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Lower Tuolumne River Instream Flow Studies: Pulse Flow Study Report

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1 BACKGROUND AND INTRODUCTION

Pursuant to the Federal Energy Regulatory Commission (Commission) order of July 16, 2009 order (128 FERC ¶ 61,035), the Turlock Irrigation District and Modesto Irrigation District (Districts) were required, in consultation with fishery resource agencies, to develop and implement an instream flow incremental methodology (IFIM) study. The Lower Tuolumne River Instream Flow Studies Study Plan (Study Plan) (Stillwater Sciences 2009), including the development of an IFIM study, was filed with the 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. A revised implementation schedule was approved under the July 21, 2010 FERC Order and a follow-up study extension request to file the Instream Flow Study Report on April 29, 2013 was approved under the December 5, 2011 FERC Order. Separate from the IFIM study component of the Study Plan, this Pulse Flow Study Report is being submitted separately, both in accordance with the Study Plan and revised implementation schedule approved by the December 5, 2011 Order and also in partial fulfillment of Ordering Paragraph (D) of the May 12, 2010 Order modifying and approving Instream Flow and Water Temperature Model Study Plans.

In order to examine the broad flow ranges identified in the July 16, 2009 Order, the Study Plan separated the study into two separate investigations. A conventional one-dimensional (1D) PHABSIM study will examine in-channel habitat conditions at flows from approximately 100 cfs up to 1,000 cfs, with a 2D hydraulic model of over-bank flows up to 5,000 cfs developed as part of this Pulse Flow Study report. Although Ordering paragraph (F) of the July 16, 2009 Order includes an IFIM study objective "to determine instream flows necessary to maximize Chinook salmon and *O. mykiss* production and survival throughout their various life stages", salmon production and/or survival is not commonly investigated using IFIM study methods. Fish abundance generally reflects the balance of competing influences upon growth and survival and has been successfully related to physical habitat variables in some circumstances (e.g., Nehring and Anderson 1993; Gallagher and Gard 1999). However, cautions by some authors (e.g., Mathur et al 1985, Shirvell 1989) regarding potential interactions between physical variables contributing to weighted usable area (WUA) estimates suggest that habitat-based results from IFIM studies may not reliably predict salmon production or survival. Nevertheless, Commission staff recognized IFIM approaches in their May 12, 2010 Order as a commonly used method in assessing instream flow needs for aquatic species, and IFIM is broadly used as a tool to inform instream flow regime development (Milhous 1973, Bovee 1982, Milhous et al. 1984, Bovee et al. 1998).

To provide information regarding habitat conditions at flows above bankfull discharge (approximately 1,200 cfs[1]), this Pulse Flow Study report includes the development of a 2D hydraulic model to assess the habitat suitability at selected study sites (locations with adjacent overbank inundation areas) during in-channel flows of 1,000–1,500 cfs as well as flows up to 5,000 cfs (Stillwater Sciences 2009). The specific objectives related to the Pulse Flow Study included in the Study Plan are to:

1. assess habitat suitability and habitat segmentation for the lower Tuolumne River fish species during pulse flow conditions; and

[1] McBain &Trush (2000) report a 1.5 yr recurrence interval discharge corresponding to bankfull conditions is approximately 2,600 cfs at the La Grange gage (USGS11289650), although floodplain inundation can occur at flows as low as 1,200 cfs in some locations.

2. gather empirical data on the relationship between water temperature and flow during pulse flow events.

To address the first objective, this Pulse Flow Study report includes an assessment of the amount, distribution and segmentation of suitable habitat area across temporarily inundated overbank habitat at flows from 1,000 cfs up to 5,000 cfs on the basis of steady-state 2D modeling of high flow stage data collected at three sites in 2011. Although an estimate of suitable over-bank habitat could be constructed from GIS on the basis of existing inundation maps, the lower Tuolumne River lacks large floodplains along much of its the length and in paragraph 38 of the May 12, 2010 Order, FERC staff cautioned against extrapolation of habitat conditions from modeling at a limited number of sites to other areas in the river. Further, due to the limits of water availability in most water year types, it should be emphasized that pulse flows are not typically provided for the purposes of maintaining extended periods of inundation such as those occurring in broad lowland floodplains of the Central Valley. In paragraph 38 of the May 12, 2010 Order FERC staff noted that “pulse flows are typically of shorter duration and intended for either the attraction/migration of fall spawners or to facilitate outmigration of juvenile fish.” To address the primary purposes of pulse flows included in the current FERC license (FERC 1996), the effectiveness of managed pulse flows in the lower Tuolumne River is examined based upon historical monitoring data related to emigration and immigration of Chinook salmon to the Tuolumne River and broader San Joaquin River basin.

To address the second objective above, this Pulse Flow Study report includes an assessment of the variation in historical water temperature data collected during scheduled pulse flows along the lower Tuolumne River, as well as variations in water temperature at in-channel and floodplain sites during extended high flow periods occurring during 2011.

2 METHODS

2.1 Field Data Collection

2.1.1 Study sites for 2D hydraulic modeling

Study sites for this investigation were selected from broad floodplain and over-bank areas identified during study planning. As summarized by McBain & Trush (2000), floodplain habitat is limited along the lower Tuolumne River due to multiple factors, and the majority of over-bank areas identified for this study occur in areas formerly occupied by dredger tailings upstream of RM 40.3. As summarized in Attachments to the initial Tuolumne River Instream Flow Study Progress Report filed with the Commission on December 9, 2010, initial study site selection was discussed at the first Lower Tuolumne River Instream Flow Study Coordination Meeting of August 26, 2010.

Acknowledging potential differences in habitat quality provided with floodplain inundation (e.g., soil organic matter and invertebrate productivity, hydroperiod, water temperatures), broad over-bank habitat occurs at the following areas within the gravel bedded zone of the lower Tuolumne River:

- New La Grange Bridge (RM 51.5)
- Riffle 4A/4B (RM 49.3 to 48.5)
- Riffle 5A (Basso Bridge)(RM 48)
- Zanker property (RM 45.5)
- Bobcat Flat (RM 44.7 to 44.2)

To expand the number of potential sites, selected floodplain restoration project sites were identified as candidate study sites and a study site selection rationale provided to interested Tuolumne River parties on December 6, 2010. Other locations farther downstream included SRP 9/10 sites (RM 25.9 to RM 25.7) the Big Bend property (RM 6.6 to RM 5.7), and the Grayson River Ranch (RM 5.1 to RM 3.9). Based upon field evaluation of floodplain inundation along the lower Tuolumne River during December 2010, preliminary sites located nearest the confluence with the San Joaquin River were not inundated at flood flows in excess of 2,000 cfs occurring during reconnaissance surveys and these sites were eliminated from further consideration. Of the remaining 4–5 sites above, three sites were selected for high flow stage monitoring during 2011 (Figure 1):

1. North of Riffle 4A/4B (RM 48.5),
2. South of Riffle 5A near Basso Bridge (RM 48.0),
3. East of the Bobcat Flat property and northwest of the Zanker property (RM 44.5).

Water levels were monitored at these three sites during periods of floodplain inundation occurring in winter/spring 2011 for use in the subsequent development of 2D hydraulic models to examine habitat suitability for juvenile Chinook salmon, steelhead/rainbow trout, and selected predator fish species.

2.1.2 High flow stage data collection

In accordance with the Study Plan, water surface level and water temperature logging transducers (Solinst® Levelogger, Solinst Canada, Ltd. Georgetown, ON) were installed in January 2011 at the locations specified in Table 2-1.

Table 2-1. Tuolumne River pulse flow study sites and pressure transducer locations.

Site description	RM	Locations			Deployment dates	
		Pressure transducer	Latitude	Longitude	Begin	End
Riffle 4A/4B	48.5	Upstream	37°39.87N	-120°29.10W	1/12/11	11/4/11
		Downstream	37°39.51N	-120°29.28W	1/12/11	7/26/11
Riffle 5A near Basso Bridge	48.0	Upstream	37°39.28N	-120°29.34W	1/12/11	7/26/11
		Middle	37°38.88N	-120°29.69W	1/12/11	7/26/11
		Downstream	37°38.76N	-120°29.72W	1/12/11	7/26/11
Bobcat Flat/Zanker	44.5	Upstream	37°37.63N	-120°31.56W	1/12/11	9/27/11
		Middle	37°37.73N	-120°32.49W	1/12/11	11/8/11
		Downstream	37°37.66N	-120°32.74W	1/12/11	11/8/11

As the raw data from the Levelogger requires correction for barometric pressure to convert pressure readings into water depth, a Solinst® Barologger was also installed and all instruments set for recording data at 15-minute intervals beginning on January 12, 2011 and ending at dates shown in Table 2-1. Additional survey data were collected to document water depths at staff gages installed at several locations within the over-bank areas at each site during high flow conditions of January 15–18 and May 16–18, 2011.

2.1.3 Topographic and bathymetric surveys at study sites

Turlock Irrigation District (TID) surveyors established local benchmarks at the three study sites between January 3–14, 2011 using Real-Time Kinematic Global Positioning System (RTK GPS) survey techniques. A Trimble R8 GNSS base station was set up over a county benchmark located on the northeastern portion of Old Basso Bridge (RM 45.5), and the base station was used to broadcast positional corrections to a roving GPS collecting field data in real time. Raw GPS observations were recorded at the base station and processed using the National Geodetic Survey (NGS) Online User Positioning Service (OPUS) to obtain a base station solution (Table 2-2), which allowed for high precision corrections to be applied to all field data.

Table 2-2. NGS OPUS solution coordinates for Old Basso Bridge survey control point (RM 45.5).

Reference frame	ITRF00	California State Plane, Zone III NAD83 (CORS96) / NAVD88
Epoch	2011.0379	2002.0000
Latitude/Northing	N 37° 38' 43.15135"	627107.951 (m)
Longitude/Easting	W 120° 29' 43.07695"	2000416.252 (m)
Ellipsoid height	23.235 (m)	23.821 (m)
Orthometric height	N/A	54.328 (m)

Follow-up RTK GPS and conventional Total Station surveys were performed at each study site to collect water surface elevation profiles, pressure transducer location/elevation, and topographic contour data. Existing topographic data was obtained from LiDAR coverage of the lower Tuolumne River (RM 52–29) developed from aerial surveys of September 21, 2005 at river flows of 321 cfs, as well as subsequent bathymetric data collection conducted as part of the Tuolumne River Coarse Sediment Management Plan (McBain & Trush 2005). To supplement and update the existing topographic/bathymetric data, additional shallow water and terrestrial topographic survey data were collected with both a Trimble S6 robotic total station and Trimble R8 GNSS receiver tied into the local survey control network at each site. Submerged channel topographic data (bathymetry) for water depths greater than 2 ft was collected with a portable tethered channel profiler that consists of a Teledyne RDI Rio Grande Acoustic Doppler Current Profiler (ADCP), Ohmex Sonarmite depth sounder, and Trimble R8 GNSS receiver mounted to an OceanScience Riverboat. All field survey data was collected in California State Plane, Zone III (FT US) coordinates and converted to UTM Zone 10 (m) coordinates for application with the 2D hydraulic model.

2.1.4 Discharge measurements and velocity profiles

Discharge measurements were collected by TID survey crews from the downstream margin of the Hwy 132 Basso Bridge (RM 47.5) using a Teledyne RDI StreamPro ADCP at flows ranging from 3,420 cfs to 2,200 cfs in January 2011. Stillwater field crews collected discharge measurements and velocity profiles with a Teledyne RDI Rio Grande ADCP at various transects within the three study sites at flows ranging from 2,078 – 3,130 cfs in May and September 2011. A summary of the discharge measurements is presented in Table 2-3 below.

Table 2-3. Lower Tuolumne River discharge measurement summary.

Date and time	Survey crew	River mile	Measured discharge (cfs)	La Grange discharge[1] (cfs)	Percent flow difference
1/10/2011 14:00	TID	47.5	3,990	3,420	15
1/12/2011 11:00			2,980	3,000	-1
1/14/2011 9:30			2,260	2,200	3
5/17/2012 14:00	Stillwater	49.5	3,130	2,990	5
5/17/2012 18:00		47.4	3,084	3,050	1
5/18/2012 8:00		45.2	3,137	3,050	3
9/8/2012 16:00		49.5	2,078	2,000	4

[1] USGS 11289650 Gage discharge data presented is provisional and subject to revision. La Grange gage is at River Mile 51.5.

2.1.5 Temperature data collection

The Districts maintain a real time monitoring (RTM) network of water temperature loggers (Hobo Pro V2 thermographs, OnSet Computer Corporation, Bourne, MA) at various locations along the lower Tuolumne River. In addition, water temperature data was recorded at over-bank locations using the supplied thermographs included in the installed pressure transducers (Solinst® Levelogger, Solinst Canada, Ltd. Georgetown, ON) at sites shown in Table 2-1. Regional air temperature data were obtained from the National Weather Service (NWS) station at Modesto Airport near RM 18. La Grange flow and water temperature data at in-channel and off-channel monitoring locations (Table 2-1) are shown in Appendix A. Water temperature varied strongly with regional air temperatures to a greater degree than flow, with the overall ranges summarized in Table 2-4 below.

Table 2-4. Tuolumne River water temperature summary at in-channel and over-bank locations.

Site	Control (RM 49.1)	Riffle 4A/4B (RM 48.5)		Riffle 5A near Basso Bridge (RM 48.0)			Bobcat Flat/Zanker (RM 44.5)			Control (RM 42.9)
Site code	R3B	PT1	PT2	PT3	PT4	PT5	PT1	PT2	PT3	R21
Deployment	In-channel	Over-bank upstream	Over-bank downstream	In-channel upstream	In-channel middle	In-channel downstream	In-channel upstream	Over-bank middle	In-channel downstream	In-channel
January 2011—Average Flow at La Grange = 4,092 cfs										
Min	9.83	8.26	9.52	9.71	9.47	9.59	9.49	9.46	9.36	9.66
Avg	10.25	9.92	9.93	10.18	9.96	10.00	9.89	9.87	9.97	10.24
Max	10.76	11.37	10.41	11.06	10.91	10.60	10.65	10.70	11.05	11.03
February 2011—Average Flow at La Grange = 3,128 cfs										
Min	9.39	7.37	9.08	9.01	8.73	8.92	8.77	8.66	8.57	9.02
Avg	9.87	9.54	9.87	9.91	9.65	9.66	9.59	9.57	9.70	9.94
Max	10.71	12.16	11.66	11.06	10.86	10.96	10.96	10.89	11.07	11.20
March 2011—Average Flow at La Grange = 5,157 cfs										
Min	9.21	8.81	8.91	8.99	8.90	8.96	8.75	8.72	8.76	9.09
Avg	9.65	9.59	9.50	9.89	9.53	9.54	9.51	9.53	9.76	9.94
Max	10.35	11.56	11.04	11.42	11.27	10.53	10.82	10.86	11.77	11.30
April 2011—Average Flow at La Grange = 7,389 cfs										
Min	9.29	8.97	8.90	9.11	8.95	8.95	8.81	8.74	8.72	9.11
Avg	9.76	9.56	9.53	9.98	9.69	9.63	9.66	9.72	10.03	10.14
Max	10.83	11.06	10.64	12.16	11.62	11.05	11.50	11.66	12.53	12.07
May 2011—Average Flow at La Grange = 3,332 cfs										
Min	9.61	9.15	9.26	9.34	9.28	9.33	9.14	9.11	9.28	9.49
Avg	10.26	10.71	10.37	10.95	10.19	10.20	10.38	10.39	10.64	10.83
Max	11.27	13.01	12.41	13.49	12.49	11.58	12.28	12.24	12.63	12.73

2.2 2D Modeling of In-Channel and Over-Bank Habitat

Because of the impracticalities of measuring local hydraulic conditions throughout a study reach during flood flow conditions, a two-dimensional (2D) hydraulic model was used to simulate hydraulic conditions at the selected study sites (Table 2-1) and estimate total usable area of suitable habitat for juvenile life stages of Tuolumne River salmonids and predator species at the selected sites (See Study Goal No. 1 in Section 1). The 2D Flow and Sediment Transport Morphological Evolution of Channels (FaSTMECH) model (Nelson and Smith, 1989) selected for this study uses water discharge and detailed channel topography and roughness estimates (i.e., Manning's n) to solve for two-dimensional distributions of depth, velocity, and boundary shear stresses across the modeled topography. The International River Interface Cooperative (IRiC) (formerly called MD_SWMS) is a front end interface that can be used with a variety of river hydraulic and habitat models including the FaSTMECH model. The basic inputs to FaSTMECH include detailed topography, roughness/drag coefficients, river discharge and water surface elevation. Basic assumptions of the model include: (1) flow is steady or any dynamic flow variations can be ignored over short time steps, (2) flow is incompressible, (3) flow is hydrostatic (i.e., vertical accelerations are neglected), and (4) turbulence is adequately treated by relating Reynolds stresses to shear using an isotropic eddy viscosity. Additional details on the FaSTMECH model can be found in Nelson and Smith (1989).

2.2.1 Model development

Existing topographic and bathymetric survey data developed as part of the Tuolumne River Coarse Sediment Management Plan (McBain & Trush 2004) implementation was used to develop a digital terrain model (DTM) representation of detailed topography for the study sites. The original DTM was stored in a Triangulated Irregular Network (TIN) format. Additional topographic and bathymetric survey data was incorporated into the existing DTM to supplement the original data and verify the resulting "surface" (topographic and bathymetric) by examining for unexplained surface discontinuities. In general, spot checks of topographic data for this study suggested minimal changes in the topographic surface developed by McBain & Trush (2004) within over-bank areas, with some corrections of the bathymetric surface of in-channel areas made on the basis of up-to-date data. The final DTM files were converted to ASCII format grid files at 1-m spacing and imported into the FaSTMECH model.

Generalized polygons representing the main channel and left and right overbank areas were developed for each study site. To account for channel roughness, a median grain size (D_{50}) attribute was selected for each polygon based on field observations and sediment grain size characterization presented in the Tuolumne River Coarse Sediment Management Plan (McBain & Trush 2004). The generalized grain size map was imported into the FaSTMECH model as part of drag coefficient estimate for the model computational mesh (i.e., the "grid" of points distributed across the DTM of the area to be modeled).

2.2.2 Model calibration and verification

Field measurements of discharge, water surface elevation, and velocity profiles were used to calibrate and verify FaSTMECH model output. Pressure transducers at each site (Table 2-1) provided a continuous record of river stage at the downstream boundary as well as at other key locations along the river channel as well as in over-bank areas. Qualitative comparison of modeled inundation area results with historical flow inundation mapping along the lower Tuolumne River corridor (TID/MID 1997) and 2010 satellite imagery that depicts flow at approximately 3,000 cfs were also used to help verify model results and modify user-specified parameters. Model calibration is an iterative process that involves parameters of discharge, water surface elevation at the downstream boundary, roughness or grain size, and lateral eddy viscosity at the modeled discharge. Additional model parameters (e.g., max. no. of iterations, relaxation parameters, etc.) were adjusted to achieve a total percent deviation of ± 3% (McDonald et al 2012) from normalized discharge at modeled cross sections. The estimated D_{50} substrate values (which affect channel roughness and therefore resistance to flow) were also adjusted between model flows in order to achieve more reliable convergence with observed water surface elevations. In some instances, a complex downstream boundary condition in the form of an eddy or non-uniform flow was predicted and the option to force the downstream velocity vectors was selected to provide uniform flow near the downstream model boundary.

2.2.3 Fish habitat availability

The Habitat Builder application was used with FaSTMECH model outputs to assess availability of suitable habitat for Tuolumne River salmonids and major predator species at the study sites (Table 2-1) for flows of 1,000 cfs, 2,600 cfs, 3,000 cfs, and 5,000 cfs. The fish habitat component of Habitat Builder allows for the computation of usable area estimates commonly used in PHABSIM analyses. The total usable area is calculated as an aggregate of the product of a composite suitability index (CSI, range of zero to 1.0) is calculated from individual suitability indices for depth and velocity evaluated at every point along the curvilinear model grid. The CSI at each node is calculated as a combination of the separate suitability indices for depth and velocity. Velocity and depth values are obtained directly from the hydrodynamic component of the 2D model. The suitability indices for each parameter are calculated by linear interpolation along an appropriate fish preference curve for an individual fish species/life stage combination.

2.2.3.1 Habitat suitability criteria for juvenile salmonids

Chinook salmon Habitat Suitability Criteria (HSC) for juvenile life stages of Chinook salmon and *O. mykiss* were selected as part of the ongoing Instream Flow Incremental Method (IFIM) study during workshops held on September 20, 2010, October 20, 2010, and February 3, 2011 (Appendix B). So called "Envelope" HSC curves, representing a range of suitable depths and velocities on the lower Tuolumne River, were developed for Chinook salmon fry (Aceituno 1990; USFWS 1988, 2010a), Chinook salmon juveniles (Aceituno 1990), *O. mykiss* fry (Hampton 1997; Moyle and Baltz 1985, TRPA 2004, and USFWS 2010b) and juvenile (TRPA 2000, USFWS 2004) life stages from selected references. The HSC workshop summaries and documentation for selected curves were filed electronically with the Commission in study progress reports on December 8, 2010 and July 29, 2011 (Appendix B).

2.2.3.2 Habitat suitability criteria for predator fish species

Habitat suitability criteria reported for adult life stages of native and non-native predator fish species were used to define available habitat area for piscivorous-sized fish that could potentially prey upon juvenile life stages of Tuolumne River salmonids. The following predator fish species were represented based upon their occurrences in the lower Tuolumne River in previous surveys (TID/MID 1992, Ford and Brown 2001), as well as their use is prior habitat assessments (McBain & Trush and Stillwater Sciences 2006):

- Largemouth bass (*Micropterus salmoides*)
- Smallmouth bass (*M. dolomieu*)
- Sacramento pikeminnow (*Ptychocheilus grandis*)
- Striped bass (*Morone saxatilis*)

Largemouth and smallmouth bass have been documented in the Tuolumne River from Old La Grange Bridge (RM 50.5) to Shiloh (RM 3.4), but smallmouth bass are typically most abundant downstream of RM 37 and largemouth bass are most abundant downstream of Hickman Bridge (RM 31.6) (Ford and Brown 2001).

Habitat suitability criteria for largemouth bass (Stuber et al. 1982) and smallmouth bass (Edwards et al. 1983) were previously used in 2D modeling for the special run-pool (SRP) 9 channel reconstruction project at RM 25.9–25.7 (McBain & Trush and Stillwater Sciences 2006) (Table 2-5). In addition to these references, habitat suitability data for Sacramento pikeminnow (PCWA

2010, YCWA 2010) as well as striped bass (Crance 1984) were used to define available habitat of adult predator life stages within the 2D hydraulic model (Table 2-5). Due to the absence of striped bass HSC for velocity, all velocities were assumed to be suitable and overall suitability was assessed on the basis of water depth.

Table 2-5. Habitat suitability criteria for adult life stages of potential predator species upon juvenile salmonids.

Species	Velocity		Depth		References
	ft/sec	index	ft	index	
Smallmouth bass	0.00	1.00	0.00	0.00	Edwards et al. 1983
	0.40	0.60	0.80	0.00	
	0.60	0.20	1.20	0.08	
	1.00	0.08	2.00	0.15	
	2.00	0.00	2.80	0.40	
	--	--	3.60	0.92	
	--	--	4.00	1.00	
Largemouth bass	0.00	1.00	0.00	0.00	Stuber et al. 1982 (velocity) Edwards et al. 1983 (depth from smallmouth bass)
	0.20	1.00	0.80	0.00	
	0.66	0.00	1.20	0.08	
	--	--	2.00	0.15	
	--	--	2.80	0.40	
	--	--	3.60	0.92	
	--	--	4.00	1.00	
Sacramento pikeminnow	0.00	0.82	0.00	0.00	PCWA 2010, YCWA 2011
	0.20	1.00	0.66	0.00	
	0.90	1.00	2.62	1.00	
	2.13	0.20	18.00	1.00	
	3.50	0.00	--	--	
Striped bass	n/a	n/a	0.00	0.00	Crance 1984
	--	--	1.40	0.00	
	--	--	6.00	1.00	

2.3 Pulse Flow Temperature Assessment

Ordering paragraph (F) of the July 16, 2009 order directs that the instream flow study evaluate spring pulse flows of 1,000 to 5,000 cfs and fall pulse flows of up to 1,500 cfs. In addition to the examination of habitat segmentation during in-channel flows of up to 1,200 cfs to be examined by 1D PHABSIM modeling as part of the ongoing IFIM study, Section 2.2 provides a description of 2D modeling of potential habitat availability within over-bank areas during spring pulse flows up to 5,000 cfs. However, since the majority of managed pulse flow releases during spring outmigration and fall upmigration of Chinook salmon occur for only short periods and at flows both above and below the 1,200 cfs threshold examined by the in-channel (1D) and floodplain (2D) modeling efforts for this study, the effectiveness of pulse flows was also evaluated on the basis of variations in instream water temperatures at several locations (See Study Goal No. 2 in Section 1). In addition to examination of variations of water temperatures at in-channel and within over-bank monitoring locations (Appendix A), plots of flow and water temperature over prior water years were examined to determine their effectiveness in extending suitable water temperatures to the San Joaquin River confluence. Lastly, a broader discussion of the effectiveness of pulse flows on salmonid emigration and immigrations is included.

2.3.1 Spring pulse flows

Hydrographs measured at La Grange (USGS gage #11289650) during spring pulse flows were examined for the period 2000–2011 to correspond generally with cooperative pulse flow experiments under the California State Water Resources Control Board (SWRCB) Decision 1641 Vernalis Adaptive Management Program (VAMP). Selected water years were those in which pulse flows were in excess of 1,000 cfs and exclusive of above normal and wet water years[2] in which flood control releases resulted in flows in excess of the spawning and rearing flow requirements in the current FERC flow schedule (e.g., excluding water years 2000–2001, 2005–2006, 2010–2011). For the selected water years, water temperature records at several RTM thermograph sites along the lower Tuolumne River were plotted, including: La Grange gage (RM 51.8), Riffle 3B (RM 49.1), Riffle 13B (RM 45.5), Riffle 19 (RM 43.3), Roberts Ferry Bridge (RM 39.5), Hughson WWTP (RM 23.6), and Shiloh Road (RM 3.4).

2.3.2 Fall pulse flows

Fall pulse (attraction) flows were also evaluated for water years 2000–2011 using flow data measured at La Grange as well as thermograph data at the locations above. Selected water years were those in which fall pulse flows were required under the current flow schedule, exclusive of Dry and Critically Dry water years occurring in 2001, 2007, and 2008 in which no Fall attraction flows were required. In addition, data for water year 2011 was also not examined due to extended high flows during late September 2011.

[2] General water year classifications used here are based on the San Joaquin Basin 60-20-20 Index and the CDWR San Joaquin Valley unimpaired runoff forecasts, as published in the various reports of CDWR Bulletin 120-3-[year], Water Conditions in California. http://cdec.water.ca.gov/cgi-progs/iodir/wsihist

3 RESULTS

3.1 2D Hydraulic Model Calibration

Comparison of modeled inundation area results with historical flow inundation mapping along the lower Tuolumne River corridor (TID/MID 1997) and 2010 satellite imagery show similar coverage of inundated habitat at flows near those modeled, and subject to potential changes in bathymetry of the channel bed as well as changes in the topography of over-bank areas. The 2D model calibration was carried out by comparison of observed and modeled water surface elevations at each site (Table 3-1), with adjustment of model parameters in order to converge with observed water surface elevations at pressure transducers at the same sites (Table 2-1). As shown in Table 3-1, the residual difference between predicted and observed water surface elevation was generally within ±0.10 ft, within the expected variability of the observed water stage time series at each site. Factors affecting the accuracy of predicted water surface elevations include: (1) uncertainty with the topographic surface, chiefly large flat bottomed (constant elevation) depressions within the over-bank areas that are likely LiDAR artifacts resulting from standing water at the time of data collection; (2) lack of detailed grain size distribution and vegetation roughness data which resulted in uniform drag coefficients to be applied across the modeled area; and (3) discontinuities in bathymetry and topography at locations nearest the downstream model boundaries.

Table 3-1. Comparison of river stage observed during 2011 monitoring period with model results.

Site	Pressure transducer	Flow (cfs)	Observed WSE (ft)	Predicted WSE (ft)	Residual (ft)
Riffle 4A/4B	Upstream	1,000	dry	dry	n/a
		1,600	dry	dry	n/a
		2,600	166.93	167.20	0.27
		3,000	168.11	168.29	0.17
		5,000	168.37	168.56	0.18
	Downstream	1,000	dry	dry	n/a
		1,600	161.42	161.49	0.07
		2,600	162.34	162.24	-0.10
		3,000	162.63	162.54	-0.09
		5,000	164.34	164.21	-0.13

Site	Pressure transducer	Flow (cfs)	Observed WSE (ft)	Predicted WSE (ft)	Residual (ft)
Riffle 5A	Upstream	1,000	158.92	158.97	0.04
		1,600	159.68	159.75	0.07
		2,600	160.63	160.71	0.08
		3,000	161.01	161.05	0.04
		5,000	162.24	162.23	-0.01
	Middle	1,000	155.41	155.40	-0.01
		1,600	155.77	155.78	0.00
		2,600	156.73	156.63	-0.10
		3,000	156.92	156.87	-0.05
		5,000	159.71	159.62	-0.10
	Downstream	1,000	155.38	155.39	0.01
		1,600	155.71	155.76	0.05
		2,600	156.63	156.60	-0.03
		3,000	156.86	156.83	-0.02
		5,000	159.58	159.56	-0.02
Bobcat Flat	Upstream	1,000	145.41	145.51	0.11
		1,600	146.00	145.98	-0.02
		2,600	146.98	146.86	-0.12
		3,000	147.18	147.13	-0.05
		5,000	148.46	148.25	-0.21
	Middle	1,000	139.21	139.31	0.10
		1,600	139.80	139.92	0.12
		2,600	140.88	140.79	-0.08
		3,000	141.11	141.16	0.05
		5,000	142.52	142.64	0.12
	Downstream	1,000	136.75	136.86	0.11
		1,600	138.12	138.18	0.05
		2,600	138.81	138.88	0.07
		3,000	139.17	139.23	0.06
		5,000	141.11	141.21	0.10

3.2 Fish Habitat Suitability Analyses

The calibrated 2D hydraulic model was used to predict suitable habitat areas for juvenile life stages of Chinook salmon and *O. mykiss*, as well as adult life stages of four potential predator species (Study Goal No. 1 in Section 1). Model simulations of fish habitat suitability at each of the three study sites (Table 2-1) were carried out at five flows in the range of those identified by the Final Study Plan: 1,000 cfs, 1,600 cfs, 2,600 cfs, 3,000 cfs, and 5,000 cfs (Figures 2–4). Appendix C provides color plots showing variations in relative habitat suitability (0.0 to 1.0) for the identified species, with generalized floodplain inundation from GIS mapping of historical aerial photography (TID/MID 1997) provided for reference outside of the immediate area of analysis within each study site. At flows of 1,600 cfs and 2,600 cfs, 2D hydraulic model simulations show suitable habitat in some pond habitats created by topographic depressions

(Appendix C) with no apparent connection with main channel. For this reason, suitable habitat areas for modeled fish species may be over-predicted at lower flows. At higher flows, habitat connectivity between pond habitats and the main channel occurred at flows above 3,000 cfs and 5,000 cfs (Appendix C). Numerical results for total inundated area (sq ft) as well as total suitable habitat area at each site are presented in the following sections.

3.2.1 Results of 2D modeling at Riffle 4B

Table 3-2 documents results of habitat suitability modeling within in-channel and over-bank areas at Riffle 4B (RM 48.5). Total inundation areas, as well as total usable area for each of the salmonid and predator species are depicted in Figure 2, with spatial distribution of suitable habitat area at each flow shown in Appendix C (Figures C1 through C40). Using the results at 1,000 cfs to approximate available habitat at bankfull conditions, suitable habitat for salmonid species is generally restricted to the channel margin, but expands in area at higher flows corresponding to inundation of over-bank areas. For Sacramento pikeminnow and striped bass at 1,000 cfs, the distribution of suitable habitat areas is comparable to juvenile salmonid life stages, with an overlap in suitable habitat areas. For black bass (largemouth and smallmouth bass) at 1,000 cfs, habitat use is restricted to backwater areas (Appendix C) due to low preferences for higher velocities (Table 2-5) found in mid-channel areas.

Table 3-2. 2D hydraulic model results of suitable habitat at Riffle 4B for salmonid juveniles and predator species.

Modeled flow (cfs)	**1,000**	**1,600**	**2,600**	**3,000**	**5,000**
Total wetted area (ft^2)	**81,158**	**109,668**	**191,903**	**262,573**	**328,022**
Total usable area for salmonid fry (ft^2)					
Chinook salmon	9,827	22,150	56,314	85,949	77,852
O. mykiss	10,405	22,541	55,364	84,893	102,902
Total usable area for salmonid juveniles (ft^2)					
Chinook salmon	15,430	22,119	63,069	102,566	112,121
O. mykiss	22,509	29,621	76,630	124,859	145,123
Total usable area for predator species (ft^2)					
Smallmouth bass	718	2,762	6,869	11,000	9,759
Largemouth bass	668	4,173	9,920	4,781	10,703
Sacramento pikeminnow	14,939	22,310	58,915	89,573	105,560
Striped bass	14,693	32,799	57,800	59,898	63,644

Relative to the results at 1,000 cfs (i.e., bankfull conditions), total inundated area increases by approximately 300–400% at flows ranging from 2,600 cfs to 5,000 cfs, respectively. Of the areas inundated at 2,600 cfs and 5,000 cfs, approximately 25–30% is suitable for Chinook salmon and *O. mykiss* fry, and 35–48% of the area is suitable for juvenile life stages of these species. For predator species at these flows, approximately 20–30% of the total inundated area is suitable for Sacramento pikeminnow and striped bass, with only 3–6% of the inundated area suitable for adult life stages of black bass. Due to greater preferences for deep water habitats by striped bass relative to salmonids (Section 2.2.3), suitable habitats for salmonids extend well up onto the over-bank areas at this site, whereas striped bass habitat use is generally restricted to main channel habitat areas. Sacramento pikeminnow habitat use patterns are similar to those for juvenile salmonids (Appendix C), whereas suitable black bass habitat is limited at high flows (Appendix C and Table 3-2).

3.2.2 Results of 2D modeling at Riffle 5A near Basso Bridge

Table 3-3 shows results of habitat suitability modeling within in-channel and over-bank areas at Riffle 5A (RM 48.0 near Basso Bridge). Total inundation areas, as well as total usable area for each of the salmonid and predator species are depicted in Figure 3, with spatial distribution of suitable habitat area at each flow shown in Appendix C (Figures C41 through C80). As with the Riffle 4A site, suitable habitat for salmonid species is generally restricted to the channel margin at 1,000 cfs. For predator species, the distribution of total usable habitat for Sacramento pikeminnow and striped bass is comparable to juvenile salmonid life stages with an overlap in suitable habitat areas. Suitable habitat for black bass is limited (Table 3-3) and generally restricted to backwater areas (Appendix C).

Table 3-3. 2D hydraulic model results of suitable habitat at Riffle 5A (Basso Bridge) for salmonid juveniles and predator species.

Modeled flow (cfs)	**1,000**	**1,600**	**2,600**	**3,000**	**5,000**
Total wetted area (ft^2)	**83,843**	**95,472**	**139,061**	**162,222**	**239,347**
Total usable area for salmonid fry (ft^2)					
Chinook salmon	10,238	15,004	43,155	49,864	53,618
O. mykiss	9,584	14,361	43,568	55,972	54,679
Total usable area for salmonid juveniles (ft^2)					
Chinook salmon	14,001	15,042	31,006	41,369	71,396
O. mykiss	30,417	28,692	42,425	55,226	99,802
Total usable area for predator species (ft^2)					
Smallmouth bass	2,095	2,766	4,109	4,347	8,340
Largemouth bass	2,390	3,889	6,347	6,205	8,245
Sacramento pikeminnow	49,970	42,562	37,860	37,921	99,754
Striped bass	20,302	24,860	28,184	28,227	37,667

At higher flows corresponding to inundation of overbank areas, variations in total usable area results with flow for each species at the Riffle 5A site are similar to those at Riffle 4B upstream (Table 3-1). Relative to the results at 1,000 cfs (i.e., bankfull conditions), inundated area increases by approximately 200–300% at flows ranging from 2,600 cfs to 5,000 cfs, respectively. Of the areas inundated at 2,600 cfs and 5,000 cfs, approximately 20–35% is suitable for Chinook salmon and *O. mykiss* fry, and 22–42% of the area is suitable for juvenile life stages of these species. For predator species at these flows, approximately 20–30% of the total inundated area is suitable for Sacramento pikeminnow and striped bass, with only 3–5% of the inundated area suitable for adult life stages of black bass.

3.2.3 Results of 2D modeling at Bobcat Flat/Zanker Property

Table 3-4 shows results of habitat suitability modeling within in-channel and over-bank areas at the Bobcat Flat/Zanker site (RM 44.5). Total inundation areas, as well as total usable area for each of the salmonid and predator species are depicted in Figure 4, with spatial distribution of suitable habitat area at each flow shown in Appendix C (Figures C81 through C120). As with the two sites upstream, suitable habitat for salmonid species is generally restricted to the channel margin at 1,000 cfs. For predator species, the distribution of total usable habitat for Sacramento pikeminnow and striped bass is comparable to juvenile salmonid life stages with an overlap in suitable habitat areas. Black bass habitat suitability is limited (Table 3-4) and generally restricted to backwater areas (Appendix C).

Table 3-4. 2D hydraulic model results of suitable habitat at Bobcat Flat/Zanker for salmonid juveniles and predator species.

Modeled flow (cfs)	1,000	1,600	2,600	3,000	5,000
Total wetted area (ft^2)	**265,261**	**306,711**	**423,083**	**477,534**	**634,478**
Total usable area for salmonid fry (ft^2)					
Chinook salmon	61,431	63,299	99,491	94,989	110,770
O. mykiss	58,968	57,823	101,839	102,468	120,304
Total usable area for salmonid juveniles (ft^2)					
Chinook salmon	90,606	91,449	113,516	121,622	188,125
O. mykiss	134,227	136,745	173,719	185,765	240,193
Total usable area for predator species (ft^2)					
Smallmouth bass	10,998	9,519	8,514	6,559	8,586
Largemouth bass	12,094	10,976	8,893	6,183	8,868
Sacramento pikeminnow	137,391	142,729	139,248	127,178	158,819
Striped bass	62,775	74,254	94,093	97,006	135,554

At higher flows corresponding to inundation of over-bank areas, variations in total usable area results with flow for each species at the Bobcat Flat/Zanker site are also similar to the upstream sites (Tables 3-2 and 3-3). However, relative to the results at 1,000 cfs (i.e., bankfull conditions), inundated area increases by only 150–240% at flows ranging from 2,600 cfs to 5,000 cfs, respectively. Of the areas inundated at 2,600 cfs and 5,000 cfs, approximately 15–20% is suitable for Chinook salmon and *O. mykiss* fry, and 30–40% of the area is suitable for juvenile life stages of these species. For predator species at these flows, approximately 20–35% of the total inundated area is suitable for Sacramento pikeminnow and striped bass, with only 1–2% of the inundated area suitable for adult life stages of black bass.

3.3 Pulse Flow Temperature Assessment

In order to provide empirical data on the relationship between water temperature and flow during short-term pulse flow events (Study Goal No. 1 in Section 1), this study examined temperature data collected during high flows occurring during 2011 that were associated with inundation of over-bank areas, and also examined water and air temperature data records at various locations along the lower Tuolumne River during historically scheduled pulse flow events occurring between 2001–2011. Appendix A provides a daily record of water temperature data at pulse flow study monitoring locations (Table 2-1) for the current study. These plots generally show lower water temperatures at monitoring sites within the over-bank areas as river discharge increases, as well as lower variations in water temperatures at floodplain locations at high river stages. Using two "control" thermographs located upstream and downstream of the study sites (Riffle 3B at RM 49.1 and Riffle 21 at RM 42.9), Table 2-4 shows average water temperatures at in-channel monitoring sites are slightly higher than at nearby sites within over-bank habitats during winter and spring, with over-bank sites exhibiting both greater and lower maximum and minimum water temperatures, respectively.

