— Non-Native Predatory Bass 1-D PHABSIM Habitat Assessment

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Cover photo: Lower Tuolumne River, January 2007.

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1 BACKGROUND

The *Lower Tuolumne River Instream Flow Studies – Final Study Plan* (Stillwater Sciences 2009) was filed with the Federal Energy Regulatory Commission (Commission) on October 14, 2009. The Study Plan was approved, pursuant to Ordering paragraphs (A) through (E) of the Commission's May 12, 2010 order. In order to examine the broad flow ranges identified in the Commission's July 16, 2009 Order, the Study Plan separated the study into two separate investigations: (1) a conventional 1-D PHABSIM model ("Instream flow Study"), which examines in-channel habitat conditions at flows from approximately 100–1,000 cfs, and (2) a 2-D hydraulic model of overbank areas, as well as adjacent in-channel locations, for flows of 1,000–5,000 cfs, developed as part of the Pulse Flow Study. The *Lower Tuolumne River Instream Flow Study–Final Report* was filed with the Commission on April 26, 2013 (Stillwater Sciences 2013). The *Pulse Flow Study Report* was submitted to the Commission on June 18, 2012 (Stillwater Sciences 2012).

Following the filing of the final report, the Commission, in its May 21, 2013 Determination on Requests for Study Modifications and New Studies for the Don Pedro Hydroelectric Project relicensing studies, required the scope of the Lower Tuolumne Instream Flow Study to be expanded to assess habitat for non-native predatory fish, including smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and striped bass (*Morone saxatilis*) using existing habitat suitability criteria (HSC) data, where available. The Districts compiled existing suitability criteria for the three bass species and distributed the draft criteria for relicensing participant review on October 30, 2013. In its November 21, 2013 letter to the Districts (provided via email), the USFWS requested that the scope of the bass analyses be expanded to include temperature criteria and early life stages (e.g., spawning/incubation, juvenile) of striped bass, largemouth bass, and smallmouth bass. Additional bass HSC were included in the Districts' Updated Study Report (USR) filed with the Commission on January 6, 2014. On April 29, 2014, the Commission issued a determination on requests for study modifications that required the assessment of bass based on HSC provided in the USR, but included no modification to address water temperature in the modeling (FERC 2014). The study reach for the non-native predatory bass habitat assessment coincides with the study reach originally chosen for development of the 1-D PHABSIM model to evaluate salmonid habitat.

This report includes the final suitability criteria and habitat assessment for non-native predatory bass as a supplement to the Lower Tuolumne River Instream Flow Study model results.

2 METHODS

2.1 Study Reach

The study reach for the Lower Tuolumne River Instream Flow Study - Non-Native Predatory Bass 1-D PHABSIM Habitat Assessment extended from river mile (RM) 29–52. This reach generally overlaps the gravel-bedded reach (RM 24–52) of the lower river, which is characterized by higher gradient, faster velocity, and lower water temperatures than those found farther downstream in the sand-bedded reach.

2.2 Habitat Suitability Criteria Availability

Use of the PHABSIM model requires application of HSC to the results of the hydraulic model in order to generate an index of habitat suitability (weighted usable area, or WUA) versus flow. Pursuant to the Commission-approved Study Plan, HSC screening criteria included the following (for salmonids), although no single criterion would qualify or disqualify a curve from further consideration. These same criteria were considered goals for the bass analysis as well; since applicable bass HSC were not as widely available, not all of these criteria could be met.

Minimum of 150 observations

- Clear identification of fish size classes
- Depth and velocity HSC
- Category II or III data (Bovee 1986)
- Comparable stream size and morphology (e.g., hydrology, stream width and depth, gradient, geomorphology, etc.)
- Source data from the lower Tuolumne River (or other Central Valley streams)
- Habitat availability data collected
- Data collected at high enough flow that depths and velocities are not biased by flow availability
- Availability of presence/absence data

The target species and life stages include:

- Smallmouth bass: fry, juvenile, spawning, embryo/incubation, and adult
- Largemouth bass: fry, juvenile, spawning/embryo, and adult
- Striped bass: juvenile, spawning/embryo, and adult

Available HSC for smallmouth bass (Edwards et al. 1983), largemouth bass (Stuber et al. 1982), and striped bass (Crance 1984) include limited Category I (binary consensus curves) data based on species habitat descriptions from literature and professional judgment (Table 1). Adult HSC from these sources were used in the overbank habitat assessment, reported in the *Lower Tuolumne River Instream Flow Studies: Pulse Flow Study Report* (Stillwater Sciences 2012), and the HSC for smallmouth bass (Edwards et al. 1983) and largemouth bass (Stuber et al. 1982) were previously used in the 2-D modeling for the special run-pool (SRP) 9 channel reconstruction project on the Lower Tuolumne River at river mile 25.9–25.7 (McBain & Trush and Stillwater Sciences 2006).

Available HSC for additional life stages of smallmouth bass and largemouth bass provided in Edwards et al. (1983) and Stuber et al. (1982) have been included. However, because depth HSC for largemouth bass are not described in Stuber et al. (1982), the prior studies on the lower Tuolumne River substituted adult smallmouth bass depth HSC from Edwards et al. (1983) for adult largemouth bass. For this assessment, the same approach was used for smallmouth bass fry and juveniles, where smallmouth bass depth HSC from Edwards et al. (1983) were substituted for largemouth bass.

Spawning depth preferences of largemouth bass are expected to vary too much from smallmouth bass to substitute depth HSC for this life stage between these two species, thus ranges reported in Moyle (2002) were used to develop largemouth bass spawning depth HSC. Index values of 1.0 were assigned to depths within the reported optimal range (1.64–6.56 ft), an index value of 0.2 to the upper observed limit (16.25 ft) and index values of 0.0 were assigned to depths below 0.5 ft and above 18.0 ft. Intermediate values were defined by a straight line between the two zero index value points and the nearest non-zero index value.

Juvenile and adult striped bass depth HSC are described in Crance (1984); however, no velocity HSC are provided. Striped bass are reported to tolerate a wide range of velocities, from 0.0 to 16.4 feet per second (fps), with an optimum range between 0.0 and 3.28 fps (Hassler 1988). For this study, velocity HSC for striped bass juveniles and adults were developed using reported ranges from Hassler (1988) and assigning an index value of 1.00 to velocities within the optimal range (0.00–3.28 fps) and an index value of 0.0 to all velocities beyond the tolerance range (>16.4 fps); intermediate values between the upper optimal range and the upper tolerance range were defined by a straight line between the two points. Spawning/embryo HSC for striped bass were adapted from EA (1994) as used in HDR (2011).

Table 1. Habitat suitability criteria summary for target species and life stages.

Species	Life stage	Depth	Velocity	Substrate	Source
Smallmouth bass	Fry	Yes[1]	Yes[1]	Yes	Edwards et al. 1983
	Juvenile	Yes[1]	Yes[1]	Yes	Edwards et al. 1983
	Spawning	Yes[1]	Yes[1]	Yes	Edwards et al. 1983
	Embryo/incubation	Yes[1]	Yes[1]	Yes	Edwards et al. 1983
	Adult	Yes[1]	Yes[1]	Yes	Edwards et al. 1983
Largemouth bass	Fry	No[2]	Yes[1]	No	Stuber et al. 1982 (velocity); Edwards et al. 1983 (depth from smallmouth bass)
	Juvenile	No[2]	Yes[1]	No	Stuber et al. 1982 (velocity); Edwards et al. 1983 (depth from smallmouth bass)
	Spawning/embryo	Yes	Yes[1]	Yes	Stuber et al. 1982 (velocity); Moyle 2002 (depth)
	Adult	No[2]	Yes[1]	No	Stuber et al. 1982 (velocity); Edwards et al. 1983 (depth from smallmouth bass)
Striped bass	Juvenile	Yes	Yes	No	Crance 1984 (depth); Hassler 1988 (velocity)
	Spawning/embryo	Yes[1]	Yes[1]	No	EA 1994 adapted from HDR 2011(depth and velocity)
	Adult	Yes	Yes	No	Crance 1984 (depth); Hassler 1988 (velocity)

1 Coordinates from Edwards et al. (1983) and Stuber et al. (1982) were developed from the graphical data.

2 Largemouth bass HSC for depth was not available in the literature; however, smallmouth bass HSC for depth were substituted for largemouth bass in prior lower Tuolumne River studies (McBain & Trush and Stillwater Sciences 2006, Stillwater Sciences 2012).

Smallmouth bass, largemouth bass, and to a lesser degree, striped bass have been regularly observed during annual snorkel surveys downstream of RM 31.5, with less frequent observations upstream to RM 50.7 (Stillwater Sciences 2016); however, none of the bass species were encountered during the site-specific HSC surveys in February, March, May, and July 2012 within the instream flow study area (just below La Grange Diversion Dam [RM 52] downstream to Waterford [RM 31]), which were conducted across a range of seasons (winter, spring, and summer) and a range of flow conditions (100 cfs, 350 cfs, and 2,000 cfs) (Stillwater Sciences 2013). Detections of largemouth bass and striped bass were made at counting weirs during 2015–2016 in conjunction with a fish migration barrier study near RM 52 (TID/MID 2017).

The HSC identified by the Commission in its April 29, 2014 determination for smallmouth bass, largemouth bass, and striped bass are shown below in Figures 1–6 and listed in Tables 2–4. Substrate criteria were unavailable for striped bass, and substrate categories for largemouth and smallmouth bass spawning were not compatible with this study due to inconsistencies in coding of size classes used in this study with reference information provided in Edwards et al. (1983; smallmouth bass) and Stuber et al (1982; largemouth bass). No cover criteria were available for any of the bass species analyzed in this report.

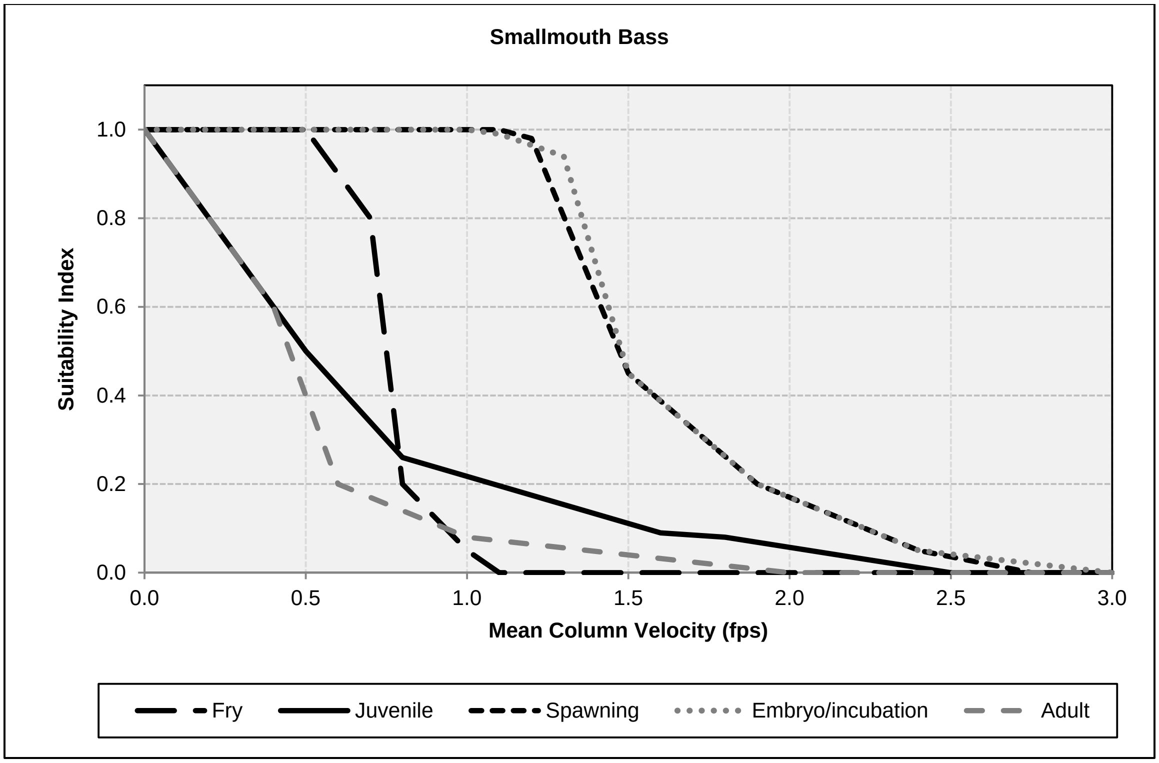

Figure 1. Smallmouth bass velocity suitability criteria for the lower Tuolumne River.

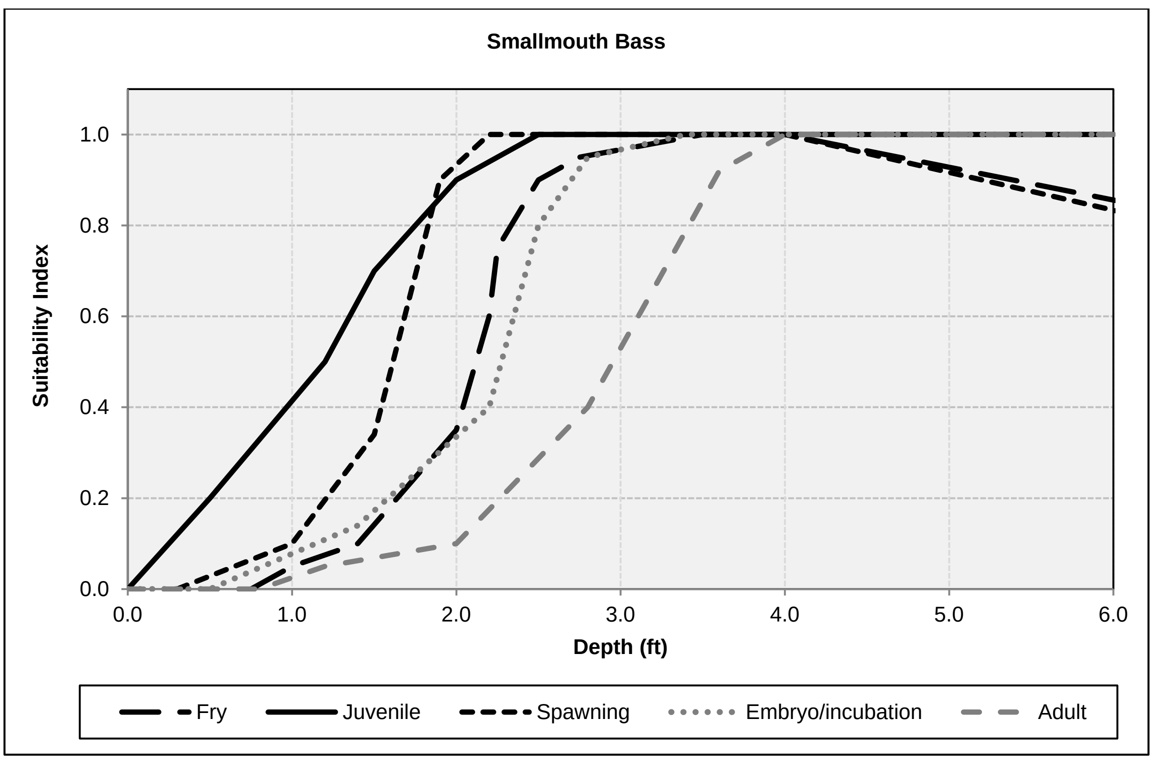

Figure 2. Smallmouth bass depth suitability criteria for the lower Tuolumne River.

Table 2. Smallmouth bass suitability criteria.

Life stage	Velocity		Depth	
	(fps)	**Index**[1]	**(ft)**	**Index**[1]
Fry	0.00	1.00	0.75	0.00
	0.50	1.00	1.00	0.05
	0.60	0.90	1.40	0.10
	0.70	0.80	2.00	0.35
	0.80	0.20	2.20	0.60
	1.00	0.05	2.25	0.75
	1.10	0.00	2.50	0.90
	2.00	0.00	2.75	0.95
	3.00	0.00	3.50	1.00
	--	--	4.00	1.00
	--	--	15.09	0.20
	--	--	20.01	0.10
	--	--	22.00	0.00
Juvenile	0.00	1.00	0.00	0.00
	0.50	0.50	0.50	0.20
	0.80	0.26	1.20	0.50
	1.60	0.09	1.50	0.70
	1.80	0.08	2.00	0.90
	2.50	0.00	2.50	1.00
	3.00	0.00	4.00	1.00
	--	--	6.00	1.00
Spawning	00	1.00	0.30	0.00
	1.00	1.00	1.00	0.10
	1.10	1.00	1.50	0.34
	1.20	0.98	1.90	0.90
	1.50	0.45	2.20	1.00
	1.90	0.20	4.00	1.00
	2.40	0.05	10.00	0.50
	2.75	0.00	25.00	00
Embryo/(incubation)	0.00	1.00	0.00	0.00
	0.20	1.00	0.50	0.00
	0.50	1.00	1.40	0.14
	1.00	1.00	2.20	0.40
	1.10	0.99	2.50	0.80
	1.30	0.94	2.60	0.85
	1.50	0.45	2.80	0.95
	1.90	0.20	3.40	1.00
	2.40	0.05	6.00	1.00
	3.00	0.00	--	--

Life stage	Velocity		Depth	
	(fps)	Index[1]	(ft)	Index[1]
Adult	0.00	1.00	0.00	0.00
	0.40	0.60	0.80	0.00
	0.60	0.20	1.20	0.05
	1.00	0.08	2.00	0.10
	2.00	0.00	2.80	0.40
	3.00	0.00	3.60	0.92
	--	--	4.00	1.00
	--	--	6.00	1.00

[1] Edwards et al. 1983

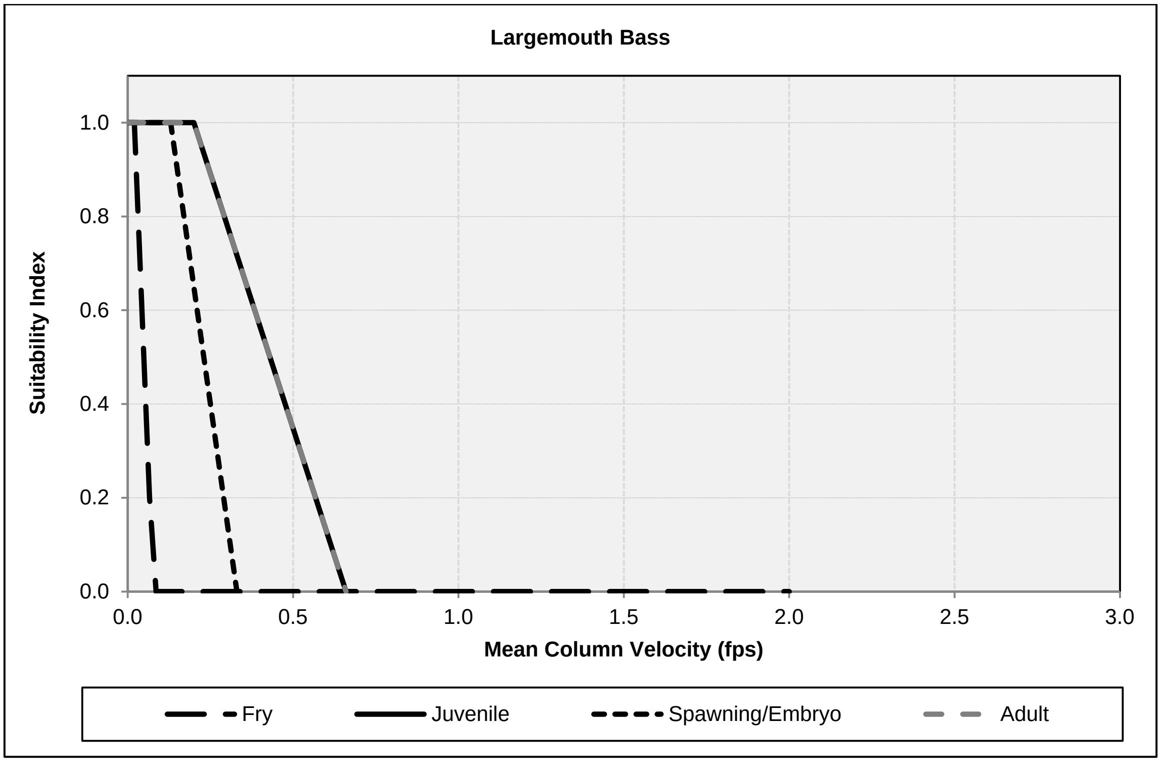

Figure 3. Largemouth bass velocity suitability criteria for the lower Tuolumne River.

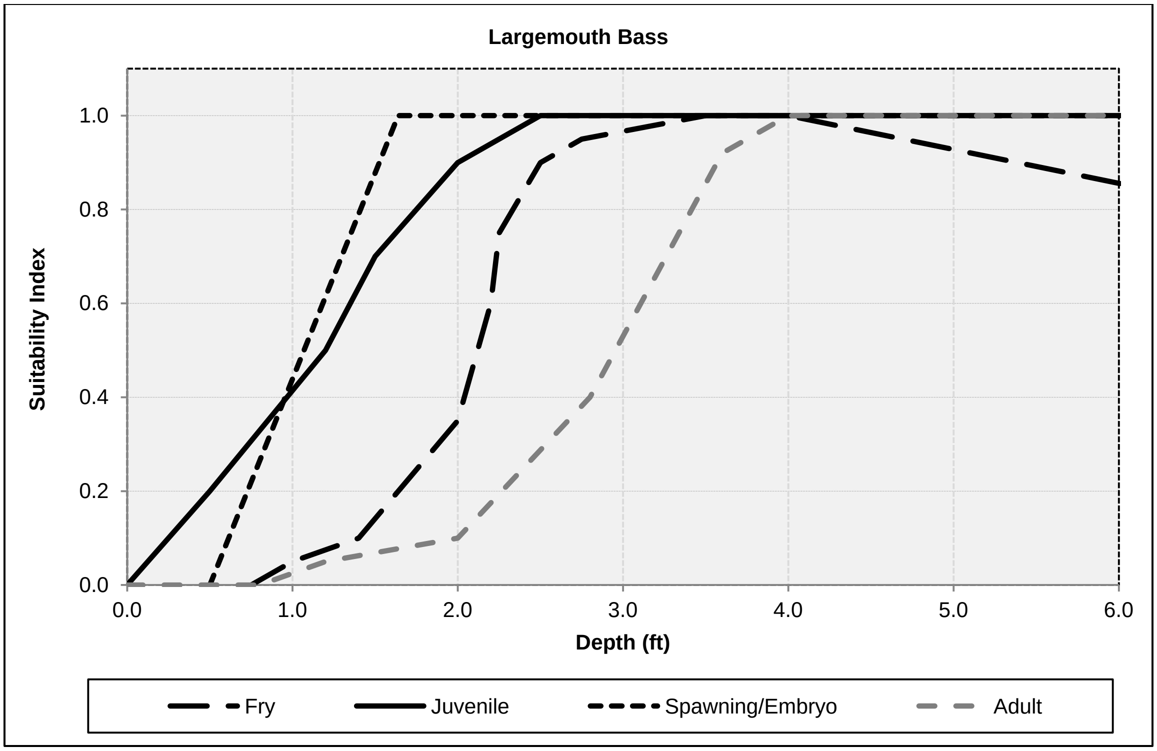

Figure 4. Largemouth bass depth suitability criteria for the lower Tuolumne River.

Table 3. Largemouth bass suitability criteria.

Life stage	Velocity[1]		Depth[2,3]	
	(fps)	Index	(ft)	Index
Fry	0.00	1.00	0.80	0.00
	0.02	1.00	1.00	0.05
	0.07	0.20	1.40	0.10
	0.09	0.00	2.00	0.35
	2.00	0.00	2.20	0.60
	--	--	2.25	0.75
	--	--	2.50	0.90
	--	--	2.75	0.95
	--	--	3.50	1.00
	--	--	4.00	1.00
	--	--	15.09	0.20
	--	--	20.01	0.10
	--	--	22.00	0.00

Life stage	Velocity[1]		Depth[2,3]	
	(fps)	**Index**	**(ft)**	**Index**
Juvenile	0.00	1.00	0.00	0.00
	0.20	1.00	0.50	0.20
	0.66	0.00	1.20	0.50
	--	--	1.50	0.70
	--	--	2.00	0.90
	--	--	2.50	1.00
	--	--	4.00	1.00
	--	--	6.00	1.00
Spawning/ Embryo	0.00	1.00	0.50	0.00
	0.10	1.00	1.60	1.00
	0.13	1.00	6.60	1.00
	0.33	0.00	16.30	0.20
	--	--	18.00	0.00
Adult	0.00	1.00	0.00	0.00
	0.20	1.00	0.80	0.00
	0.66	0.00	1.20	0.05
	--	--	2.00	0.10
	--	--	2.80	0.40
	--	--	3.60	0.92
	--	--	4.00	1.00
	--	--	6.00	1.00

[1] Stuber et al. 1982
[2] HSC for smallmouth bass (Edwards et al. 1983), as used in previous lower Tuolumne studies (McBain and Trush and Stillwater Sciences 2006; Stillwater Sciences 2012)
[3] HSC for smallmouth bass spawning/embryo developed from data in Moyle (2002).

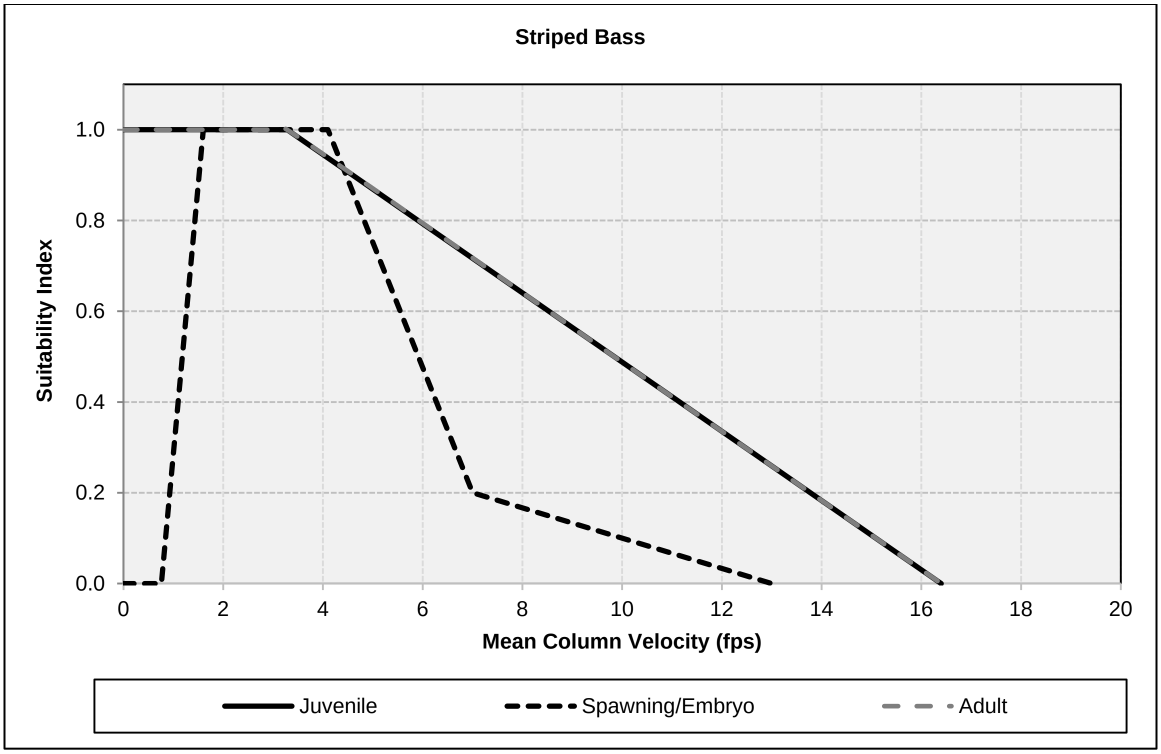

Figure 5. Striped bass velocity suitability criteria for the lower Tuolumne River.

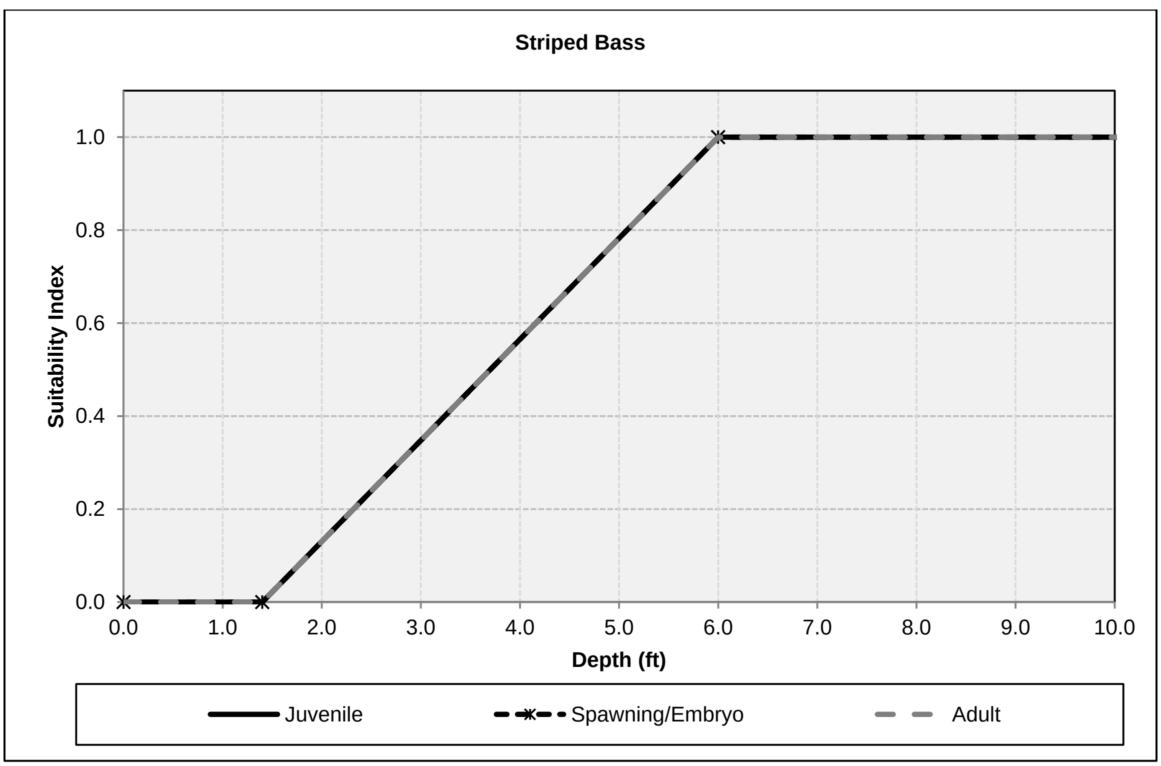

Figure 6. Striped bass depth suitability criteria for the lower Tuolumne River.