In response to the July 16, 2009 Order, the existing HEC5Q water temperature model was used to examine the relationship between flow and water temperature at various time periods during the year in specified reaches of the lower Tuolumne River (Stillwater Sciences 2011). Modeling results showed that extending the preferred water temperature ranges described in the July 16, 2009 Order requires increased flow magnitudes during May as well as late September, corresponding generally to the spring outmigration and fall upmigration periods for Chinook salmon. To provide empirical data on the relationship between water temperature and flow during short-term pulse flow events, water temperatures at selected thermograph sites downstream of La Grange Dam were plotted along with flow at La Grange (USGS gage #11289650). Appendix D provides summary plots for spring and fall pulse flow periods between water year 2000–2011 as well as daily average air temperature for the city of Modesto, CA during spring (April–May) and fall (early October). Results for the spring and fall pulse flow periods are detailed in the following sections.

3.3.1 Water temperature distribution during spring pulse flows

Appendix D (Figures D1 through D6) shows variations in daily water temperature at seven locations as well as La Grange flow (USGS gage #11289650) and air temperature at Modesto during the spring (outmigration) pulse flow periods. Pulse flows appear to reduce daily average water temperatures at the Shiloh Road location (RM 3.4) under some conditions. However, the increased extent of cool water habitat is dependent upon ambient air temperatures, with spring pulse flows greater than 1,000 cfs required to reduce daily average water temperatures to near 15ºC (59ºF) in several years (short 1-2 week pulse flows in April/May of 2002, 2003, 2004, and 2008). In years with reduced pulse flow magnitude or higher ambient air temperatures (reduced pulse flows provided in portions of April/May 2004, 2007, 2009), average daily water temperatures were above 15ºC (59ºF) during the spring pulse flow period and showed greater variation with ambient air temperatures than with pulse flow magnitude.

3.3.2 Water temperature distribution during fall pulse flows

Appendix D (Figures D7 through D13) shows variations in daily water temperatures as well as La Grange flow (USGS gage #11289650) and air temperature at Modesto. Fall pulse (attraction) flows do not appear to reduce daily average water temperatures at the Shiloh Road location (RM 3.4) under most flow conditions below 500–600 cfs. Although daily average water temperatures were near or below 18ºC (64.4ºF) during fall pulse flows in all years examined (2002–2006, 2009–2010), ambient air temperatures strongly influence downstream water temperatures and only the October 2010 pulse flow of 800–900 cfs appeared to influence temperatures at the Shiloh Road location.

4 DISCUSSION

4.1 Variations in Fish Habitat with High Flows Associated with Over-bank Habitat Inundation

As outlined in the Final Study Plan, 2D modeling carried out for this study was used to assess suitability and habitat segmentation for the lower Tuolumne River fish species during pulse flow conditions. Overall, the results of the study show increased flows are associated with increased areas of suitable over-bank habitat for juvenile life stages of Tuolumne River salmonids as flows increase above bankfull discharge, with suitable habitat area more rapidly increasing between discharges of 1,000 cfs to 3,000 cfs. Potential habitat availability for predator species at locations and flows modeled for this study suggest that floodplain inundation flows may effectively separate habitat used by black bass species (largemouth and smallmouth bass) as well as striped bass at these specific floodplain locations. However, modeling results also show similar habitat area availability and spatial distribution of suitable habitat for juvenile salmonids and Sacramento pikeminnow, suggesting that separation of salmonid juveniles from primary predator species through inundation of over-bank habitats may not be possible in all cases. Further, several reaches with pool habitats lack adjacent floodplain habitats (McBain & Trush 2000) and the probability of encounter between predators and juvenile salmonids remains in these pool habitats even under high flow conditions (McBain & Trush and Stillwater Sciences 2006).

Below, we discuss the results of the current study in comparison with GIS analyses by USFWS (2008) as well as direct sampling of fish habitat use within floodplain habitats conducted as part of post-construction restoration project monitoring at several sites along the lower Tuolumne River.

4.1.1 Comparisons with USFWS (2008) GIS analysis

Using GIS analysis of inundation areas developed by the Districts (TID/MID 1997), the USFWS (USFWS 2008) previously submitted to the Commission on September 16, 2008, a report on flow-overbank inundation relationships for potential fall-run Chinook salmon and steelhead/ rainbow trout (*O. mykiss*) juvenile outmigration habitat in the Tuolumne River, providing information under the USFWS's Central Valley Improvement Act (CVPIA) to assist in determining instream flow needs for the Tuolumne River. The main objective of USFWS (2008) report was to use GIS methods to estimate the area of floodplain inundated under various flows. The greatest rate of increase in overbank area occurred between 1,000 to 3,100 cfs. This flow range is consistent with the large increases in suitable habitat area found in the current study. In terms of potential fish habitat use of inundated floodplains of the lower Tuolumne River, the habitat-maximizing flow range identified by USFWS (2008) (i.e., 1,000 cfs to 3,000 cfs shown to represent the largest increase in habitat area) was also associated with the greatest incidence of juvenile Chinook salmon stranding documented in historical floodplain surveys at various years from 1986 to 2000 (TID/MID 2001). However, since the USFWS (2008) study did not examine habitat suitability or habitat use of juvenile salmonids and predator species within over-bank habitats, flow vs. area relationships developed by this study greatly over-estimate the amounts of suitable habitat for salmonid rearing as a function of flow.

In comparing the results of USFWS (2008) to the current study, the results here suggest that for the sites studied, flow increases from near bankfull conditions of 1,100 cfs to flows of 3,000 cfs and 5,000 cfs would increase suitable rearing habitat areas on the basis of depth and velocity alone by approximately 20–30% for salmonid fry, and 30–40% for juvenile salmonids. However, in addition to concerns regarding the timing and duration of inundation from pulse flow events, it is unclear whether the sites studied here are representative of the river as a whole or other sites referenced by USFWS (2008) (e.g., Sommer et al. 2001, 2005 [Yolo Bypass]; Jeffres et al. 2006 [Cosumnes River]). Although some overbank habitat is available for the full length of the lower Tuolumne River, not all sites are inundated at the same flows. Much of the river corridor is confined by natural bluffs and levees (McBain & Trush 2000) and the extent and quality of this habitat as rearing habitat is unknown. A large portion of the area is occupied by dredger tailings extending from RM 51.5 as far downstream as RM 40.3. Tailings in some of these areas were reclaimed for use in the New Don Pedro Dam construction (McBain & Trush 2000). The over-bank areas formerly overlain with dredger tailings are characterized by floodplains 2–3 times wider than other portions of the river corridor. In contrast to the approximately 60,000 acres of inundated floodplain habitat area occurring along the Yolo Bypass of the Sacramento River (Sommer et al. 2001, 2005), it is apparent that over-bank habitats along the Tuolumne River do not provide the same relative benefits as other river floodplain habitats studied in lowland portions of the Central Valley. Further, the remnant dredger pits and multiple connected backwaters along the lower Tuolumne River have been noted for juvenile Chinook stranding concerns (TID/MID 2001) and may actually create favorable habitat for predator species.

4.1.2 Comparisons with fish habitat use sampling at restoration project sites

The potential benefits of general floodplain rearing for juvenile Chinook salmon have been highlighted in recent reports from the Yolo Bypass (Sommer et al. 2001, 2005) and the lower Cosumnes River floodplain (Jeffres et al. 2006). However, recognizing that increased spring outflow is well associated with increased duration of floodplain inundation as well as overall increases in juvenile Chinook salmon production (TID/MID 2005), the results of the current study do not necessarily predict actual fish habitat use or whether in-channel rearing habitat is currently limiting salmonid populations. Below, we discuss the results of juvenile salmon and predator monitoring conducted at several restoration projects completed along the lower Tuolumne River with objectives to alter salmonid and predator habitat suitability and use within in-channel and overbank habitats. In some cases, projects were constructed by lowering and re-contouring floodplain habitat to allow inundation at lower flows, whereas in other cases projects were constructed by removal of private levees that border the lower Tuolumne River. It should be noted that extensive floodplain habitat restoration has been recently conducted at the Bobcat Flat property (RM 44.7 to 44.2) by the Friends of the Tuolumne (now called the Tuolumne River Conservancy, Inc.), but no results of pre- or post-project monitoring of fish habitat use were available for inclusion in this report.

4.1.2.1 Gravel Mining Reach—7/11 Restoration Project results

The 7/11 Restoration Project (RM 40.3 to 37.7) was completed in 2003 as the first phase of a larger restoration of the Gravel Mining Reach, which extends from RM 40.3 to RM 34.4 (McBain & Trush 2004). The project was designed to convey flows of up to approximately 15,000 cfs through the main channel and associated floodplain with the elimination of connectivity to off-channel mining pits. Pre-project Chinook salmon rearing habitat was mapped during flows of 254–265 cfs in 1999 (McBain & Trush and Stillwater Sciences 2006). Post-project habitat was mapped at flows of 185 cfs in 2002. Compared to 1999, Chinook salmon rearing habitat in 2002 was reduced by 150,700 ft^2 (64%) for fry and 494,500 ft^2 (47%) for juveniles. The observed reduction in fry and juvenile habitat area is likely partially attributable to the reduction in flows between pre- and post-project monitoring. Fry habitat area is expected to increase with increasing flows as lateral bars become inundated at higher flows. Although no direct fish sampling has been conducted, project designs include a bankfull channel designed to convey 5,000 cfs with the potential for increased floodplain habitat use at still higher flows (i.e., up to 15,000 cfs). Based upon the results of the current study (Section 3.2), suitable habitat area at inundation flows higher than the 5,000 cfs modeled for the current study would likely occupy a smaller proportion of the total area inundated due to increased water depths and velocities across the inundated floodplain.

4.1.2.2 SRP 9 Restoration Project results

Habitat suitability modeling was previously conducted for in-channel pool habitat as well as reconstructed floodplain habitat as part of the Special Run Pool (SRP) 9 restoration project near RM 25.7 (McBain & Trush and Stillwater Sciences 2006). The project was completed in 2001 under direction of the Tuolumne River Technical Advisory Committee (TRTAC) with the objectives to 1) reduce habitat for largemouth bass, 2) improve coarse sediment bedload routing through the reach, and 3) construct a geomorphically functional channel and floodplain. The project design consisted of filling of pool habitat to provide improved channel and floodplain function. The reconstructed channel conveys up to approximately 1,500 cfs with higher flows conveyed to the floodplain. The River 2D model (Steffler and Blackburn 2002) was used to compare Chinook salmon fry and juvenile habitat for pre- and post-project conditions over a range of flows. Similar to the results of this study, 2D modeling results showed the greatest benefits for increased Chinook salmon fry and juvenile rearing habitat at floodplain inundation flows exceeding 1,000 cfs. Post-project monitoring for the SRP 9 project found juvenile Chinook salmon and piscivore-sized bass captured during the surveys within inundated floodplain or in nearshore main channel habitat (McBain & Trush and Stillwater Sciences 2006). These results are generally consistent with the results of the current study, which showed lower habitat suitability for juvenile salmonids and black bass at in-channel locations, with the current study showing relatively higher salmonid suitability at over-bank locations (Appendix C).

4.1.2.3 Comparisons with Big Bend Floodplain Restoration Project monitoring

The Big Bend Floodplain Restoration Project (RM 6.6 to RM 5.7) was completed by the Tuolumne River Trust in 2004. The project involved selective levee breaching and restoration on approximately 250 acres of former agricultural lands to improve channel-floodplain connectivity, to allow natural regeneration of native riparian species, allow floodplain inundation at a greater frequency, and improve spawning habitat for Sacramento splittail and rearing habitat for juvenile Chinook salmon and steelhead trout (Stillwater Sciences 2008). Seining results over two high flow years (2005–2006) showed that juvenile Chinook salmon and other native species were generally concentrated in areas of the floodplain that received conveyance flow from the upstream portion of the site and thus had lower water temperatures and higher DO concentrations (Stillwater Sciences 2008). Non-native and predator species occurred in all of the inundated fields, but were most abundant in standing water areas where the lack of conveyance flows resulted in higher water temperatures and lower DO concentrations. Conditions at this site were not typical of overbank locations assessed for the current study, and inundation occurred generally through back water effects rather than over-bank flows.

4.1.2.4 Comparisons with Grayson River Ranch Project monitoring

The Grayson River Ranch Restoration Project (RM 5.1 to RM 3.9) was completed by the Friends of the Tuolumne in the year 2000, followed by re-vegetation of the site. The project site consists of two sloughs on a restored floodplain that are designed to provide habitat at high flows. The sloughs, along with sites on the main channel were sampled using seining methods to assess utilization of fish species under high flow conditions during 2005 ranging from approximately 3,800–6,000 cfs (Fuller and Simpson 2005). Results of the sampling showed that conveyance flows from the main channel onto the floodplain were blocked by an upstream levee and that the sloughs were inundated primarily as backwater habitat. Correspondingly, the predominant species found in the sloughs was common carp (*Cyprinus carpio*). No salmonids were found during sampling. Although no subsequent surveys have been conducted at this site, the functionality of the project as a conveyance floodplain was expected to occur once the upstream levee had been breached during a large flood event. Like the results at the adjacent Big Bend site (Section 4.1.2.3), it is apparent that floodplain habitat availability at this site would be limited at flows of 1,000 cfs to 5,000cfs examined for the current study.

4.2 Use of Pulse Flows during Salmon Upmigration and Outmigration

In addition to findings of higher maximum water temperatures at floodplain locations during periods of floodplain inundation, empirical data on the relationship between water temperature and flow during pulse flow events suggests that increased flows during the spring (outmigration) as well as during the fall pulse (attraction) flows result in reduced water temperatures at in-channel locations over a portion of the lower Tuolumne River. Spring pulse flows provided under the current FERC license for the Don Pedro Project (FERC 1996) are typically released between mid-April and mid-May of each year. Review of historical water temperature data shows greater variation with ambient air temperatures at sites along the lower Tuolumne River, with flows greater than 1,000 cfs required to reduce daily average water temperatures to near 15ºC (59ºF) at the Shiloh Road thermograph location (RM 3.4)(Appendix D). Only the highest fall pulse flows (800–900 cfs) appeared to affect water temperatures at this location. Because of the limited response of downstream water temperatures to pulse flow operations, the discussion below focuses on other mechanistic linkages between pulse flows and salmonid outmigration and upmigration in the Tuolumne River.

Both spring outmigration pulse flows as well as fall attraction pulse flows have been included in the current FERC (1996) license for the Tuolumne River. The results of the current study show only minor relationships with water temperatures at locations farthest downstream on the lower Tuolumne River. Use of spring outmigration pulses are intended to support outmigration success, which is generally supported by reported observations of increased capture frequency in rotary screw trap monitoring following rapid changes in flow (increases as well as decreases) as well as turbidity (e.g., TID/MID 2011). However, the effectiveness of spring pulse flows on subsequent outmigrant survival through the Delta is only weakly supported by the earliest Vernalis Adaptive Management Program (VAMP) survival experiments using coded wire tag (CWT) releases (Hankin et al. 2010). Although recent acoustic tag monitoring conducted since 2006 supports the effects of spring outmigration flows and suggests differences in route-specific survival for outmigrating salmon in the Delta, difficulties in discrimination of acoustic tags in live salmon smolts vs. those consumed by predator fish have likely confounded conclusions of many of these studies (Vogel 2011).

The use of fall attraction flows for Chinook salmon may be separable into two potential explanatory mechanisms: 1) to provide suitable conditions to allow upstream migration, whether related to water temperature, dissolved oxygen, or river stage, or 2) to provide some kind of homing cue that allows returning fish to ascend to their natal rearing areas for spawning. In exploring whether upmigrating fish wait for pulse flows to provide suitable conditions for upmigration and spawning (No. 1), a flow-related concept suggests that increases in river stage that allowed coastal fish to ascend physical barriers (e.g., waterfalls and log jams). Although this strategy has not been well documented for Chinook salmon in large floodplain rivers of the Central Valley, studies of Atlantic salmon (*Salmo salar*) have shown returning adults will wait in the estuary until there is a stormflow "freshet" (Heggberget et al. 1988, Thorstad and Heggberget 1998; Smith and Laughton 1994 as cited in Hogasen 1998). However, since fall attraction flows produce little if any changes in river stage or velocity in the Delta, this suggests the up-migration timing of San Joaquin basin salmonids might be related to other flow-related signals such as water quality (e.g., temperature, turbidity, DO)(Alabaster 1989), or non-flow signals such as rapid barometric pressure changes (Smith 1985 as cited in Hogasen 1998).

In one of the only direct studies of San Joaquin basin salmonids (Hallock et al. 1970), CDFG biologists attached sonic tags to adult salmon entering the Delta in four successive years (1964–1967) and monitored their subsequent movements with a network of monitoring stations. Water quality barriers related to temperature and DO barriers at the Stockton ship channel in particular were cited as primary controllers of upstream migration. Studies of fall-run Chinook salmon in the Klamath River indicated weak relationships between upmigration timing and water temperature (Strange 2010) and as indicated in this study, pulse flows examined in the Tuolumne River over 2001–2011 have only limited effects on downstream water temperatures near the river mouth, and likely no observable effects upon water temperatures in the lower San Joaquin River. The relationship between arrival timing of upmigrant spawners and the timing or magnitude of tributary fall attraction flows has not been established because no additional adult tracking studies in the San Joaquin River basin have been conducted since Hallock et al. (1970),

In examining the second potential mechanism validating the use of attraction flows related to homing, studies in other estuaries that support salmon migrations have shown that homing from the ocean is related to olfactory cues that are specific to the water and sediment chemistry of each tributary (Hasler et al. 1978; Ricker 1972). The potential management decisions regarding the use of pulse flows to improve homing fidelity would be to reduce the rates of straying between nearby river basins. However, little to no data exist to examine whether straying rates are affected by tributary-specific pulse flows separate from long-standing hatchery marking programs in the San Joaquin River (Merced River Fish Facility) and Sacramento River (Coleman National Fish Hatchery, Nimbus, Feather River, and Mokelumne River hatcheries).

5 CONCLUSIONS

Overall, the results of the study show pulse flows above bankfull discharge are associated at the locations studied with short-term increases in suitable over-bank habitat area for juvenile life stages of Tuolumne River salmonids. Suitable habitat areas for juvenile salmonid life stages most rapidly increase between bankfull discharges on the order of 1,000 cfs, to flows of 3,000 cfs corresponding to floodplain inundation, and increase less rapidly at nearly all sites studied herein up to the highest flows modeled (5,000 cfs). The highest frequency of stranding and entrapment of juvenile Chinook salmon in historical stranding surveys (1990–1992, 1994–1996, 1999–2000) occurred at sites similar to those used in this study (RM 48.8 to RM 45.9) at flows between 1,100–3,100 cfs (TID/MID 2001). Thus, in addition to concerns related to the water supply implications of attempting to provide and maintain floodplain inundation flows during non-flood conditions, it is likely that there is some tradeoff between potential benefits of additional rearing habitat and the stranding and entrapment of juvenile salmonids as high-flows recede from over-bank areas.

Based upon the results of this study, potential predation risk to juvenile salmonids within inundated over-bank areas may be reduced by the increases in habitat area that effectively reduce the encounter frequency of predators and prey, and provide additional hiding cover in flooded vegetation, as well as the inability of larger piscivores to access the increased area of shallow water edge habitat. Differences in species habitat suitability at the flows modeled for this study show that floodplain inundation flows may effectively separate habitat used by juvenile salmonids from habitat used by black bass species (largemouth and smallmouth bass) as well as striped bass. However, modeling results show similar habitat area availability and spatial distribution for both juvenile salmonids as well as for Sacramento pikeminnow adults, suggesting that separation of salmonid juveniles from primary predator species through inundation of over-bank habitats may not be possible in all cases. Lastly, several reaches with pool habitats inhabited by predator species lack adjacent floodplain habitats (McBain & Trush 2000) and the probability of encounter between predators and juvenile salmonids remain high in larger pool habitat locations even under pulse flow conditions.

This study evaluated habitat availability at a limited number of locations selected based upon the areas likely to be inundated within the flow range identified by the Study Plan. The majority of floodplain habitat available at the flows studied (1,000 cfs to 5,000 cfs) is limited to several disturbed areas between RM 51.5 and RM 42 formerly overlain by dredger tailings. It should be noted that extensive floodplain habitat does not occur at downstream locations due to higher flow thresholds required for floodplain inundation. For example, inundation thresholds for portions of the floodplain at the Big Bend property (RM 5.7) ranged from 4,000 cfs to near 10,000 cfs (Stillwater Sciences 2008).

In examining the relationship of water temperatures with pulse flows, increased flows during the spring (outmigration) as well as during the fall pulse (attraction) flows result in reduced water temperature over portions of the lower Tuolumne River. Spring pulse flows appear to reduce daily average water temperatures at the Shiloh Road thermograph location (RM 3.4) near the confluence with the San Joaquin River under some conditions. In contrast to the spring pulse flows, however, only the highest fall pulse flows (800–900 cfs) appeared to affect water temperatures at the San Joaquin River confluence.

The results of both ongoing in-river RST monitoring as well as in Delta outmigrant tracking and survival studies generally support the use of increased spring "pulse" flows during April-May as a means of improved juvenile outmigrant survival from tributaries to the Sacramento and San Joaquin River Delta. However, little to no data has been identified to date linking the provision of fall pulse flows or relating potential water temperature effects to variations in arrival timing and potential straying of fall-run Chinook salmon or any Central Valley steelhead arriving in the lower Tuolumne River.

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Figures

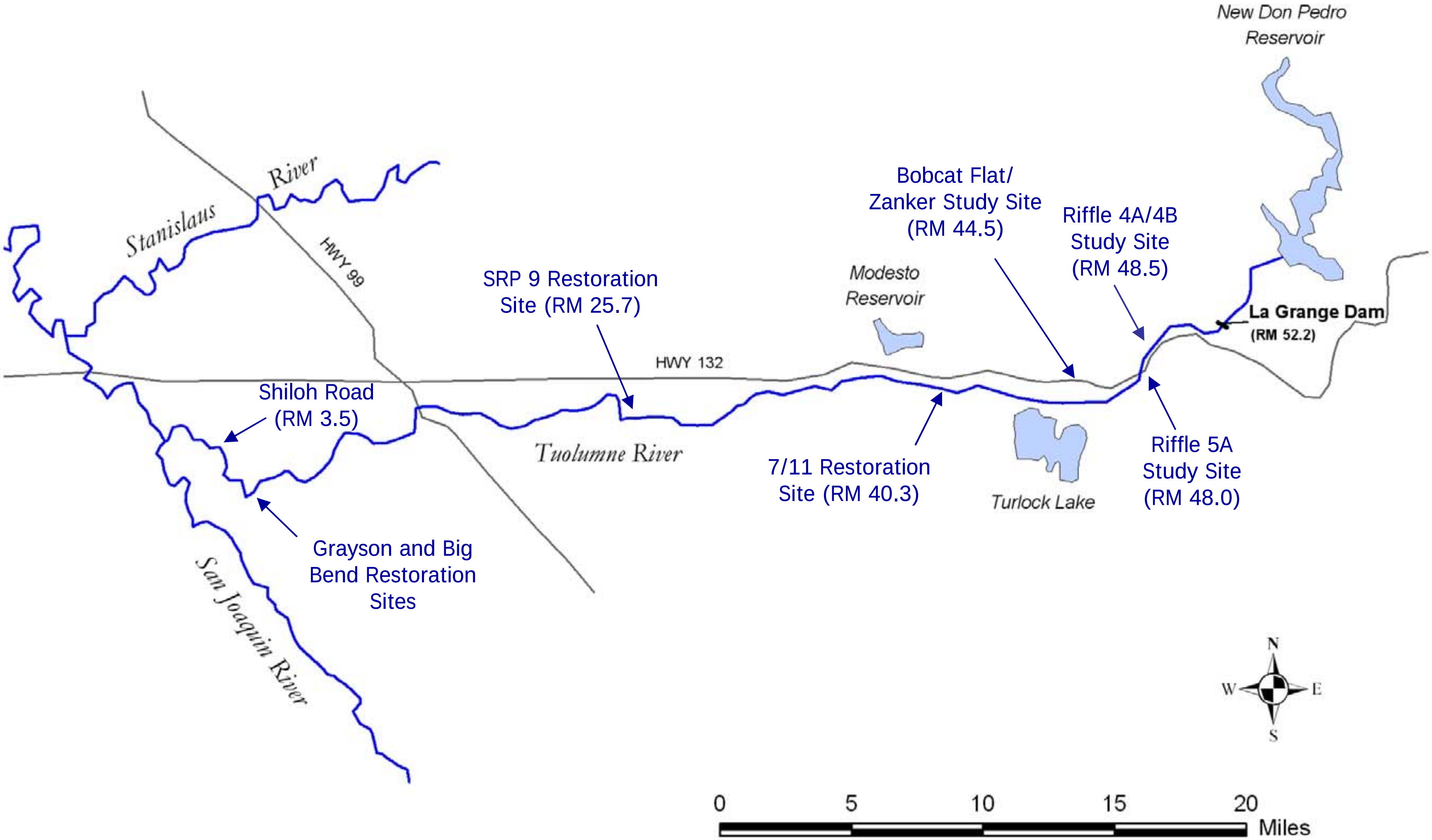


Figure 1. Pulse flow study and floodplain restoration sites on the lower Tuolumne River.

Stillwater Sciences

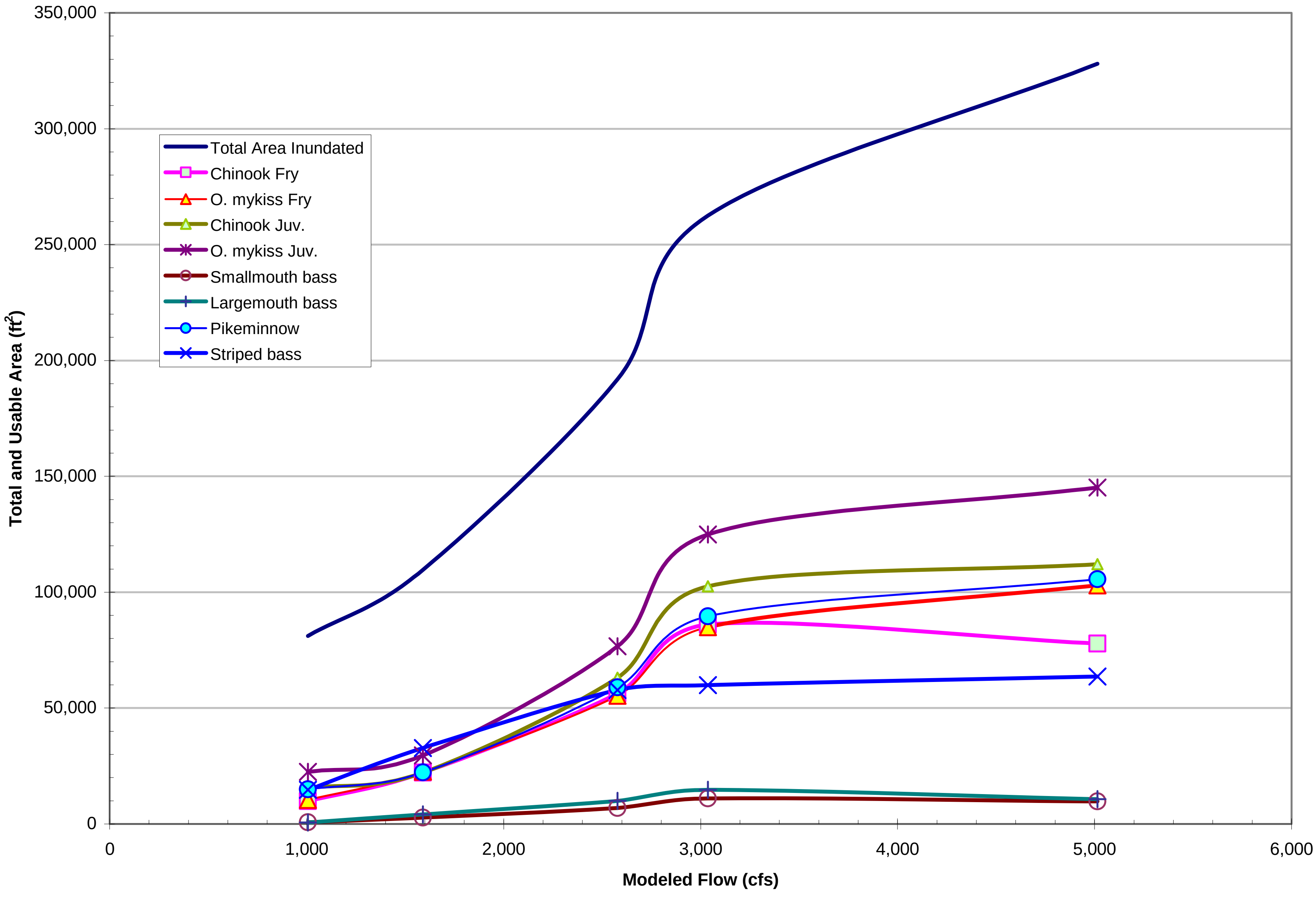


Figure 2. Total and Usable Areas at Riffle 4A/4B site (RM 48.5) for juvenile life stages of Tuolumne River salmonids and adult predators.

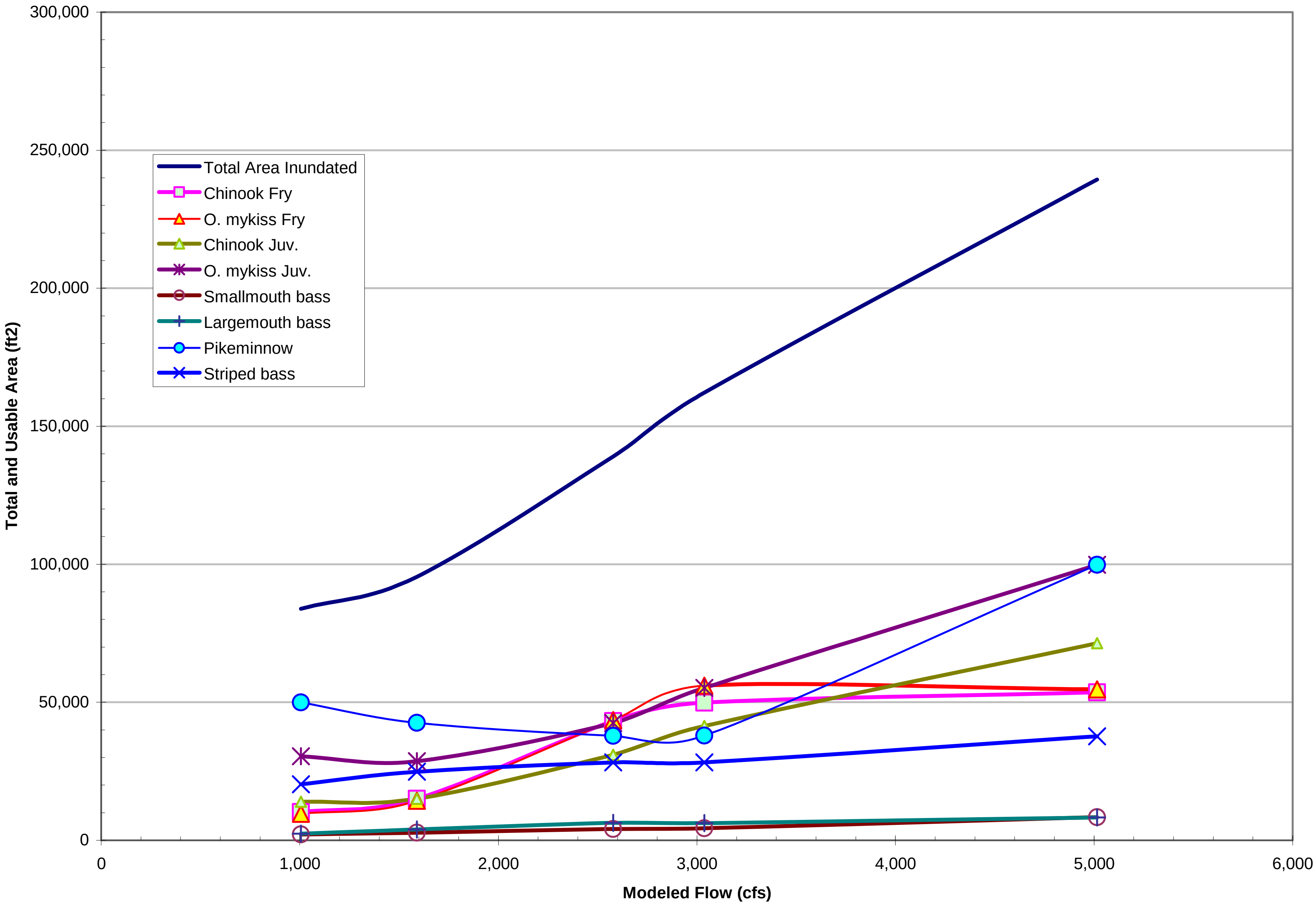


Figure 3. Total and Usable Areas at Riffle 5A (Basso Br.) site (RM 48.0) for juvenile life stages of Tuolumne River salmonids and adult predators.

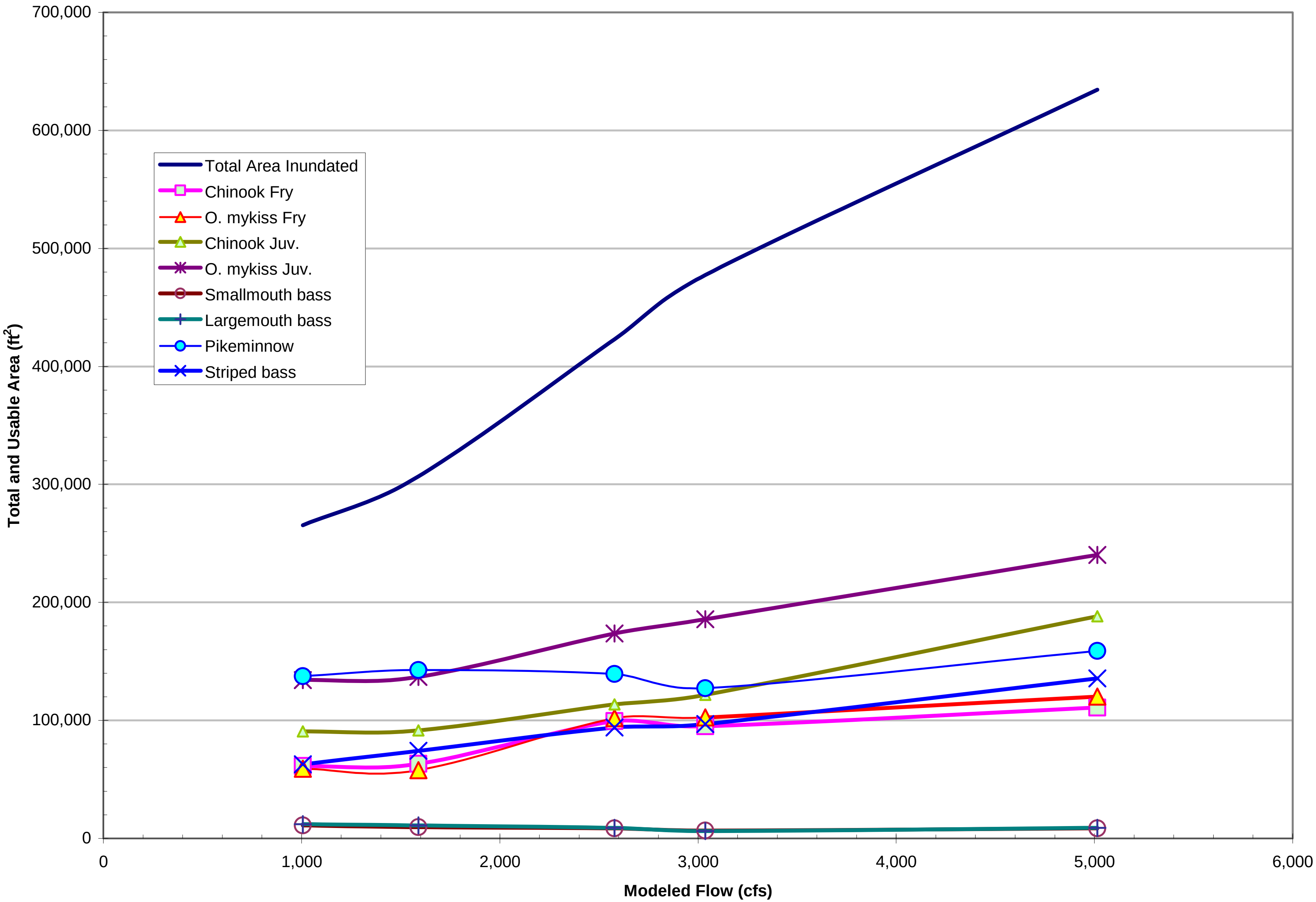


Figure 4. Total and Usable Areas at Bobcat Flat/Zanker site (RM 44.5) for juvenile life stages of Tuolumne River salmonids and adult predators.

Appendices

Appendix A

Water temperature data at in-channel and off-channel pulse flow study monitoring locations

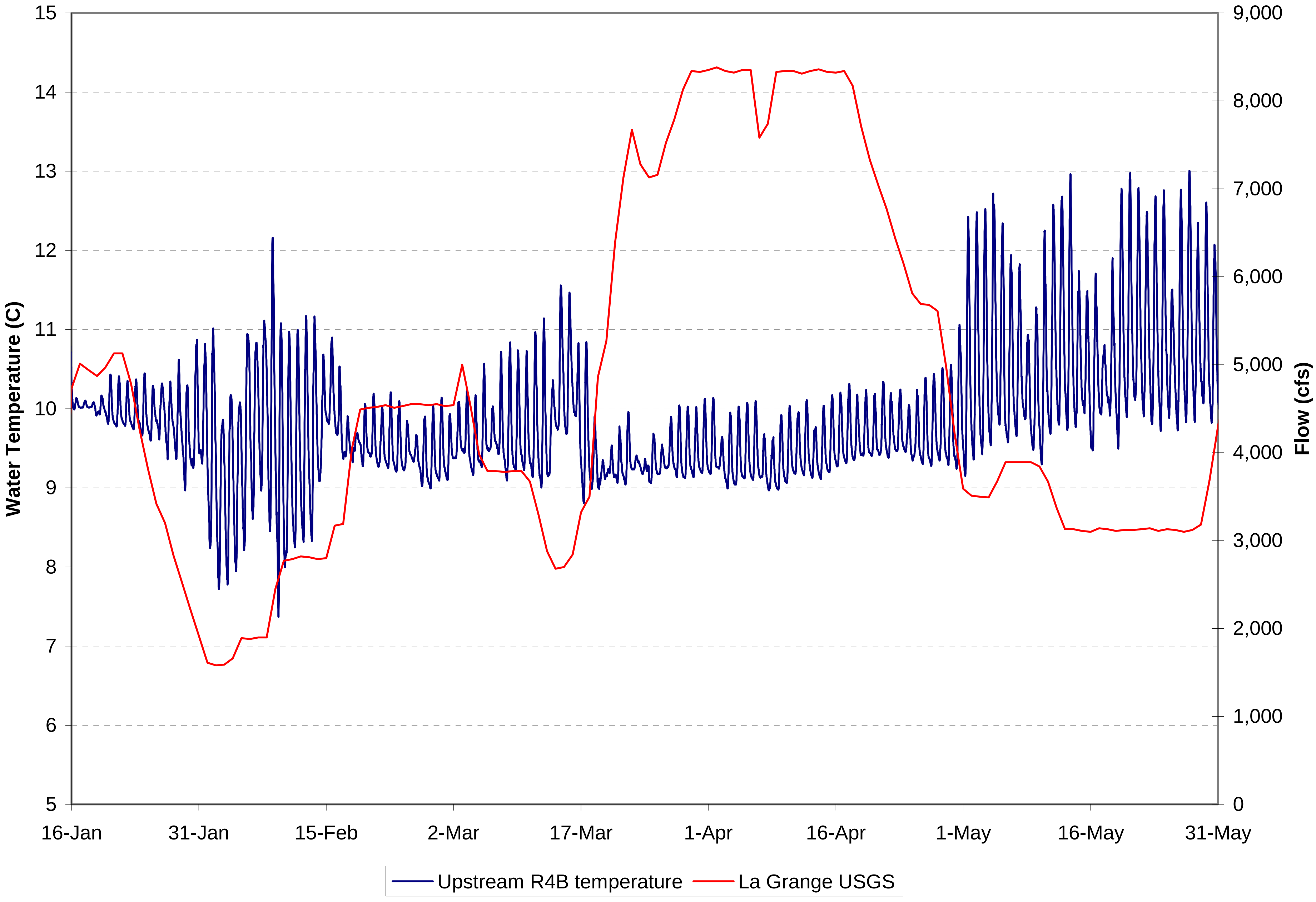


Figure A1. Water temperature on floodplain as recorded by pressure transducer at upstream R4B location and flow at La Grange USGS station during January – May 2011.