Table 4. Striped bass suitability criteria.

Life Stage	Velocity[1,2] (fps)	Velocity[1,2] Index	Depth[2,3] (ft)	Depth[2,3] Index
Juvenile	0.00	1.00	0.00	0.00
	3.00	1.00	1.40	0.00
	3.28	1.00	6.00	1.00
	9.84	0.50	30.00	1.00
	16.40	0.00	100.00	0.00
Spawning/Embryo	0.00	0.00	0.00	0.00
	0.76	0.00	1.40	0.00
	1.60	1.00	6.00	1.00
	4.10	1.00	30.00	1.00
	7.00	0.20	100.00	0.00
	13.00	0.00	--	--
Adult	0.00	1.00	0.00	0.00
	3.00	1.00	1.40	0.00
	3.28	1.00	6.00	1.00
	9.84	0.50	30.00	1.00
	16.40	0.00	100.00	0.00

[1] Juvenile and adult HSC from Hassler (1988)
[2] Spawning/embryo HSC from EA Engineering, Inc. (1994) as adapted from HDR (2011)
[3] Juvenile and adult HSC from Crance (1984)

2.3 Habitat Time Series

A Habitat Time Series (HTS) analysis was conducted to assess how habitat values for each species and life stage vary over time, under different water year type scenarios. Water year types selected for analysis are the five San Joaquin Basin 60-20-20 Index types: Critical, Dry, Below Normal, Above Normal, and Wet, as represented by Water Years 2008-2012 (the most recent years of these index types) and presented in Table 5.

Table 5. San Joaquin Basin 60-20-20 Index, corresponding water year types, and representative water years used for habitat time series analysis in the lower Tuolumne River instream flow study.

San Joaquin Basin 60-20-20 Index[1]	Water Year Type	Representative Water Year
2.06	Critical	2008
2.18	Dry	2012
2.73	Below Normal	2009
3.55	Above Normal	2010
5.59	Wet	2011

[1] DWR Bulletin 132 calculated index

Daily flow values for the lower Tuolumne River were obtained from the USGS gaging station downstream of La Grange Diversion Dam (No. 11289560) and were compiled for all Water Year types. No downstream adjustments for accretion or depletion are required in the PHABSIM assessment reach (RM 51.7 to RM 29.0).[1] The associated WUA values were assigned based on the daily flows using a lookup table of WUA values from the PHABSIM results, interpolated to 5 cfs intervals, within the study reach.

Periodicity for adult and juvenile bass life stages includes all months of the year, since the species are resident (Table 6). Periodicities for bass fry, spawning, and incubation periods are from Moyle (2002).

Table 6. Bass species/life stage periodicity for the lower Tuolumne River.

Species	Life stage	Fall			Winter			Spring			Summer		
		O	N	D	J	F	M	A	M	J	J	A	S
Smallmouth bass	Fry	■	■	■					■	■	■	■	■
	Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
	Spawning								■	■	■		
	Adult	■	■	■	■	■	■	■	■	■	■	■	■
Largemouth bass	Fry	■						■	■	■	■	■	■
	Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
	Spawn/Embryo						■	■	■	■			
	Adult	■	■	■	■	■	■	■	■	■	■	■	■
Striped bass	Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
	Spawning/Embryo							■	■	■	■		
	Adult	■	■	■	■	■	■	■	■	■	■	■	■

3 RESULTS

3.1 Weighted Usable Area

Results of the PHABSIM analysis of WUA versus flow relationships for each species and life stage are presented in Figures 7–12 and Tables 7–9. In order to facilitate comparisons across species and life stages, the results are presented and discussed based on normalized y-axis scales of "percent of maximum" WUA (Figures 7, 9, and 11), and area (ft^2 per 1,000 ft of stream) (Figures 8, 10, and 12).

Results for smallmouth bass show that, in general, potential habitat for all life stages is maximized at low flows, with peak WUA values (≥95 percent of maximum) at flows less than approximately 150 cfs, followed by declining, but still relatively high WUA values (≥80 percent of maximum), between 200–300 cfs for all life stages except spawning, then a continued decline to approximately 700 cfs before generally stabilizing over the

[1] The reach represented in the PHABSIM assessment includes RM 51.7 to RM 29.0. Accretion/depletion studies performed by the Districts suggest that flow changes along the study reach (which is upstream of Dry Creek and does not contain major tributaries) are relatively small compared to the scale of most HTS flows and the associated WUA reporting increments, and therefore the HTS results are not adjusted for these changes.

remaining range of simulated flows (Figures 7 and 8). Results for smallmouth bass spawning show peak WUA values at approximately 150 cfs, with a steady decline, but still relatively high WUA values (≥80 percent of maximum) up to near 700 cfs, followed by a slightly more gradual decline over the remaining range of simulated flows (Figures 7 and 8).

Results for largemouth bass show that potential habitat for all life stages is maximized at low flows, with peak WUA values (≥95 percent of maximum) at flows of approximately 50–75 cfs, followed by sharply declining, but still relatively high WUA values for adults and juveniles (≥80 percent of maximum) between approximately 75 and 175 cfs, then continued decline to approximately 600 cfs before remaining relatively stable over the remaining range of simulated flows (Figures 9 and 10). Spawning WUA remains relatively high (≥80 percent of maximum) at flows below approximately 100 cfs, while fry WUA remains relatively high at flows below approximately 75 cfs (Figures 9 and 10).

Results for striped bass juveniles and adults show that potential habitat is maximized at high flows, with peak WUA values (≥95 percent of maximum) at flows of approximately 1,100–1,200 cfs and relatively high WUA values (≥80 percent of maximum) near 600 cfs; WUA values steadily decrease from 600 cfs down to 50 cfs (Figures 11 and 12). Results for striped bass spawning show a similar pattern, with peak WUA at 1,200 cfs and steadily decreasing values down to 50 cfs (Figures 11 and 12).

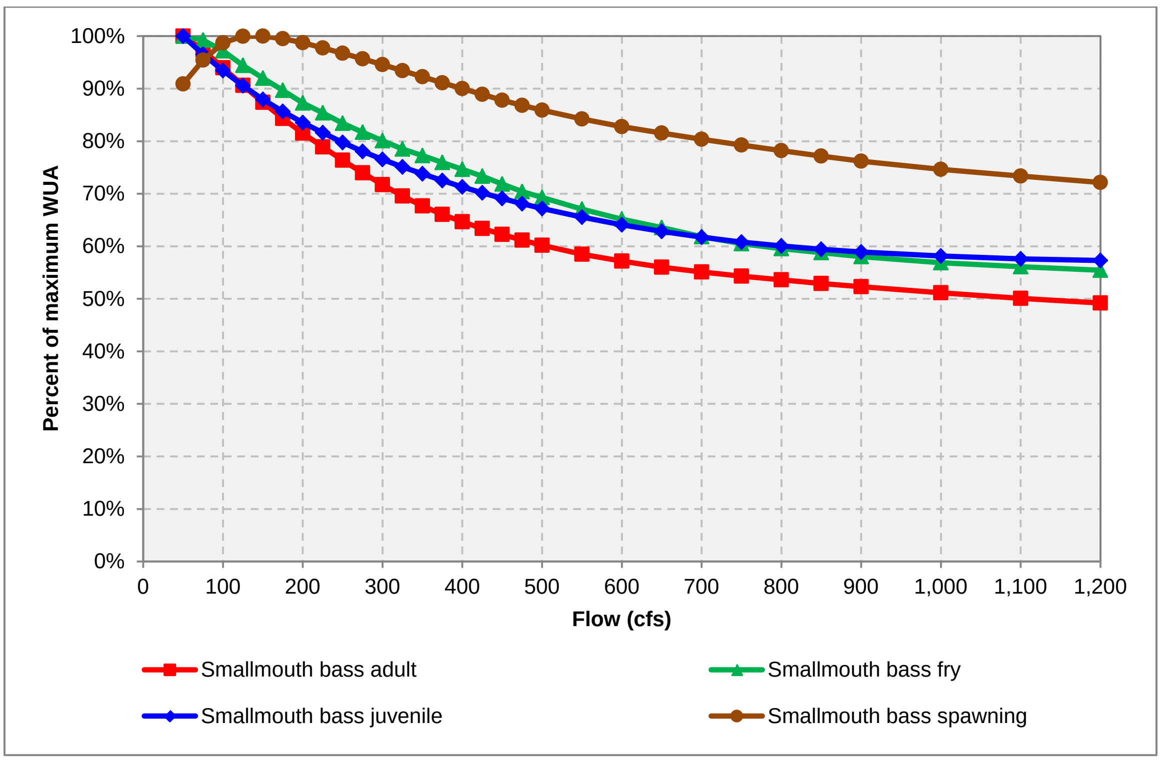

Figure 7. Smallmouth bass WUA results, as percent of maximum, for the lower Tuolumne River.

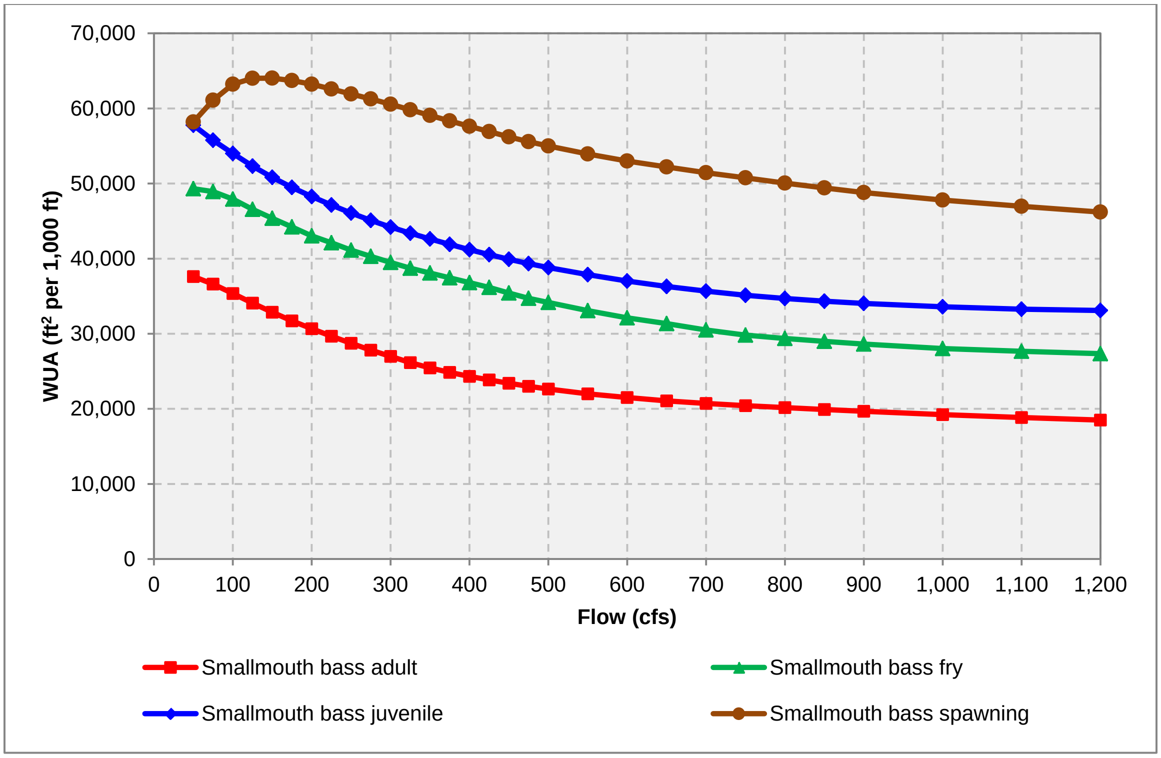

Figure 8. Smallmouth bass WUA results for the lower Tuolumne River.

Table 7. Smallmouth bass WUA results for the lower Tuolumne River.

Simulated discharge (cfs)	Smallmouth bass Adult (ft^2 per 1,000 ft)	Smallmouth bass Fry (ft^2 per 1,000 ft)	Smallmouth bass Juvenile (ft^2 per 1,000 ft)	Smallmouth bass Spawning (ft^2 per 1,000 ft)
50	37610.66	49310.66	57773.70	58199.90
75	36611.94	48927.60	55770.23	61098.27
100	35347.07	47923.05	53999.15	63212.45
125	34084.69	46564.54	52325.03	64012.41
150	32865.55	45366.45	50813.19	64026.90
175	31715.21	44219.46	49483.60	63704.52
200	30662.41	43032.75	48264.62	63229.00
225	29674.75	42100.73	47147.08	62576.96
250	28728.19	41127.22	46076.09	61932.08
275	27819.37	40289.66	45094.30	61255.46
300	26975.41	39492.55	44205.92	60551.09
325	26158.49	38717.59	43384.86	59821.62
350	25454.39	38092.27	42623.51	59070.07
375	24847.25	37453.20	41895.79	58340.84
400	24316.35	36806.94	41198.35	57625.40
425	23843.06	36166.16	40539.48	56923.76
450	23413.27	35428.60	39923.32	56217.39
475	23006.28	34716.06	39343.97	55578.75
500	22638.29	34172.25	38817.39	54998.96
550	22001.59	33069.77	37862.84	53928.51
600	21500.04	32120.23	37024.50	53001.94
650	21071.31	31343.73	36304.18	52206.00
700	20723.56	30491.73	35672.17	51451.68
750	20431.97	29827.51	35129.46	50749.29
800	20162.74	29370.15	34700.83	50066.66
850	19905.37	28986.40	34334.89	49406.96
900	19678.22	28620.87	34030.82	48794.57
1000	19234.36	28037.51	33597.60	47789.30
1100	18842.04	27667.26	33276.92	46971.28
1200	18506.79	27344.17	33098.41	46203.30