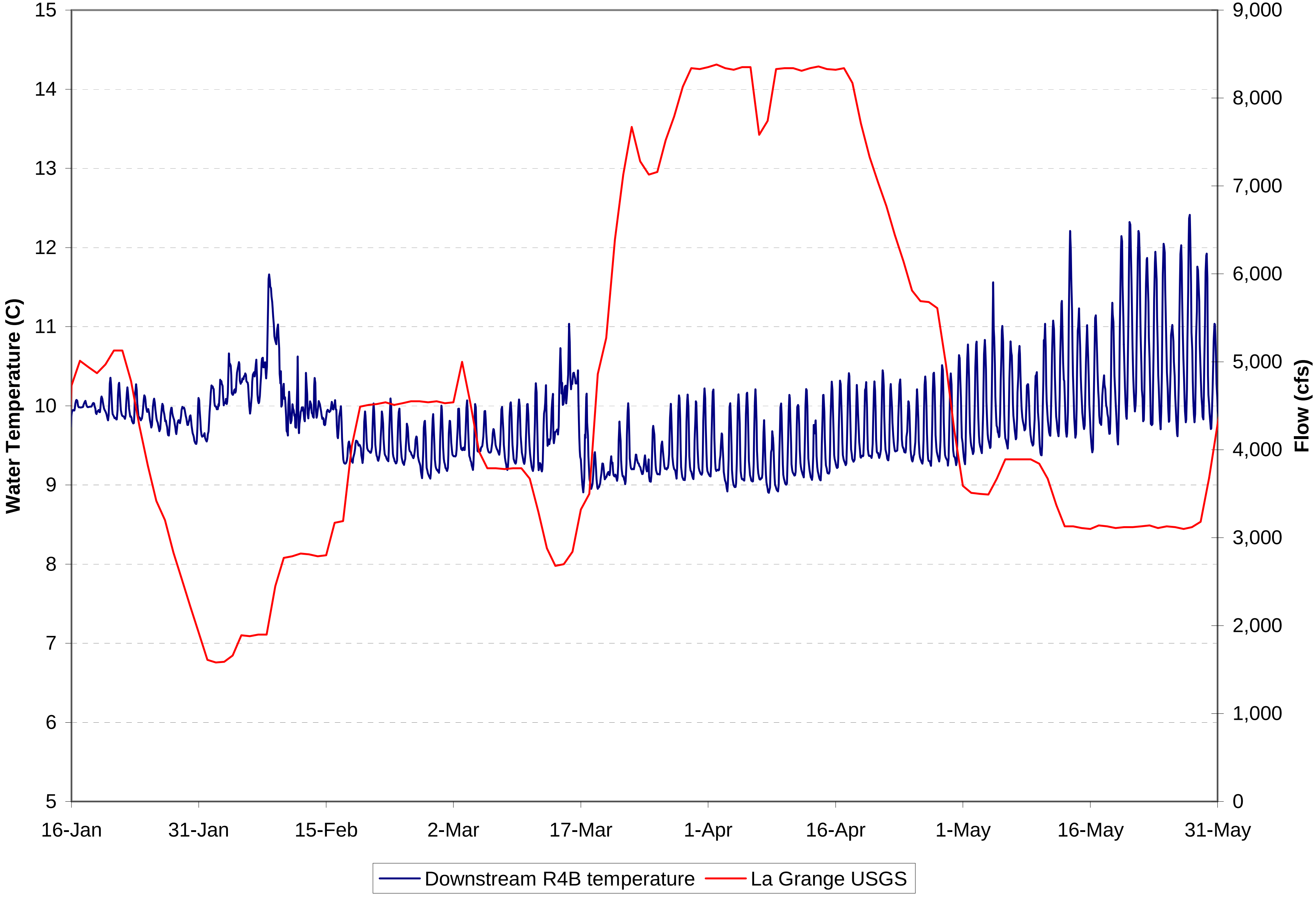


Figure A2. Water temperature on floodplain as recorded by pressure transducer at downstream R4B location and flow at La Grange USGS station during January – May 2011.

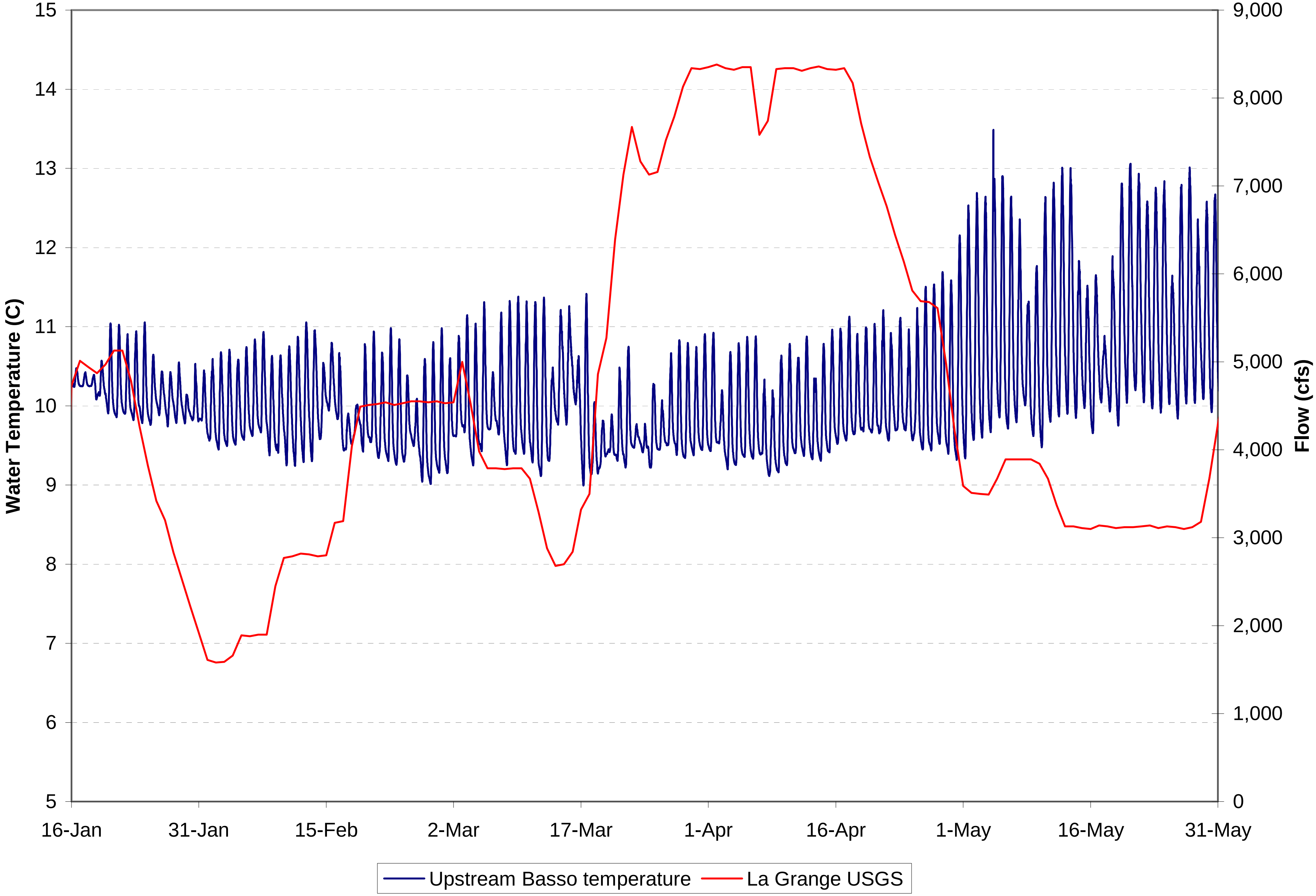


Figure A3. Water temperature in main channel as recorded by pressure transducer at upstream Basso location and flow at La Grange USGS station during January – May 2011.

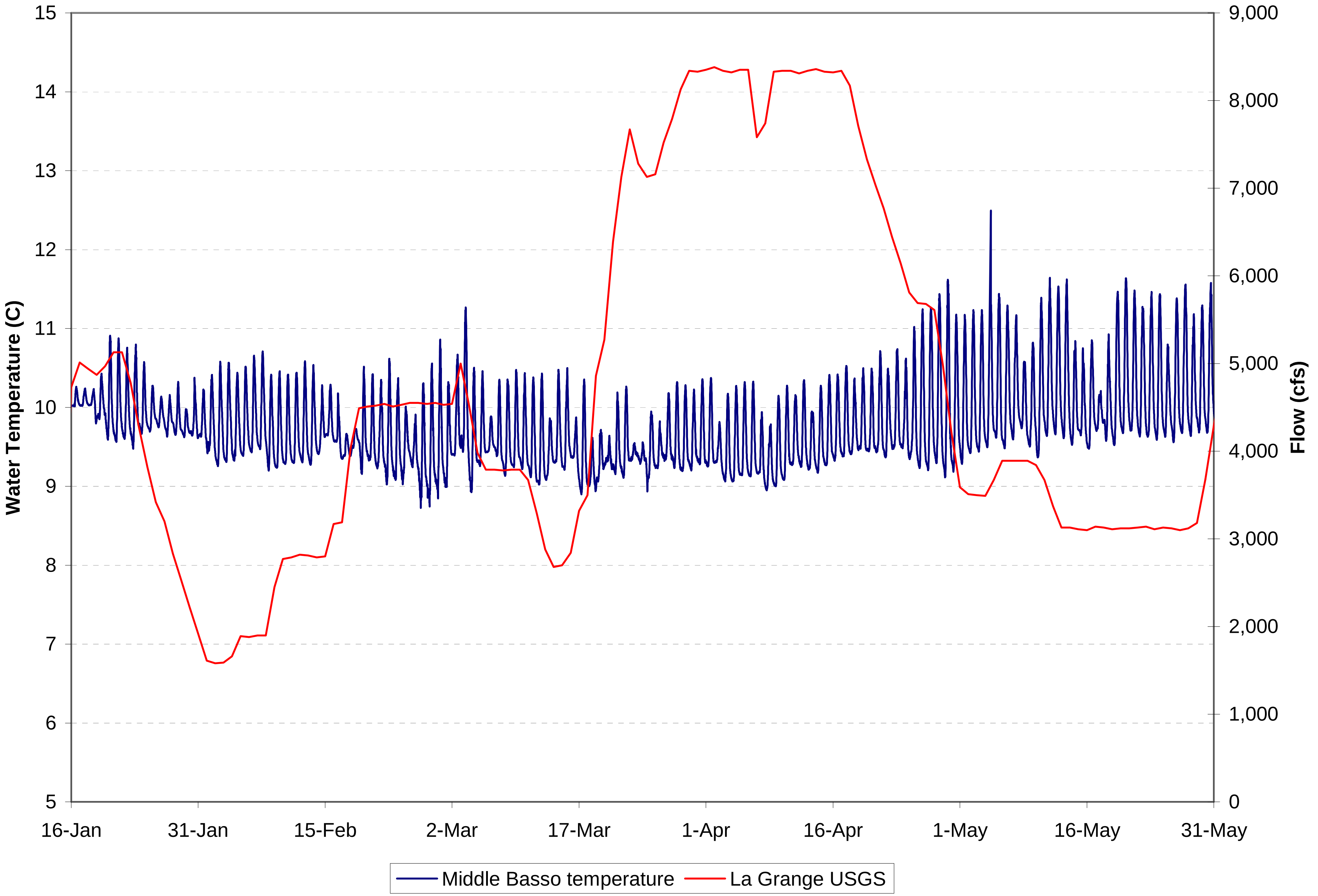


Figure A4. Water temperature in main channel as recorded by pressure transducer at middle Basso location and flow at La Grange USGS station during January – May 2011.

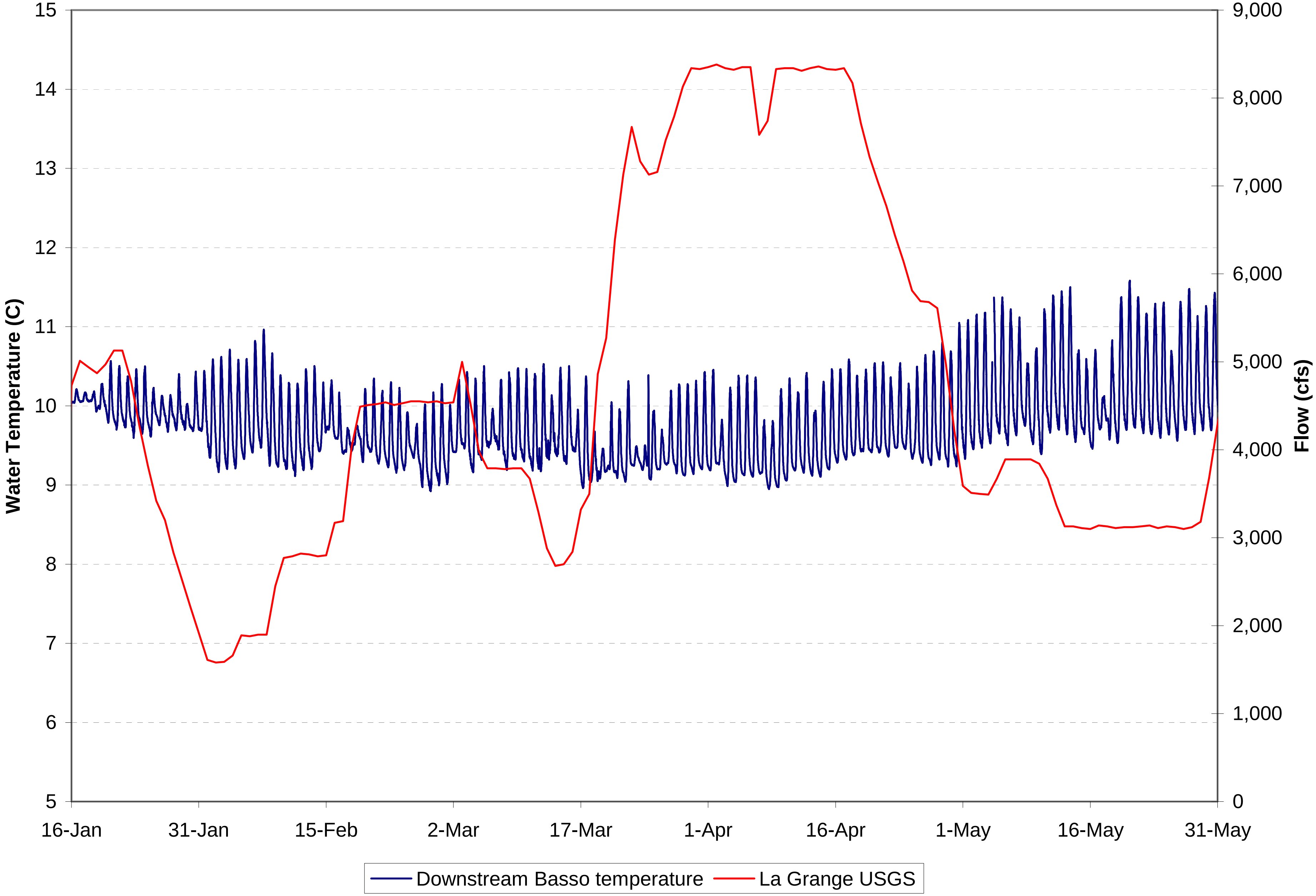


Figure A5. Water temperature in main channel as recorded by pressure transducer at downstream Basso location and flow at La Grange USGS station during January – May 2011.

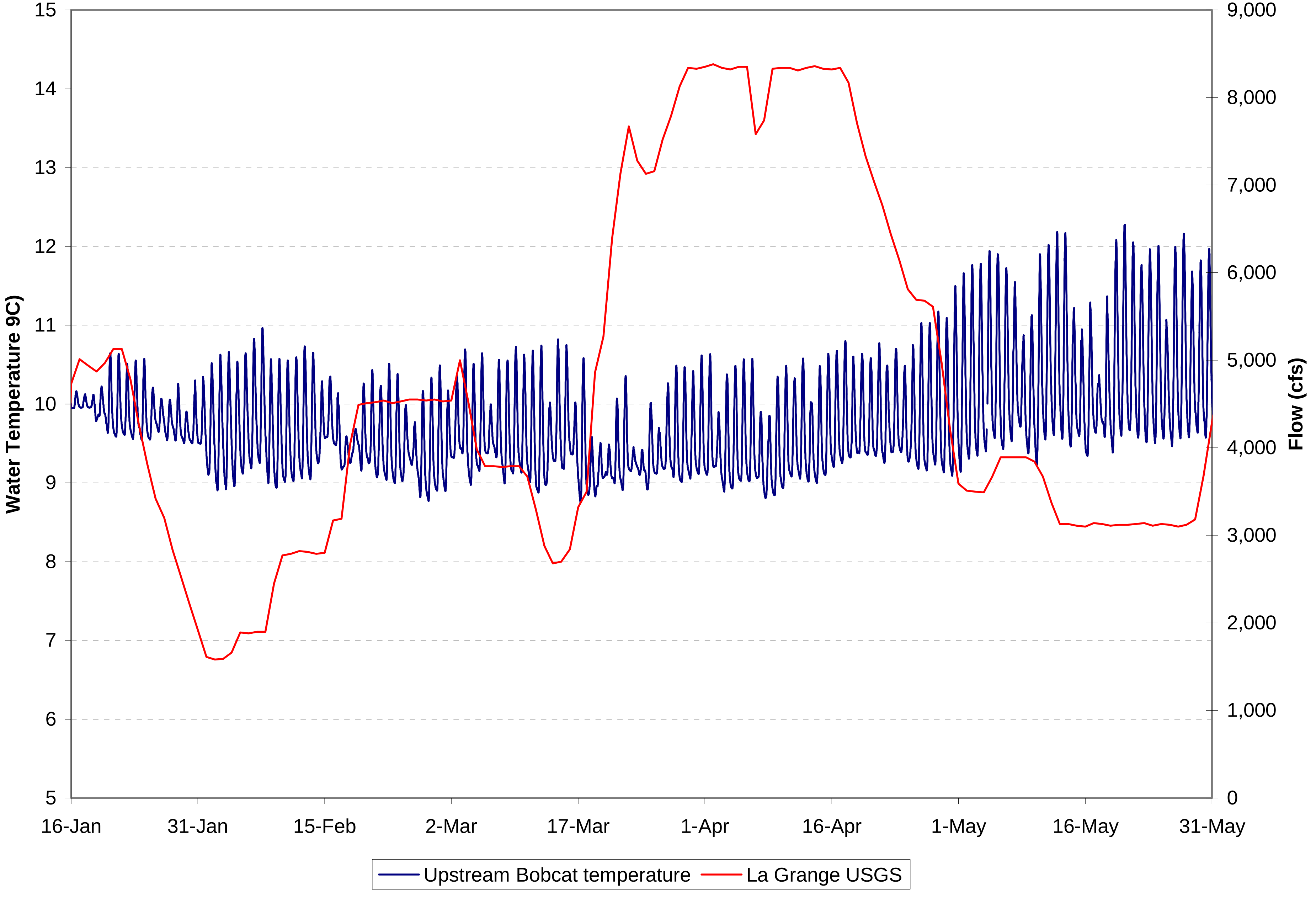


Figure A6. Water temperature in main channel as recorded by pressure transducer at upstream Bobcat Flat location and flow at La Grange USGS station during January – May 2011.

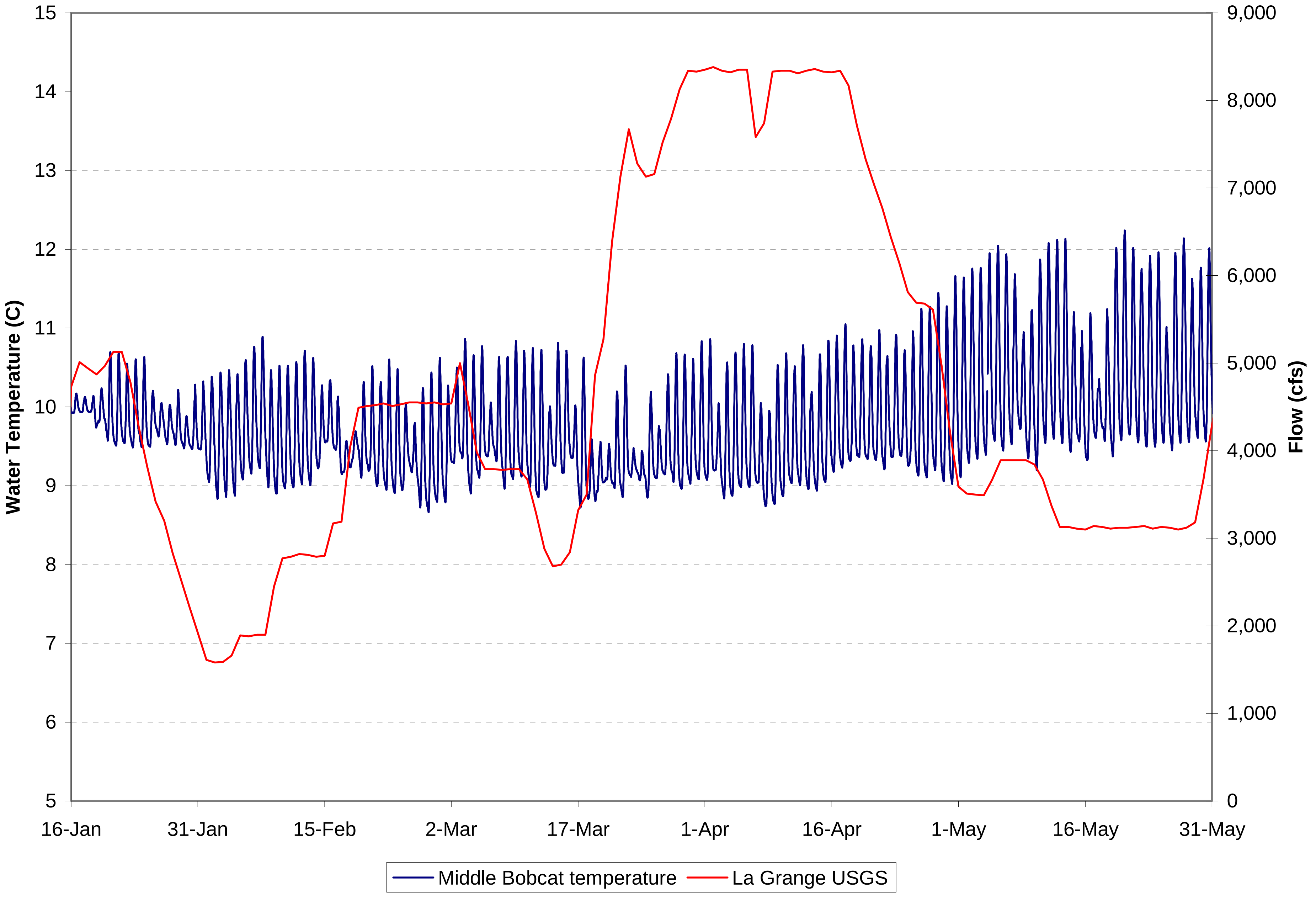


Figure A7. Water temperature on floodplain as recorded by pressure transducer at middle Bobcat Flat location and flow at La Grange USGS station during January – May 2011.

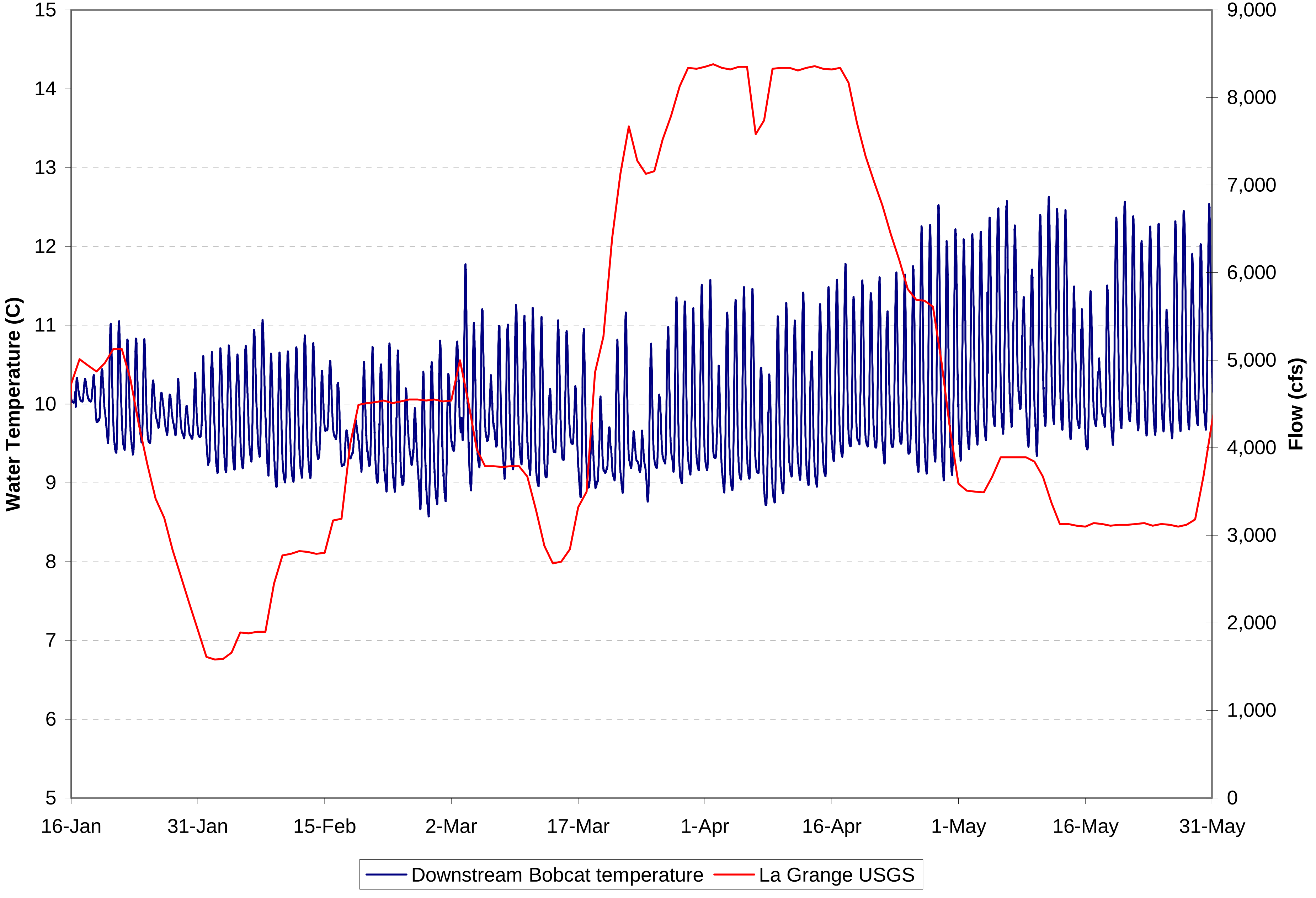


Figure A8. Water temperature in main channel as recorded by pressure transducer at downstream Bobcat Flat location and flow at La Grange USGS station during January – May 2011.

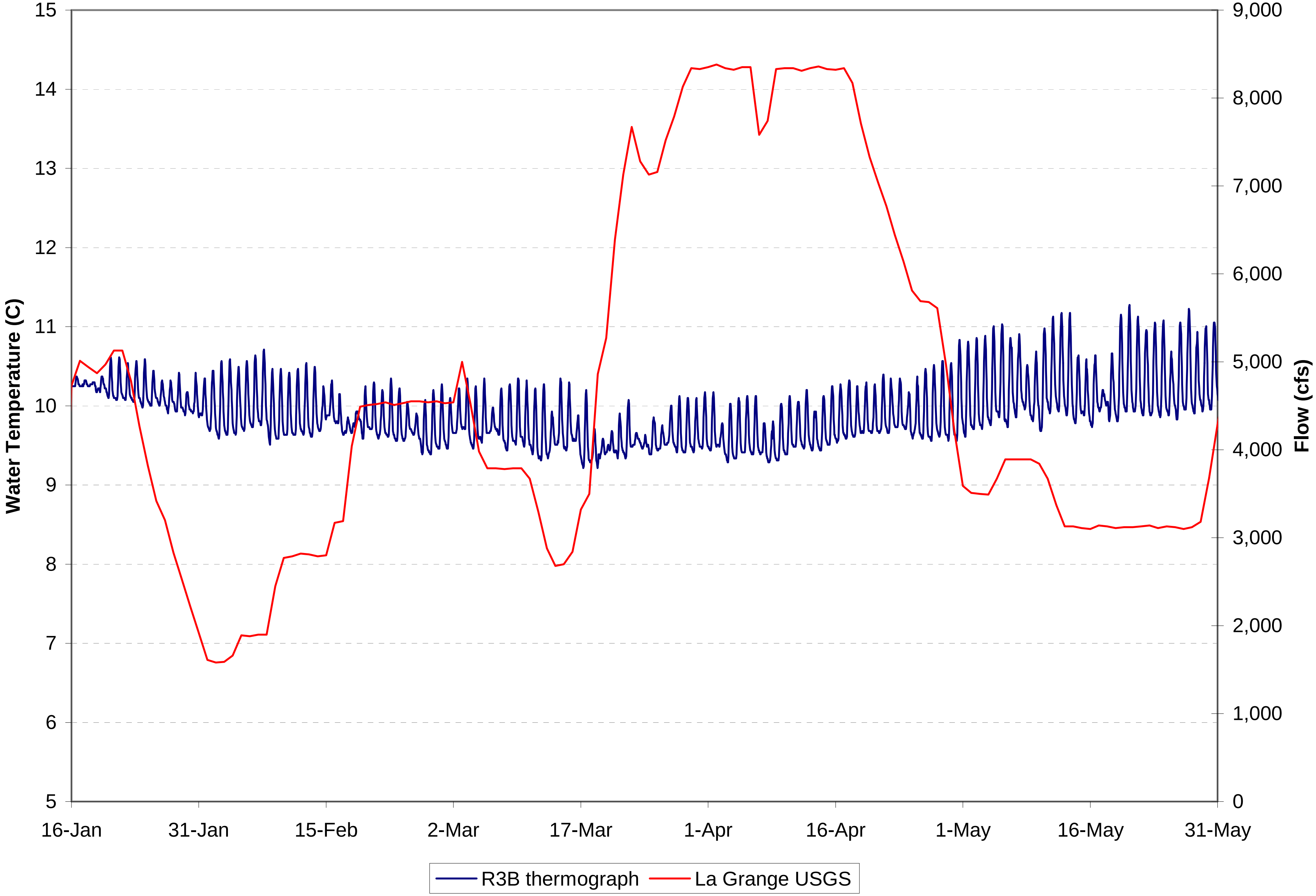


Figure A9. Water temperature in main channel as recorded by thermograph at Riffle 3B location and flow at La Grange USGS station during January – May 2011.

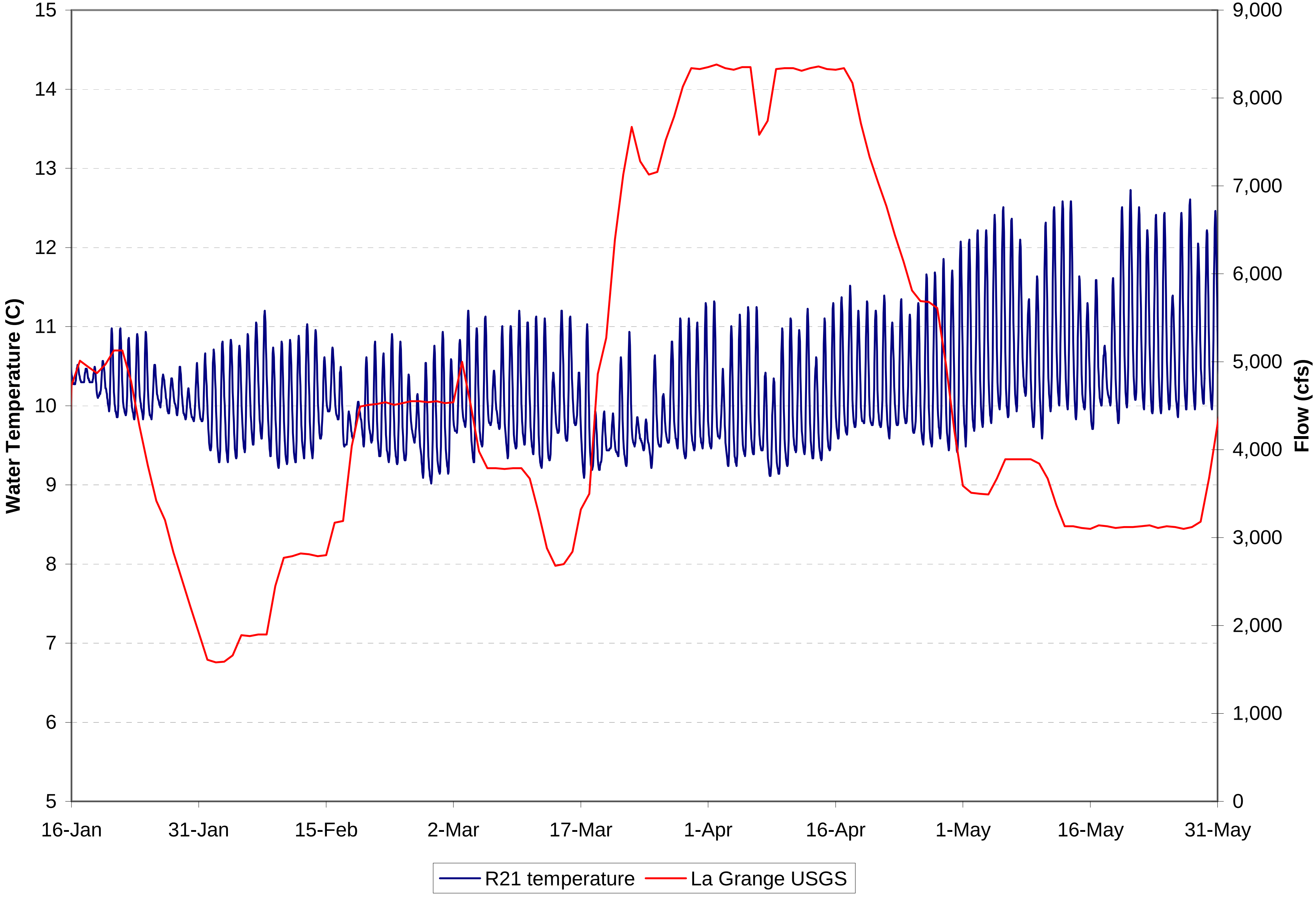


Figure A10. Water temperature in main channel as recorded by thermograph at Riffle 21 location and flow at La Grange USGS station during January – May 2011.

Appendix B

Summaries of IFIM Habitat Suitability Criteria workshops held on September 20, 2010, October 20, 2010 and February 3, 2011

Lower Tuolumne River Instream Flow Study
Study Coordination Meeting #2 — Summary
Monday, September 20, 2010, 10 AM – 5 PM Stillwater Sciences
279 Cousteau Place, Davis, CA

Attendees:

Scott Wilcox (Stillwater)
Russ Liebig (Stillwater)
Bob Hughes (CDFG)
Ron Yoshiyama (CCSF-SF)
Allison Boucher (TRC)
Zac Jackson (USFWS)
Shaara Ainsley (FishBio)

The purpose of this meeting was to compile, review, and discuss available salmon and steelhead Habitat Suitability Criteria (HSC) for the lower Tuolumne River, select HSC where possible, identify additional HSC literature data gathering needs, and discuss related topics. Scott Wilcox provided a brief overview of HSC and why they were needed for the IFIM study.

The technical group sequentially reviewed HSC and associated metadata from various sources for each species and lifestage, and either (1) selected HSC, (2) reduced the sources of HSC being considered, and/or (3) identified data needs and next steps. Decisions and/or actions on HSC for each species and lifestage are noted below.

Chinook Salmon Spawning

- A wide range of HSC from various sources were reviewed, and the CDFG site-specific Tuolumne curves matched the central tendencies of the other data sets well.
- **Action Item**: confirm that the number of observations and the methodology used in the CDFG spawning study were sufficiently robust. [Subsequent data searches by Stillwater revealed that 318 observations were used for the curves, and 10 study sites were spread over 9.2 miles that represented all of the dominant spawning reach. Thus, there does not seem to be an issue with data robustness.]
- **Decision**: Use site-specific Tuolumne River data for depth and velocity, from the CDFG study conducted in ~1982.

Tuolumne River Chinook Salmon Spawning Depth and Velocity Criteria*

Depth	Suitability Index	Velocity	Suitability Index
0.00	0.00	0.00	0.00

0.50	0.00	0.70	0.00
0.60	0.12	0.80	0.06
0.70	0.23	0.90	0.17
0.80	0.27	1.05	0.36
0.90	1.00	1.25	0.42
2.60	1.00	1.40	1.00
2.70	0.15	2.60	1.00
2.80	0.12	2.70	0.62
2.90	0.08	2.80	0.56
3.00	0.00	2.90	0.45
		3.05	0.22
		3.20	0.17
		3.80	0.07
		4.40	0.00

*From CDFG 1982

- **Decision:** Adopt, with small modifications based on data from other streams, the site-specific substrate HSC from CDFG. Other streams indicated frequent use of 1-2 inch gravel, which the site-specific Tuolumne data did not (perhaps due to availability limitations). Final substrate criteria agreed to by the technical group are specified below.

Tuolumne River Chinook Salmon Spawning Substrate Criteria*

Substrate	**Size (inches)**	**Suitability Index**
Organic, silt, sand, small gravel	Up to 1.0	0.0
Medium gravel	1-2	0.5
Large gravel	2-3	1.0
Very small cobble	3 – 4.5	1.0
Small cobble	4.5-6	0.7
Medium Cobble	6-9	0.0
Large cobble, boulder, bedrock	>9	0.0

*Adapted from CDFG 1982 with minor expansion to indicate suitability of 1-2 inch gravel.

- The technical group agreed that additional site-specific data collection for spawning would not lead to a decision narrow the HSC curves, and that sufficient additional data to justify expanding the curves was not possible given the current size of the population. Therefore, given that the current data set is robust at 318 observations, and is already site-specific, no additional site-specific data collection for spawning is planned.

Chinook Salmon Juveniles

The Stanislaus velocity HSC provided good representation of the central tendencies of the larger data set. Stanislaus depth HSC curve peaked slightly more to the right of most of the rest of the data sets.

- **Decisions:** (1) Use the Stanislaus HSC for velocity. (2) Use the Stanislaus HSC for depth, with a minor modification to include the peaks of other curves in the 1.31 – 2.10 foot depth range. (3) Do not apply substrate criteria to juveniles, since they do not typically select habitat based on substrate and may occur over the entire range of substrate possibilities.

Tuolumne River Chinook Salmon Juvenile Depth and Velocity Criteria*

Depth	Suitability Index	Velocity	Suitability Index
0.00	0.00	0.00	0.92
0.10	0.01	0.10	0.96
0.20	0.02	0.20	1.00
0.30	0.05	0.30	0.99
0.40	0.10	0.40	0.99
0.50	0.17	0.50	0.98
0.60	0.27	0.60	0.97
0.70	0.36	0.70	0.97
0.80	0.42	0.80	0.96
1.31	1.00	0.90	0.96
2.10	1.00	1.00	0.95
2.20	0.93	1.10	0.94
2.30	0.86	1.20	0.94
2.40	0.78	1.30	0.93
2.50	0.71	1.40	0.92
2.60	0.64	1.50	0.92
2.70	0.57	1.60	0.91
2.80	0.49	1.70	0.79
2.90	0.42	1.80	0.68
3.00	0.41	1.90	0.56
3.10	0.39	2.00	0.44
3.20	0.38	2.10	0.33
3.30	0.36	2.20	0.28
3.40	0.35	2.30	0.24
3.50	0.34	2.40	0.19
3.60	0.32	2.50	0.15
3.70	0.31	2.60	0.10
3.80	0.29	2.70	0.06
3.90	0.28	2.80	0.01
4.00	0.25	3.40	0.01
4.10	0.18	3.50	0.00

4.20	0.12		
4.30	0.08		
4.40	0.05		
4.50	0.03		
4.60	0.03		
4.70	0.02		
7.00	0.02		
7.10	0.00		

*From Stanislaus River. Depth curve modified.

Chinook Salmon Fry

Site-specific Tuolumne River HSC for fry are available. These HSC were compared to the fry HSC from the Stanislaus River (Stanislaus River data were used for juvenile HSC). The similarity between the two data sets, and their similarity to the central tendency of other data sets, was not as great as the technical group had hoped, and some type of hybrid curve was considered. Decisions on depth and velocity HSC for this life stage were deferred to the next meeting, pending review of the reports and metadata that may provide some insight on reasons for the differences.

Decision: As specified for the juvenile life stage, do not apply substrate criteria to fry.

Steelhead Adults

The technical group reviewed a few HSC from the literature, and initially focused on resident rainbow trout curves provided by the USFWS that are being used for steelhead on the Merced project, since they already had some level of agency concurrence. Several questions were raised about the origin of the curves, and the rationale for their use.

Since the Tuolumne River O. mykiss population is almost entirely resident, the technical group concurred that review of some Central Valley rainbow trout curves should be considered as well.

Action: Zac Jackson will research the background and source of the HSC being used for the Merced Project. Stillwater will compile some rainbow trout HSC for consideration. These will all be reviewed at the next HSC meeting.

Upcoming meeting dates:

Site Selection Meeting, October 5, 2010
HSC development 2nd meeting, October 20, 2010 at Stillwater in Davis, 9:00.

Lower Tuolumne River Instream Flow Study
Study Coordination Meeting #4 — Summary
Wednesday, October 20, 2010, 9 AM – 5 PM Stillwater Sciences
279 Cousteau Place, Davis, CA

Attendees:

Scott Wilcox (Stillwater)
Russ Liebig (Stillwater)
Bob Hughes (CDFG)
Ron Yoshiyama (CCSF-SF)
Allison Boucher (TRC)
Mark Gard (USFWS)
Jim Inman (FishBio)

The purpose of this workshop was to compile, review, and discuss available steelhead Habitat Suitability Criteria (HSC) for the lower Tuolumne River, select remaining HSC where possible, identify additional HSC literature data gathering needs, and discuss related topics. Chinook salmon HSC were discussed at the September 20, 2010 workshop. Scott Wilcox provided a brief overview of remaining action items from the September 20 workshop and introduced the revised *O. mykiss* HSC data packet, which was expanded to include additional rainbow trout curves following the September 20 meeting.

The technical group sequentially reviewed *O. mykiss* HSC and associated metadata from various sources for each lifestage, and either (1) selected HSC, (2) reduced the sources of HSC being considered, and/or (3) identified data needs and next steps. Decisions and/or actions on HSC for each species and lifestage are noted below.

O. mykiss Adults

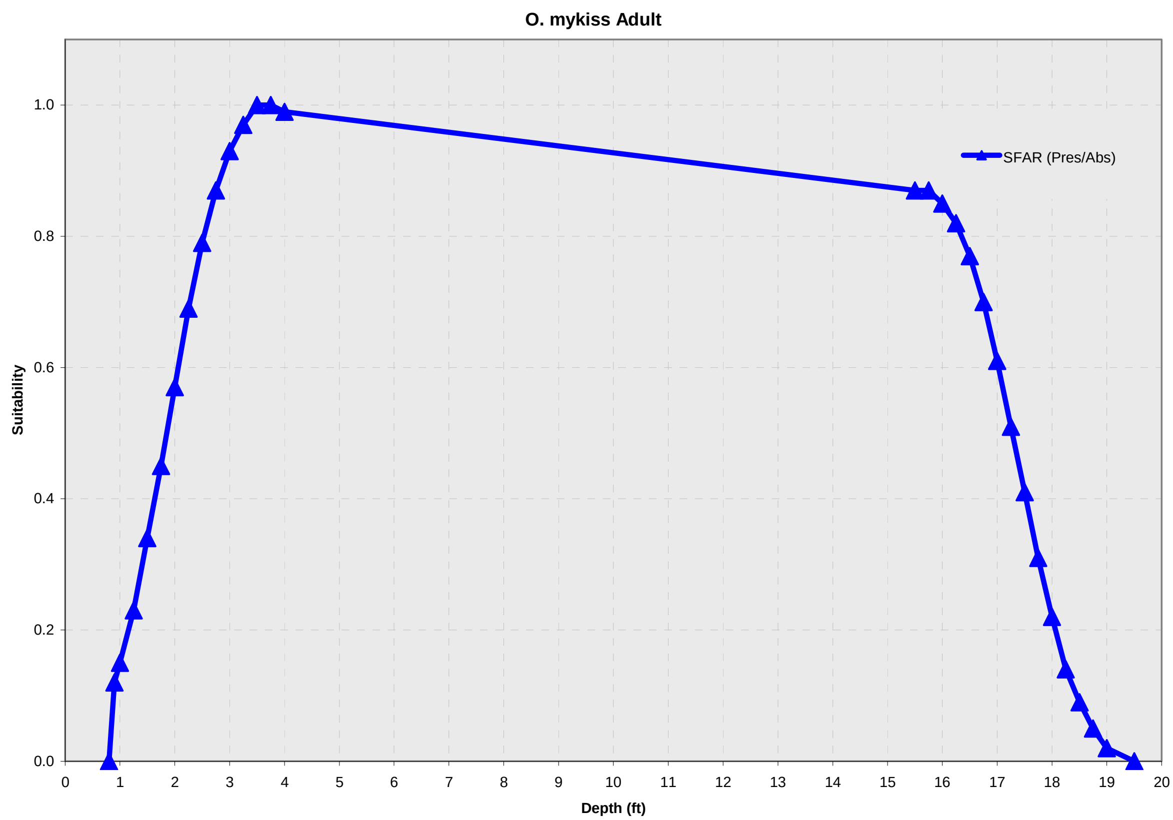
- The technical group had reviewed HSC during the September 20, 2010 workshop and initially focused on resident rainbow trout curves provided by the USFWS that are being used for the Merced project (SF American logistic regression curve). However, since the Tuolumne River *O. mykiss* population is almost entirely resident, the technical group concurred that review of additional Central Valley rainbow trout curves should be considered as well. Stillwater subsequently compiled additional rainbow trout HSC for comparison and consideration, and Bob Hughes reviewed the origin of the Merced curves. All of these data were reviewed and discussed by the group on October 20.
- The process for HSC selection generally used the following steps: 1) review tabular metadata for all HSC; 2) "filter" HSC datasets to consider further based on selection criteria in the study plan such as number of observations, category of criteria, geography, stream similarity, elevation, etc.; 3) review graphs of filtered HSC and discuss outliers, representative datasets, or development of a consensus curve.

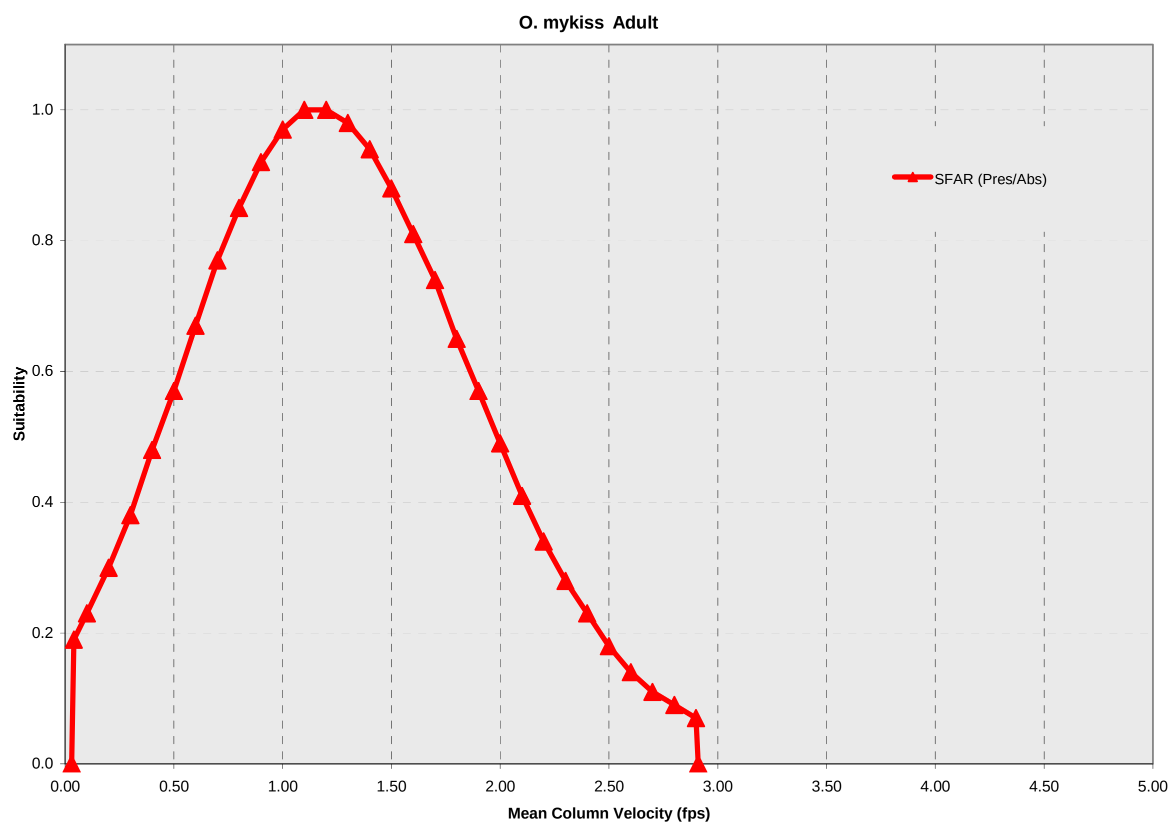
- **Decision**: The workshop group concurred on use the South Fork American River Logistic Regression (Pres/Abs) curves ("SFAR Pres/Abs") proposed by the USFWS for both velocity and depth.

Tuolumne River *O. mykiss* Adults Depth and Velocity Criteria*

Velocity (fps)	Suitability Index	Depth (ft)	Suitability Index
0.03	0.00	0.80	0.00
0.04	0.19	0.90	0.12
0.10	0.23	1.00	0.15
0.20	0.30	1.25	0.23
0.30	0.38	1.50	0.34
0.40	0.48	1.75	0.45
0.50	0.57	2.00	0.57
0.60	0.67	2.25	0.69
0.70	0.77	2.50	0.79
0.80	0.85	2.75	0.87
0.90	0.92	3.00	0.93
1.00	0.97	3.25	0.97
1.10	1.00	3.50	1.00
1.20	1.00	3.75	1.00
1.30	0.98	4.00	0.99
1.40	0.94	15.50	0.87
1.50	0.88	15.75	0.87
1.60	0.81	16.00	0.85
1.70	0.74	16.25	0.82
1.80	0.65	16.50	0.77
1.90	0.57	16.75	0.70
2.00	0.49	17.00	0.61
2.10	0.41	17.25	0.51
2.20	0.34	17.50	0.41
2.30	0.28	17.75	0.31
2.40	0.23	18.00	0.22
2.50	0.18	18.25	0.14
2.60	0.14	18.50	0.09
2.70	0.11	18.75	0.05
2.80	0.09	19.00	0.02
2.90	0.07	19.50	0.00
2.91	0.00		

* From USFWS 2004: Flow-habitat relationships for adult and juvenile rainbow trout in the Big Creek Project. USFWS Energy Planning and Instream Flow Branch. 31pp.


O. mykiss Adult
SFAR (Pres/Abs)
Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Depth (ft)


O. mykiss Adult
SFAR (Pres/Abs)
Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Mean Column Velocity (fps)

***O. mykiss* Spawning**

A wide range of HSC from various sources were reviewed; however, one single curve could not be identified to best fit the *O. mykiss* populations in the Tuolumne River. Therefore envelope curves were developed for depth and velocity, and a curve reflecting the central tendency of the data was developed for substrate, based on the Upper Trinity and Yuba curves.

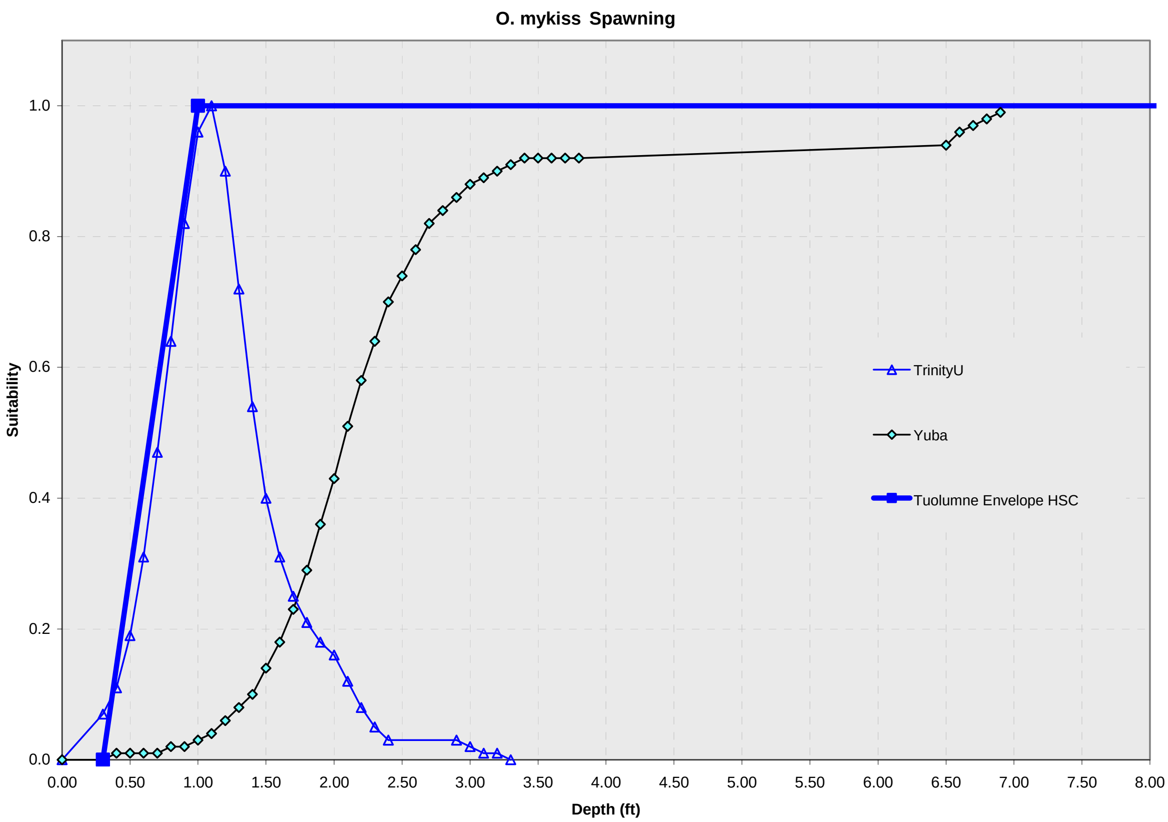
- **Decision:**
  - Velocity: Use an envelope curve including the ascending limb of the Upper Trinity curve to (x, y = 1.1, 1.0) over to (2.6, 1.0) of the Yuba curve, then straight-line down to (4.4, 0.0).
  - Depth: Use an envelope curve from (0.3, 0.0) to (1.0, 1.0) to (100.0, 1.0).
  - Substrate: Final substrate criteria agreed to by the technical group are specified below.

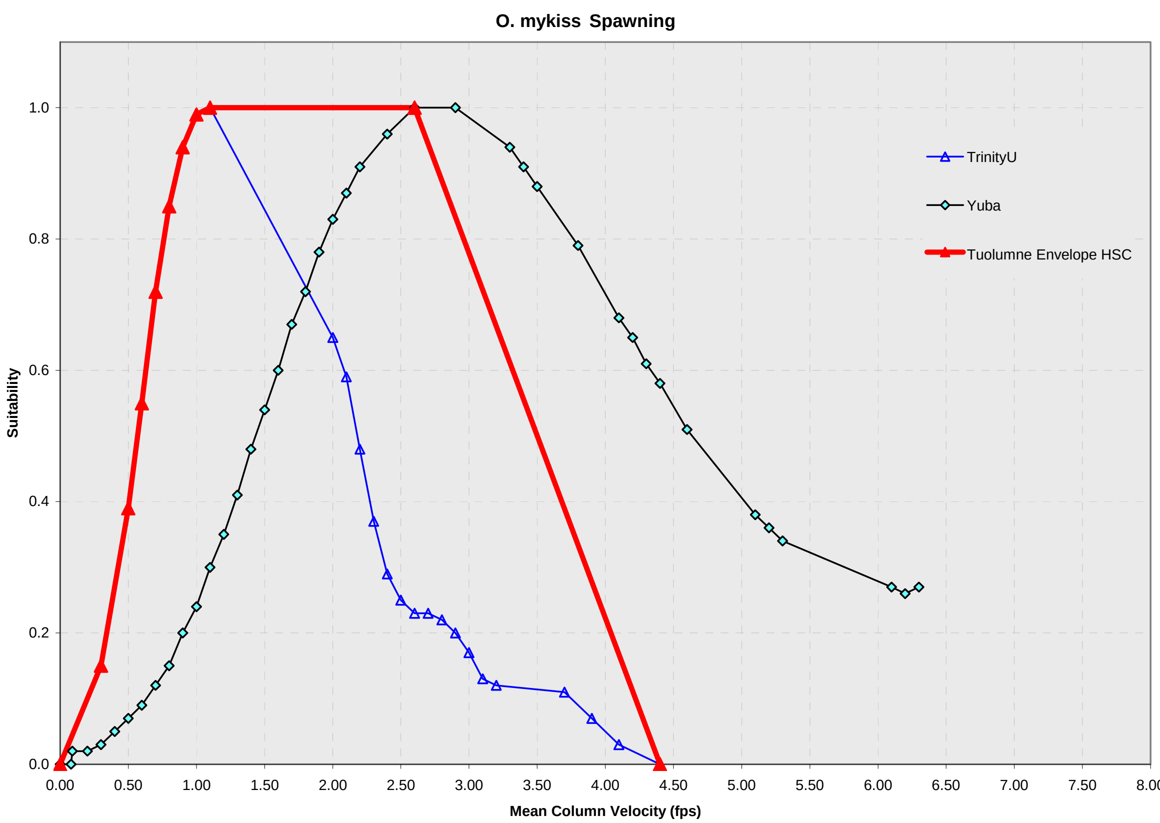
Tuolumne River *O. mykiss* Spawning Depth and Velocity Criteria

Velocity (fps)	Suitability Index	Depth (ft)	Suitability Index
0.00	0.00	0.30	0.00
0.30	0.15	1.00	1.00
0.50	0.39	100.00	1.00
0.60	0.55		
0.70	0.72		
0.80	0.85		
0.90	0.94		
1.00	0.99		
1.10	1.00		
2.60	1.00		
4.40	0.00		

Tuolumne River *O. mykiss* Spawning Substrate Criteria

Substrate	Size (inches)	Suitability Index
Organic, silt, sand, small gravel	Up to 1.0	0.38
Medium gravel	1-2	1.0
Large gravel	2-3	0.85
Very small cobble	3 – 4.5	0.28
Small cobble	4.5-6	0.05
Medium Cobble	6-9	0.00
Large cobble, boulder, bedrock	>9	0.00


O. mykiss Spawning
Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
Depth (ft)
TrinityU
Yuba
Tuolumne Envelope HSC


O. mykiss Spawning
Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
Mean Column Velocity (fps)
TrinityU
Yuba
Tuolumne Envelope HSC

O. mykiss **Fry**

A wide range of HSC from various sources were reviewed that displayed similar results for fry. USFWS Yuba River curves were presented in the "filtered" data sets, but they varied from the central tendency of the other curves due to the statistical approach used to generate them.

- **Action Item:** Mark Gard to provide the underlying histograms and report for the Yuba River *O. mykiss* HSC prior to the November 22 meeting for comparison to other data.

O. mykiss **Juveniles**

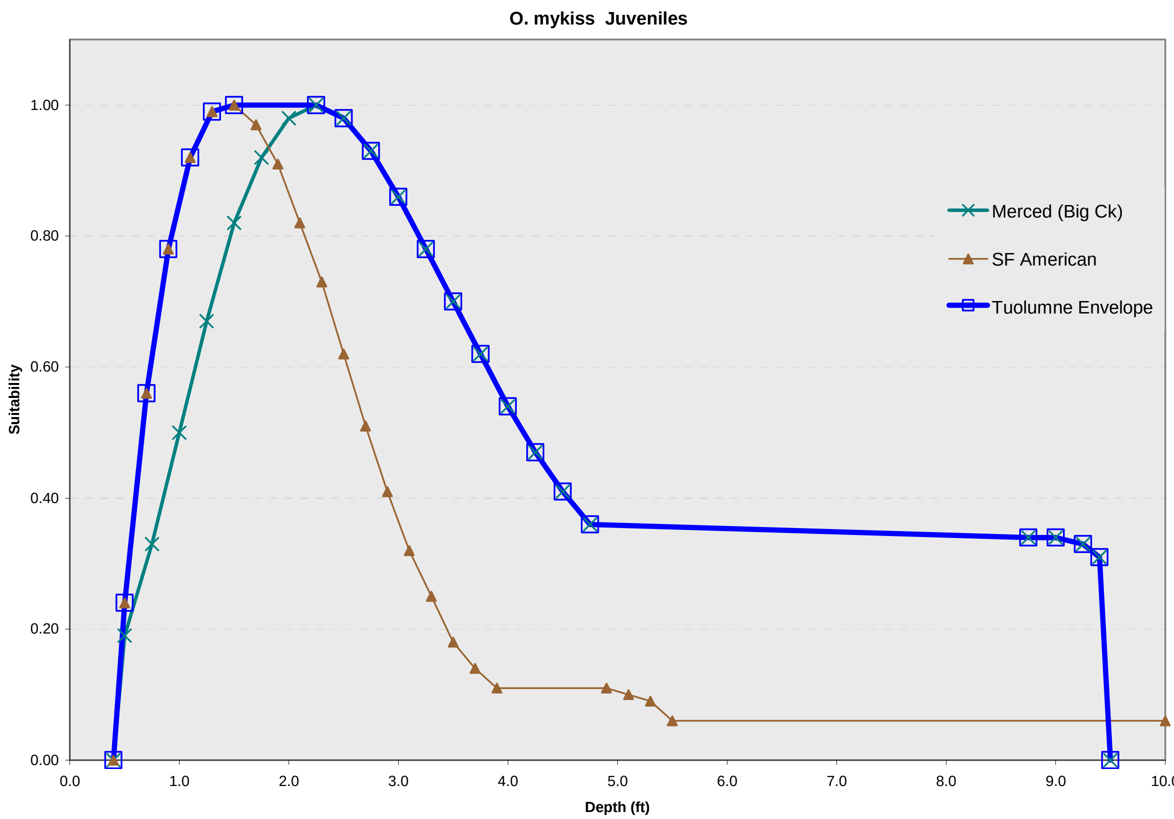
Decision: Recommended an envelope curve including the ascending limb of the SF American polynomial regression curve up to y=1, and across on y=1, following the descending limb of the SF American logistic regression curve. No substrate criteria to be applied to juveniles.

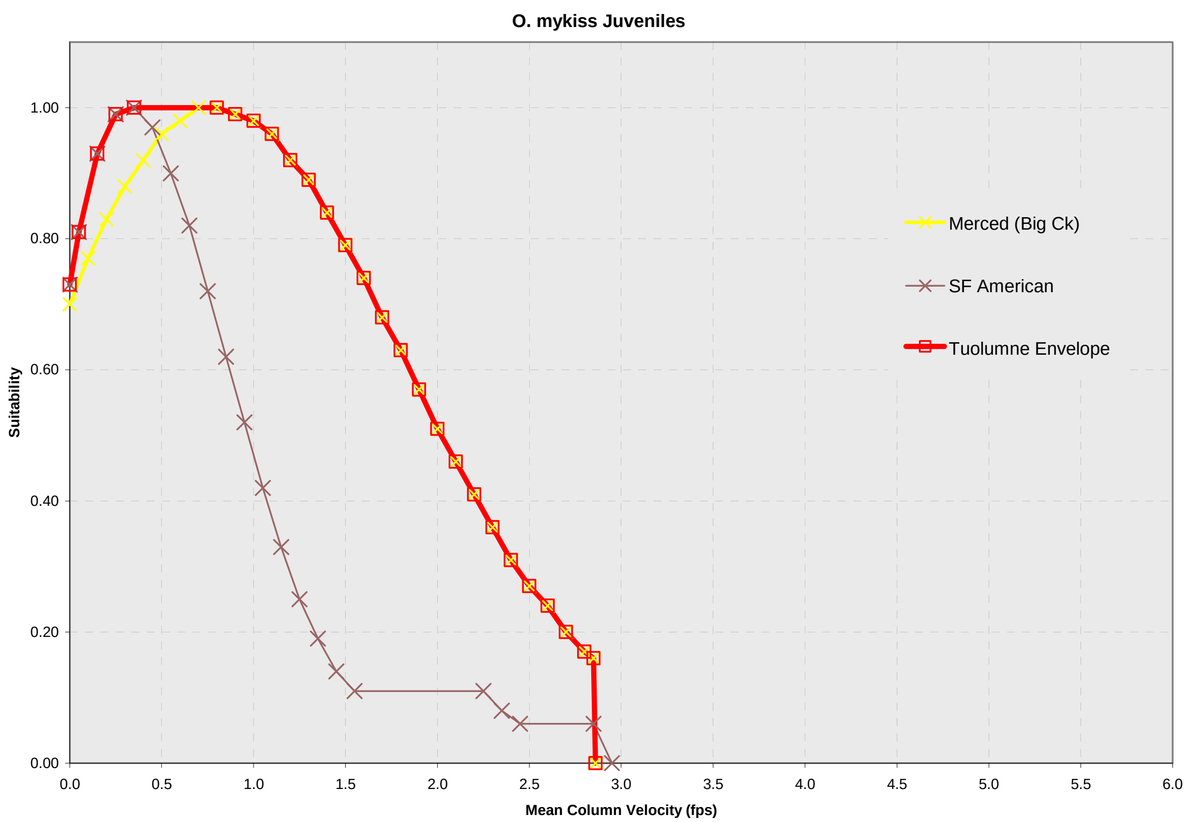
Upcoming meeting dates:

A third HSC development workshop was tentatively scheduled for November 22, 2010 at Stillwater in Davis, 9:00 AM, but was postponed due to subsequent scheduling and data availability conflicts. The next workshop is anticipated in early January.

Tuolumne River *O. mykiss* Juvenile Depth and Velocity Criteria

Velocity (fps)	Suitability Index	Depth (ft)	Suitability Index
0.00	0.73	0.40	0.00
0.05	0.81	0.50	0.24
0.15	0.93	0.70	0.56
0.25	0.99	0.90	0.78
0.35	1.00	1.10	0.92
0.80	1.00	1.30	0.99
0.90	0.99	1.50	1.00
1.00	0.98	2.25	1.00
1.10	0.96	2.50	0.98
1.20	0.92	2.75	0.93
1.30	0.89	3.00	0.86
1.40	0.84	3.25	0.78
1.50	0.79	3.50	0.70
1.60	0.74	3.75	0.62
1.70	0.68	4.00	0.54
1.80	0.63	4.25	0.47
1.90	0.57	4.50	0.41
2.00	0.51	4.75	0.36
2.10	0.46	8.75	0.34
2.20	0.41	9.00	0.34
2.30	0.36	9.25	0.33
2.40	0.31	9.40	0.31
2.50	0.27	9.50	0.00
2.60	0.24		
2.70	0.20		
2.80	0.17		
2.85	0.16		
2.86	0.00		


O. mykiss Juveniles
Suitability
Depth (ft)
Merced (Big Ck)
SF American
Tuolumne Envelope
0.00
0.20
0.40
0.60
0.80
1.00
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0


O. mykiss Juveniles
Suitability
Mean Column Velocity (fps)
Merced (Big Ck)
SF American
Tuolumne Envelope
0.00
0.20
0.40
0.60
0.80
1.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0

Lower Tuolumne River Instream Flow Study
Study Coordination Workshop #5 — Summary
Thursday, February 3, 2011, 9:00
Stillwater Office, Davis, CA

Attendees:

Scott Wilcox (Stillwater)	Ron Yoshiyama (CCSF-SF)
Russ Liebig (Stillwater)	Allison Boucher (TRC)
Bob Hughes (CDFG)	Dave Boucher (TRC)
Jenny O'Brien (CDFG)	Mark Gard (USFWS)
Steve Tsao (CDFG)	Zac Jackson (USFWS)
Bill Cowan (CDFG)	Shaara Ainsley (FishBio)

The purpose of this workshop was to compile, review, and discuss available *O. mykiss* and Chinook salmon Habitat Suitability Criteria (HSC) for the lower Tuolumne River, select remaining HSC where possible, identify additional HSC literature data gathering needs, and discuss related topics. HSC for Chinook salmon and *O. mykiss* were previously selected at the September 20, 2010 and October 20, 2010 workshops where the group had come to consensus on suitability criteria for Chinook salmon spawning (depth, velocity, and substrate), and juvenile (depth and velocity) lifestages, and *O. mykiss* spawning (depth, velocity, and substrate), adult (depth and velocity), and juvenile (depth and velocity) life stages. The group had decided at the September 20, 2010 workshop to not apply substrate criteria to the juvenile and fry life stages.

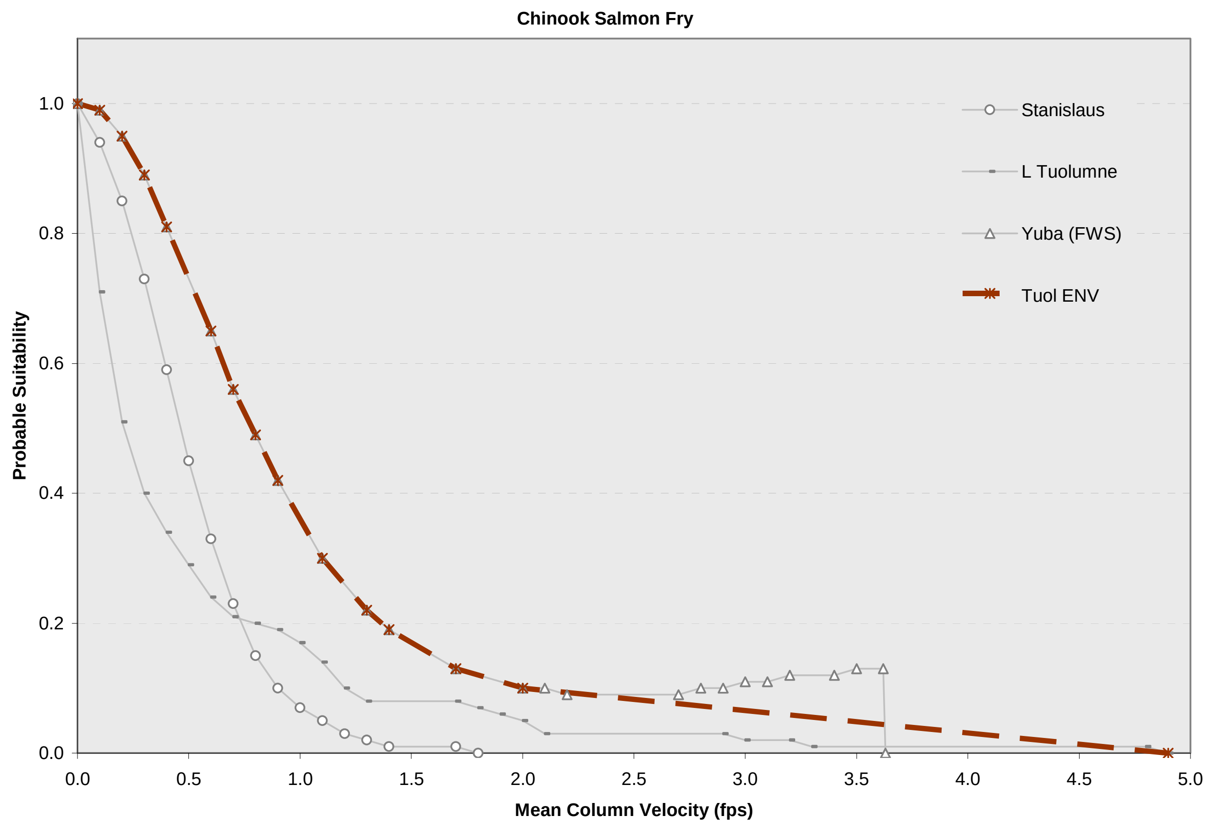
Scott Wilcox provided a brief overview of remaining action items from the previous workshops and introduced the revised Chinook salmon and *O. mykiss* HSC data packet compiled from USFWS data provided since the October workshop. The technical group reviewed Chinook salmon fry HSC and *O. mykiss* fry and adult HSC from various sources. The technical group also reviewed available cover HSC for Chinook salmon fry and *O. mykiss* fry provided by USFWS. Decisions and/or actions on HSC for each species and lifestage are noted below.

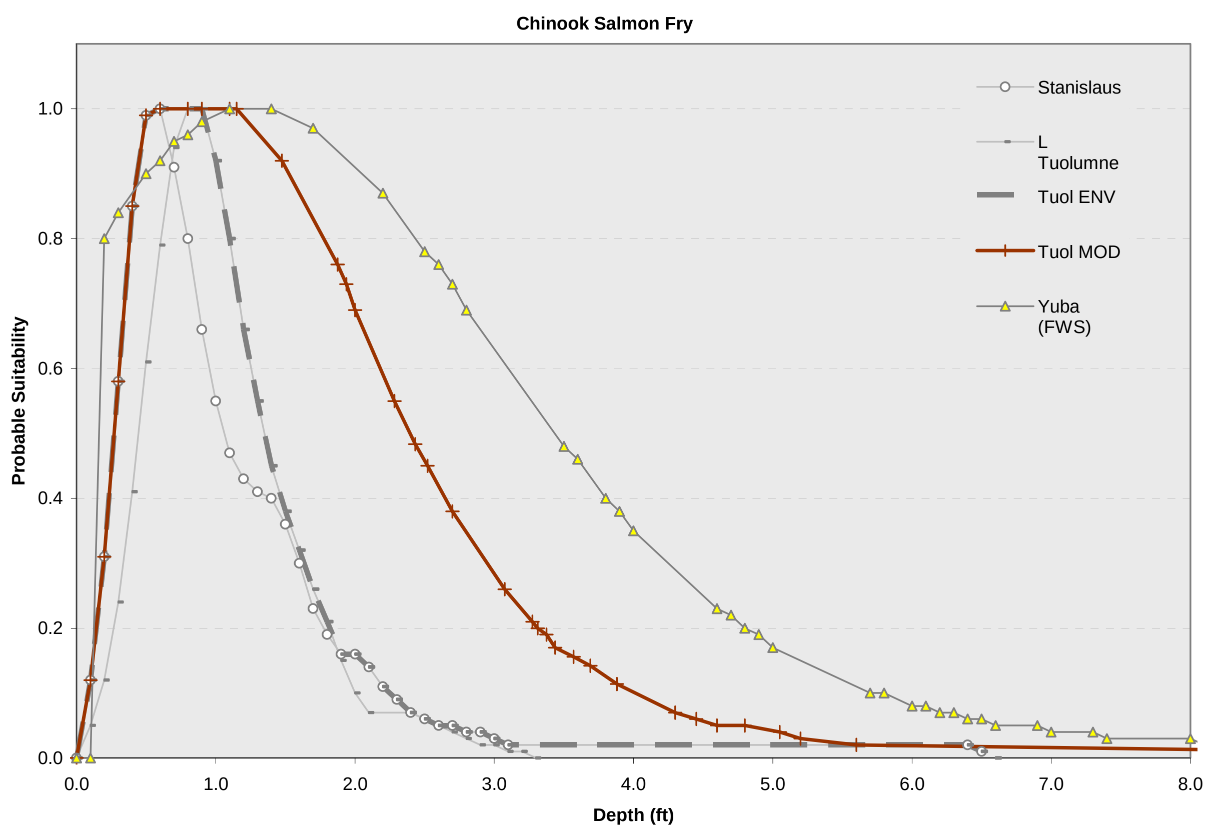
Chinook salmon fry

- The technical group had reviewed HSC during the September 20, 2010 workshop and initially narrowed the curve search to curves developed for the Tuolumne River and neighboring Stanislaus River. The similarity between the two data sets, and their similarity to the central tendency of other data sets, was not as great as the technical group had hoped, and some type of hybrid curve was considered. Decisions on depth and velocity HSC for this life stage had been deferred, pending review of the Tuolumne and Stanislaus reports that may provide some insight on reasons for the differences.

- Prior to the February 3, 2011 meeting, USFWS supplied additional background information for HSC they developed on the Yuba River, as well as additional unpublished HSC data they collected from Clear Creek.
- The group originally considered an "envelope" curve over the Stanislaus and Tuolumne curves, since the Stanislaus curve may have better correction for availability (being Category III curves), but the Tuolumne curve shows some greater utilization of higher velocities. When consensus was not reached, the group re-considered the Yuba River curves.
- **Velocity Decision**: The group concurred on the use of a modified Yuba River HSC curve for velocity (Tuol ENV). The modified curve was equal to the Yuba curve up to (2.0, 0.1), at which point the curve follows a straight line to (4.9, 0.0), the end point of the Tuolumne curve (see attached graphic and coordinate Table).
- **Depth**: The group did not come to consensus on the depth HSC curve. The most thoroughly discussed options included:
    1. An "envelope" over the Stanislaus and Tuolumne curves (Tuol ENV)
    2. Use an average between the envelope curve (Tuol ENV) and Yuba curves using the ascending limb of the Stanislaus curve, over to the Yuba curve at (1.1, 1.0) and down between the average of Tuol ENV and Yuba curves (Tuol MOD)
    3. Use the ascending limb of the Stanislaus curve, then the descending limb of the Yuba curve.

  Lacking consensus on this parameter, the Districts plan to apply option #2, since this option seemed to have the broadest support among the stakeholders present at the workshop.
- **Cover**: The group discussed the idea of using existing cover codes. Because of limited availability of published cover HSC and wide variation in codes, this item had been previously discussed as data to collect during field surveys in 2011, rather than trying to adapt other coding systems. Existing curves from the Yuba River and Clear Creek were presented by USFWS. The applicability, complexity, and sample size of the various cover code data were discussed. Possible use of Sacramento River cover codes was discussed, although the data were not presented or reviewed. Stillwater will consider combining cover data from various sources (including the USFWS Sacramento River Data) into a simplified cover code that could be circulated for comment.