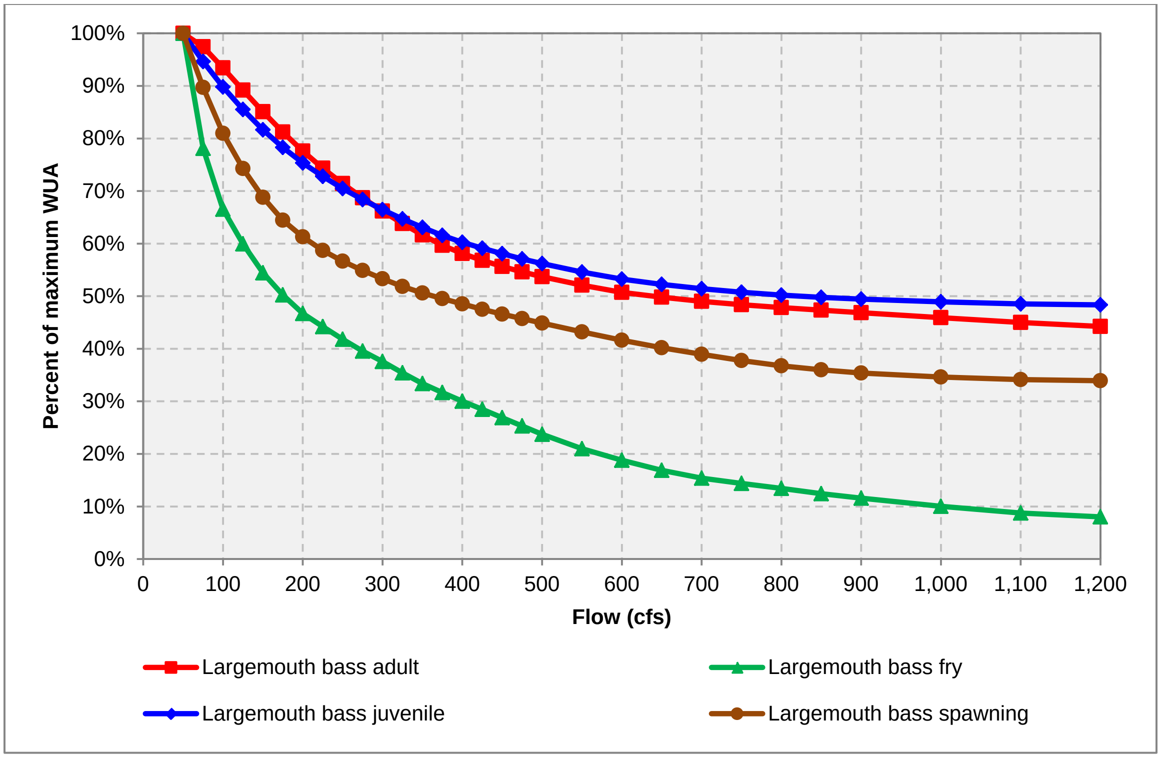

Figure 9. Largemouth bass WUA results, as percent of maximum, for the lower Tuolumne River.

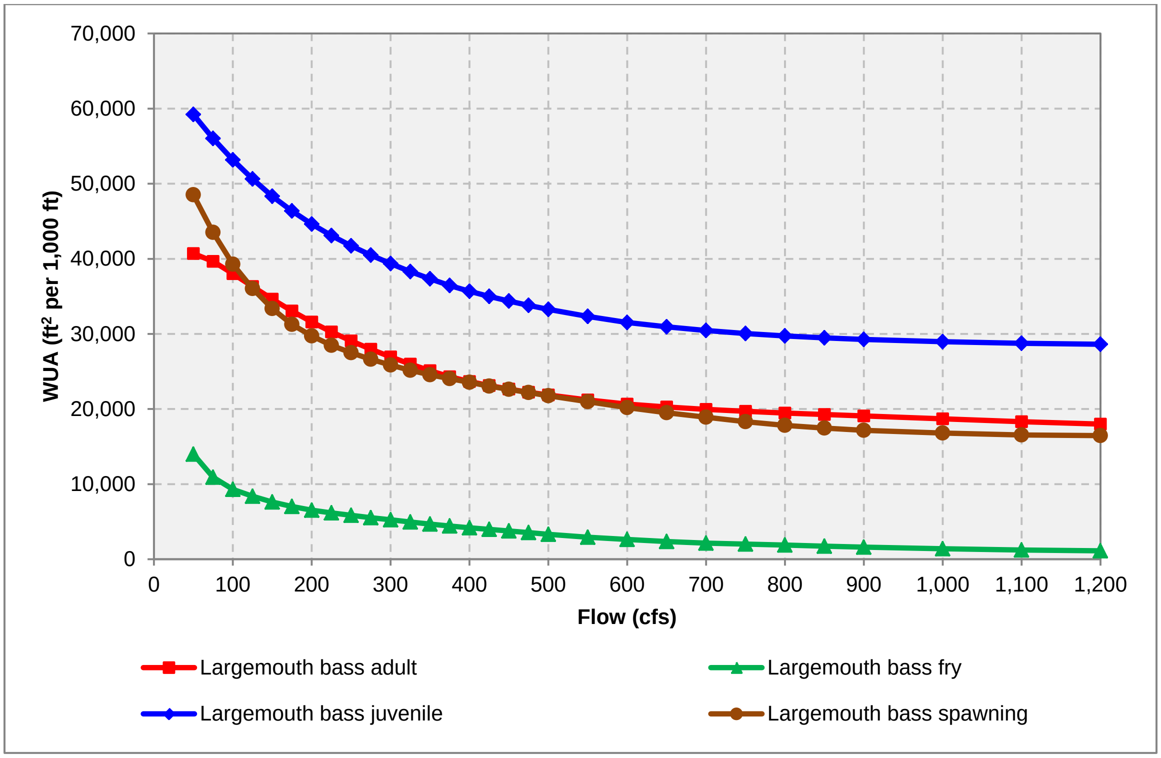

Figure 10. Largemouth bass WUA results for the lower Tuolumne River.

Table 8. Largemouth bass WUA results for the lower Tuolumne River.

Simulated discharge (cfs)	Largemouth bass Adult (ft^2 per 1,000 ft)	Largemouth bass Fry (ft^2 per 1,000 ft)	Largemouth bass Juvenile (ft^2 per 1,000 ft)	Largemouth bass Spawning (ft^2 per 1,000 ft)
50	40708.30	13986.69	59208.52	48515.43
75	39660.01	10925.04	56030.40	43523.37
100	38028.38	9309.50	53173.39	39278.38
125	36307.90	8384.29	50625.91	36037.17
150	34630.44	7615.32	48333.27	33383.59
175	33060.92	7024.77	46364.44	31269.05
200	31593.51	6533.97	44617.68	29736.39
225	30266.65	6181.81	43098.60	28471.83
250	29070.50	5846.35	41725.87	27486.13
275	27965.84	5531.88	40485.91	26631.64
300	26936.18	5257.14	39356.47	25858.24
325	25974.16	4953.01	38305.81	25155.79
350	25100.98	4670.15	37345.91	24553.38
375	24296.33	4431.32	36439.19	24034.65
400	23655.09	4198.35	35675.69	23547.57
425	23123.31	3984.85	34998.55	23048.12
450	22655.45	3762.26	34387.26	22607.91
475	22235.46	3541.44	33807.18	22182.08
500	21863.61	3318.32	33279.36	21766.90
550	21202.93	2934.48	32327.16	20966.97
600	20654.24	2629.89	31526.25	20196.27
650	20270.83	2362.34	30940.88	19503.86
700	19953.88	2151.64	30455.76	18900.41
750	19692.86	2013.76	30053.86	18324.60
800	19468.30	1879.08	29725.62	17825.72
850	19271.07	1740.78	29476.14	17456.39
900	19076.58	1621.91	29266.97	17167.47
1000	18688.89	1403.11	28974.01	16794.71
1100	18320.70	1225.05	28744.11	16556.73
1200	18004.61	1122.49	28626.26	16464.03

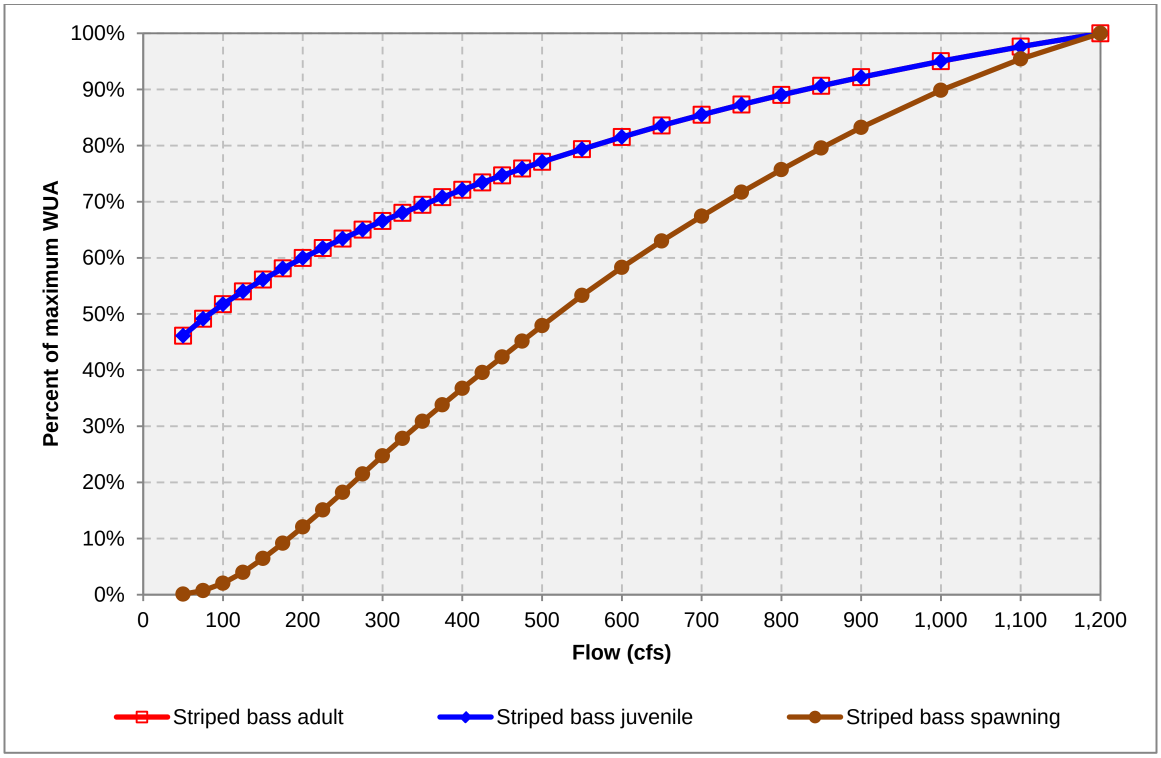

Figure 11. Striped bass WUA results, as percent of maximum, for the lower Tuolumne River.

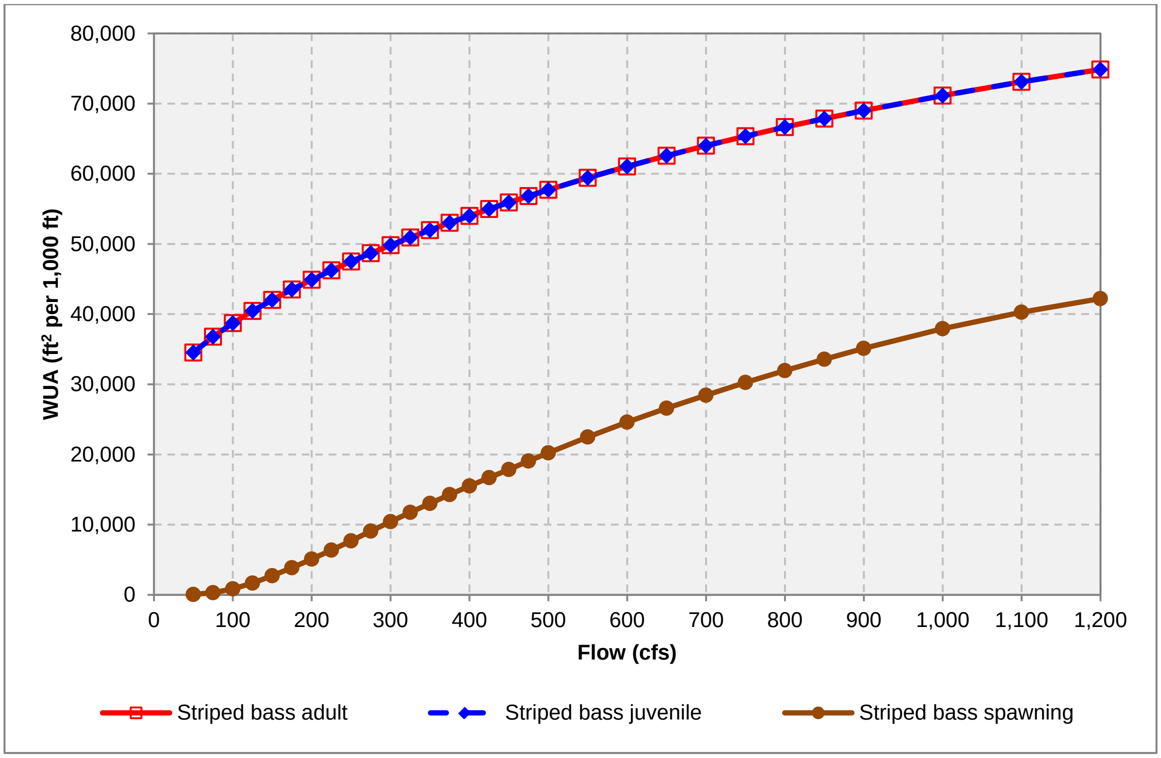

Figure 12. Striped bass WUA results for the lower Tuolumne River.

Table 9. Striped bass WUA results for the lower Tuolumne River.

Simulated discharge (cfs)	Striped bass Adult (ft^2 per 1,000 ft)	Striped bass Juvenile (ft^2 per 1,000 ft)	Striped bass Spawning (ft^2 per 1,000 ft)
50	34532.77	34532.77	40.21
75	36790.11	36790.11	307.32
100	38727.53	38727.53	857.51
125	40454.49	40454.49	1668.59
150	42032.46	42032.46	2725.19
175	43512.25	43512.25	3859.33
200	44907.97	44907.97	5084.73
225	46238.02	46238.02	6359.34
250	47496.52	47496.52	7691.60
275	48689.15	48689.15	9072.57
300	49829.50	49829.50	10426.24
325	50917.92	50917.92	11737.14
350	51981.80	51981.80	13029.51
375	53013.36	53013.36	14271.87
400	54005.24	54005.24	15503.92
425	54971.85	54971.85	16696.47
450	55918.05	55918.05	17865.28
475	56837.52	56837.52	19056.71
500	57728.43	57728.43	20226.59
550	59426.49	59426.49	22494.32
600	61038.31	61038.31	24597.31
650	62566.66	62566.66	26583.42
700	64012.49	64012.49	28449.41
750	65367.32	65367.32	30252.34
800	66652.73	66652.73	31955.28
850	67864.13	67864.13	33579.97
900	69015.12	69015.12	35124.22
1000	71157.95	71157.95	37914.49
1100	73102.74	73102.74	40277.25
1200	74873.45	74873.45	42202.64

3.2 Habitat Time Series

HTS results for each of five water year types (Table 5) and three species and life stage combinations (Table 1) are presented in Figures 13–27. The time periods used in the habitat time series analysis include periods when individual life stages are most typically observed within the study reach, or could theoretically be present, based on the periodicity summarized in Table 6.