Chinook Salmon Fry
Probable Suitability
Mean Column Velocity (fps)
Stanislaus
L Tuolumne
Yuba (FWS)
Tuol ENV
0.0
0.2
0.4
0.6
0.8
1.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

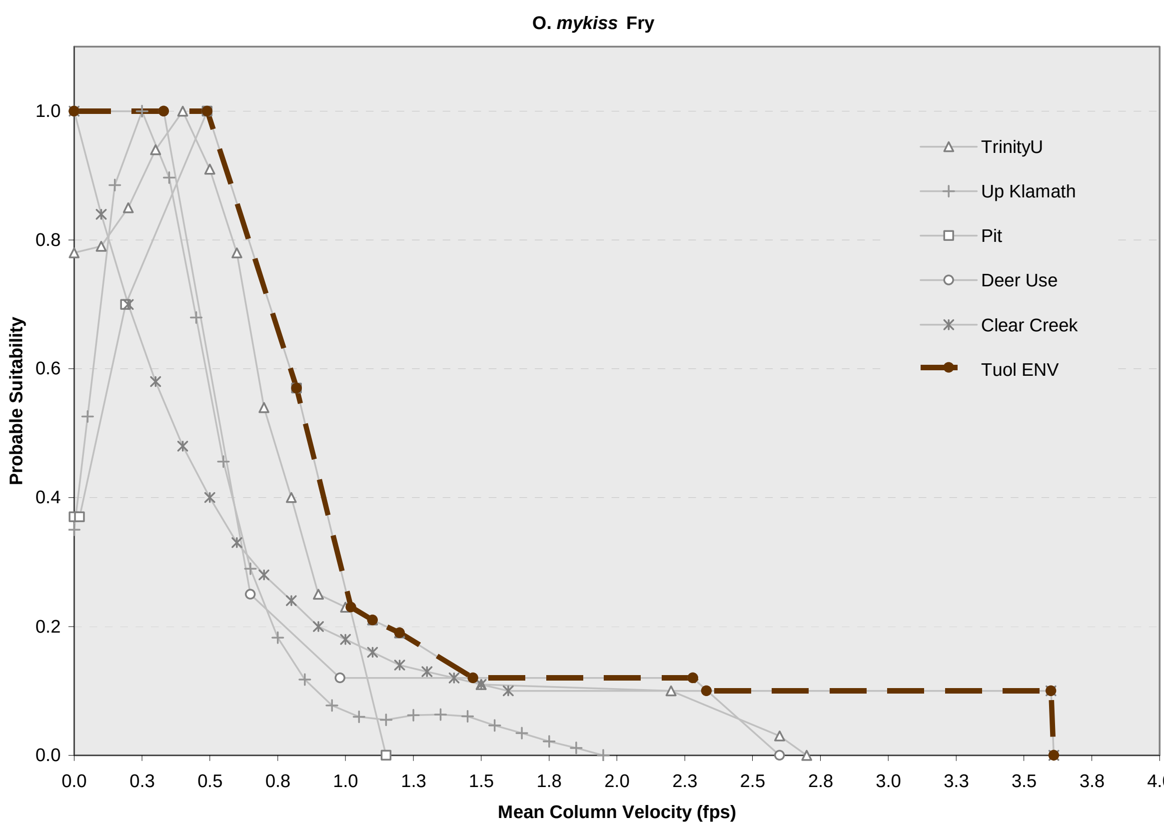

Chinook Salmon Fry
Probable Suitability
Depth (ft)
Stanislaus
L Tuolumne
Tuol ENV
Tuol MOD
Yuba (FWS)
0.0
0.2
0.4
0.6
0.8
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

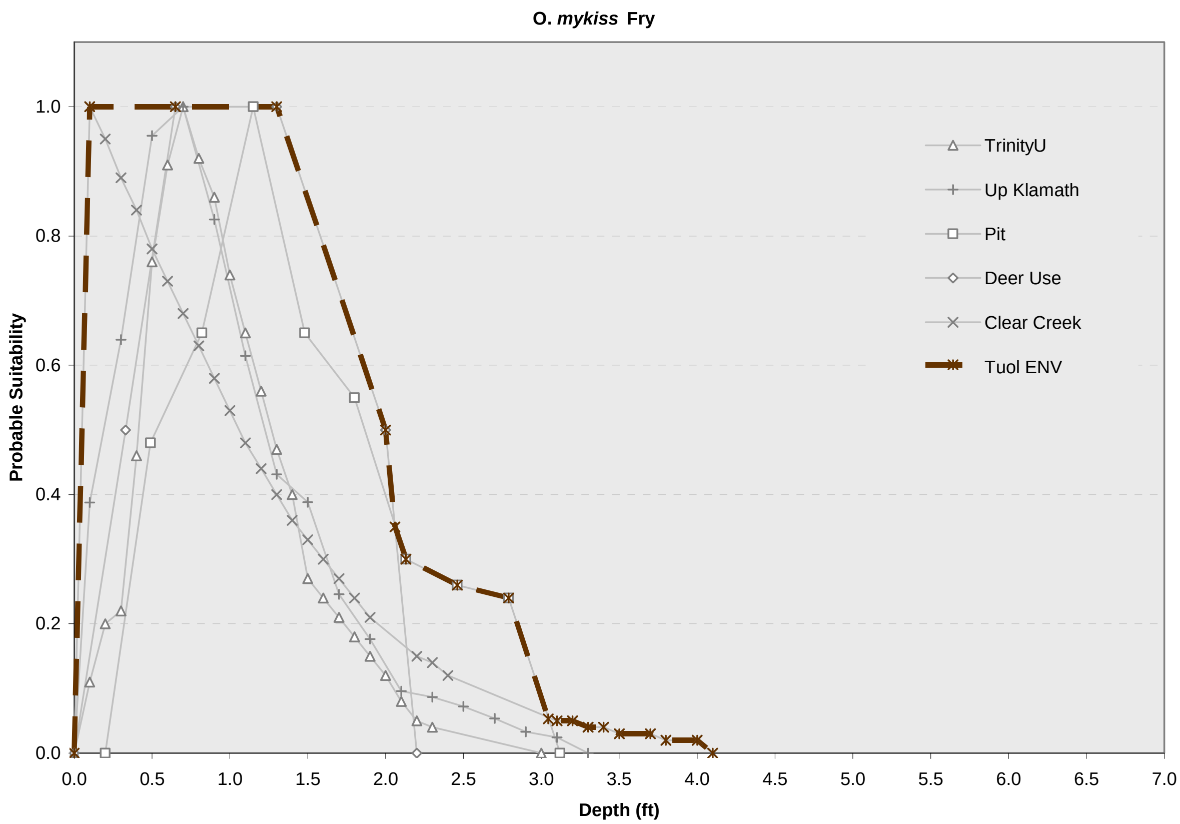
Chinook Salmon Fry: Velocity suitability criteria and three most discussed depth suitability criteria remaining following discussion on February 3, 2011

Tuol ENV		Tuol ENV		Tuol MOD		Yuba (FWS)	
Velocity	**Index**	**Depth**	**Index**	**Depth**	**Index**	**Depth**	**Index**
0	1	0.0	0.00	0.0	0.00	0.0	0.00
0.1	0.99	0.1	0.12	0.1	0.12	0.1	0.00
0.2	0.95	0.2	0.31	0.2	0.31	0.2	0.80
0.3	0.89	0.3	0.58	0.3	0.58	0.3	0.84
0.4	0.81	0.4	0.85	0.4	0.85	0.5	0.90
0.6	0.65	0.5	0.99	0.5	0.99	0.6	0.92
0.7	0.56	0.6	1.00	0.6	1.00	0.7	0.95
0.8	0.49	0.8	1.00	0.8	1.00	0.8	0.96
0.9	0.42	0.9	1.00	0.9	1.00	0.9	0.98
1.1	0.3	1.0	0.92	1.1	1.00	1.1	1.00
1.3	0.22	1.1	0.80	1.2	1.00	1.4	1.00
1.4	0.19	1.2	0.66	1.5	0.92	1.7	0.97
1.7	0.13	1.3	0.55	1.9	0.76	2.2	0.87
2	0.1	1.4	0.45	1.9	0.73	2.5	0.78
4.90	0.00	1.5	0.38	2.0	0.69	2.6	0.76
		1.6	0.32	2.3	0.55	2.7	0.73
		1.7	0.26	2.4	0.48	2.8	0.69
		1.8	0.21	2.5	0.45	3.5	0.48
		1.9	0.16	2.7	0.38	3.6	0.46
		2.0	0.16	3.1	0.26	3.8	0.40
		2.1	0.14	3.3	0.21	3.9	0.38
		2.2	0.11	3.3	0.2	4.0	0.35
		2.3	0.09	3.4	0.19	4.6	0.23
		2.4	0.07	3.4	0.17	4.7	0.22
		2.5	0.06	3.6	0.16	4.8	0.20
		2.6	0.05	3.7	0.14	4.9	0.19
		2.7	0.05	3.9	0.11	5.0	0.17
		2.8	0.04	4.3	0.07	5.7	0.10
		2.9	0.04	4.5	0.06	5.8	0.10
		3.0	0.03	4.6	0.05	6.0	0.08
		3.1	0.02	4.8	0.05	6.1	0.08
		6.4	0.02	5.1	0.04	6.2	0.07
		6.5	0.01	5.2	0.03	6.3	0.07
		6.6	0.00	5.6	0.02	6.4	0.06
				12.6	0.00	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

O. mykiss Fry

- A wide range of HSC from various sources were reviewed during the October 20, 2010 HSC workshop that displayed similar results for fry. USFWS Yuba River curves were presented in the "filtered" data sets, but they varied from the central tendency of the other curves due to the statistical approach used to generate them. USFWS subsequently provided the report and curves with underlying fish utilization histograms for discussion.
- The USFWS suggested the workshop group drop the Yuba *O. mykiss* fry curves from consideration due to the limited number of observations, but to add USFWS unpublished Clear Creek fry curves instead.
- **Decision**: The workshop group concurred on the use of an envelope curve for both depth and velocity around the Trinity U., Up Klamath, Pit, Deer Use, and Clear Creek curves, generally following the most inclusive ("outside") parts of the curve.





Tuolumne River suitability criteria for *O. mykiss* fry

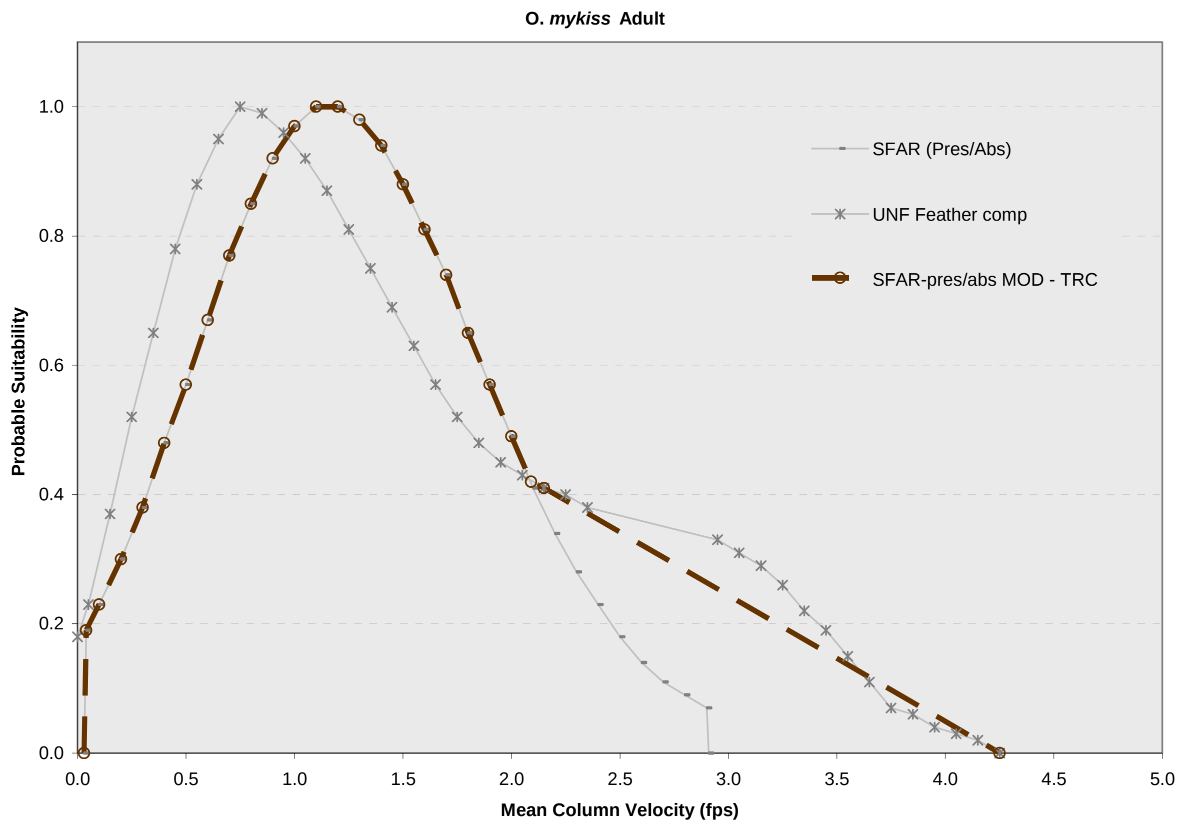
Velocity	Tuol ENV Index	Depth	Tuol ENV Index
0.00	1.00	0.00	0.00
0.33	1.00	0.10	1.00
0.49	1.00	0.65	1.00
0.82	0.57	1.30	1.00
1.02	0.23	2.00	0.50
1.10	0.21	2.06	0.35
1.20	0.19	2.13	0.30
1.47	0.12	2.46	0.26
2.28	0.12	2.79	0.24
2.33	0.10	3.05	0.05
3.60	0.10	3.10	0.05
3.61	0.00	3.20	0.05
		3.30	0.04
		3.40	0.04
		3.50	0.03
		3.70	0.03
		3.80	0.02
		4.00	0.02
		4.10	0.00

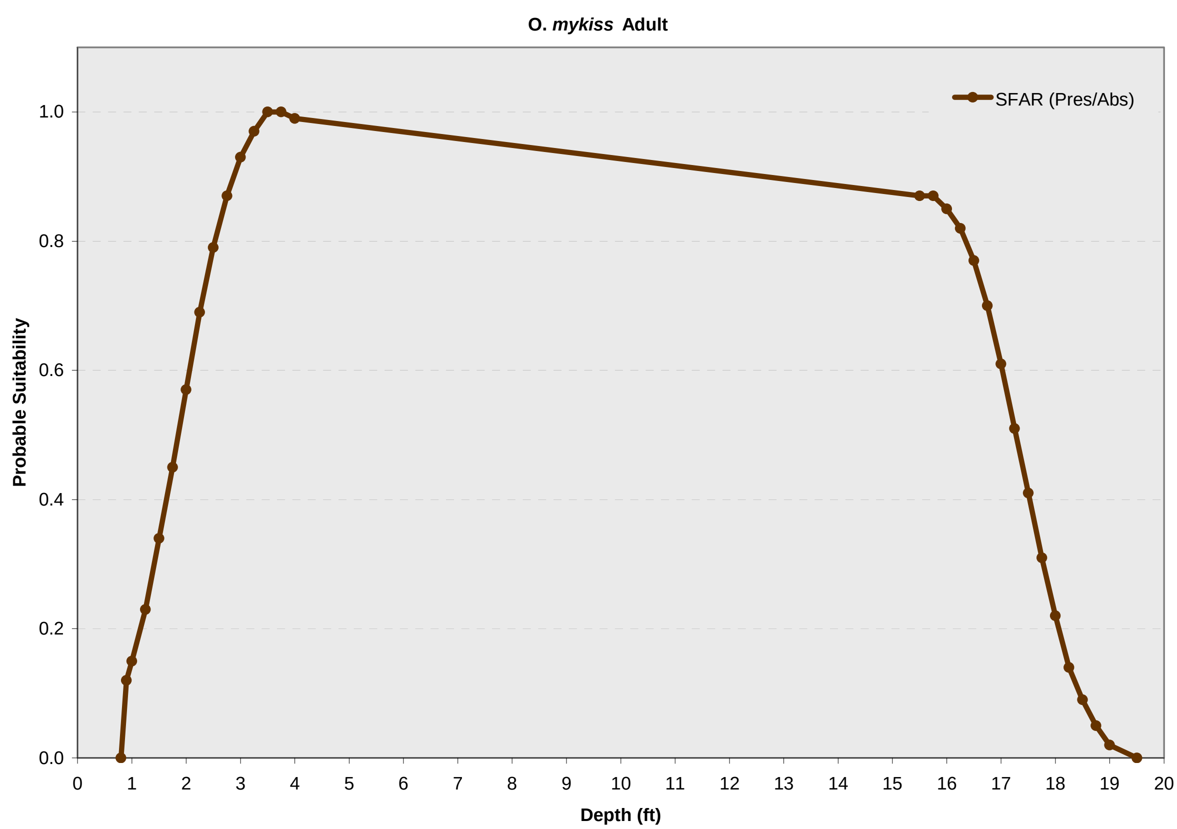
O. mykiss **Adult**

- The workshop group had previously discussed use of the South Fork American River Logistic Regression (Pres/Abs) curves (SFAR Pres/Abs) proposed by the USFWS for both velocity and depth, and concurrence of the group was reported in the October 20, 2010 meeting summary. TRC suggested that the reported concurrence was in error in regard to their opinion, so the group re-opened the discussion.
- **Decision**: In response to TRC requests, the workgroup agreed to keep the South Fork American River Logistic Regression (Pres/Abs) curve (SFAR Pres/Abs) for depth, and use a modified curve for velocity. The modified velocity curve (SFAR Pres/Abs MOD-TRC) was equal to the SFAR Pres/Abs curve up to its intersection with the Upper North Fork Feather River composite curve (2.09, 0.42), at which point the modified curve follows a straight line to (4.25, 0.0), the end point of the UNF Feather comp curve.

<u>Post-Workshop Correspondence</u>

Subsequent to this February 3, 2011 workshop, TRC transmitted the attached email (Attachment #1) dated March 20, 2011, withdrawing their support for *O. mykiss* decisions regarding habitat suitability criteria.


O. *mykiss* Adult
Probable Suitability
Mean Column Velocity (fps)
SFAR (Pres/Abs)
UNF Feather comp
SFAR-pres/abs MOD - TRC
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


O. *mykiss* Adult
Probable Suitability
Depth (ft)
SFAR (Pres/Abs)
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Tuolumne River suitability criteria for *O. mykiss* adults

Velocity	SFAR pres/abs MOD-TRC Index	Depth	SFAR (Pres/Abs) Index
0.03	0.00	0.80	0.00
0.04	0.19	0.90	0.12
0.10	0.23	1.00	0.15
0.20	0.30	1.25	0.23
0.30	0.38	1.50	0.34
0.40	0.48	1.75	0.45
0.50	0.57	2.00	0.57
0.60	0.67	2.25	0.69
0.70	0.77	2.50	0.79
0.80	0.85	2.75	0.87
0.90	0.92	3.00	0.93
1.00	0.97	3.25	0.97
1.10	1.00	3.50	1.00
1.20	1.00	3.75	1.00
1.30	0.98	4.00	0.99
1.40	0.94	15.50	0.87
1.50	0.88	15.75	0.87
1.60	0.81	16.00	0.85
1.70	0.74	16.25	0.82
1.80	0.65	16.50	0.77
1.90	0.57	16.75	0.70
2.00	0.49	17.00	0.61
2.09	0.42	17.25	0.51
2.15	0.41	17.50	0.41
4.25	0.00	17.75	0.31
		18.00	0.22
		18.25	0.14
		18.50	0.09
		18.75	0.05
		19.00	0.02
		19.50	0.00

HSC development status

The following table summarizes sources of HSC curves to be used in the Tuolumne River Instream Flow Study.

Species	Life Stage	Depth	Velocity	Substrate[1]	Cover
Fall Chinook salmon	Spawning	L Tuolumne Sept 20, 2010	L Tuolumne Sept 20, 2010	Tuol/Wentworth Sept 20, 2010[2]	--
	Juvenile	Stanislaus (modified) Sept 20, 2010	Stanislaus Sept 20, 2010	--	TBD
	Fry	Tuol ENV[3] Feb 03, 2011	Tuol ENV Feb 03, 2011	--	TBD
O. mykiss	Adult	SFAR Pres/Abs Oct 20, 2010	SFAR Pres/Abs Oct 20, 2010 or SFAR Pres/Abs MOD-TRC Feb 2, 2011[4]	--	TBD
	Spawning	Tuolumne ENV Oct 20, 2010	Tuolumne ENV Oct 20, 2010	Tuolumne ENV Oct 20, 2010	--
	Juvenile	Tuolumne ENV Oct 20, 2010	Tuolumne ENV Oct 20, 2010	--	TBD
	Fry	Tuol ENV Feb 03, 2011	Tuol ENV Feb 03, 2011	--	TBD

1 The workgroup decided not to apply substrate criteria to fry and juvenile life stages since they do not typically select habitat based on substrate and may occur over a full range of possibilities.

2 Adapted from CDFG 1982 with minor expansion to indicate suitability of 1-2 inch gravel.

3 Lacking consensus on this parameter, the Districts plan to apply the Tuolumne Envelope curve (Tuol ENV) since this option seemed to have the broadest support among the stakeholders present at the workshop.

4 Although TRC subsequently withdrew their support for *O. mykiss* HSC curves, the Districts tentatively plan to use, or at least include, the *O. mykiss* adult curve (SFAR Pres/Abs MOD-TRC) modified at TRC's request.

Upcoming meeting dates:

There are no additional HSC meetings scheduled at this time. Additional meetings may be required following the collection of field data in 2011.

Appendix C

Relative Habitat Suitability for Salmonid Juveniles and Predator Species

Figure C-1. Riffle 4B results at 1,000 cfs for Chinook salmon fry.

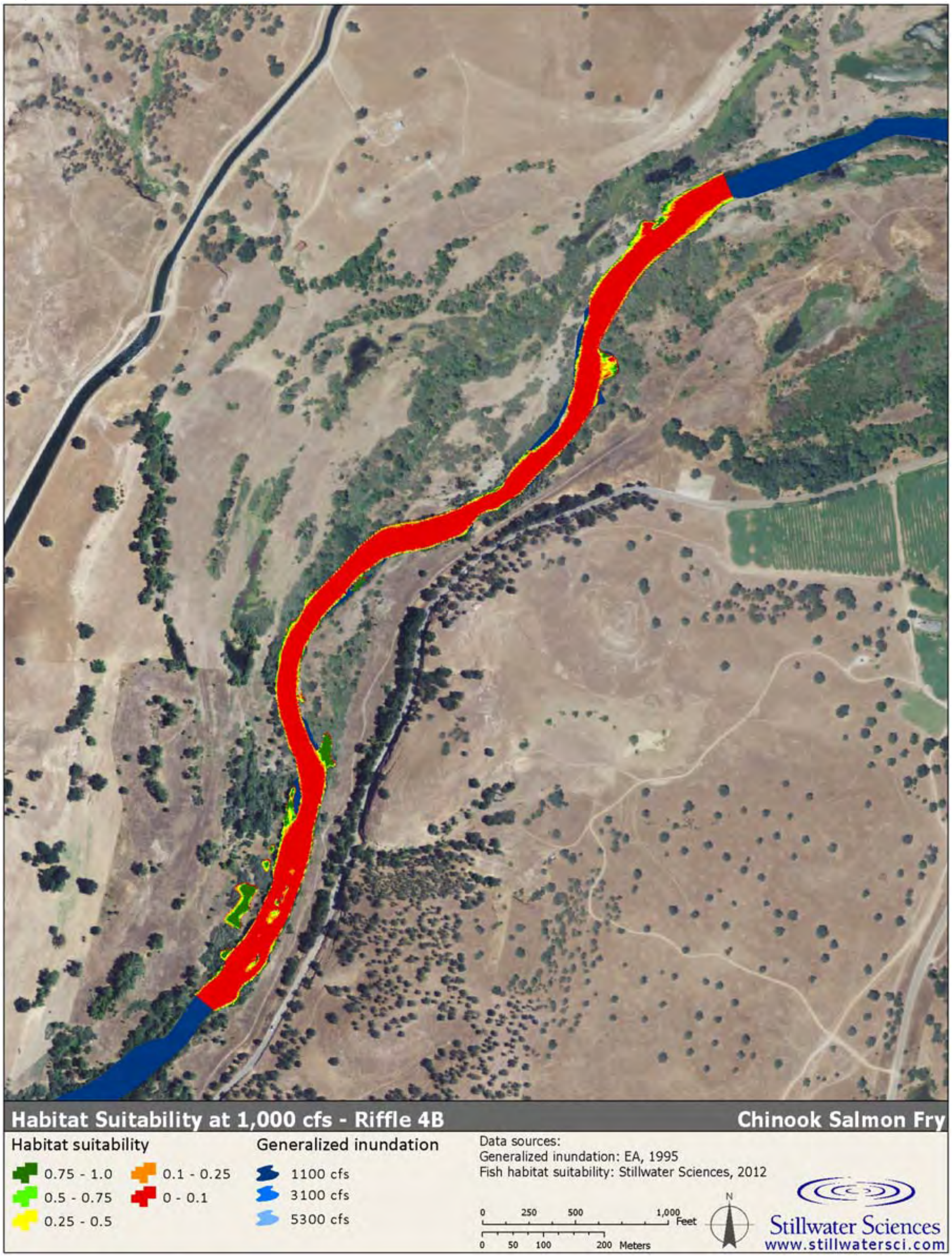


Figure C-2. Riffle 4B results at 1,000 cfs for *O. mykiss* fry.

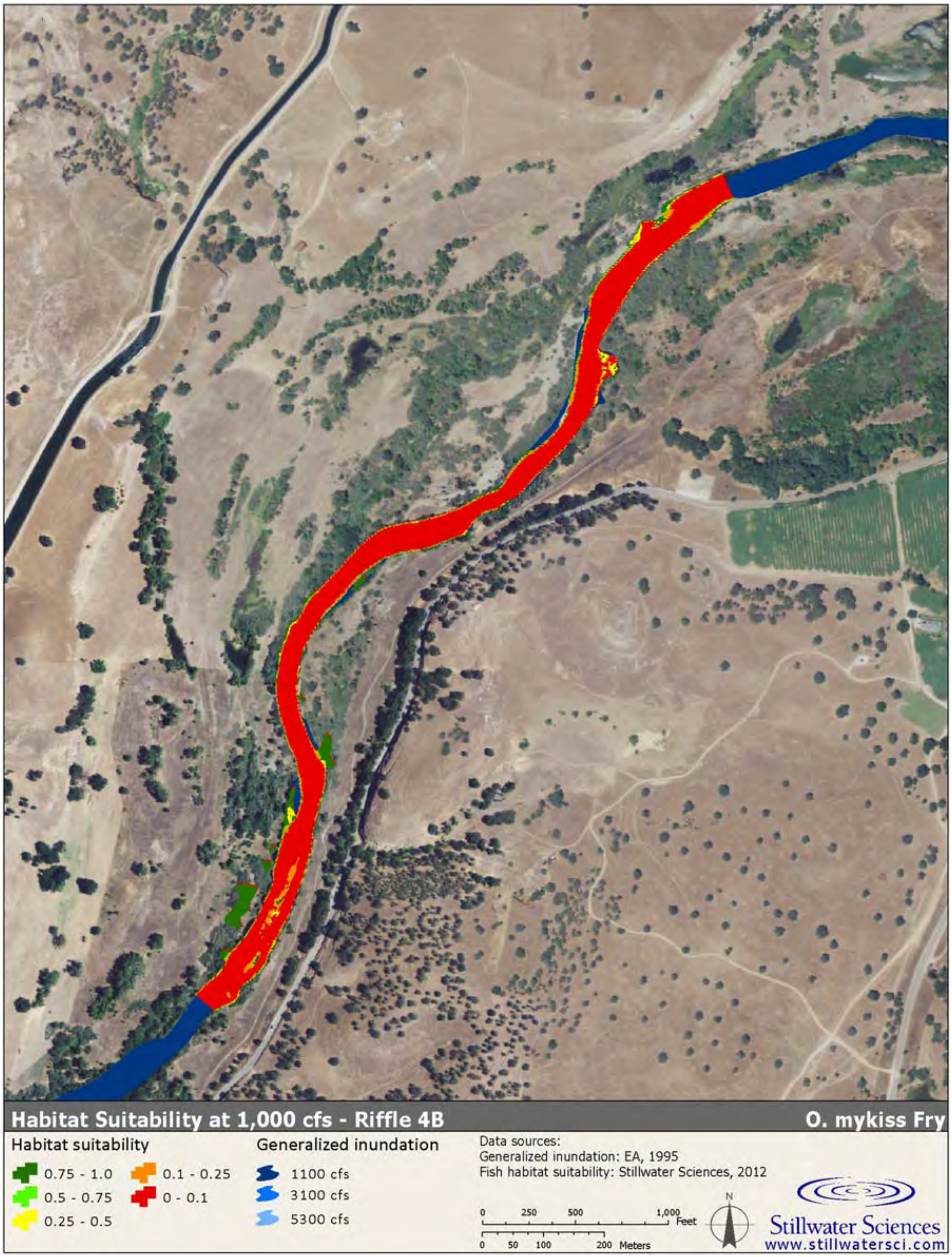


Figure C-3. Riffle 4B results at 1,000 cfs for Chinook salmon juveniles.

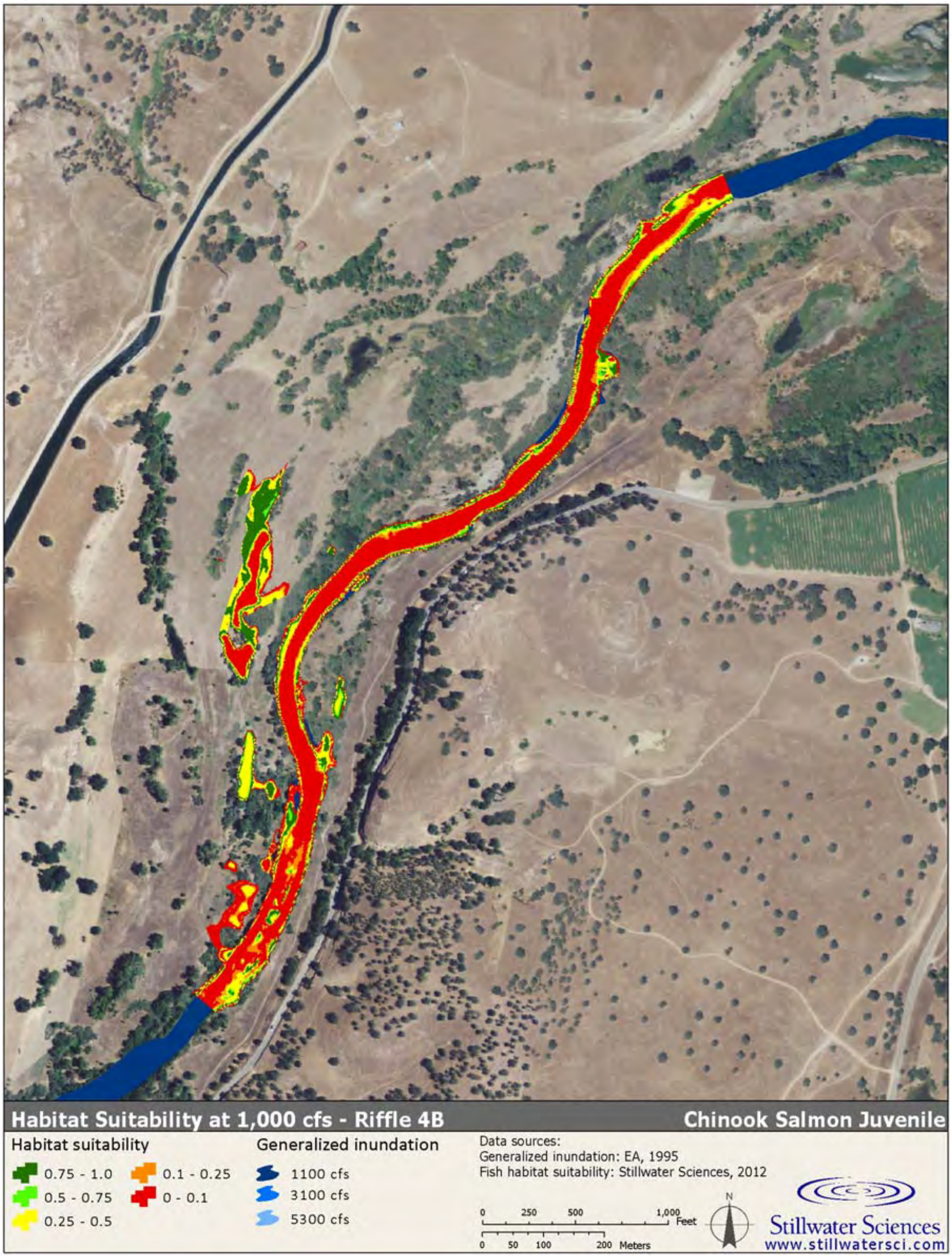


Figure C-4. Riffle 4B results at 1,000 cfs for *O. mykiss* juveniles.

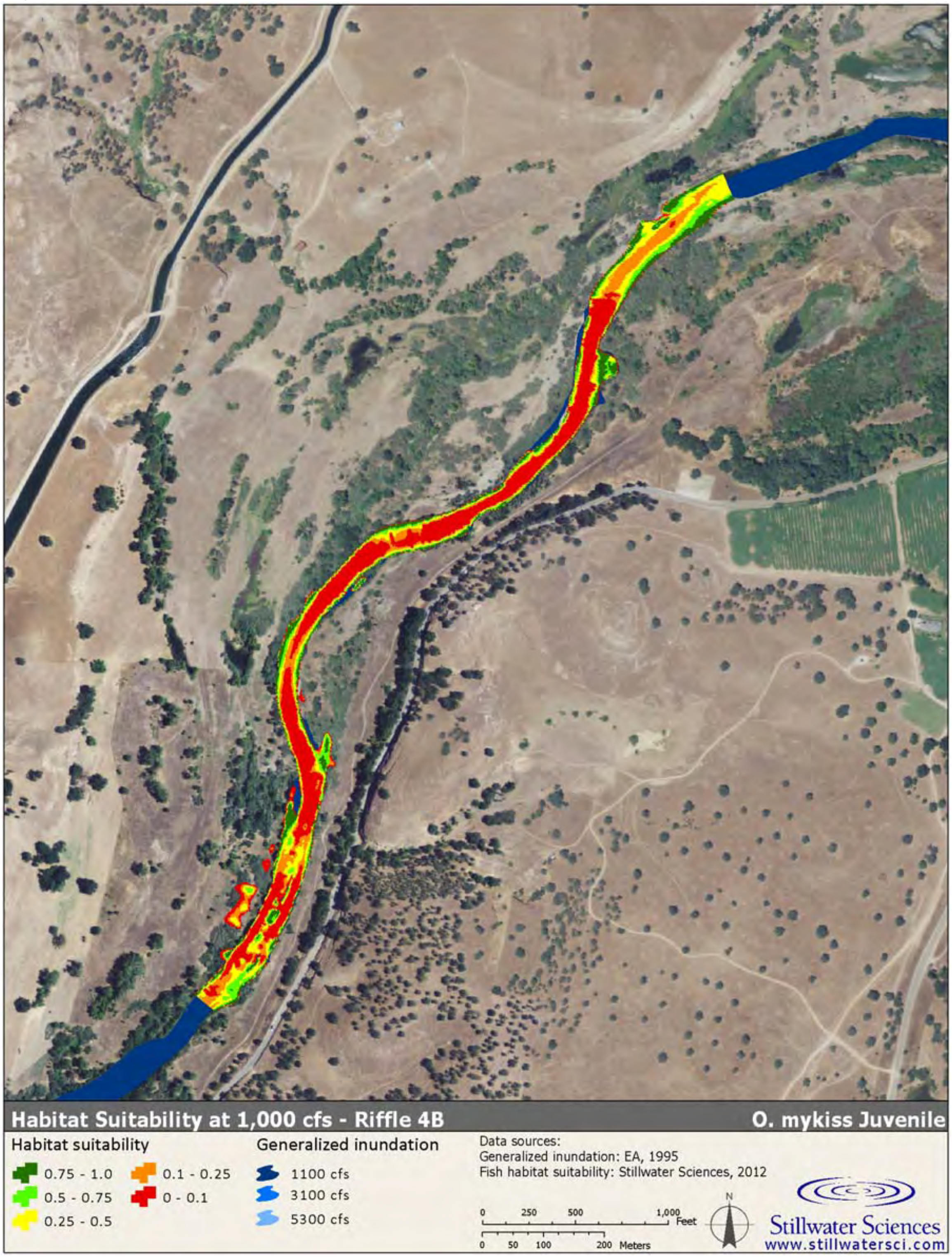


Figure C-5. Riffle 4B results at 1,000 cfs for smallmouth bass adults.

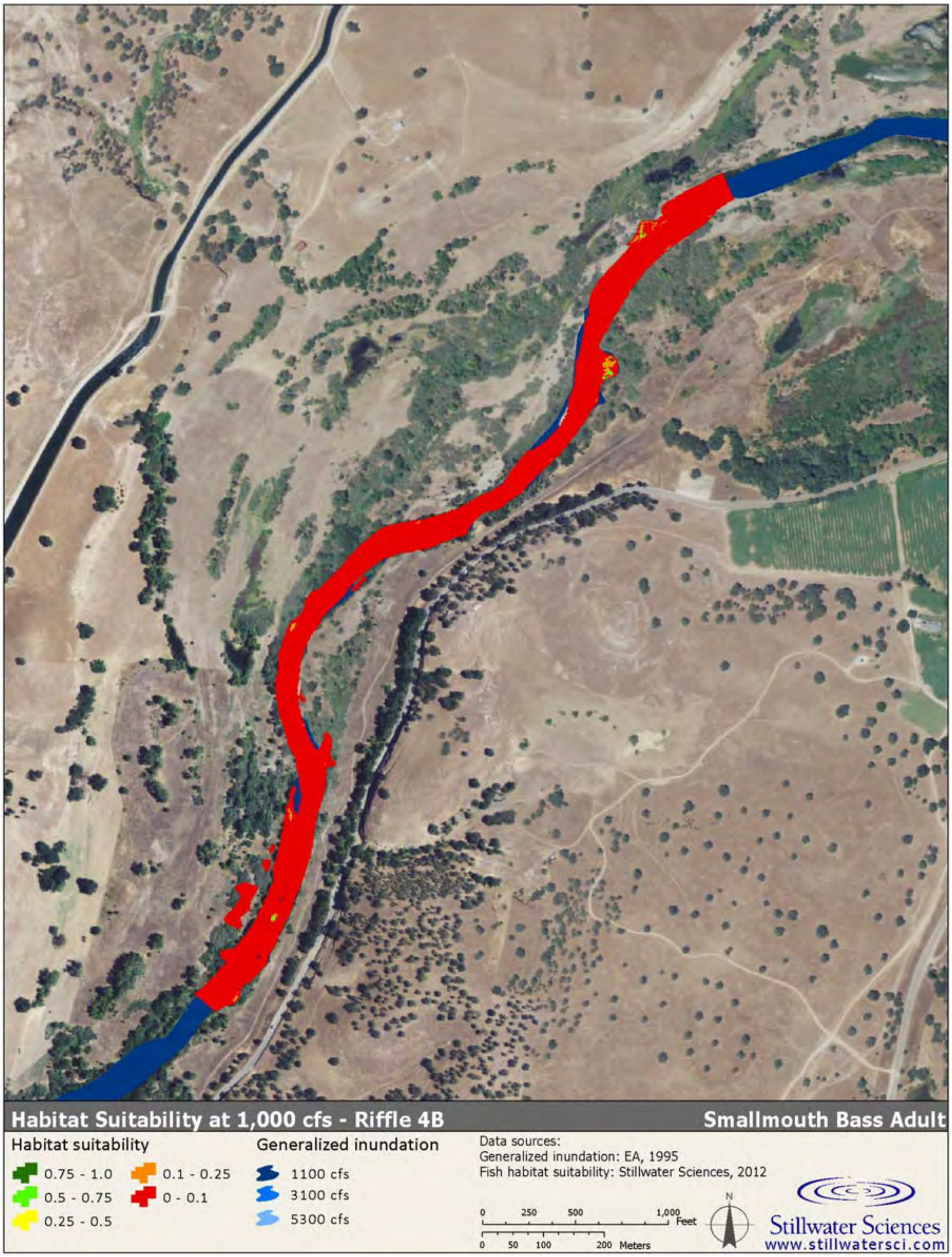


Figure C-6. Riffle 4B results at 1,000 cfs for largemouth bass adults.