Consistent with previous HTS analysis of Chinook salmon and *Oncorhynchus mykiss* (Stillwater Sciences 2013) and Pacific lamprey and splittail (Stillwater Sciences 2014), WUA values were maintained at the 1,200 cfs level for flows over the WUA extrapolation limit of 1,200 cfs. This approach assumes that in-channel WUA will not get significantly higher (or will get higher, then descend again) or lower (or go lower and rise again or level off) than where it was at 1,200 cfs. This is a conservative approach, but it does have the drawback that all flows above 1,200 cfs will return the same WUA value (e.g., "flatline") and a depiction of potential variability at higher flows is lost. Figures 28–30 present HTS results across all water year types for combined species in order to facilitate comparisons of patterns between water year types.

Under Critical, Dry, and Below Normal year scenarios, smallmouth bass and largemouth bass WUA remains relatively stable during most of the year, with decreases in WUA corresponding to high spring flows. Under Above Normal and Wet year scenarios, higher flows and lower WUA values are present over longer periods and WUA is minimized as flow increases up to 1,200 cfs. The combined spawning periods for smallmouth and largemouth bass extend from March into July. Higher flows during the spawning period decrease spawning WUA for both smallmouth and largemouth bass.

In contrast, striped bass WUA is minimized at lower flows and increases as flows increase. Under Critical, Dry, and Below Normal year scenarios, WUA for adults and juveniles remains low during most of the year, with the exception of higher flow periods during the spring. Under Above Normal and Wet year scenarios, higher flows, and correspondingly higher WUA, are present over a longer period and extend into summer months. Striped bass spawning occurs during April–July and spawning WUA is near maximum in all water year types during spring and remains high into summer months in Above Normal and Wet year scenarios.

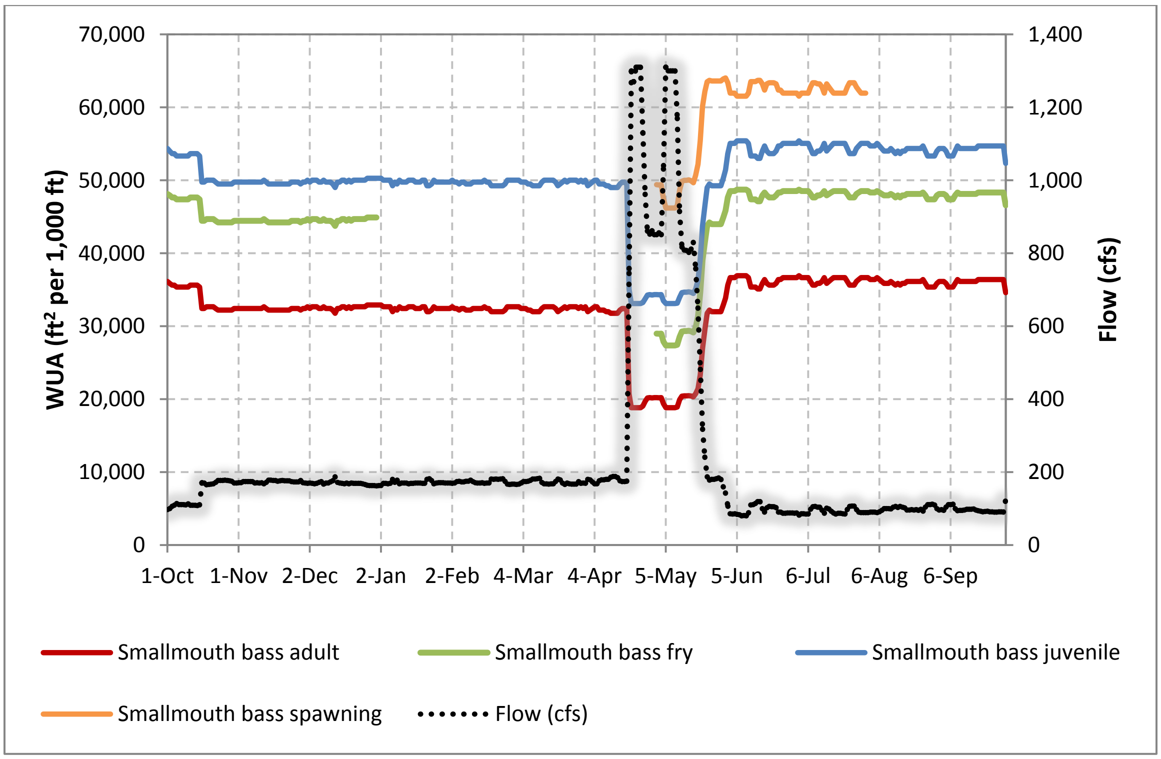

Figure 13. Habitat Time Series results for lower Tuolumne River smallmouth bass in a Critical water year (2008).

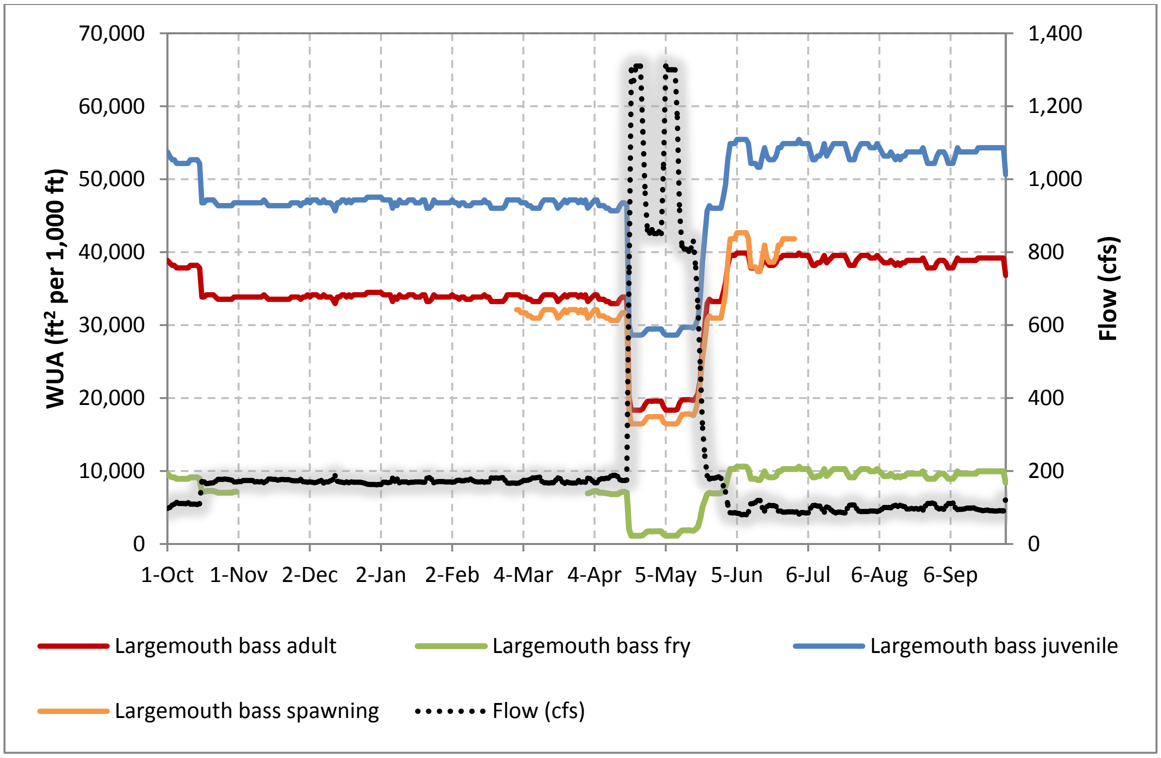

Figure 14. Habitat Time Series results for lower Tuolumne River largemouth bass in a Critical water year (2008).

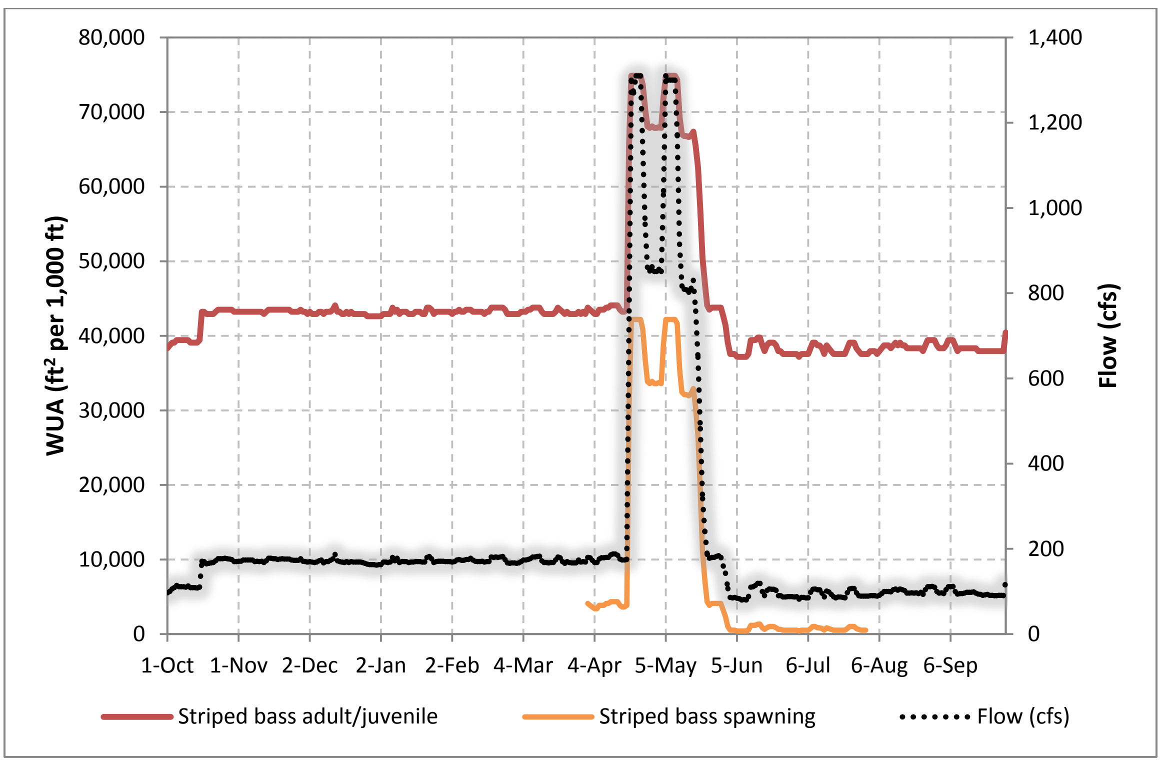

Figure 15. Habitat Time Series results for lower Tuolumne River striped bass in a Critical water year (2008).

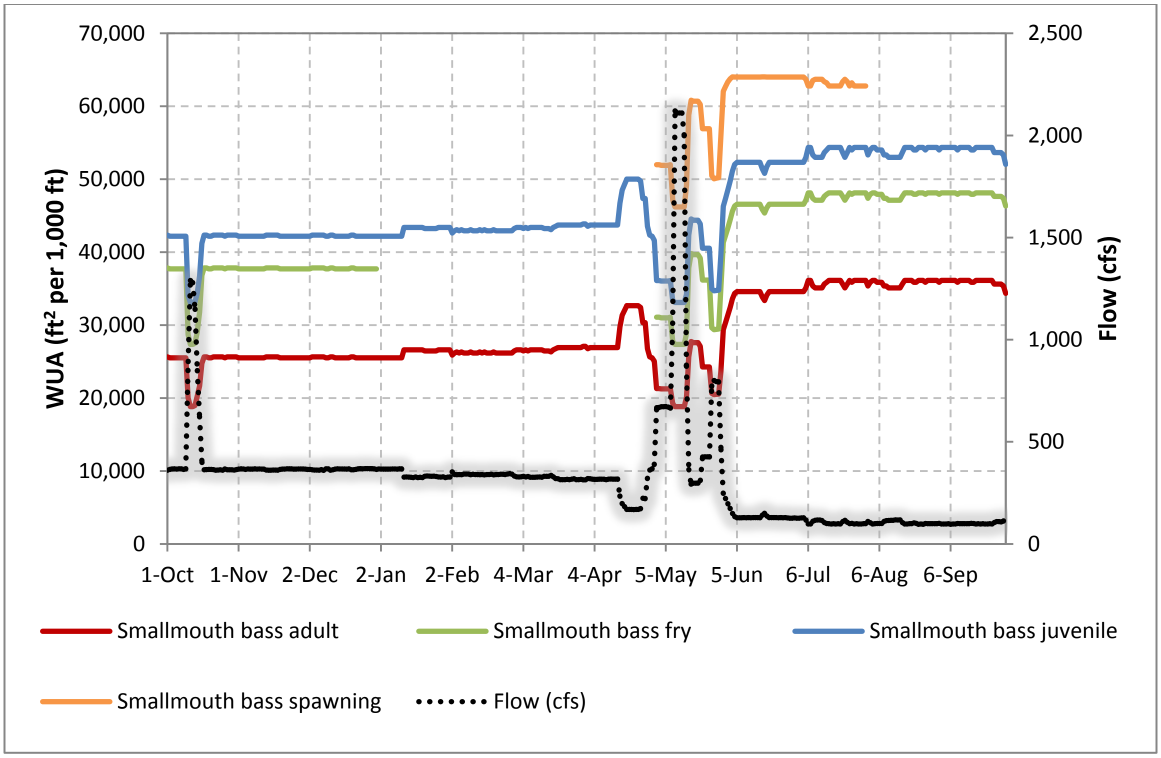

Figure 16. Habitat Time Series results for lower Tuolumne River smallmouth bass in a Dry water year (2012).

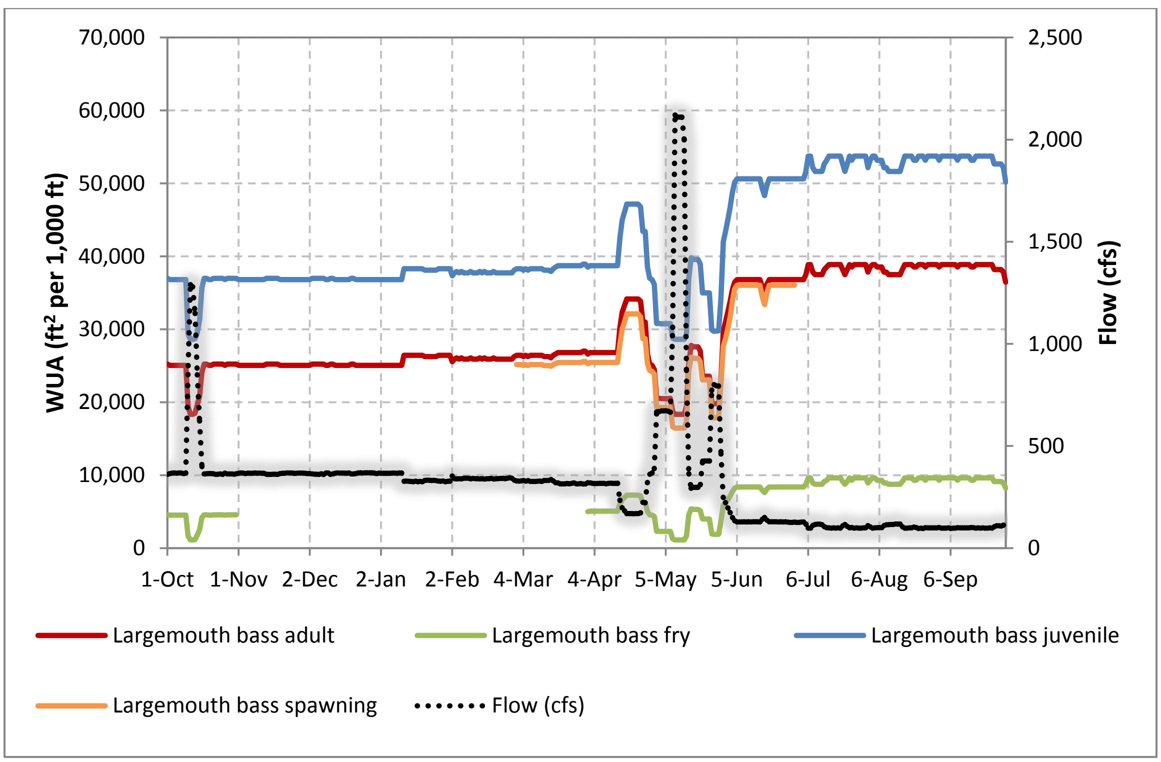

Figure 17. Habitat Time Series results for lower Tuolumne River largemouth bass in a Dry water year (2012).