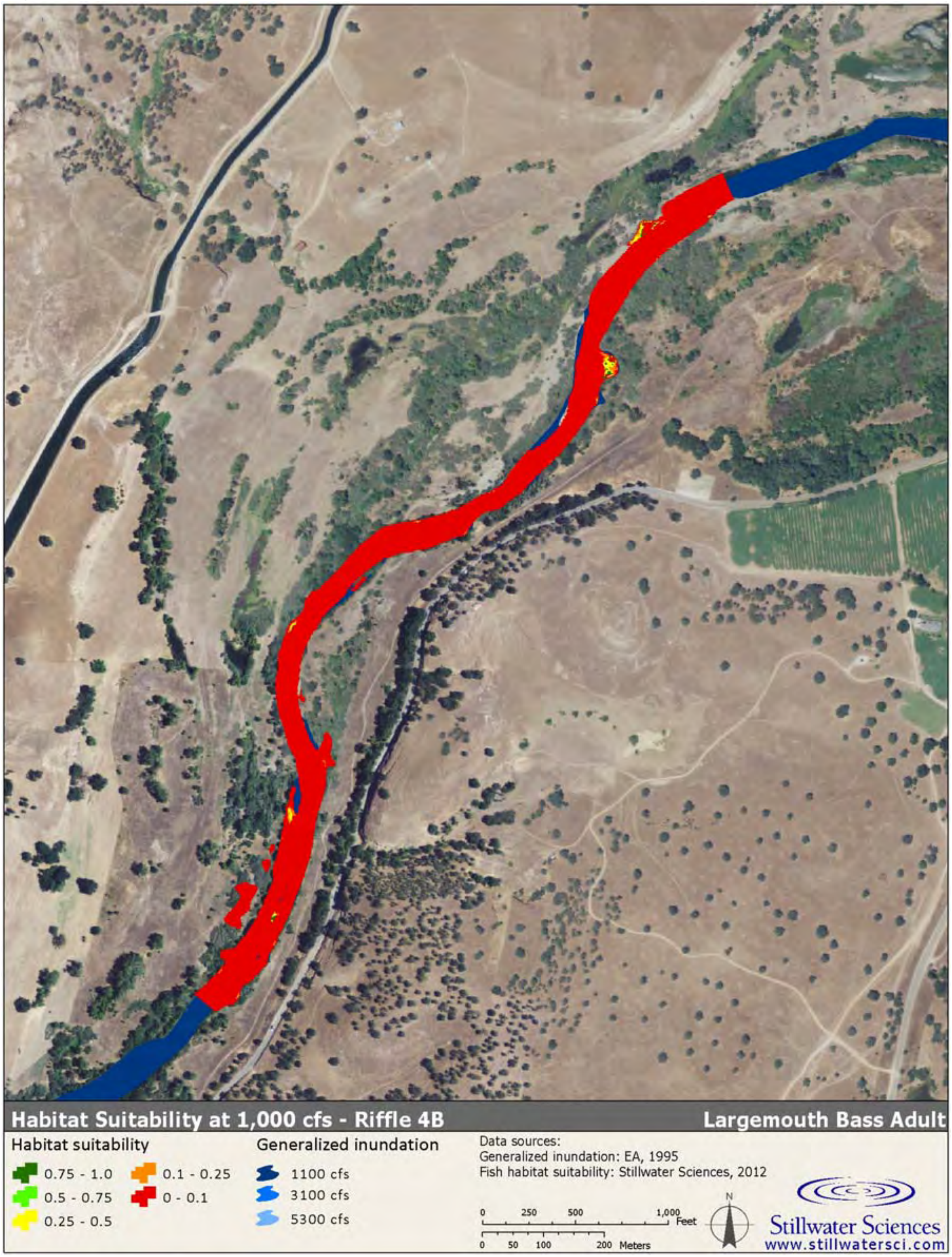


Figure C-7. Riffle 4B results at 1,000 cfs for Sacramento pikeminnow adults.

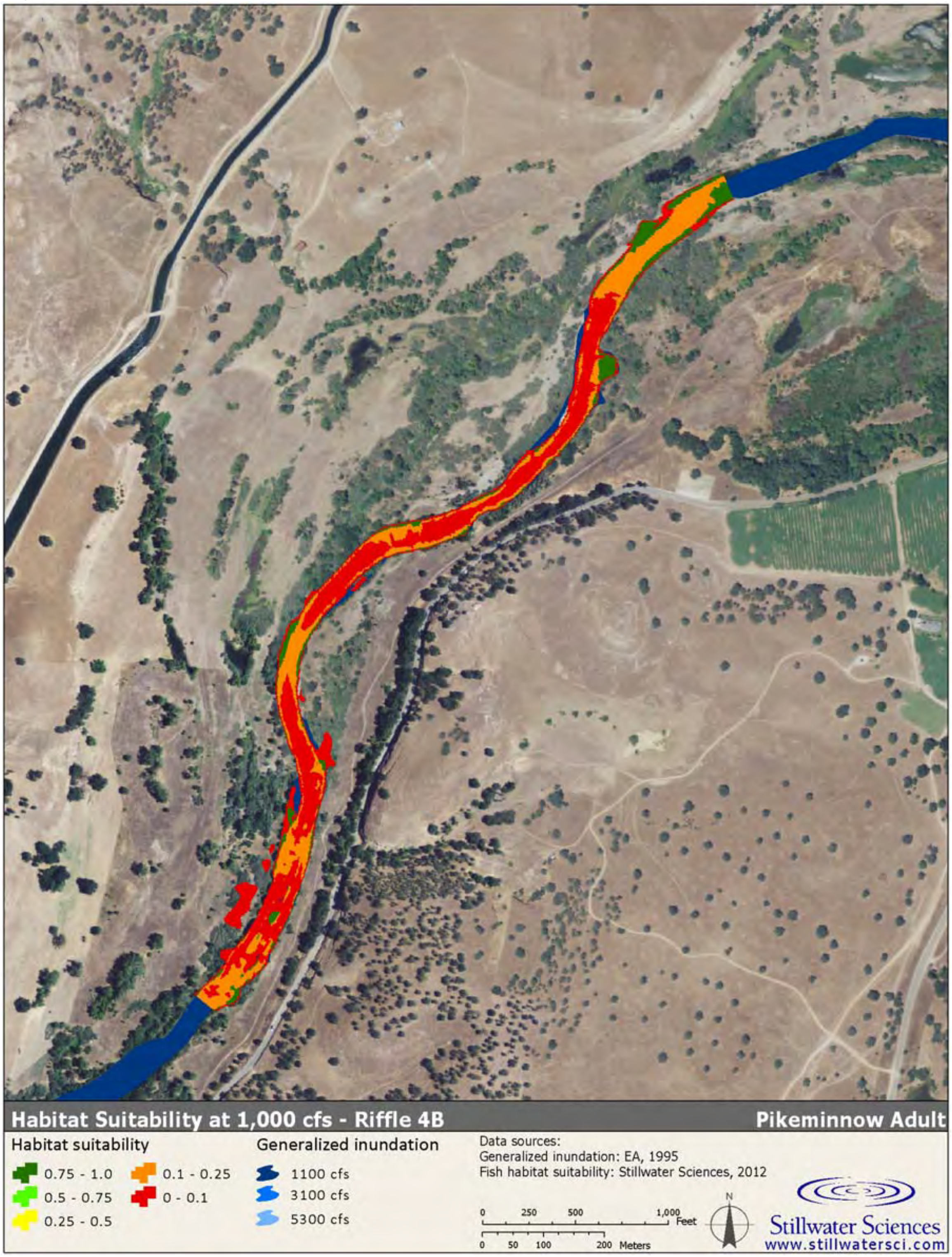


Figure C-8. Riffle 4B results at 1,000 cfs for striped bass adults.

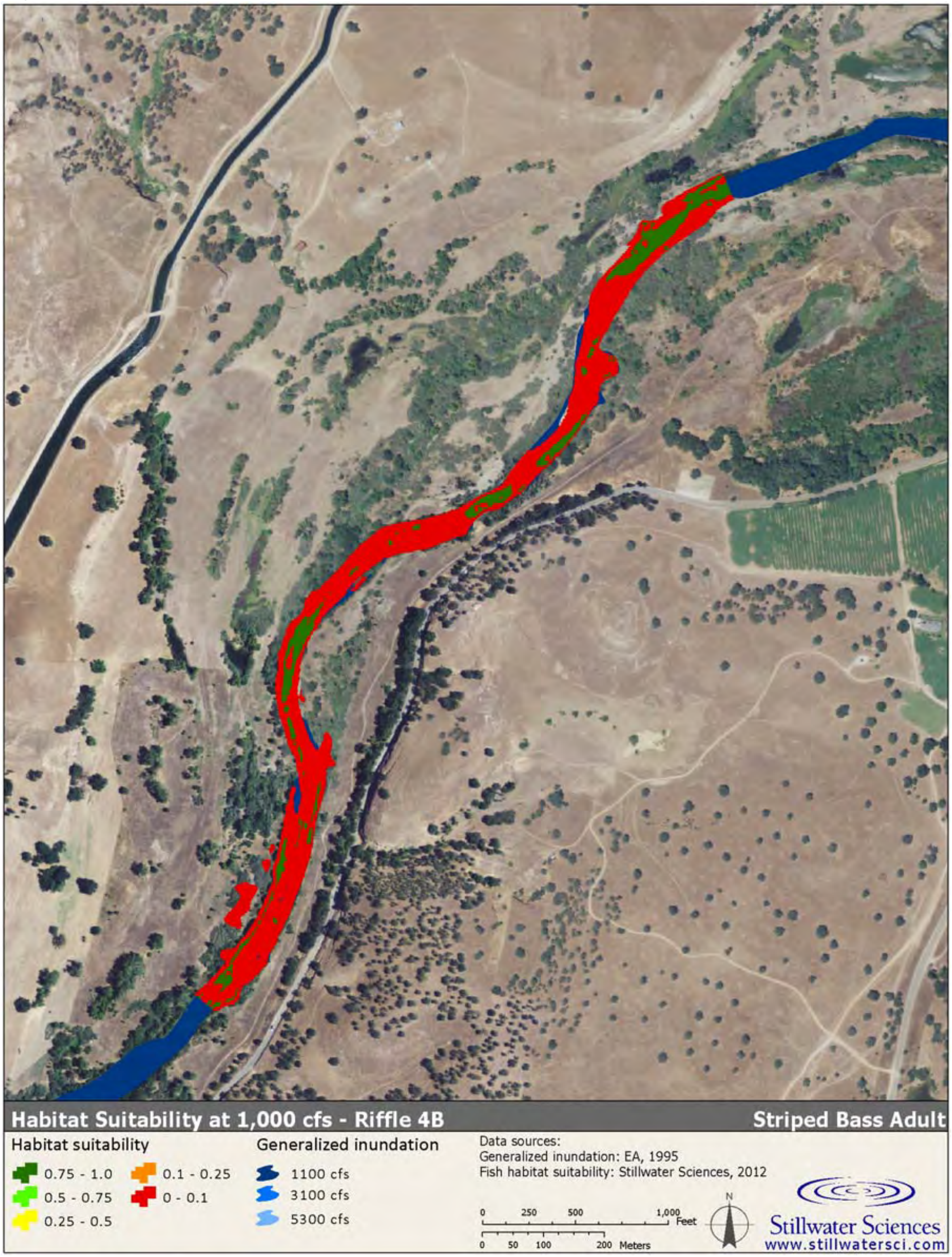


Figure C-9. Riffle 4B results at 1,600 cfs for Chinook salmon fry.

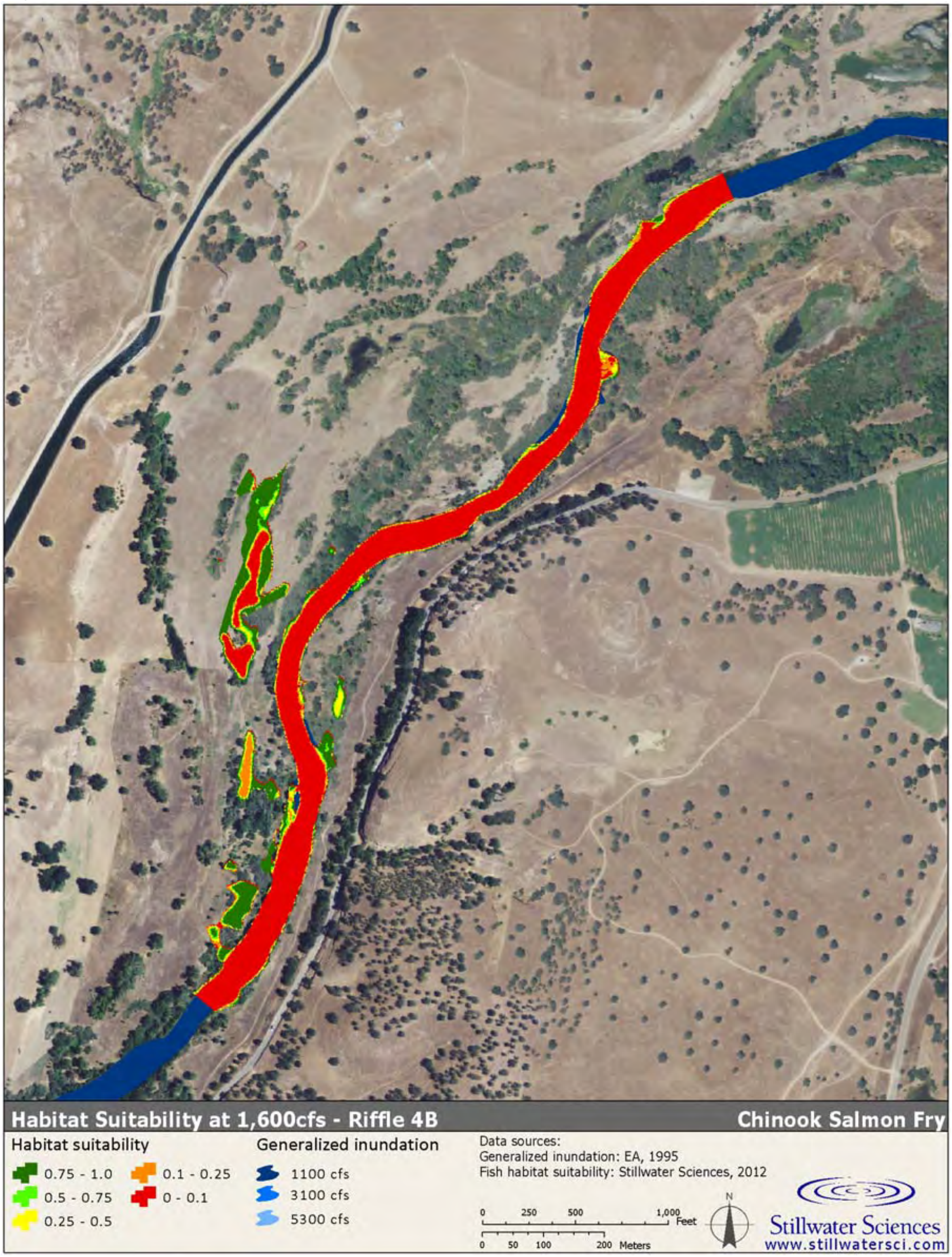


Figure C-10. Riffle 4B results at 1,600 cfs for *O. mykiss* fry.

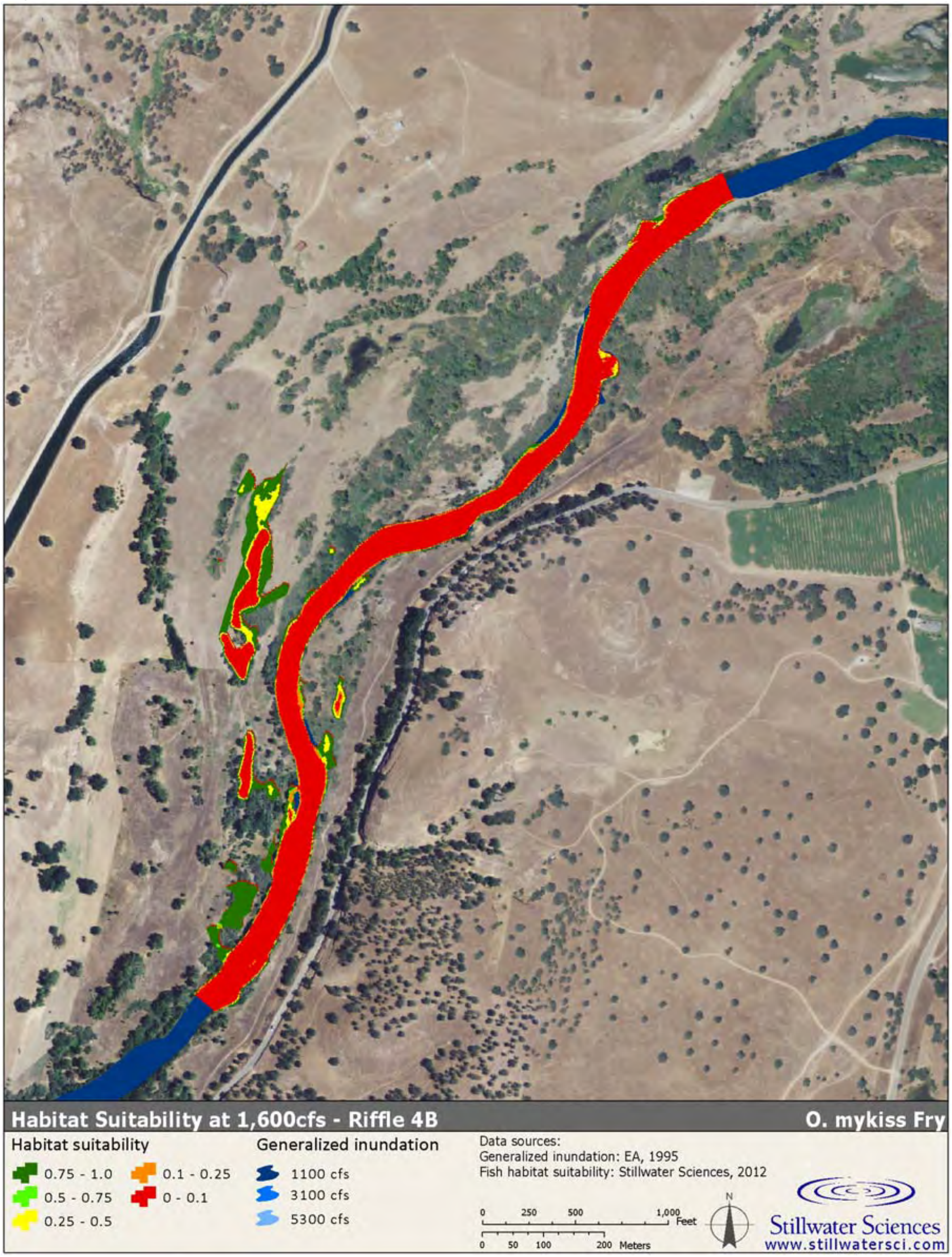


Figure C-11. Riffle 4B results at 1,600 cfs for Chinook salmon juveniles.

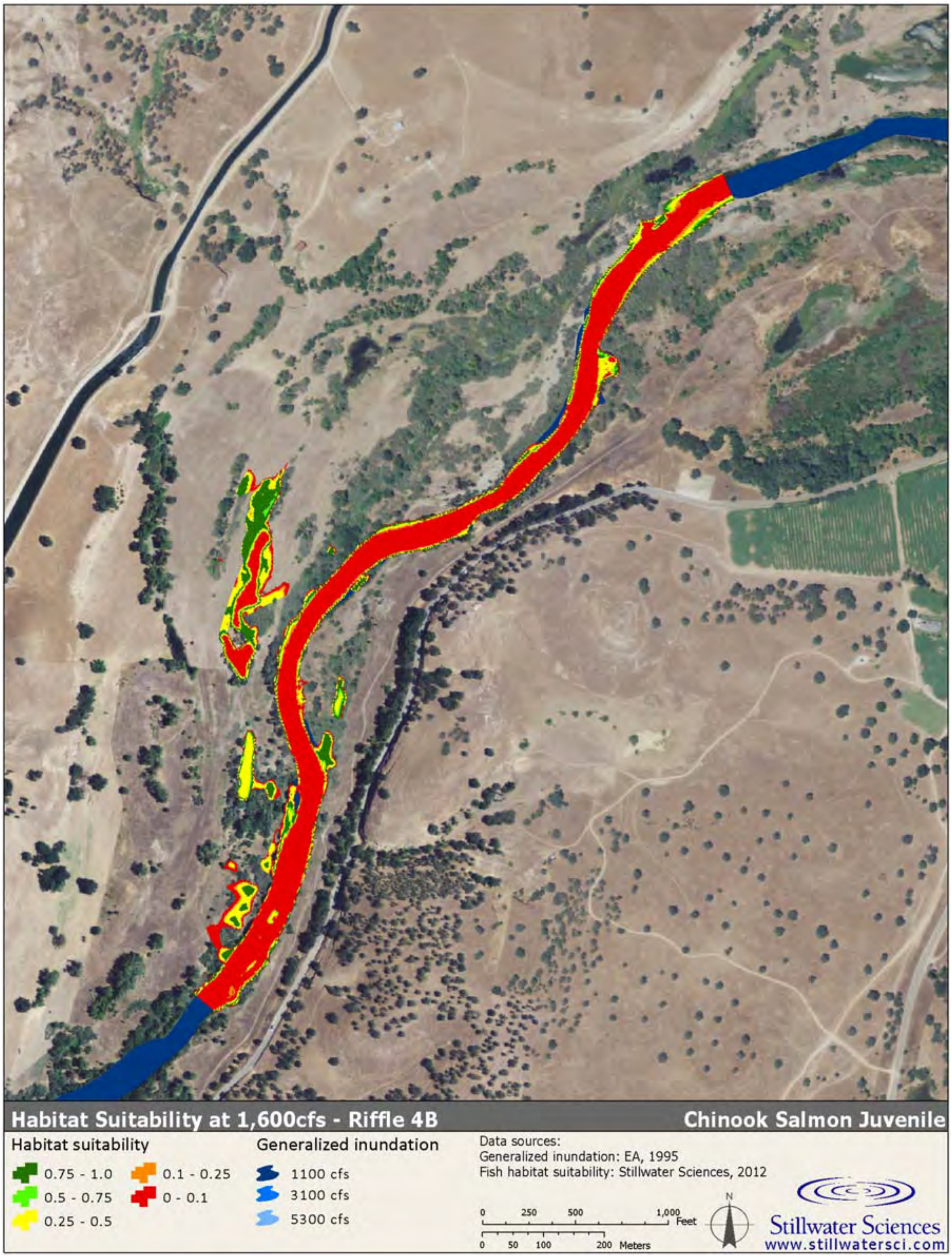


Figure C-12. Riffle 4B results at 1,600 cfs for *O. mykiss* juveniles.

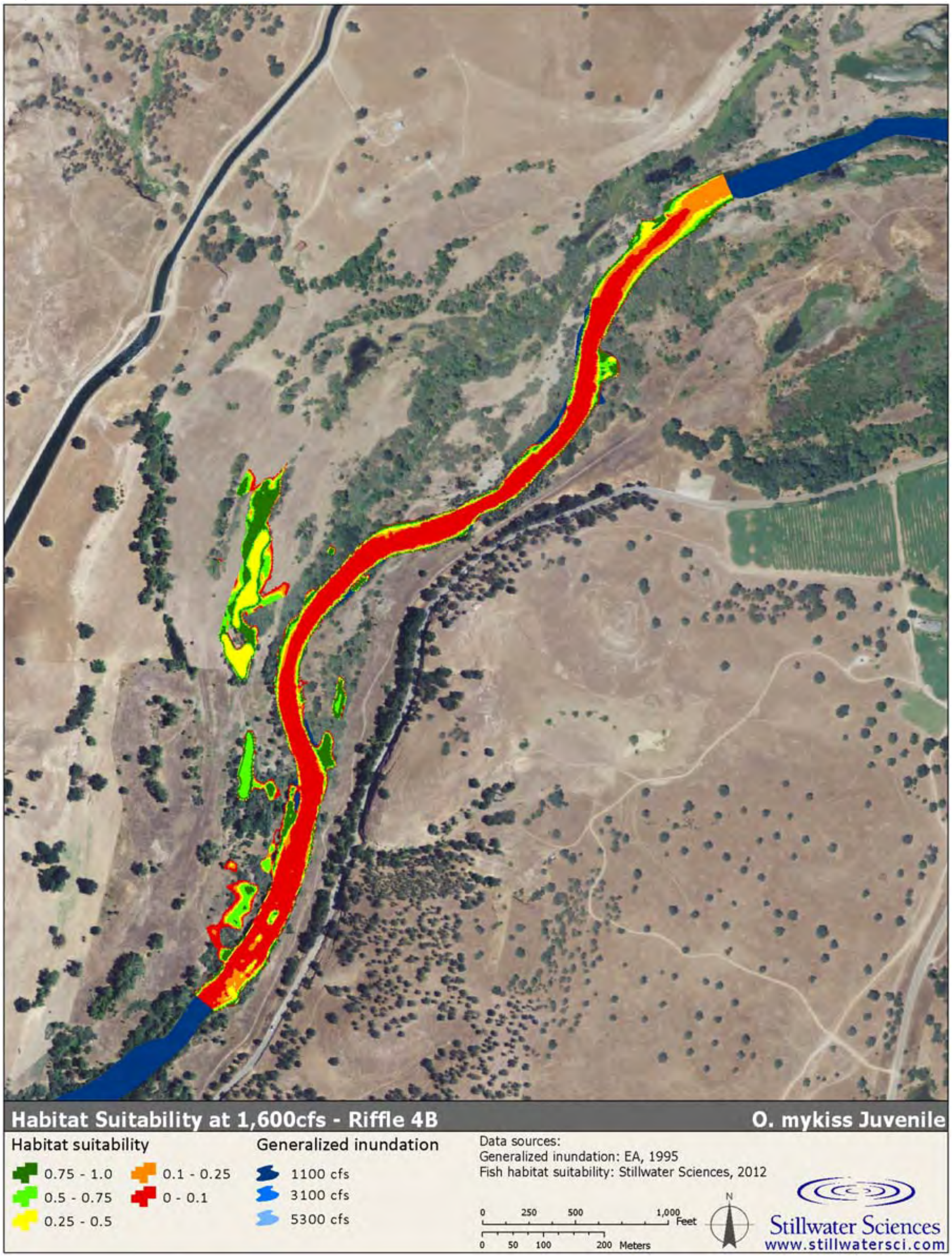


Figure C-13. Riffle 4B results at 1,600 cfs for smallmouth bass adults.

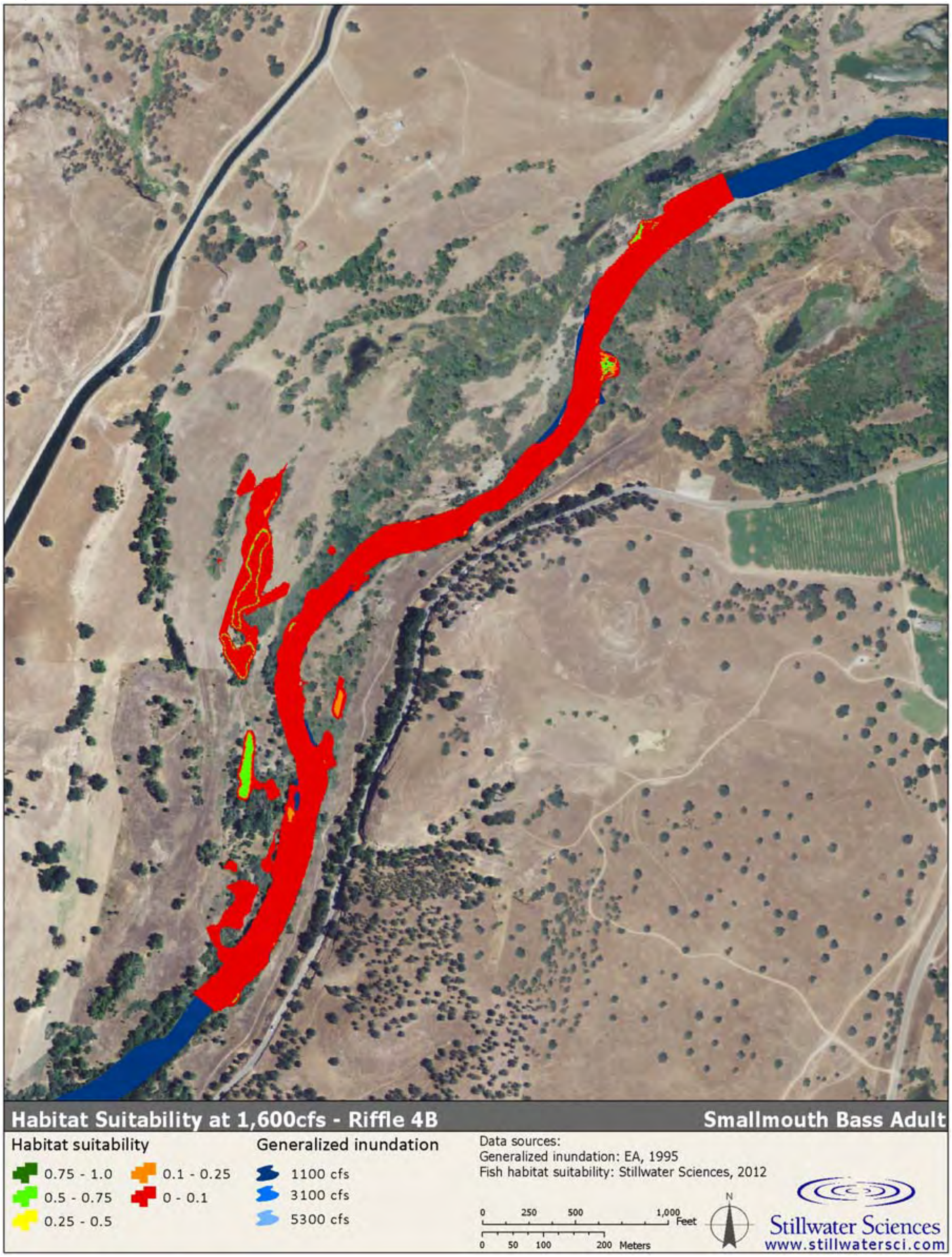


Figure C-14. Riffle 4B results at 1,600 cfs for largemouth bass adults.

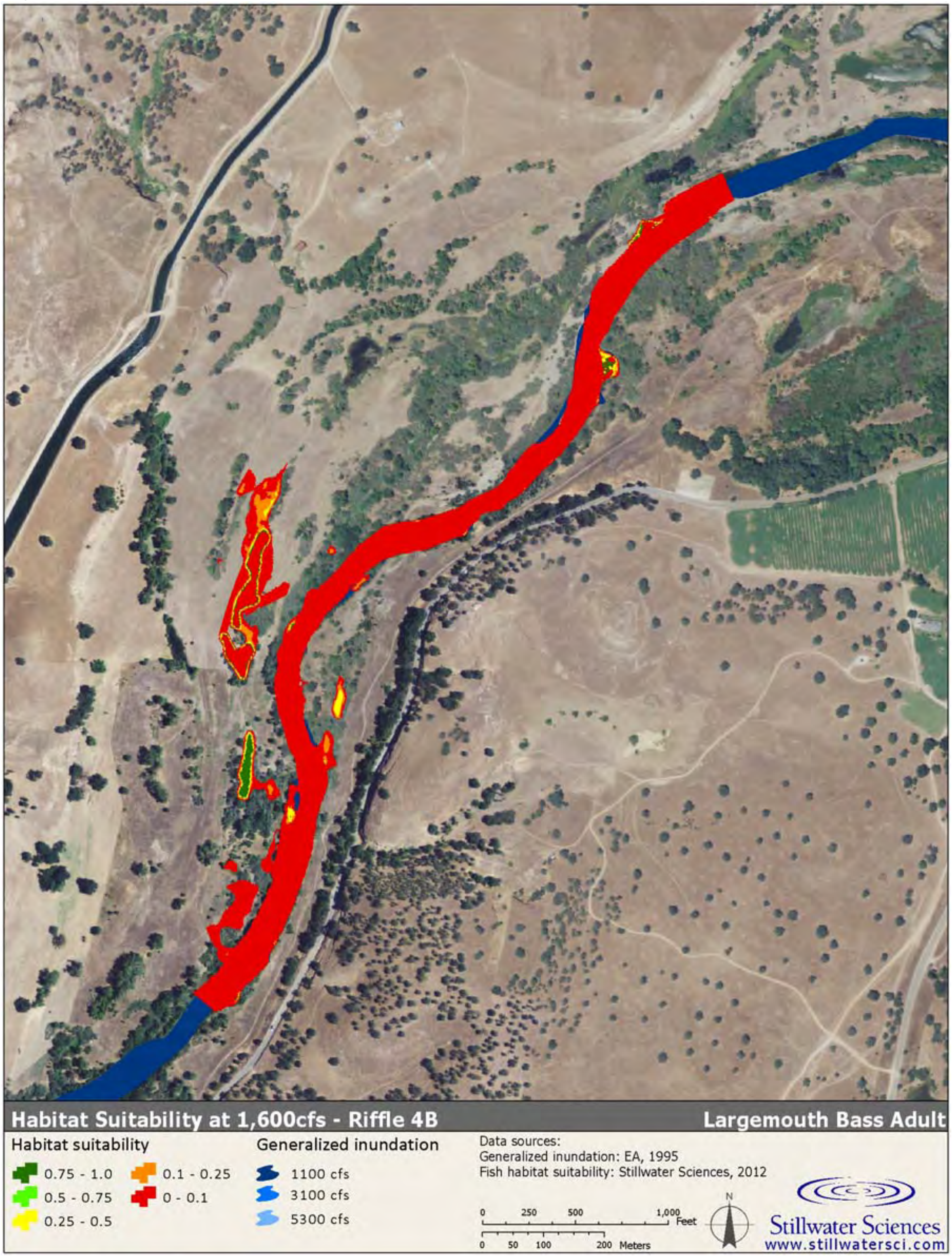


Figure C-15. Riffle 4B results at 1,600 cfs for Sacramento pikeminnow adults.

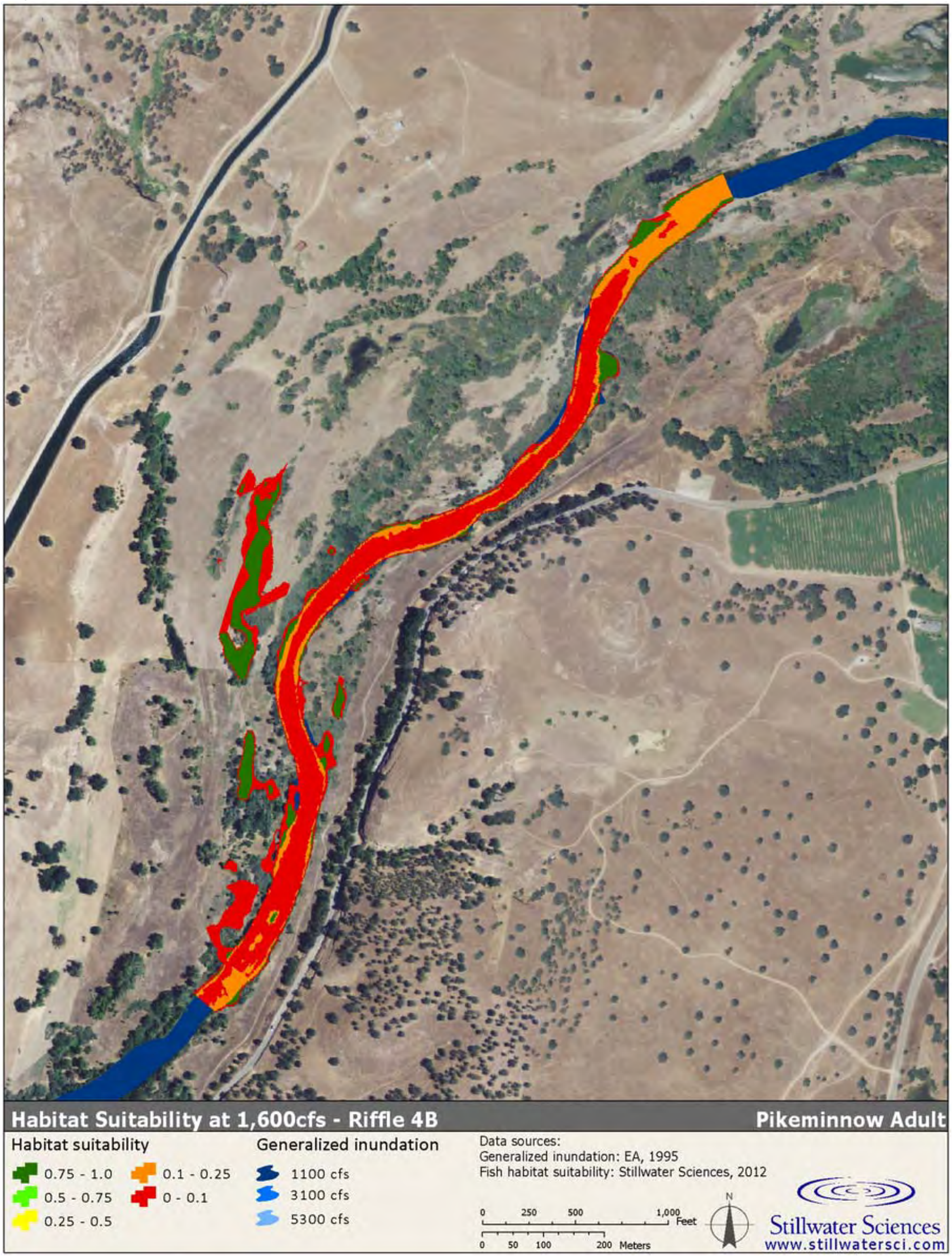


Figure C-16. Riffle 4B results at 1,600 cfs for striped bass adults.

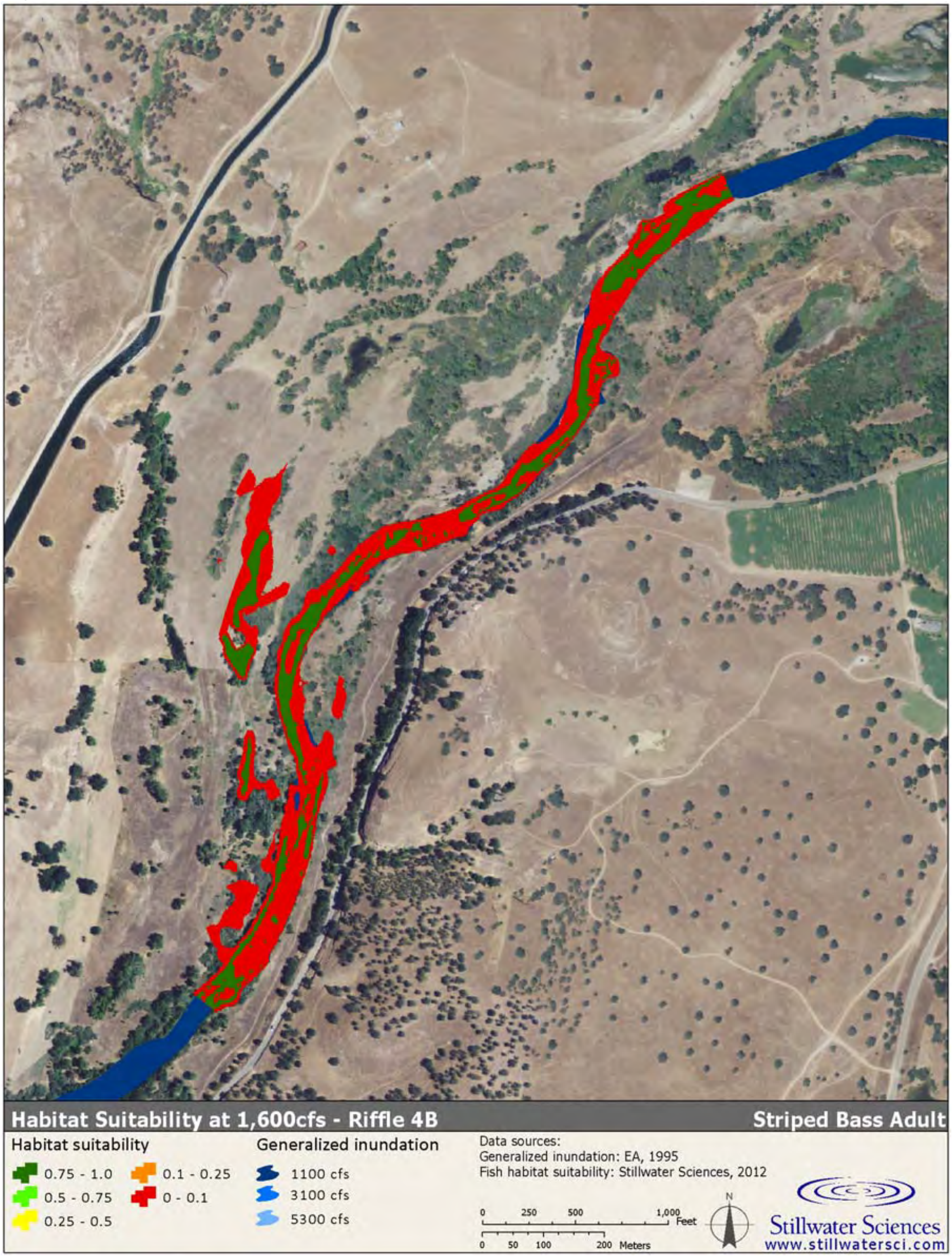


Figure C-17. Riffle 4B results at 2,600 cfs for Chinook salmon fry.