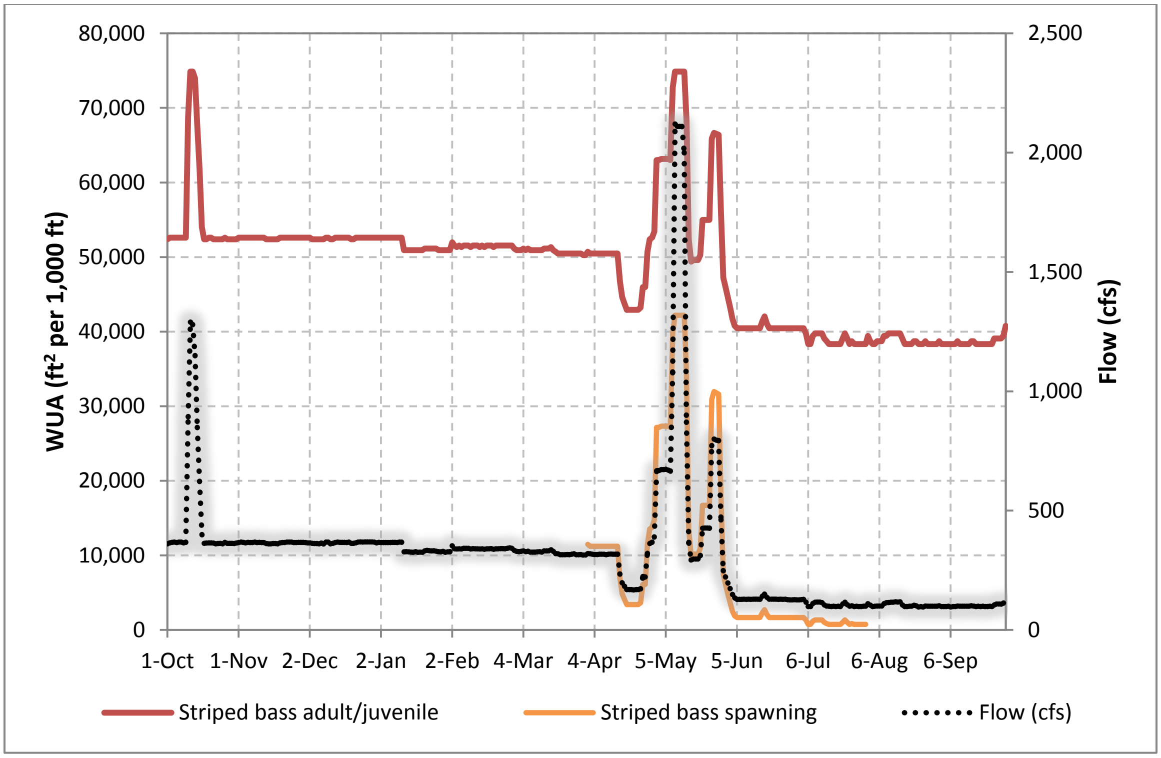

Figure 18. Habitat Time Series results for lower Tuolumne River striped bass in a Dry water year (2012).

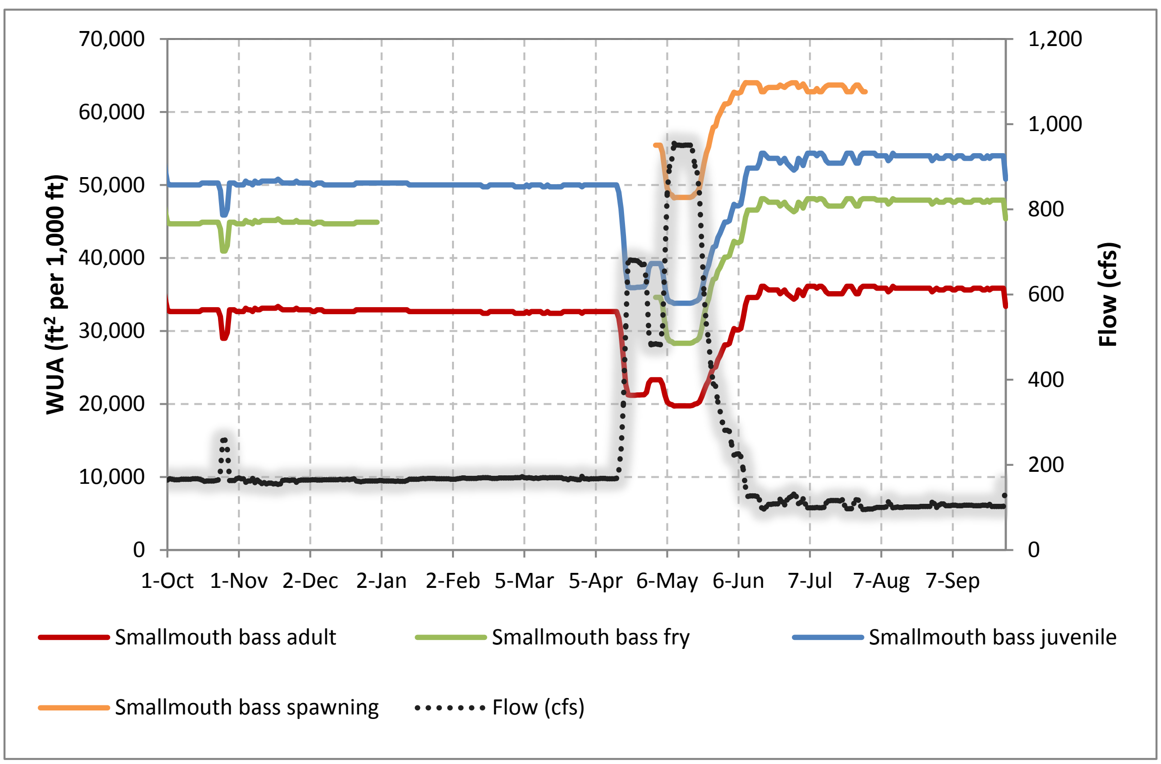

Figure 19. Habitat Time Series results for lower Tuolumne River smallmouth bass in a Below Normal water year (2009).

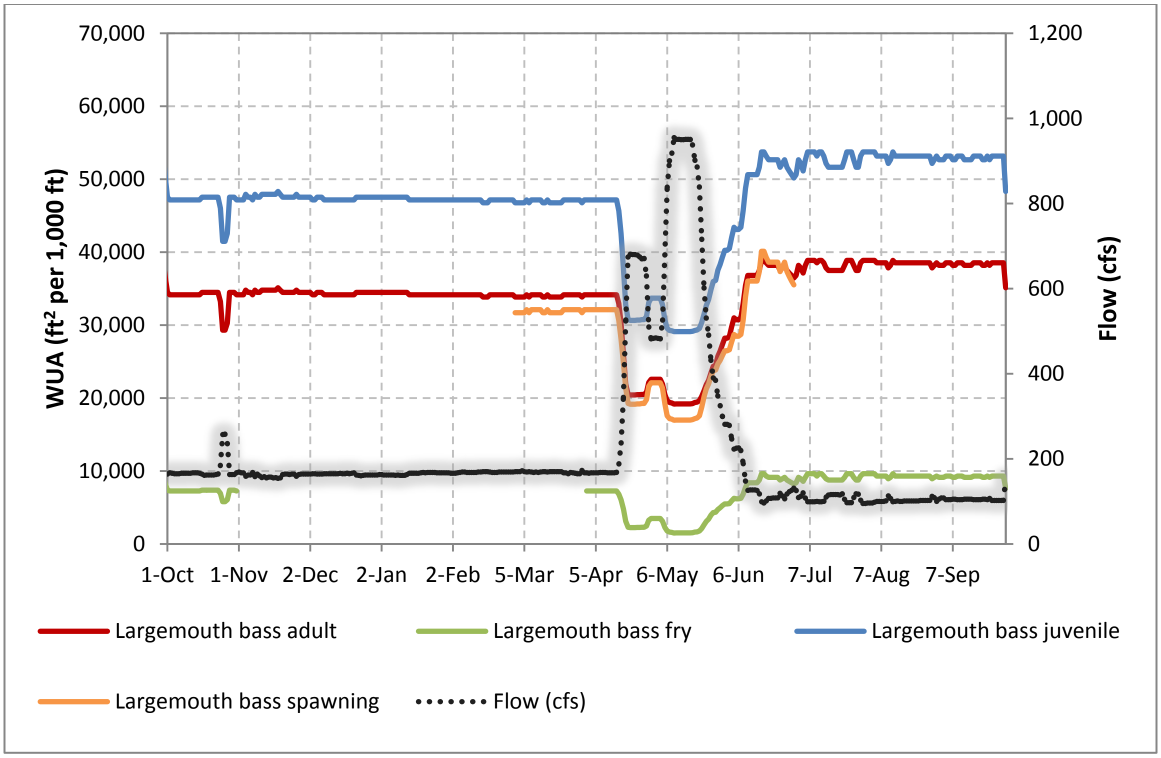

Figure 20. Habitat Time Series results for lower Tuolumne River largemouth bass in a Below Normal water year (2009).

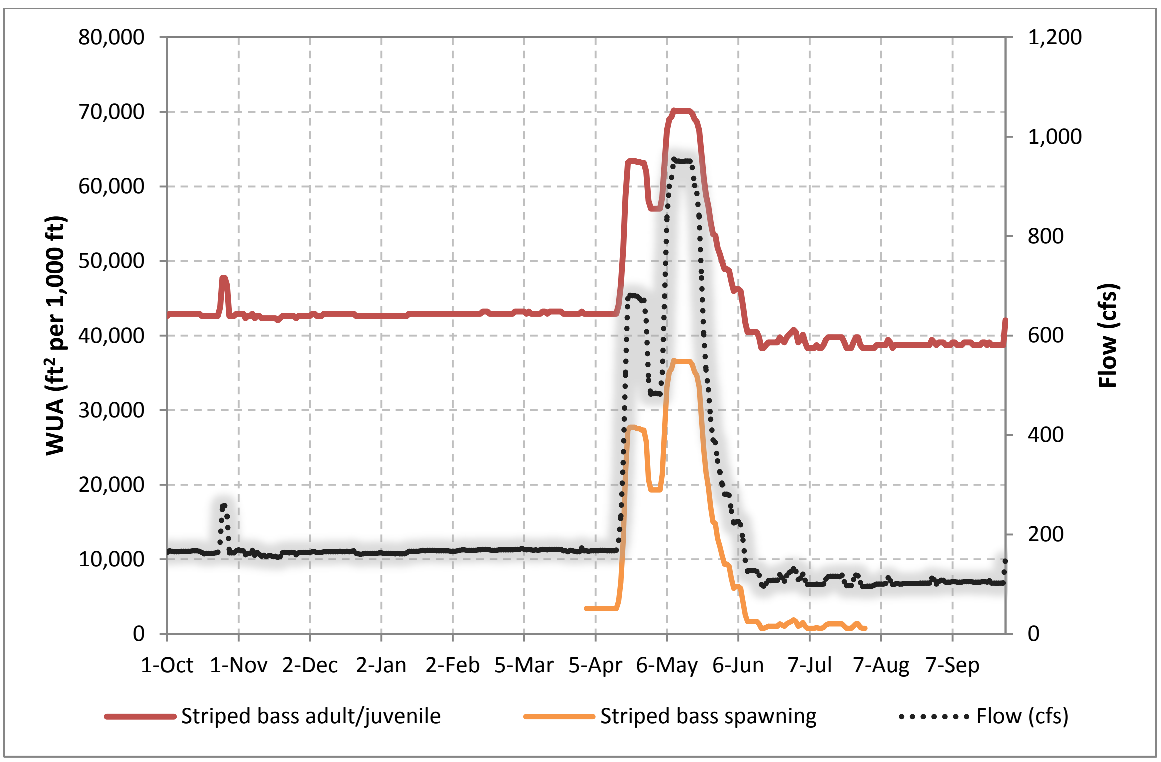

Figure 21. Habitat Time Series results for lower Tuolumne River striped bass in a Below Normal water year (2009).

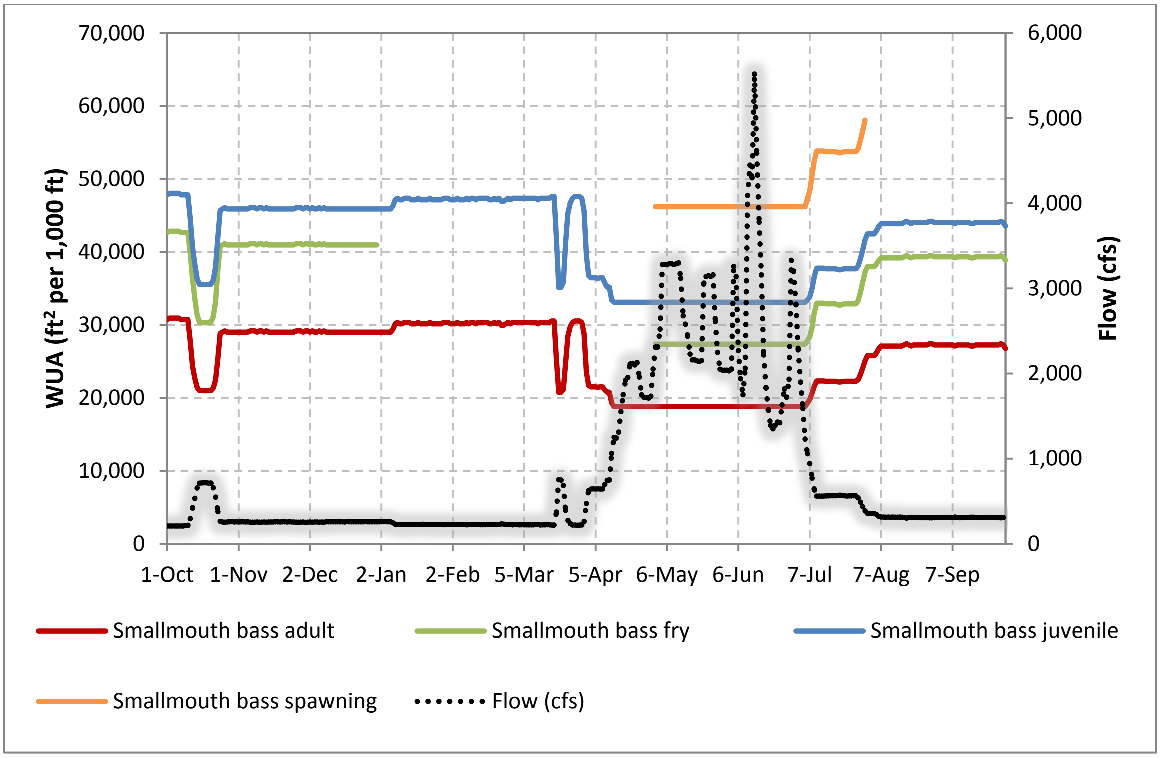

Figure 22. Habitat Time Series results for lower Tuolumne River smallmouth bass in an Above Normal water year (2010).

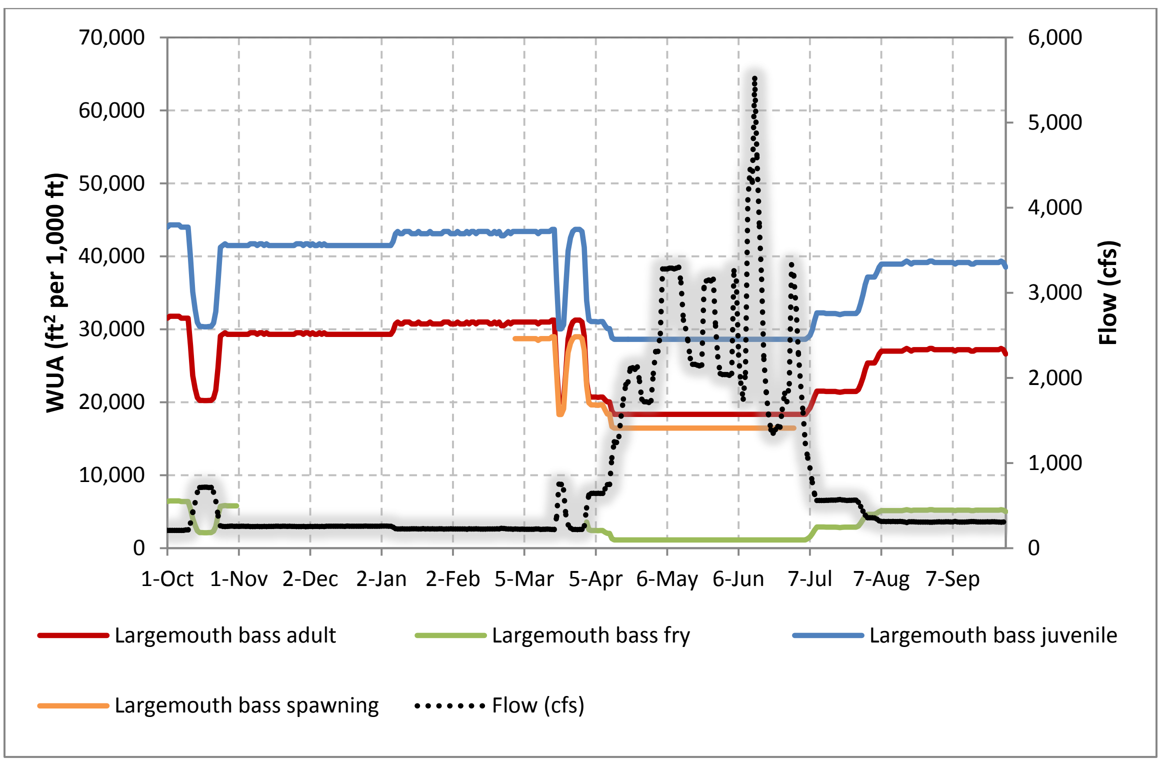

Figure 23. Habitat Time Series results for lower Tuolumne River largemouth bass in an Above Normal water year (2010).

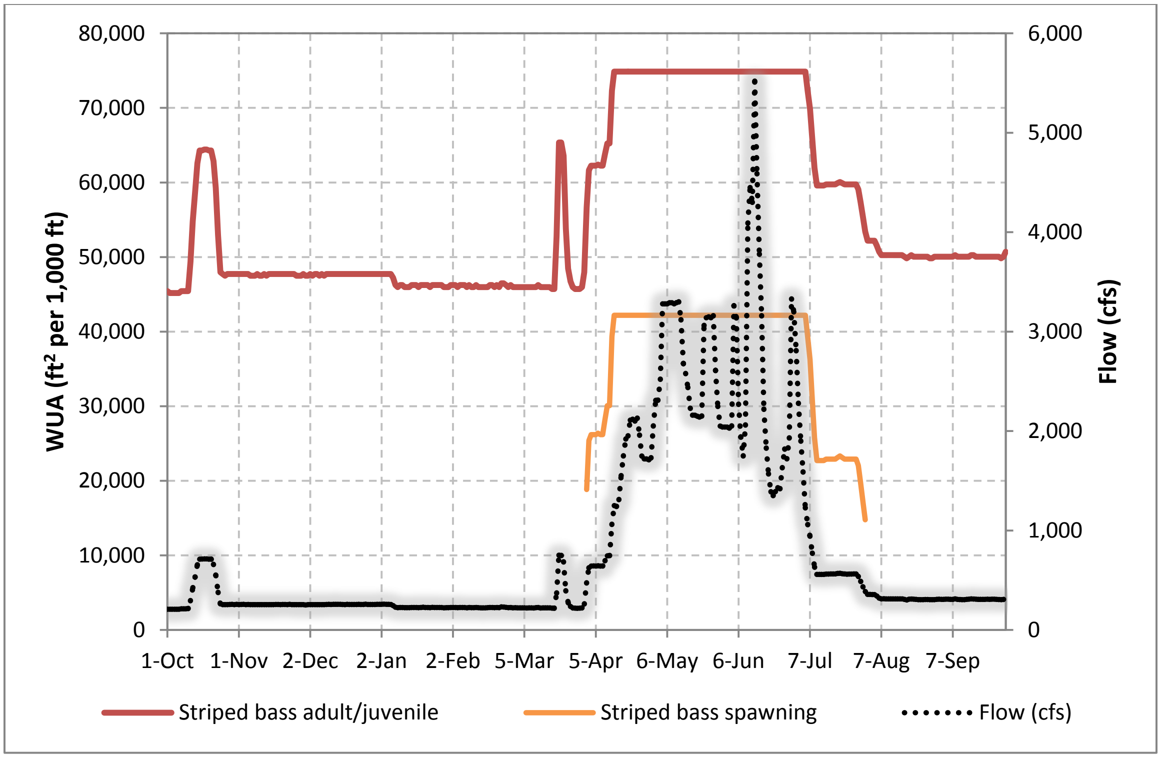

Figure 24. Habitat Time Series results for lower Tuolumne River striped bass in an Above Normal water year (2010).

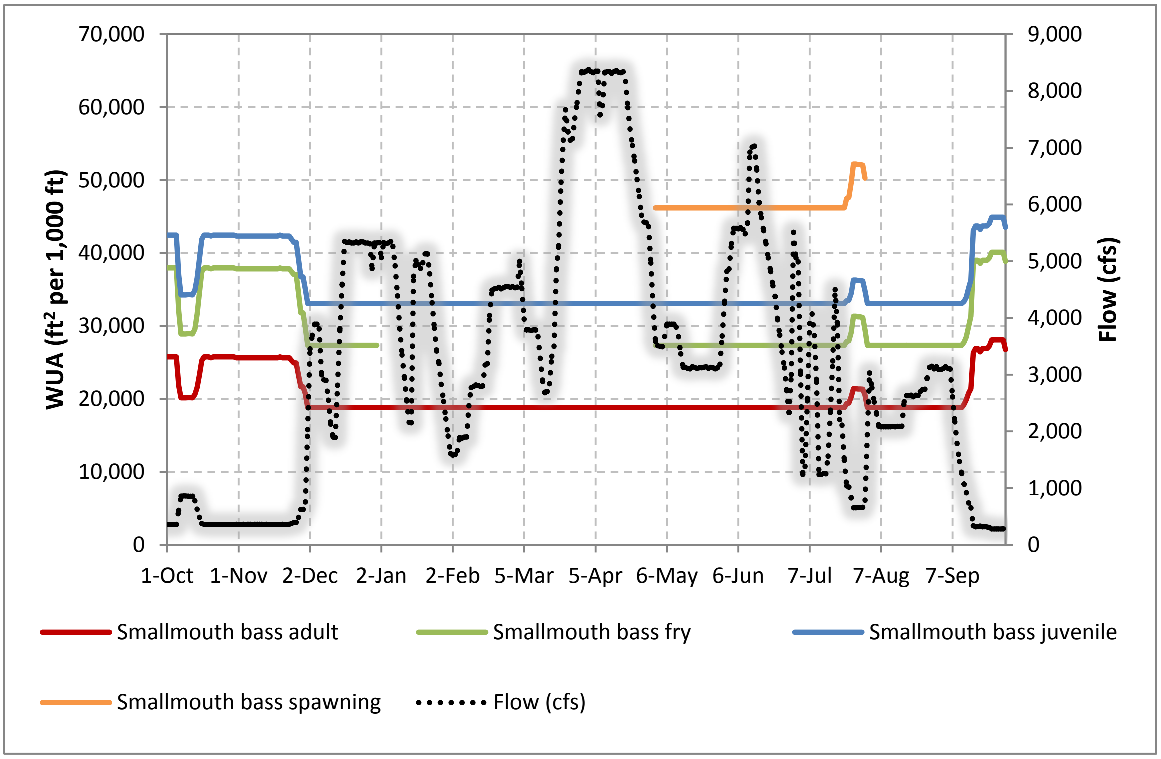

Figure 25. Habitat Time Series results for lower Tuolumne River smallmouth bass in a Wet water year (2010).

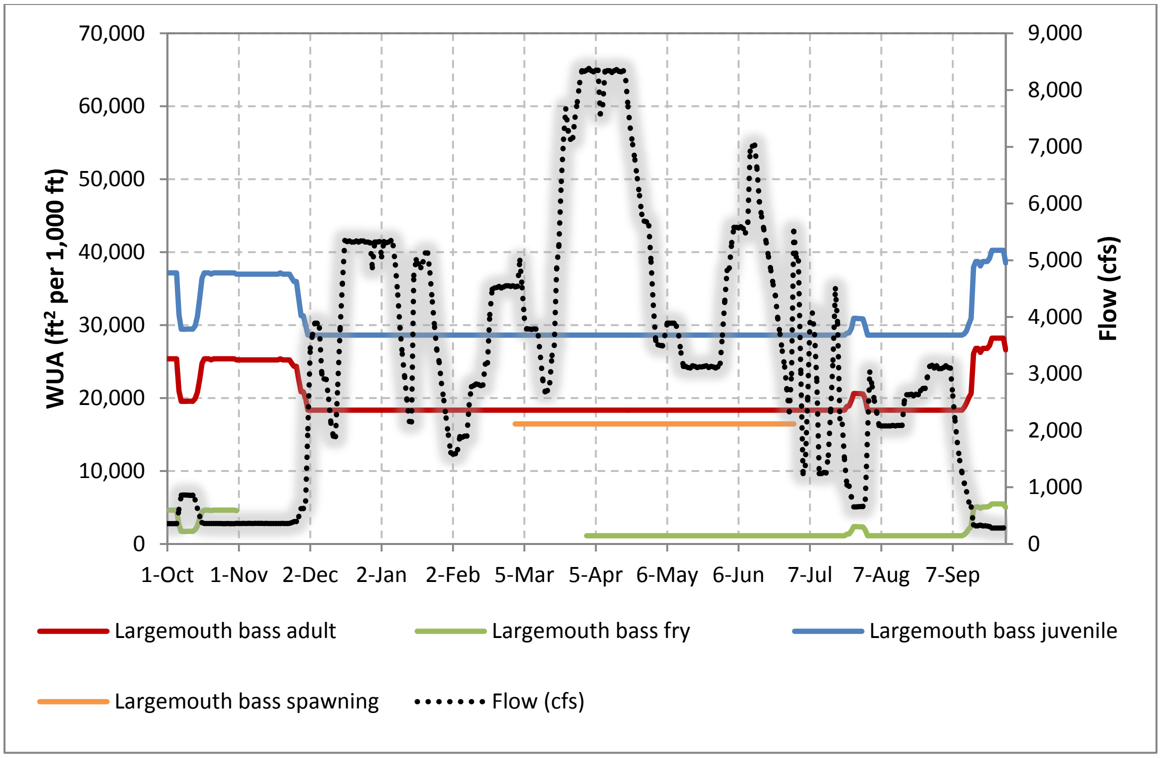

Figure 26. Habitat Time Series results for lower Tuolumne River largemouth bass in a Wet water year (2010).

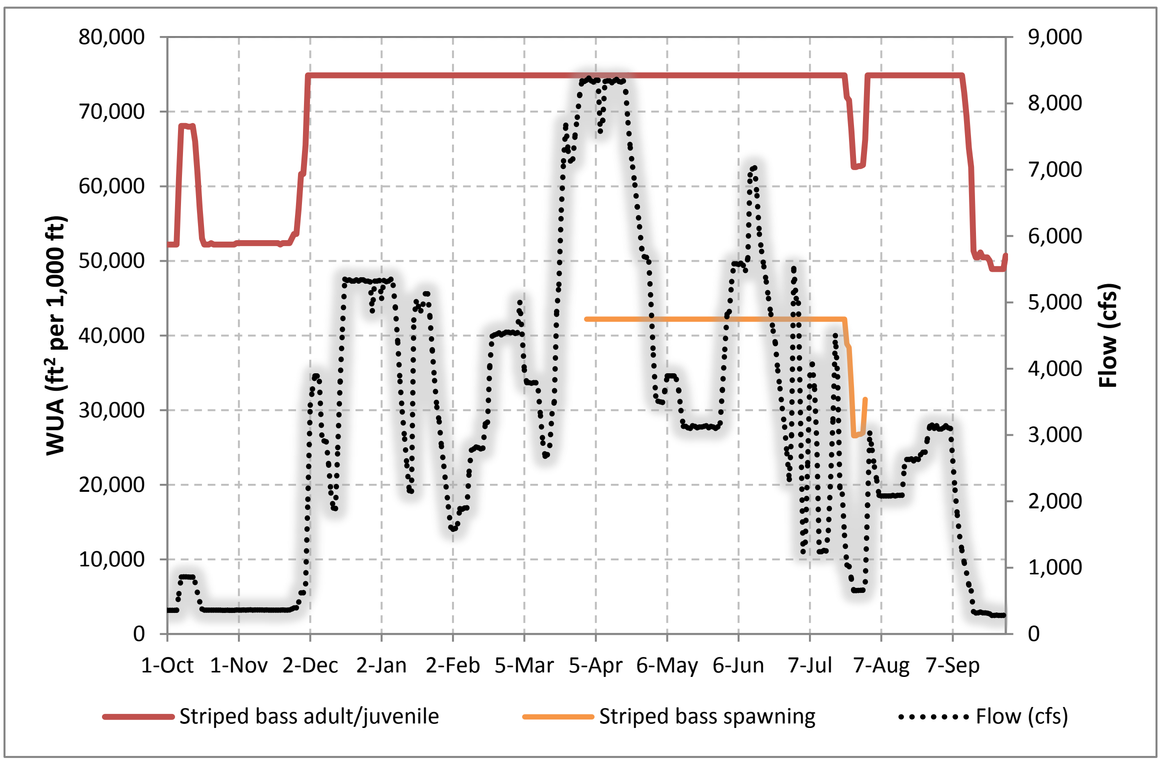

Figure 27. Habitat Time Series results for lower Tuolumne River striped bass in a Wet water year (2010).