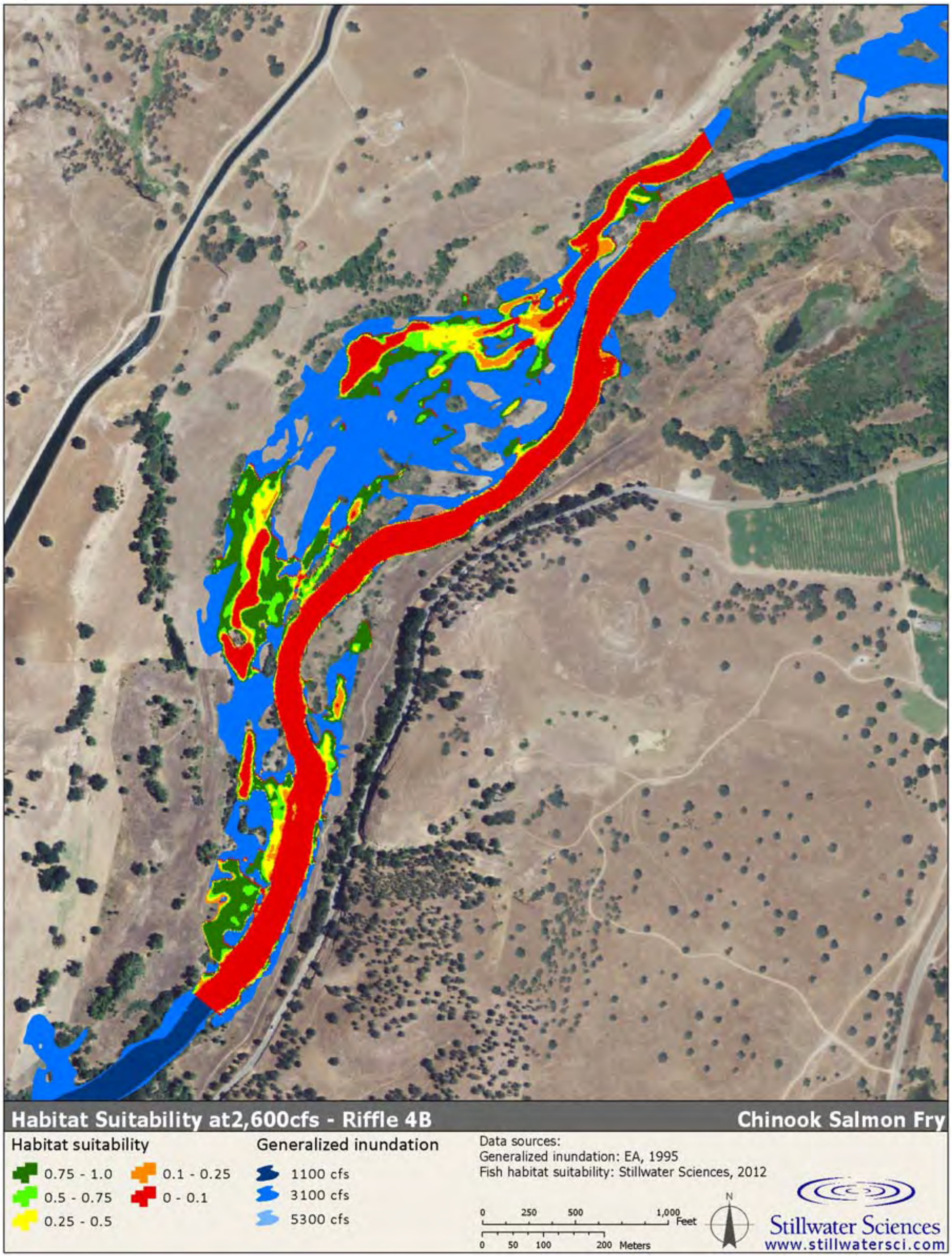


Figure C-18. Riffle 4B results at 2,600 cfs for *O. mykiss* fry.

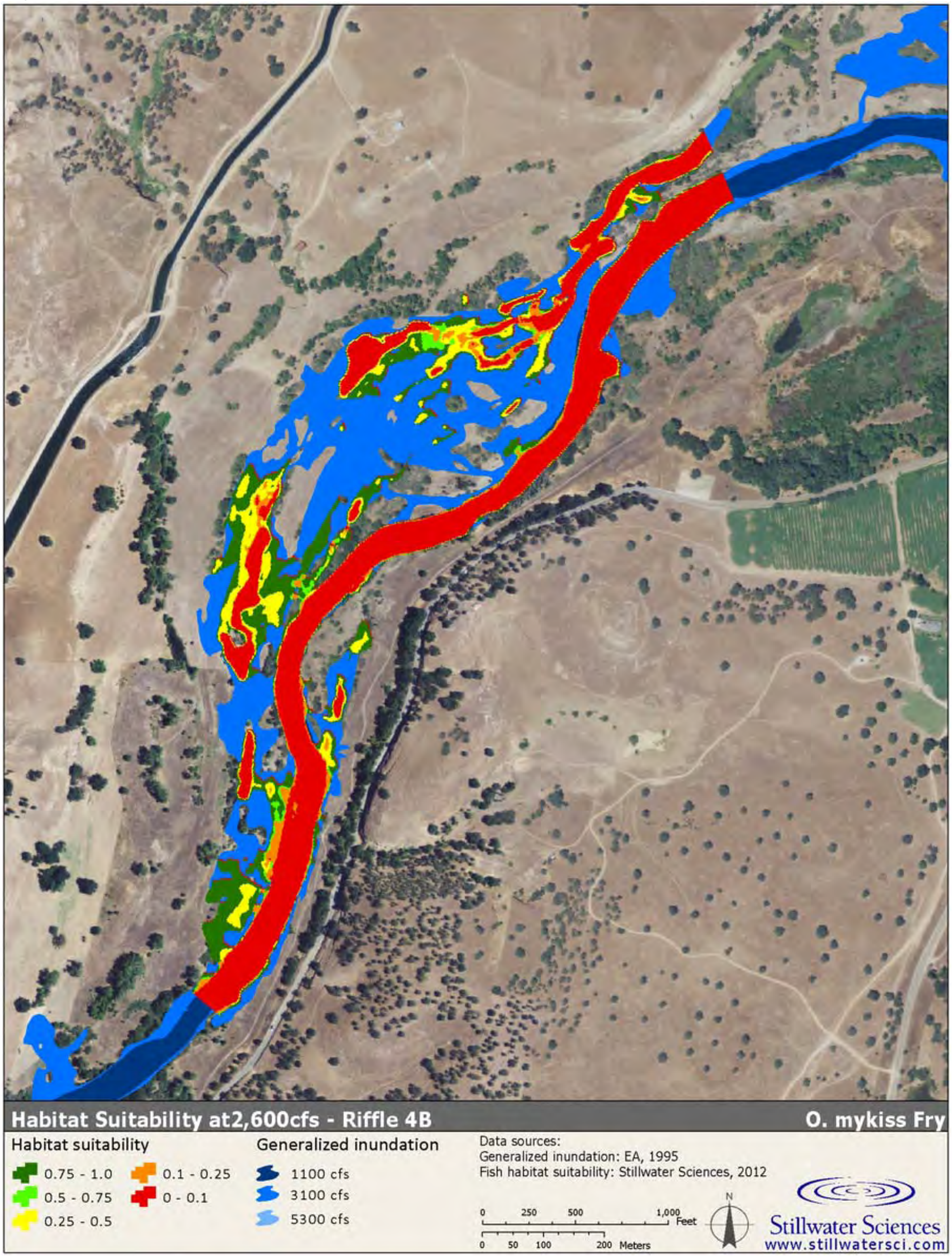


Figure C-19. Riffle 4B results at 2,600 cfs for Chinook salmon juveniles.

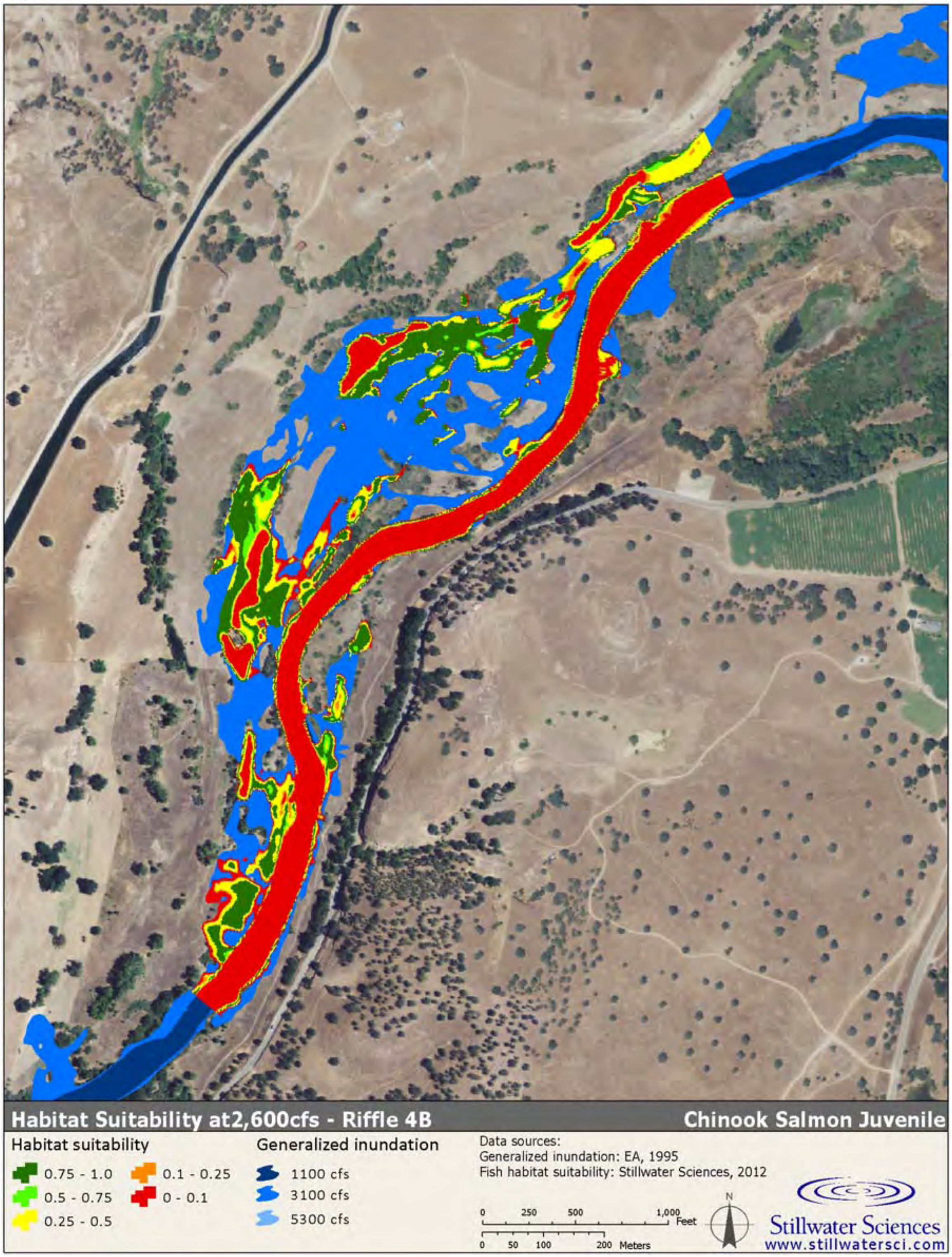


Figure C-20. Riffle 4B results at 2,600 cfs for *O. mykiss* juveniles.

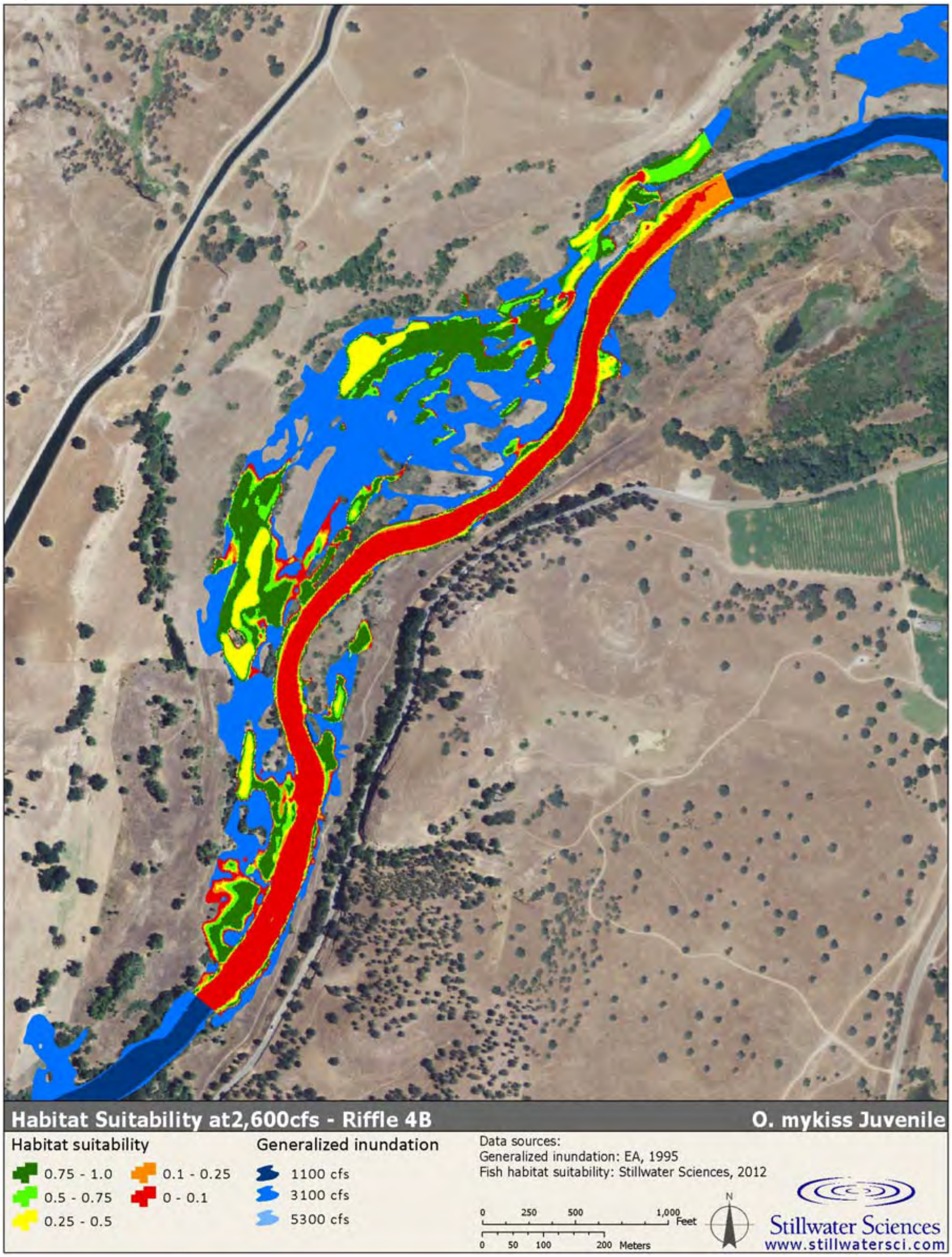


Figure C-21. Riffle 4B results at 2,600 cfs for smallmouth bass adults.

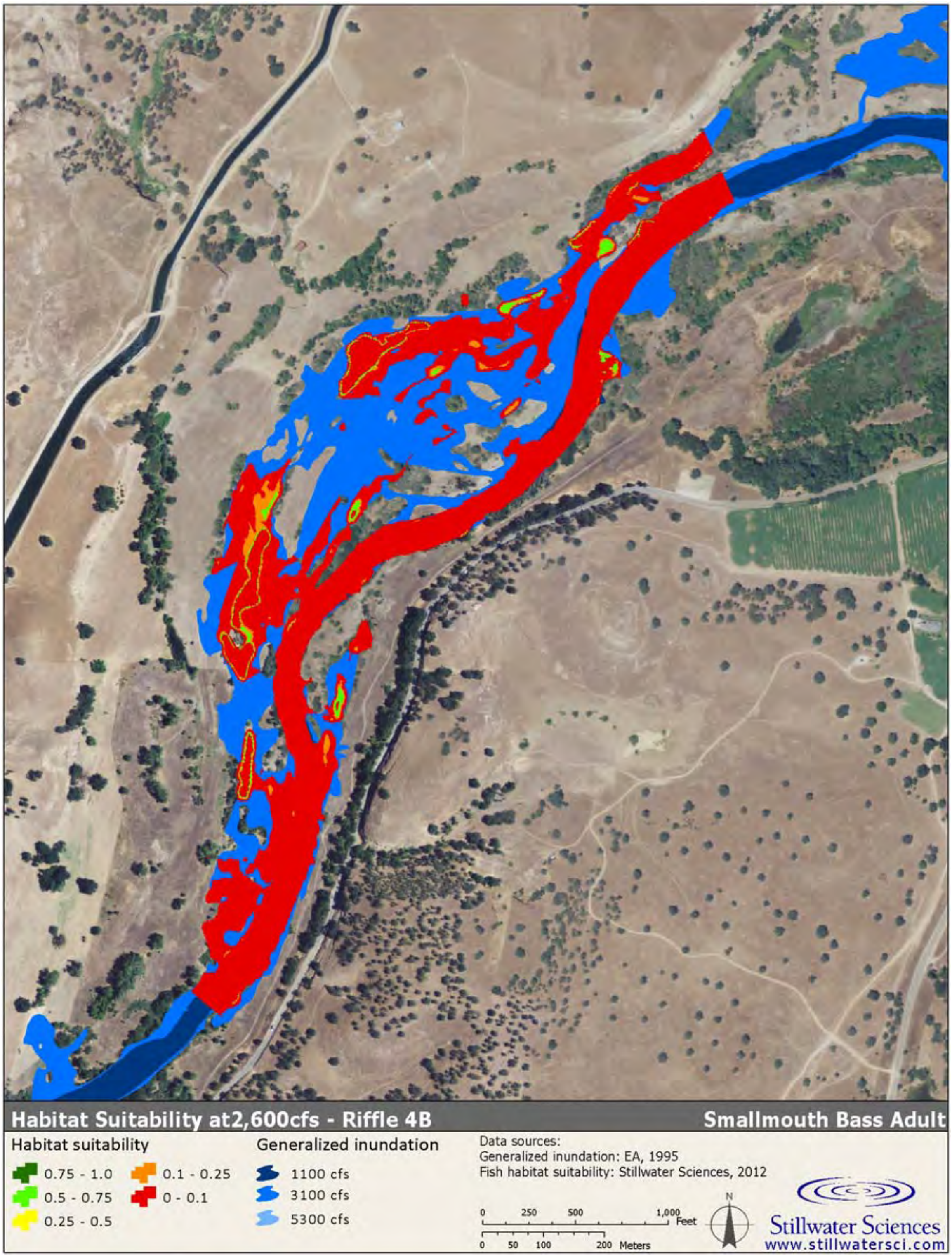


Figure C-22. Riffle 4B results at 2,600 cfs for largemouth bass adults.

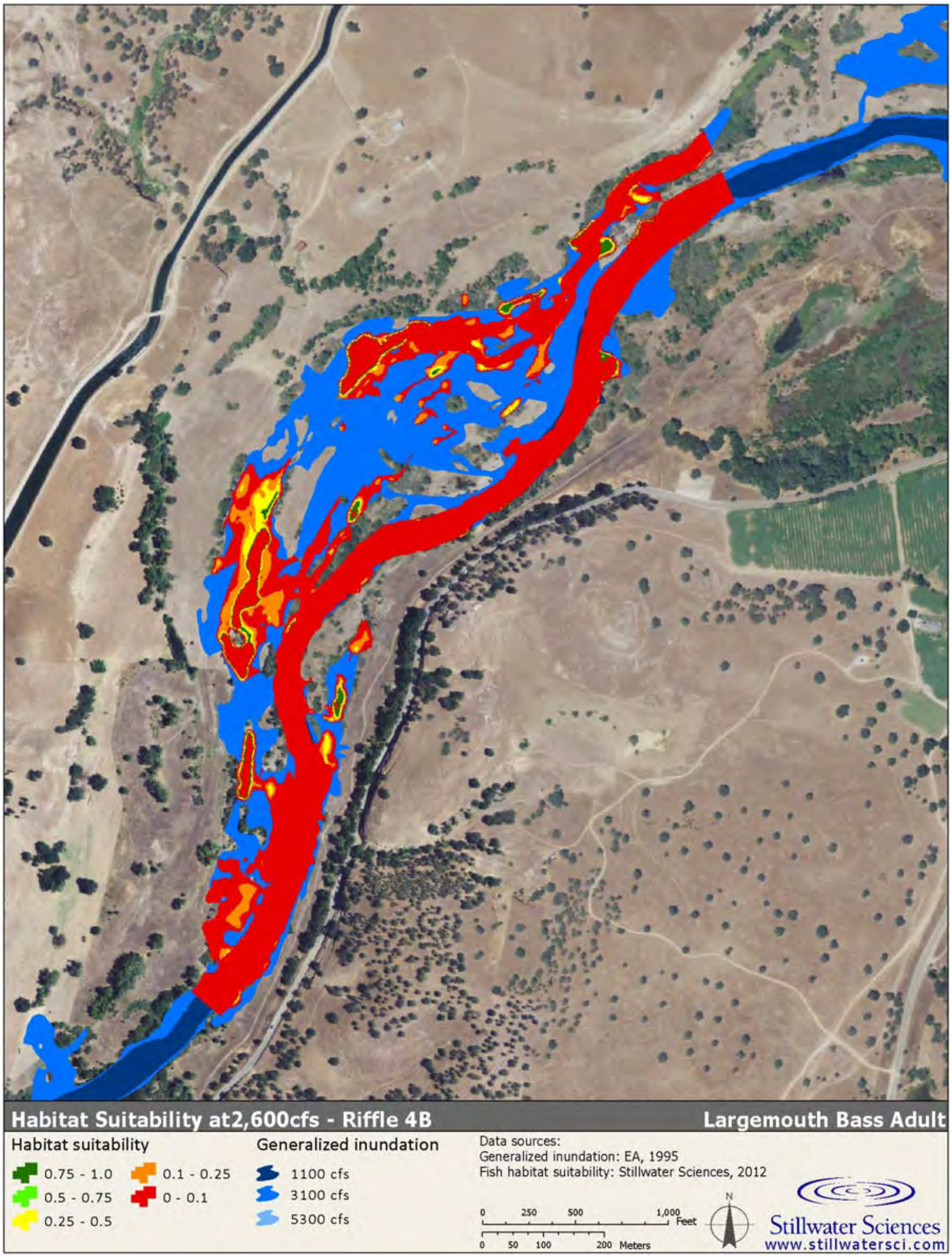


Figure C-23. Riffle 4B results at 2,600 cfs for Sacramento pikeminnow adults.

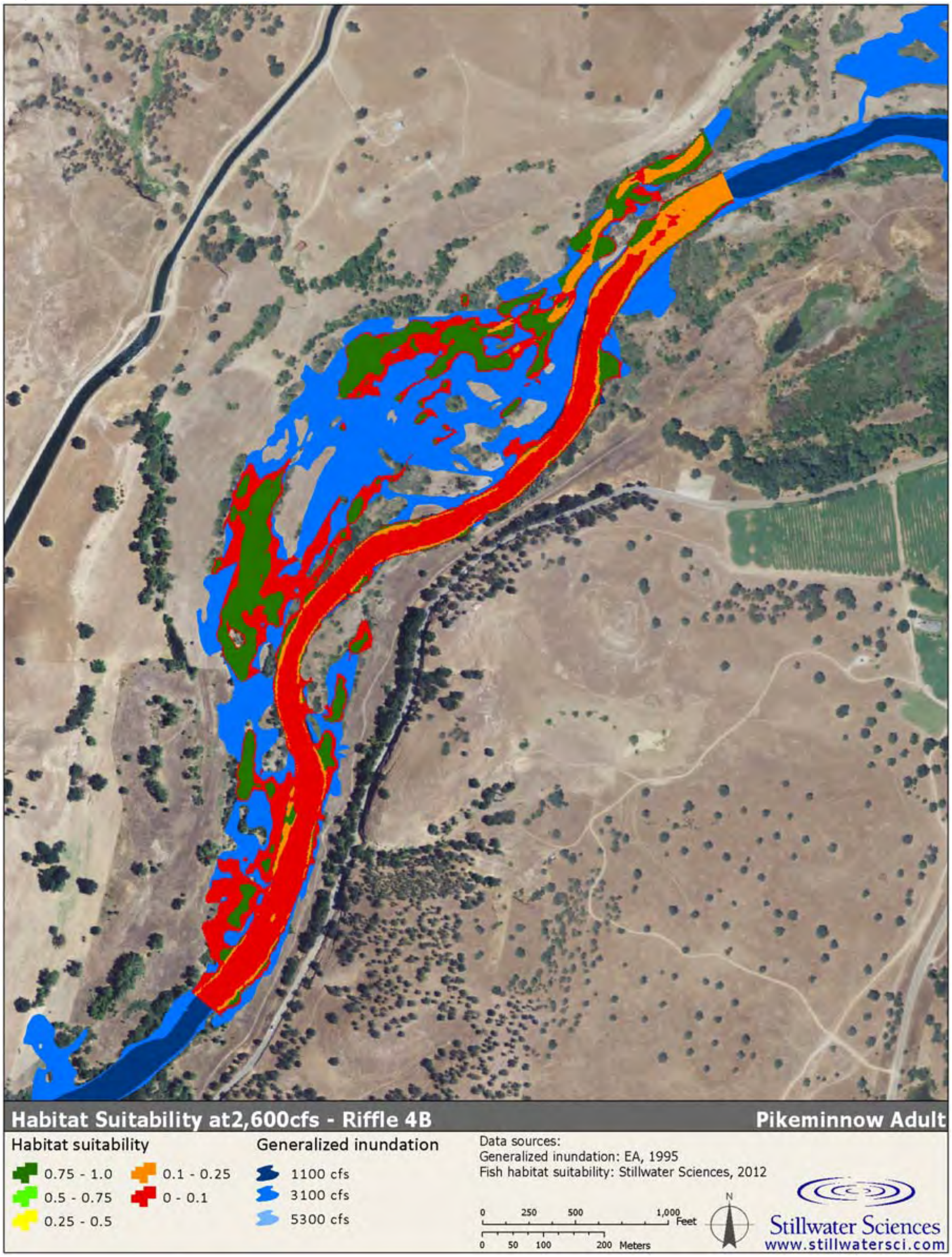


Figure C-24. Riffle 4B results at 2,600 cfs for striped bass adults.

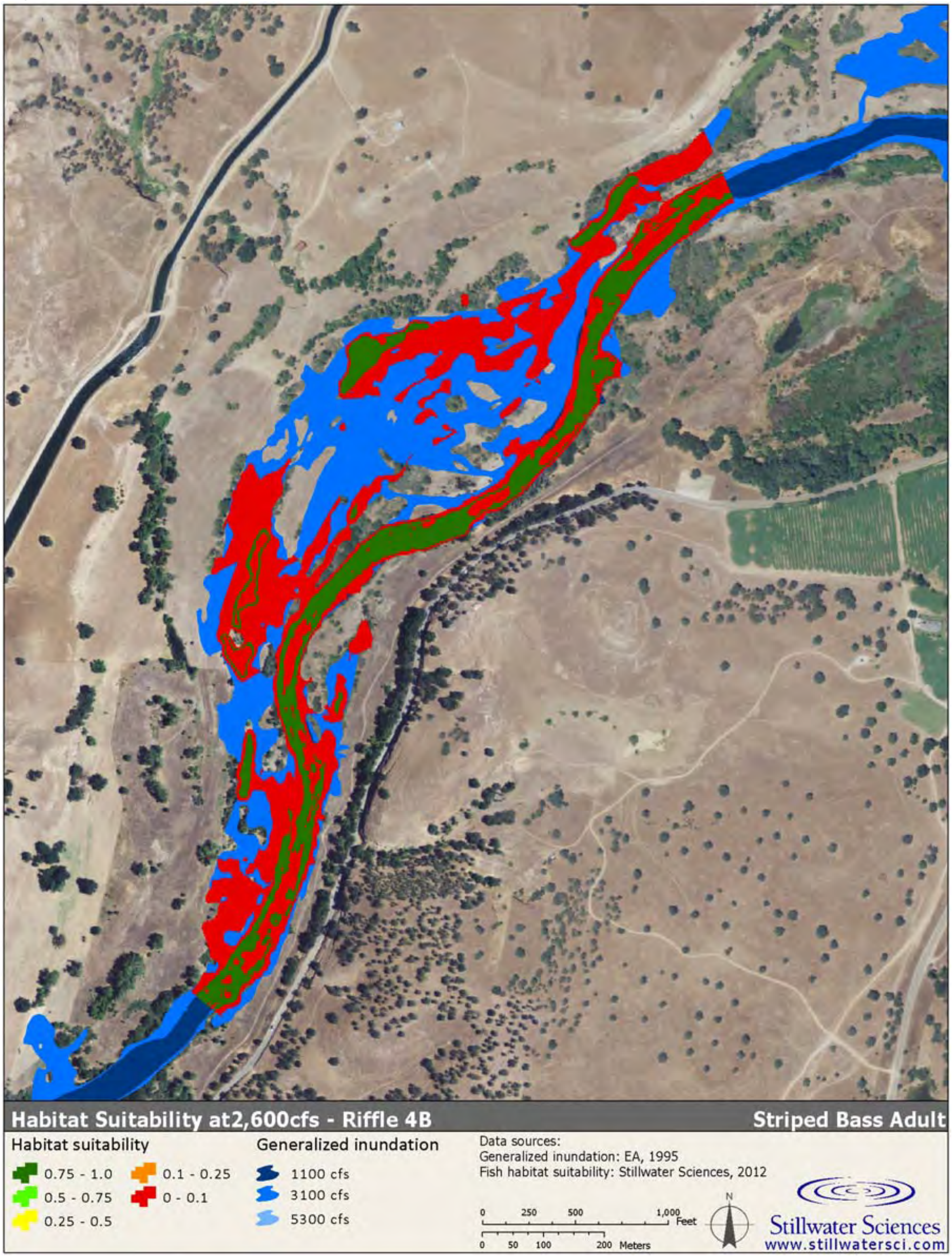


Figure C-25. Riffle 4B results at 3,000 cfs for Chinook salmon fry.

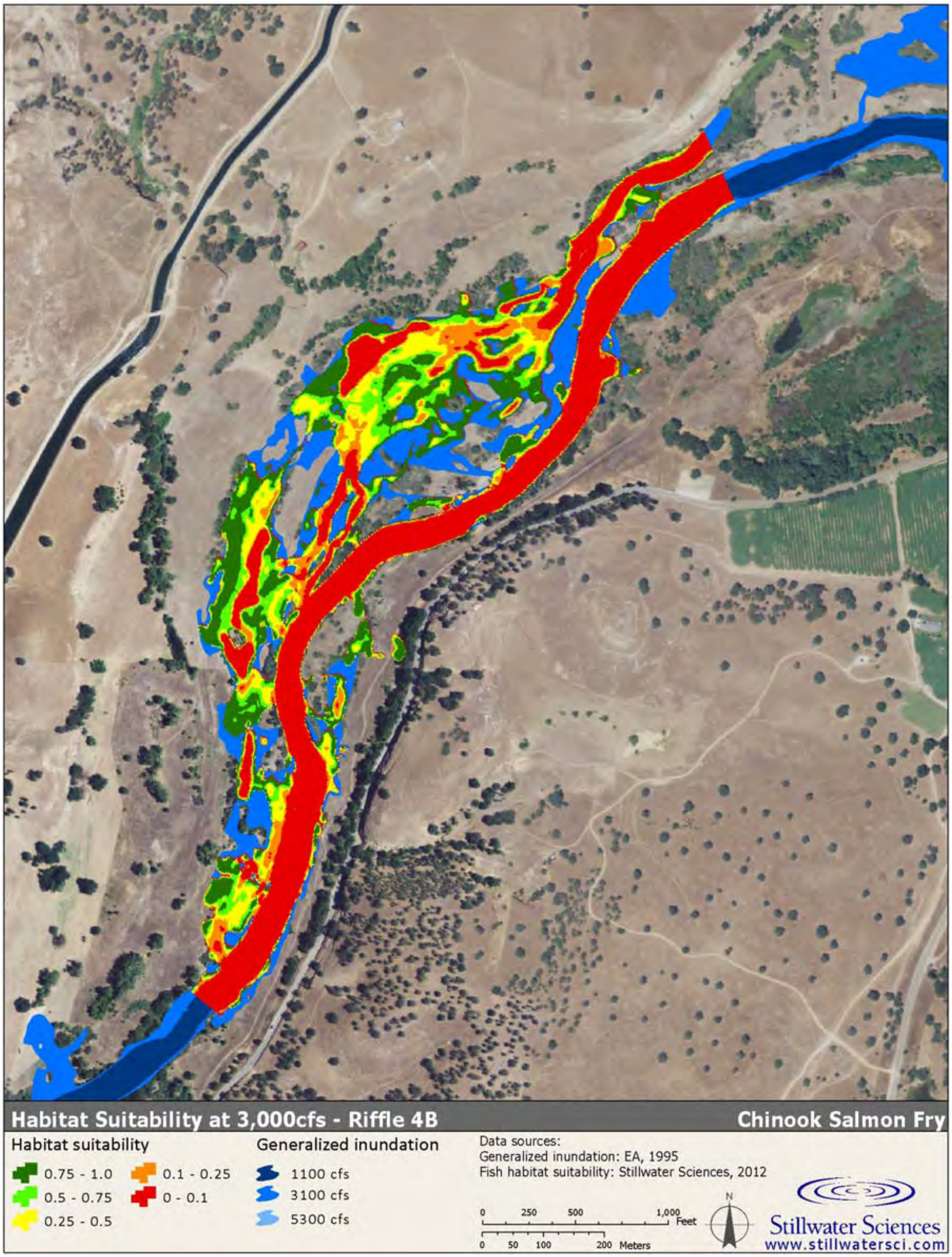


Figure C-26. Riffle 4B results at 3,000 cfs for *O. mykiss* fry.

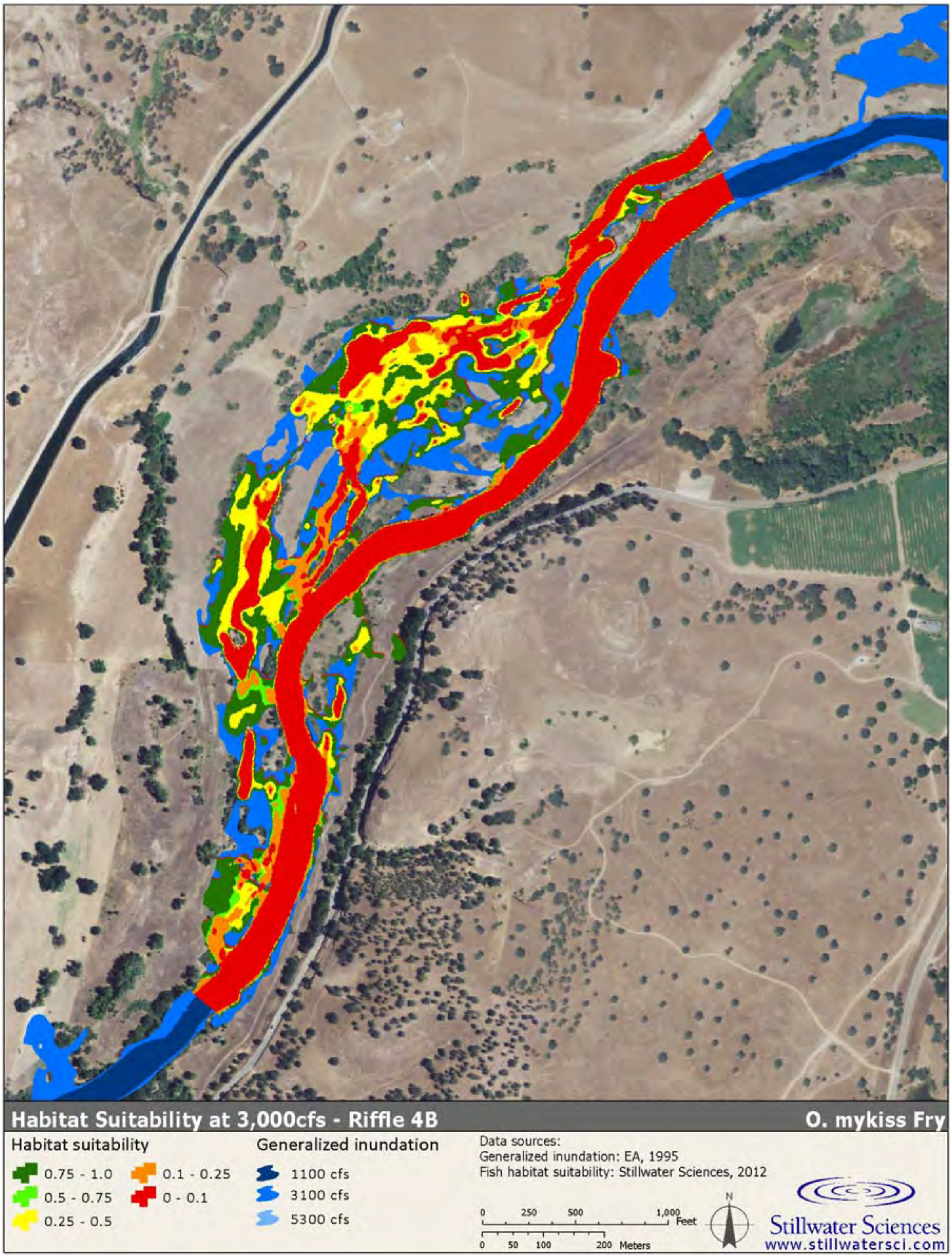


Figure C-27. Riffle 4B results at 3,000 cfs for Chinook salmon juveniles.