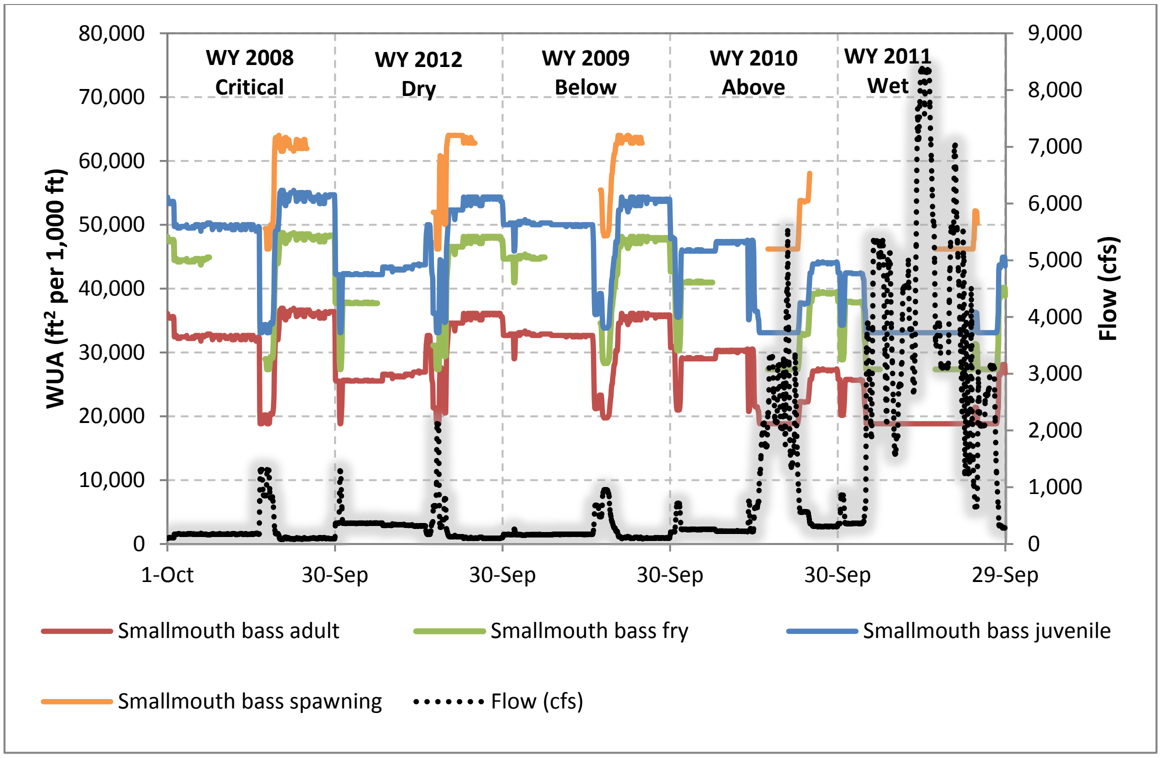

Figure 28. Habitat Time Series results for lower Tuolumne River smallmouth bass across all water year types.

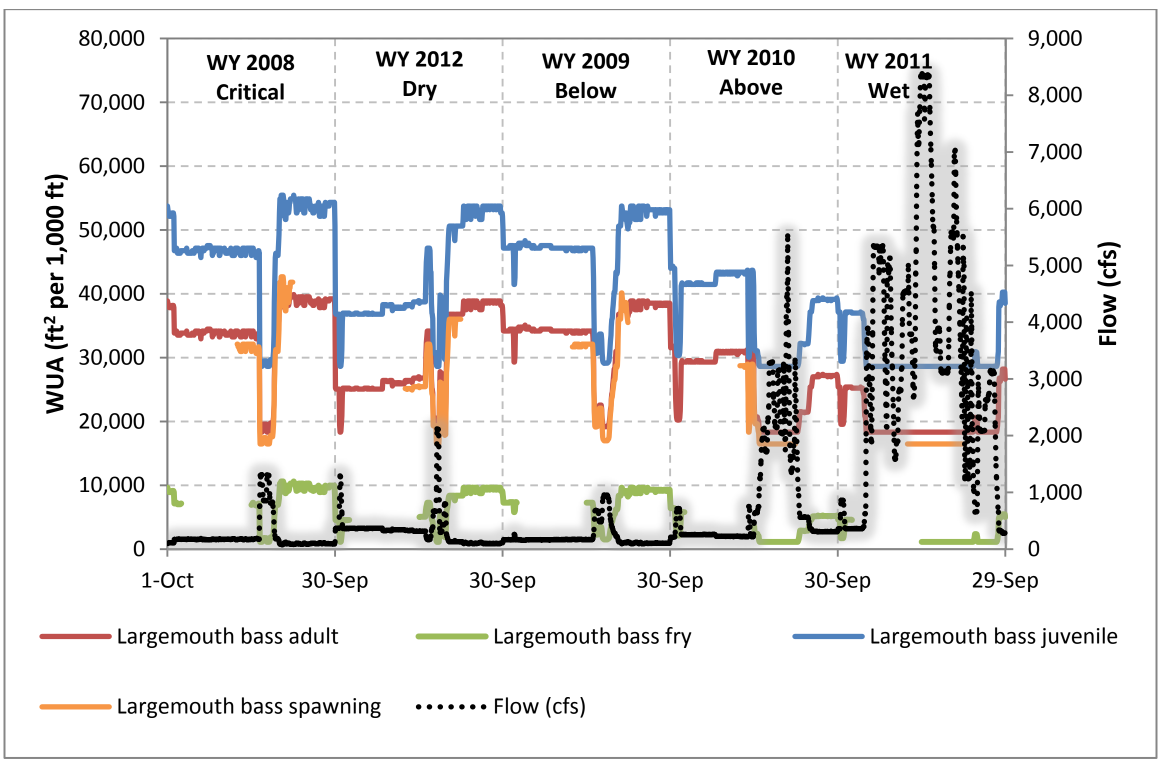

Figure 29. Habitat Time Series results for lower Tuolumne River largemouth bass across all water year types.

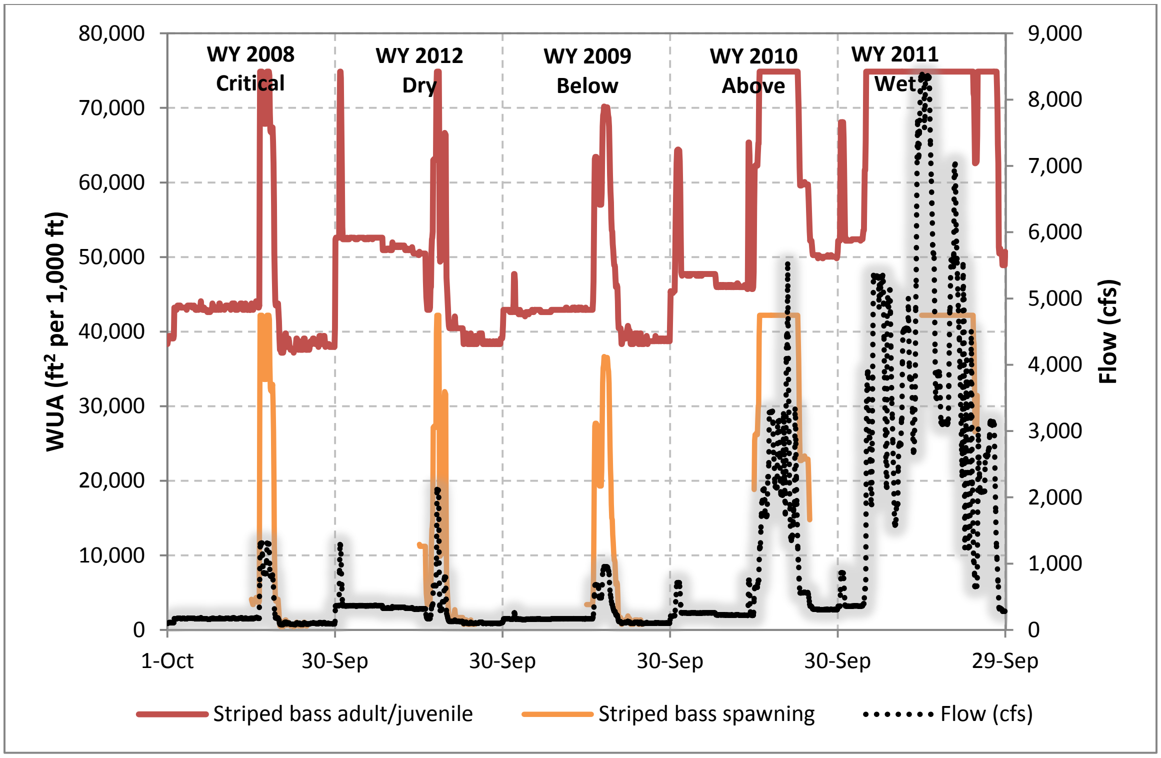

Figure 30. Habitat Time Series results for lower Tuolumne River striped bass across all water year types.

4 DISCUSSION

4.1 Non-native predatory bass in the Lower Tuolumne River

Although bass are present in the study reach, they occur primarily downstream of approximately RM 31 (Brown and Ford 2002, TID/MID 2013). The instream flow study reach (RM 29–52) is within the higher gradient, faster velocity, gravel-bedded reach (i.e., RM 24-52), which is characterized by lower water temperatures than areas farther downstream. Most of the lower Tuolumne River between RM 0 and 31 is within the lower gradient, lower velocity, sand-bedded reach (i.e., RM 0-24), which has relatively higher water temperatures. The model applied in this study was developed primarily for use in evaluating salmonid habitat with the study reach (Stillwater Sciences 2009). As a result, the WUA results presented in this report for bass are not necessarily applicable to the river downstream of RM 29, where most of the bass occur.

Within the higher gradient, gravel-bedded reach (RM 29-52), adult and juvenile life stages of bass are present in low numbers year-round (TID/MID 2013) across all of the modeled flows. Habitat availability (as measured by WUA) for adult and juvenile smallmouth bass and largemouth bass is maximized at lower flows. In contrast, habitat availability for adult and juvenile striped bass is maximized at higher flows. Similarly, habitat availability for smallmouth bass and largemouth bass spawning is maximized at lower flows, while spawning habitat for striped bass increases with flow.

The utility of the requested application of bass HSC to the instream model area above RM 29 (the primary salmonid habitat) is somewhat limited by the disparity between the model reach (upstream of RM 29) and the reach of primary bass use (downstream of RM 29). The results do, however, reinforce the observation that the deeper, lower velocity, warmer areas downstream of RM 29 provide better physical habitat conditions for largemouth and smallmouth bass, consistent with where the species are most abundant. The larger range of suitable velocities for striped bass appears to broaden their tolerance for physical habitat conditions throughout the lower Tuolumne River, provided there is adequate depth.

5 REFERENCES

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper No. 21. Instream Flow Group. U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Brown, L.R., and T. Ford. 2002. Effects of flow on the fish communities of a regulated California river: implications for managing native fishes. River Research and Applications 18:331-342.

Crance, J. H. 1984. Habitat suitability index models and instream flow suitability curves: inland stocks of striped bass. U.S. Fish and Wildlife Service FWS/OBS-82/10.85.

EA Engineering, Science, and Technology, Inc. 1994. Sinclair Hydroelectric Project relicensing technical studies (FERC Project No. 1951) habitat suitability criteria. Prepared for Georgia Power Company by EA, Sparks, GA.

Edwards, E. A., G. Gebhart, and O. E. Maughan. 1983. Habitat suitability information: smallmouth bass. U.S. Department of Interior, Fish and Wildlife Service.

FERC (Federal Energy Regulatory Commission). 2014. Determination on Requests for Study Modifications for the Don Pedro Hydroelectric Project. April 29.

FishBio. 2016. Fall/winter migration monitoring at the Tuolumne River weir. 2015 annual report. Prepared for Turlock Irrigation District and Modesto Irrigation District by FishBio, Oakdale, California.

Hassler, T. J. 1988. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) – striped bass. U.S. Fish and Wildlife Service. Biological Report 82(11.82). U.S. Army Corps of Engineers, TR EL-82-4. 29 pp.

HDR Engineering, Inc. 2011. Harris Advanced Reactor Project Instream Flow Study Report. Appendix A. Habitat suitability technical memo. Prepared by HDR Engineering, Inc. for Progress Energy Carolinas, Inc. December 1.

McBain & Trush and Stillwater Sciences. 2006. Lower Tuolumne River predation assessment final report. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Delta Authority.

Moyle, P.B. 2002. Inland fishes of California. University of California Press, Berkeley.

Stillwater Sciences. 2009. Lower Tuolumne River instream flow studies: Final study plan. Prepared by Stillwater Sciences, Berkeley, California, for Turlock Irrigation District, Turlock, California, and Modesto Irrigation District, Modesto, California.

Stillwater Sciences. 2012. Lower Tuolumne River instream flow studies: Pulse Flow Study Report. Final. Prepared by Stillwater Sciences, Berkeley, California, for Turlock Irrigation District, Turlock, California, and Modesto Irrigation District, Modesto, California.

Stillwater Sciences. 2013. Lower Tuolumne River Instream Flow Study – Final Report. Prepared by Stillwater Sciences, Davis, California, for Turlock and Irrigation District, Turlock, California, and Modesto Irrigation District, Modesto, California.

Stillwater Sciences. 2014. Lower Tuolumne River Instream Flow Study – Pacific lamprey and Sacramento splittail 1-D PHABSIM habitat assessment. Prepared by Stillwater Sciences, Davis, California for Turlock and Irrigation District and Modesto Irrigation District, California.

Stillwater Sciences. 2016. 2015 Lower Tuolumne River Annual Report. Report 2015-5: 2015 Snorkel Report and Summary Update. Prepared by Stillwater Sciences, Berkeley, California, for Turlock Irrigation District, Turlock, California, and Modesto Irrigation District, Modesto, California. November.

Stuber, R. J., G. Gebhart, and O. E. Maughan. 1982. Habitat suitability information: Largemouth bass. U.S. Department of Interior, Fish and Wildlife Service.

Turlock Irrigation District and Modesto Irrigation District (TID/MID). 2017. La Grange Project Fish Barrier Assessment Study Report. Prepared by FISHBIO. September 2017.

_____. 2013. Predation Study Report (W&AR-07). Prepared by FISHBIO. December 2013.