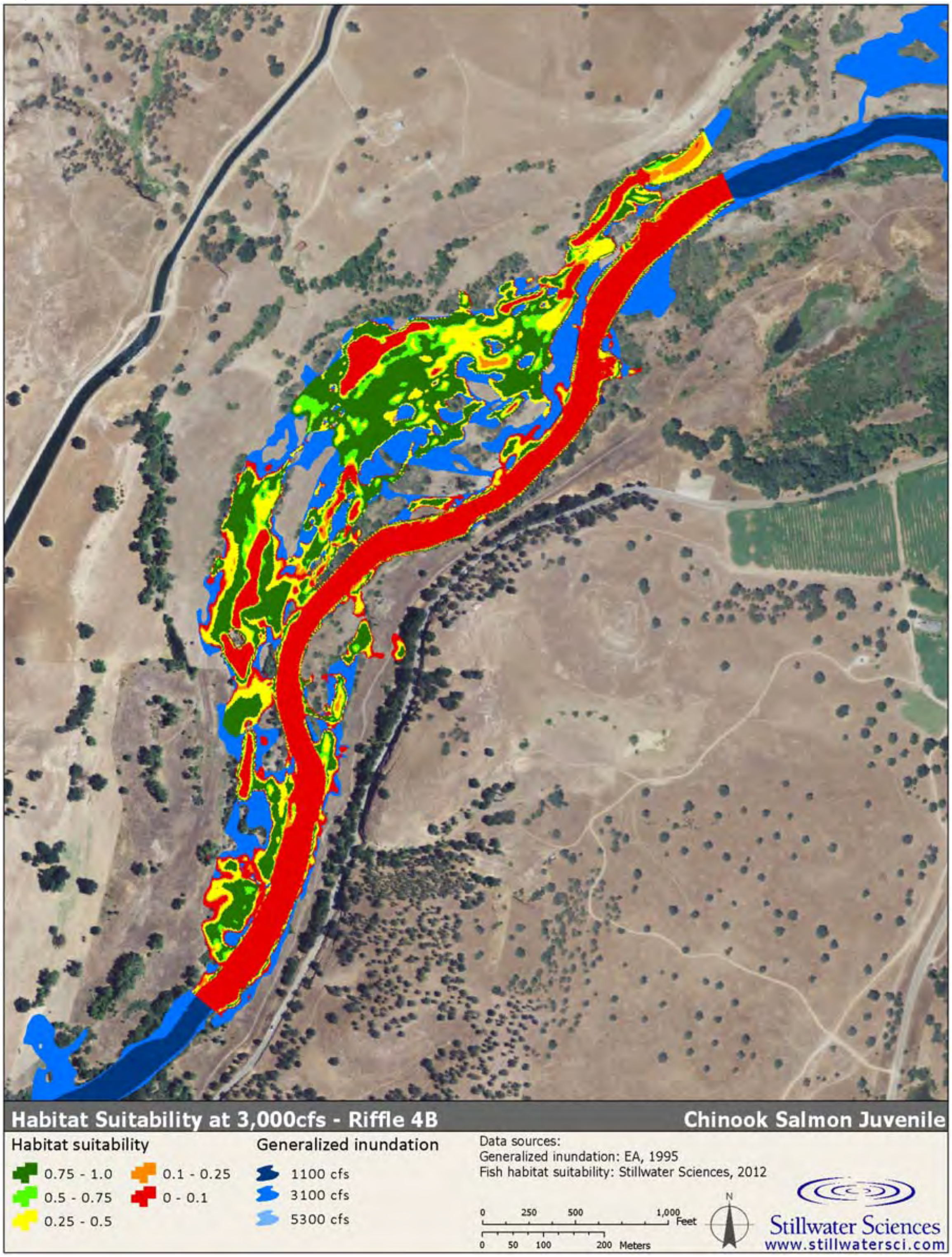


Figure C-28. Riffle 4B results at 3,000 cfs for *O. mykiss* juveniles.

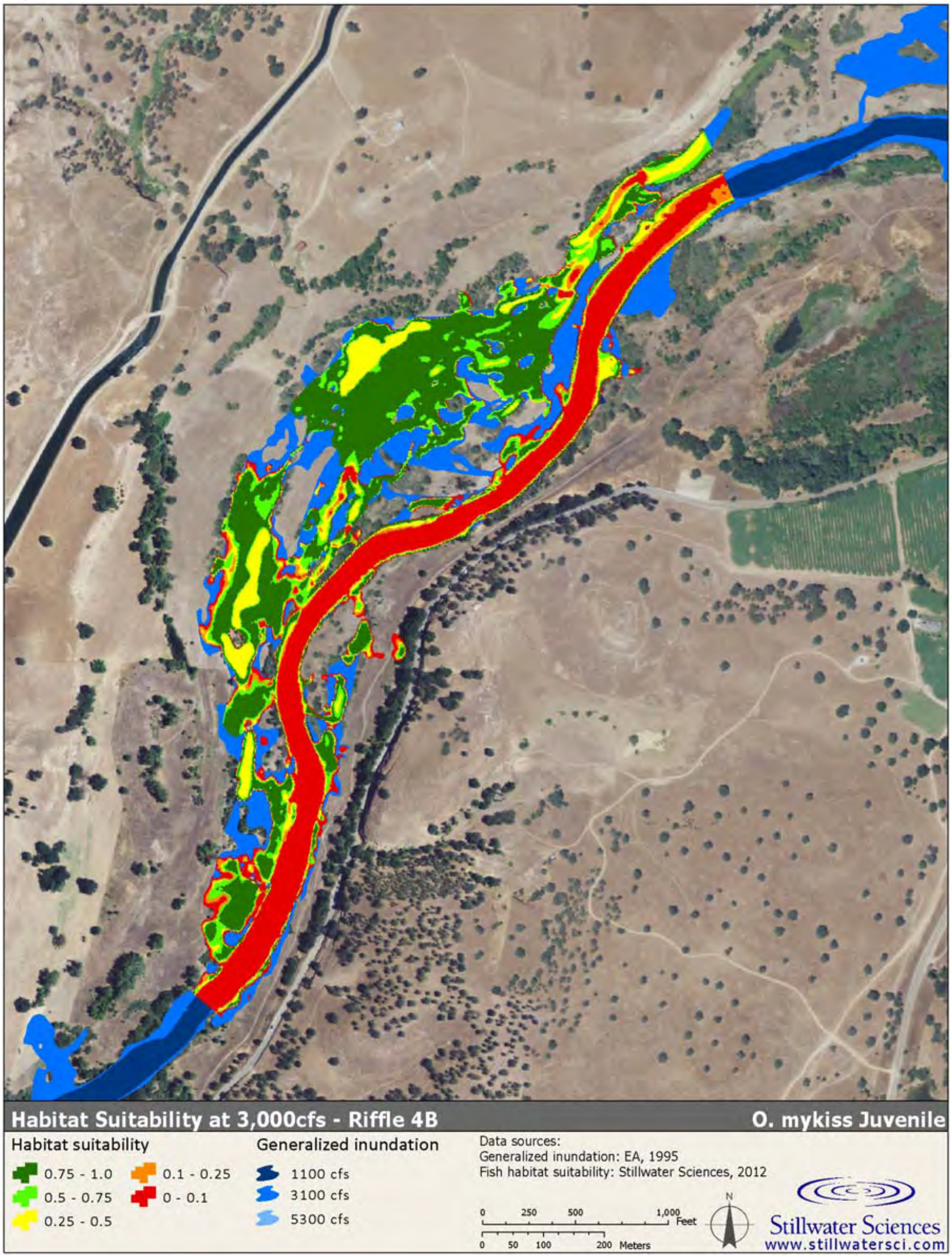


Figure C-29. Riffle 4B results at 3,000 cfs for smallmouth bass adults.

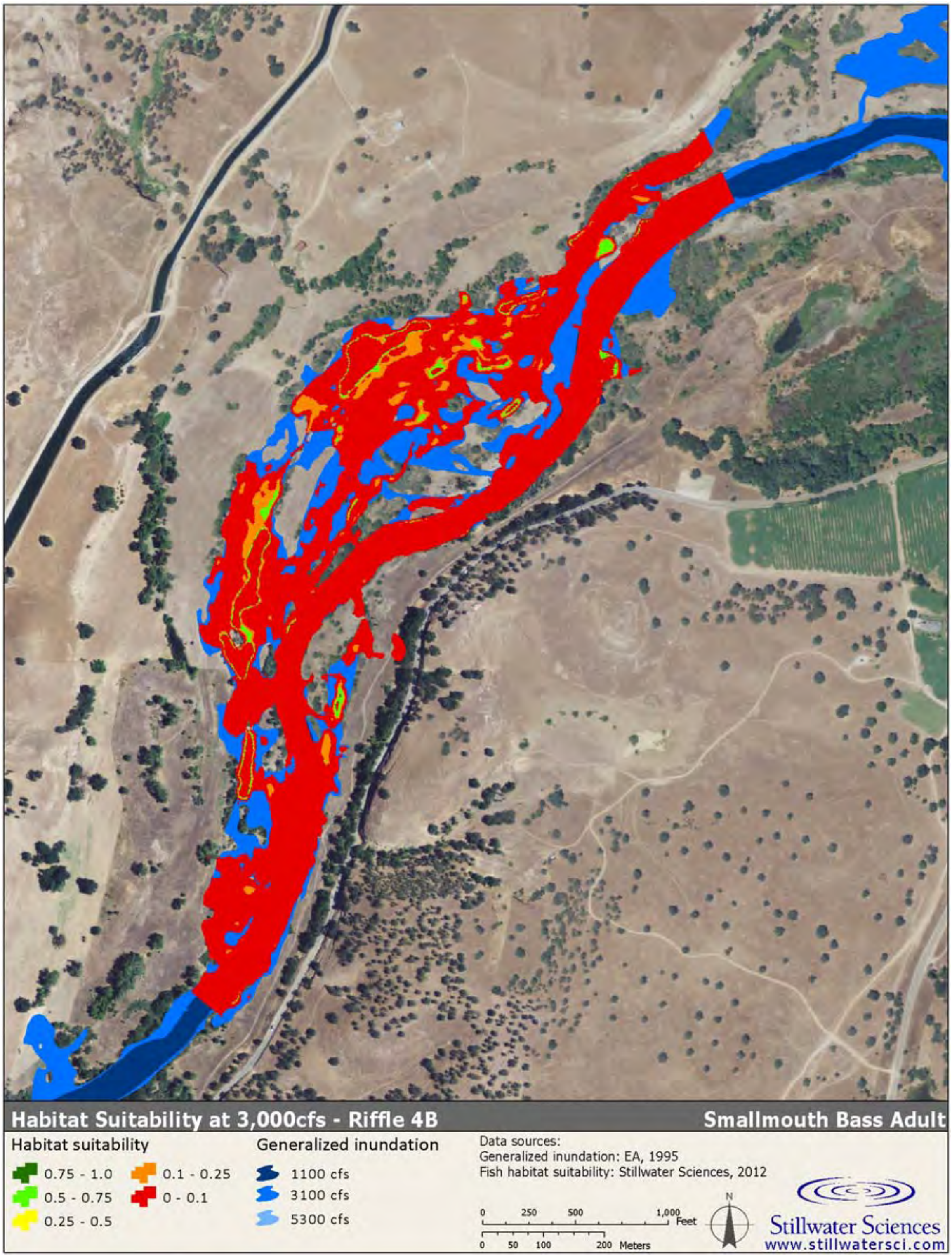


Figure C-30. Riffle 4B results at 3,000 cfs for largemouth bass adults.

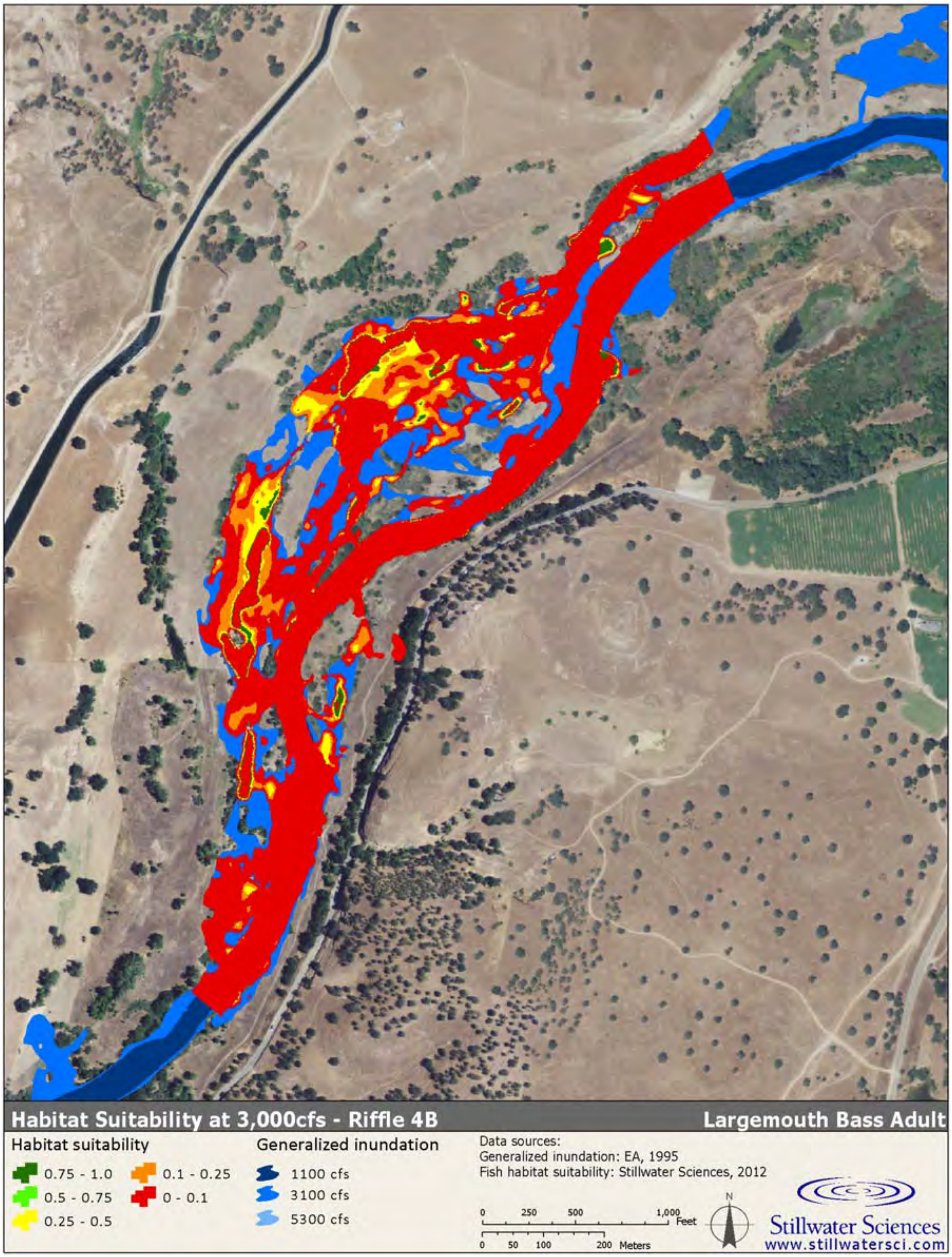


Figure C-31. Riffle 4B results at 3,000 cfs for Sacramento pikeminnow adults.

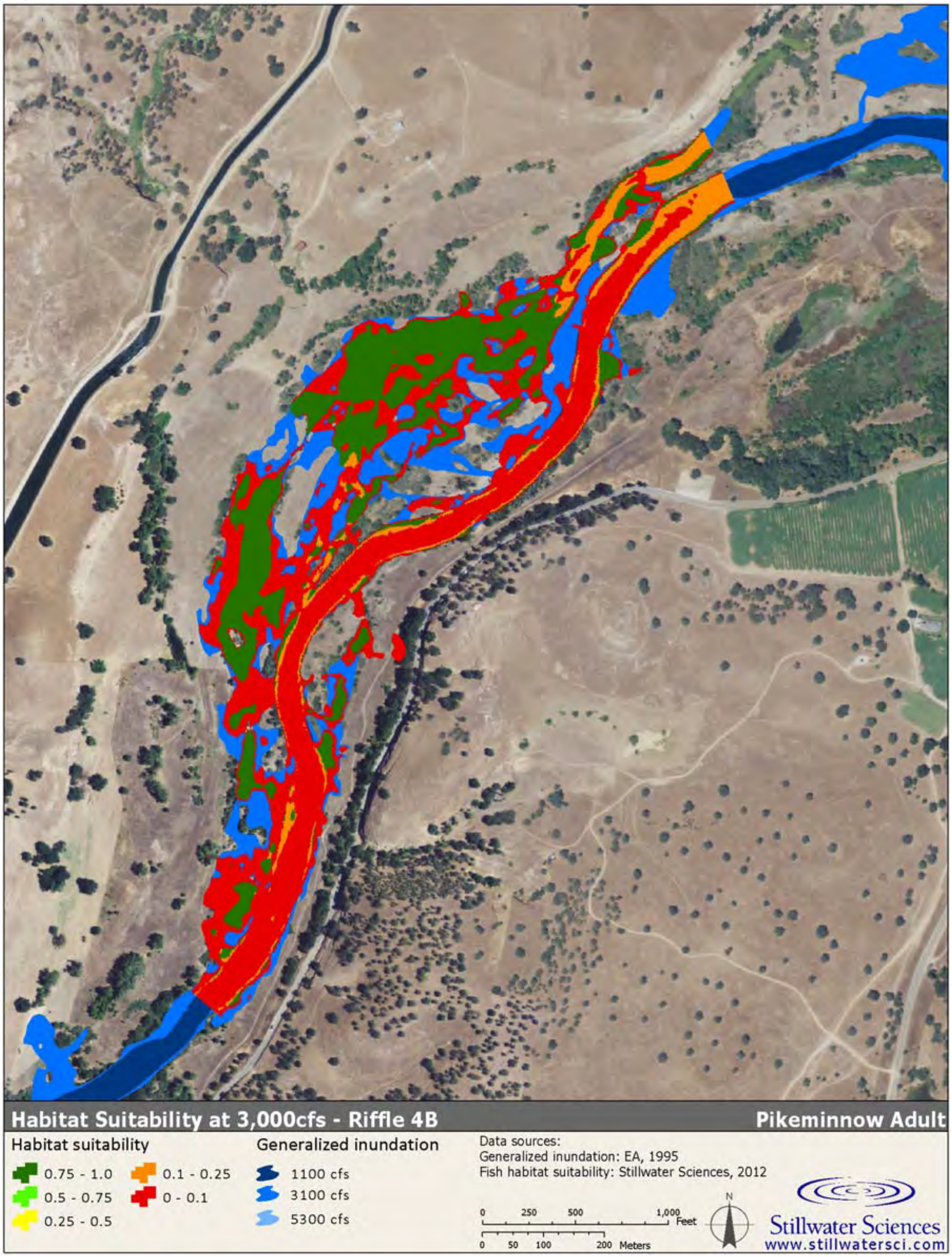


Figure C-32. Riffle 4B results at 3,000 cfs for striped bass adults.

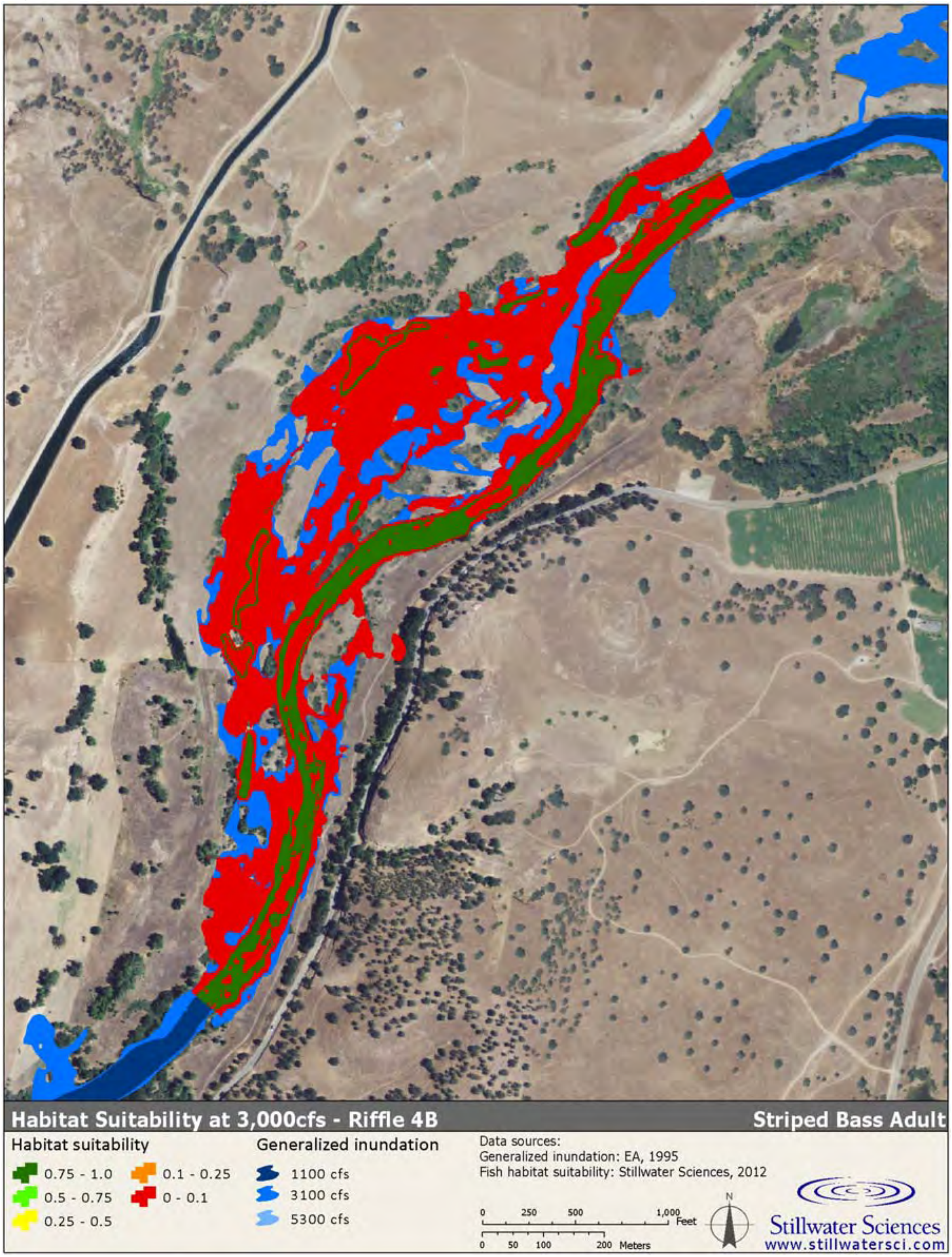


Figure C-33. Riffle 4B results at 5,000 cfs for Chinook salmon fry.

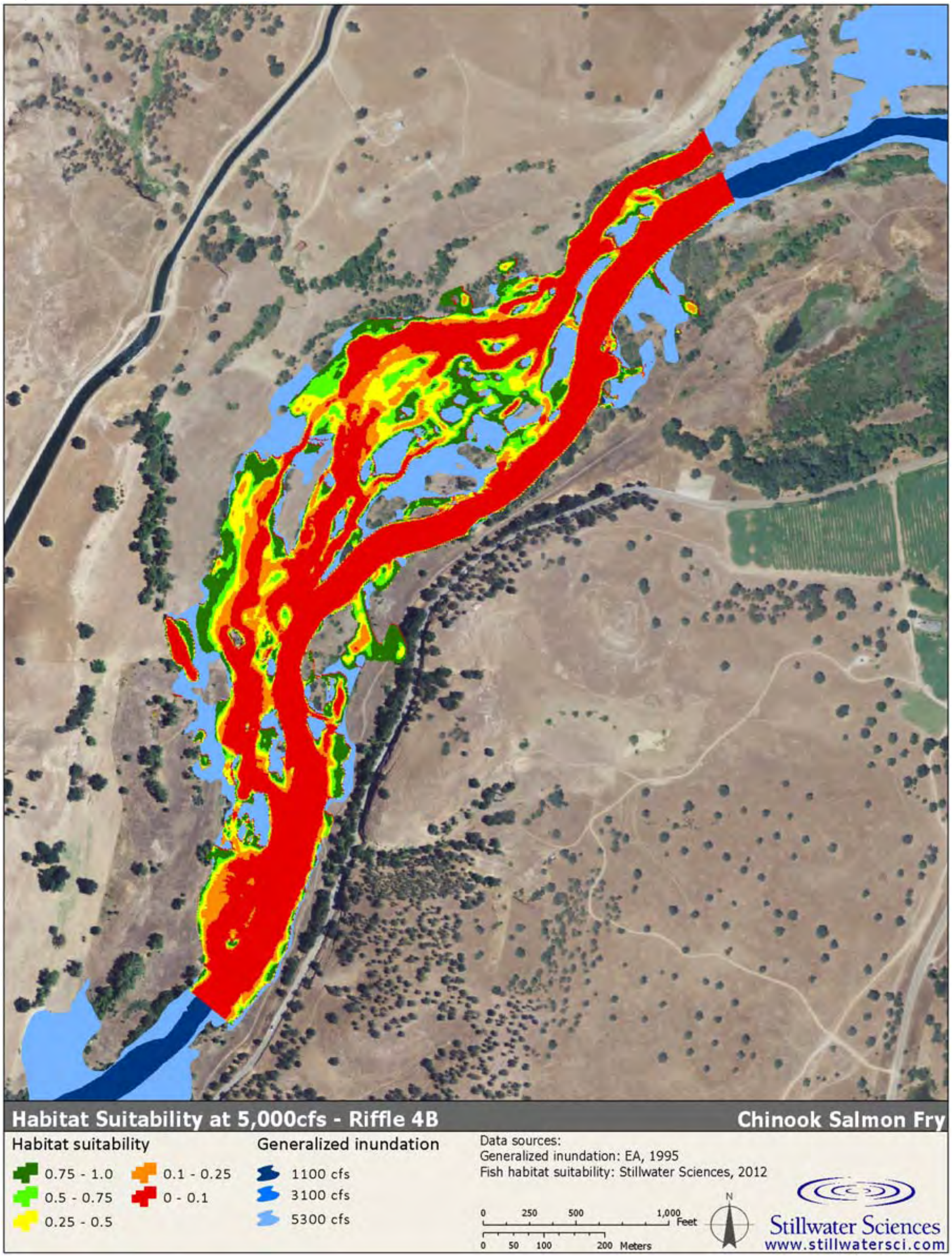


Figure C-34. Riffle 4B results at 5,000 cfs for *O. mykiss* fry.

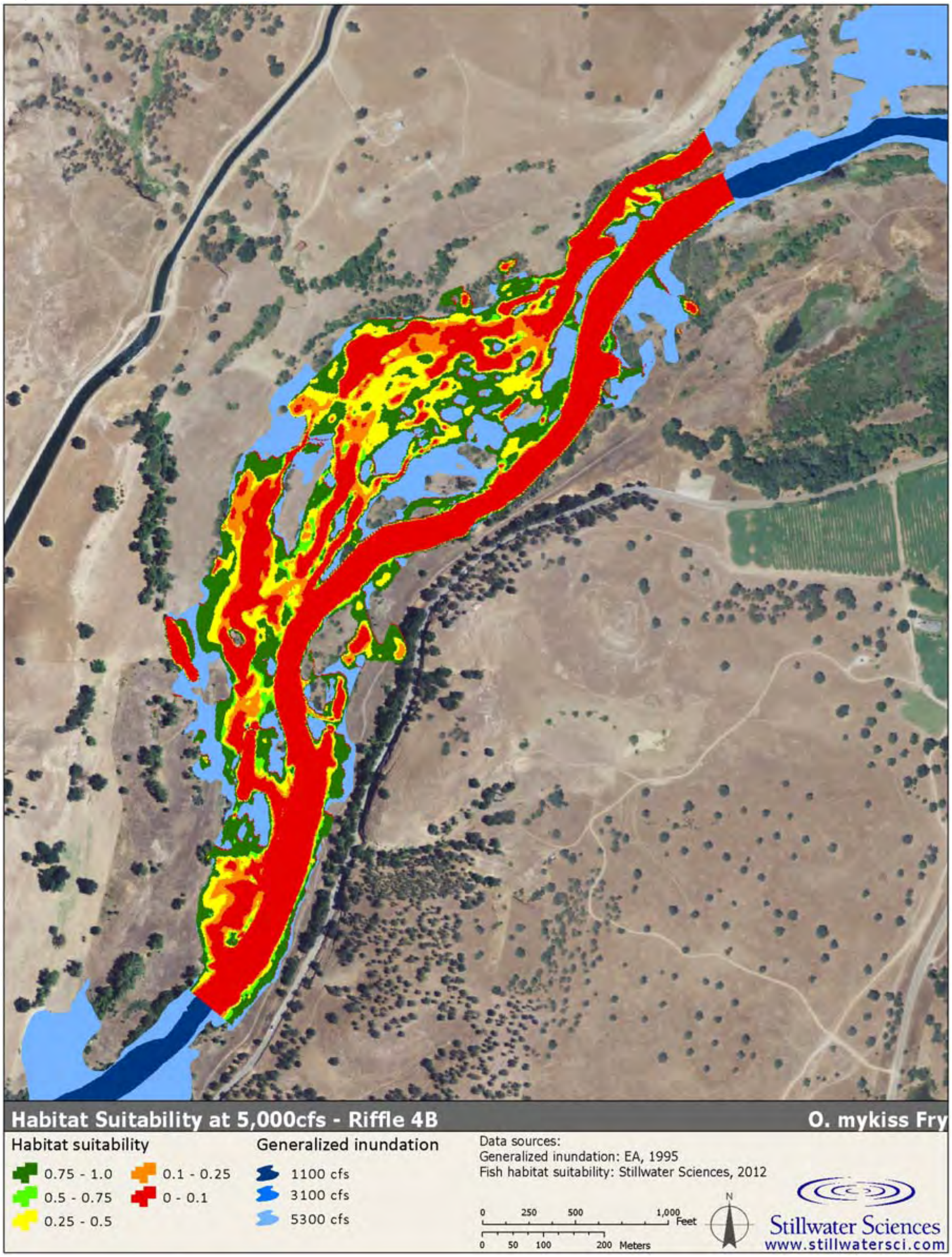


Figure C-35. Riffle 4B results at 5,000 cfs for Chinook salmon juveniles.

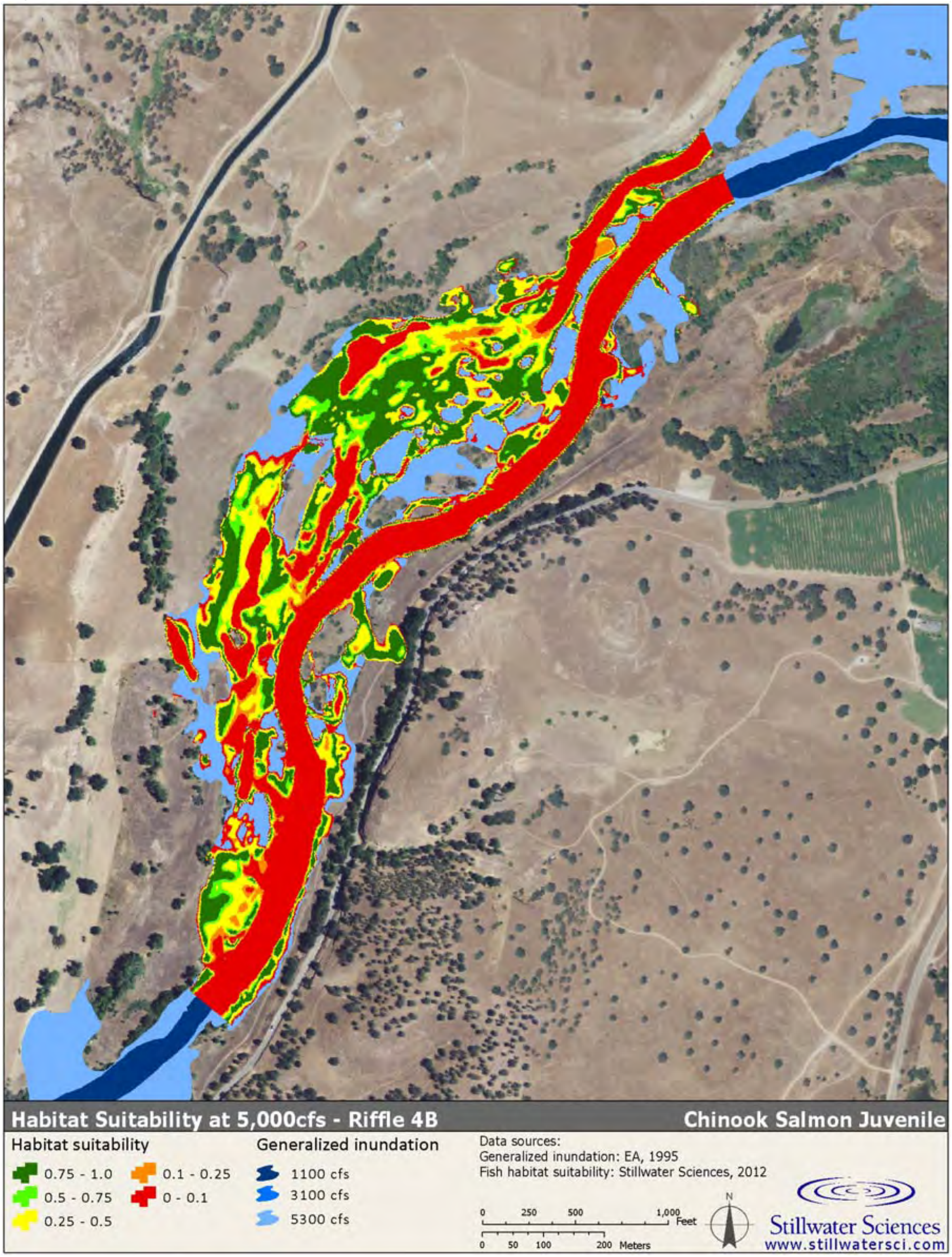


Figure C-36. Riffle 4B results at 5,000 cfs for *O. mykiss* juveniles.

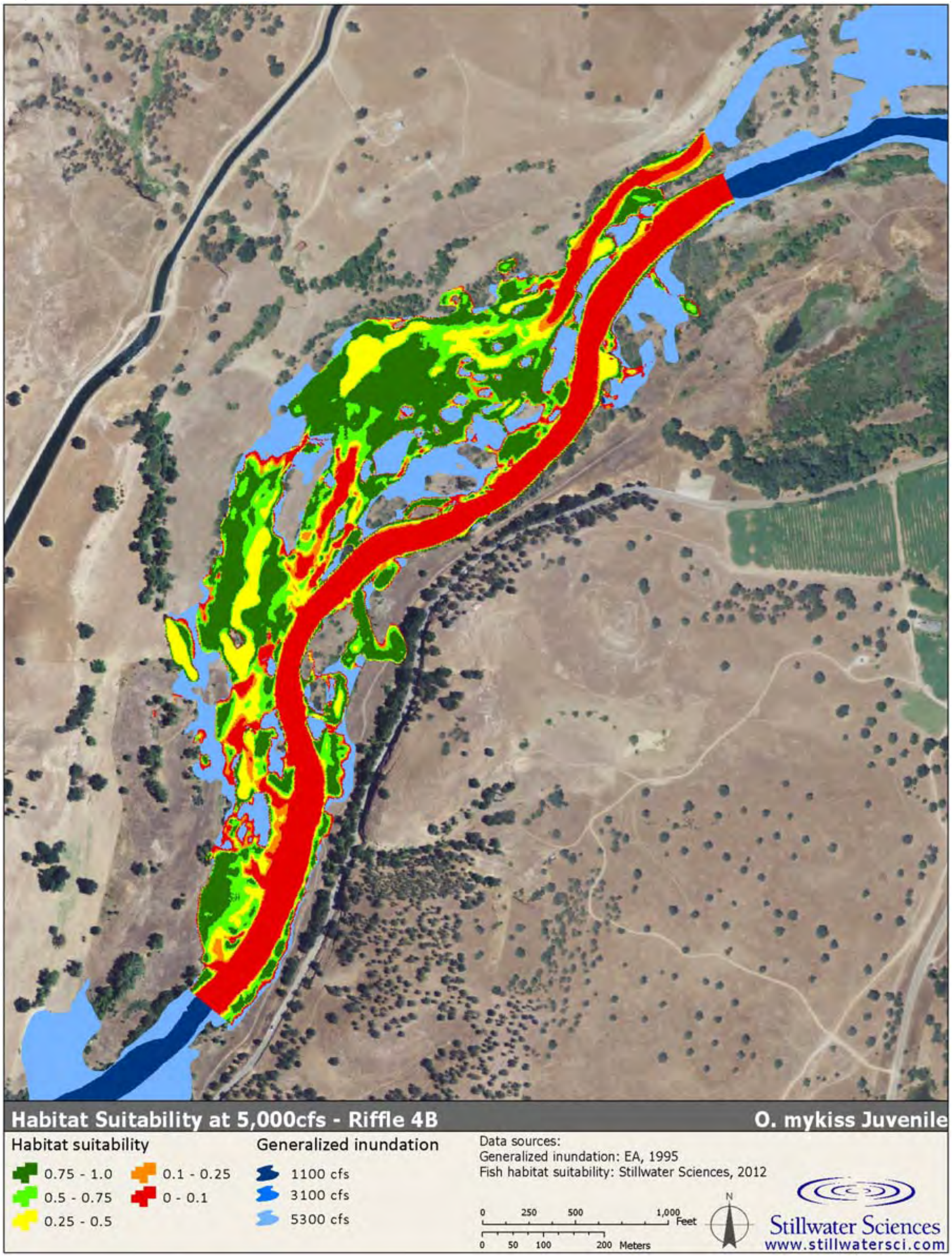


Figure C-37. Riffle 4B results at 5,000 cfs for smallmouth bass adults.

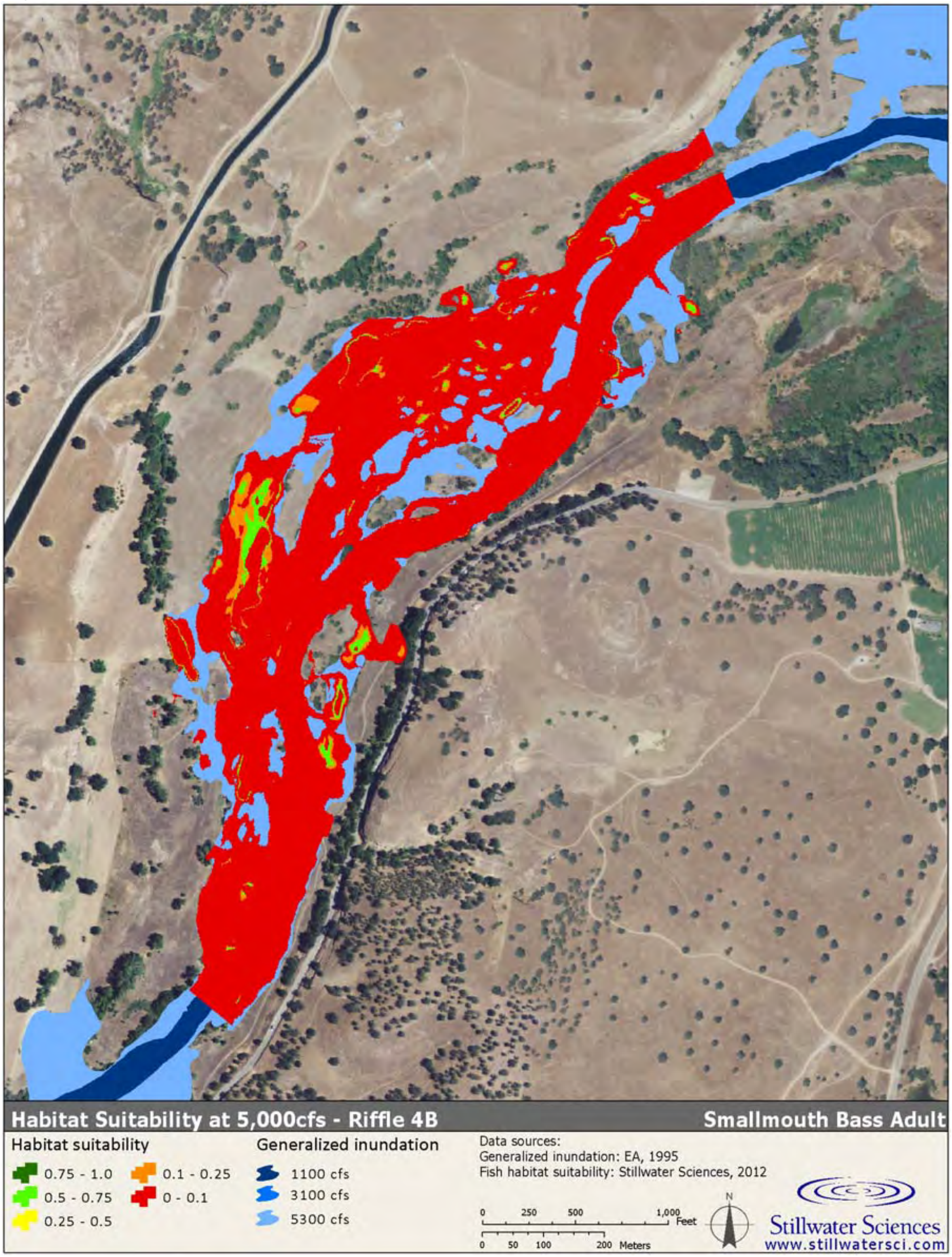


Figure C-38. Riffle 4B results at 5,000 cfs for largemouth bass adults.

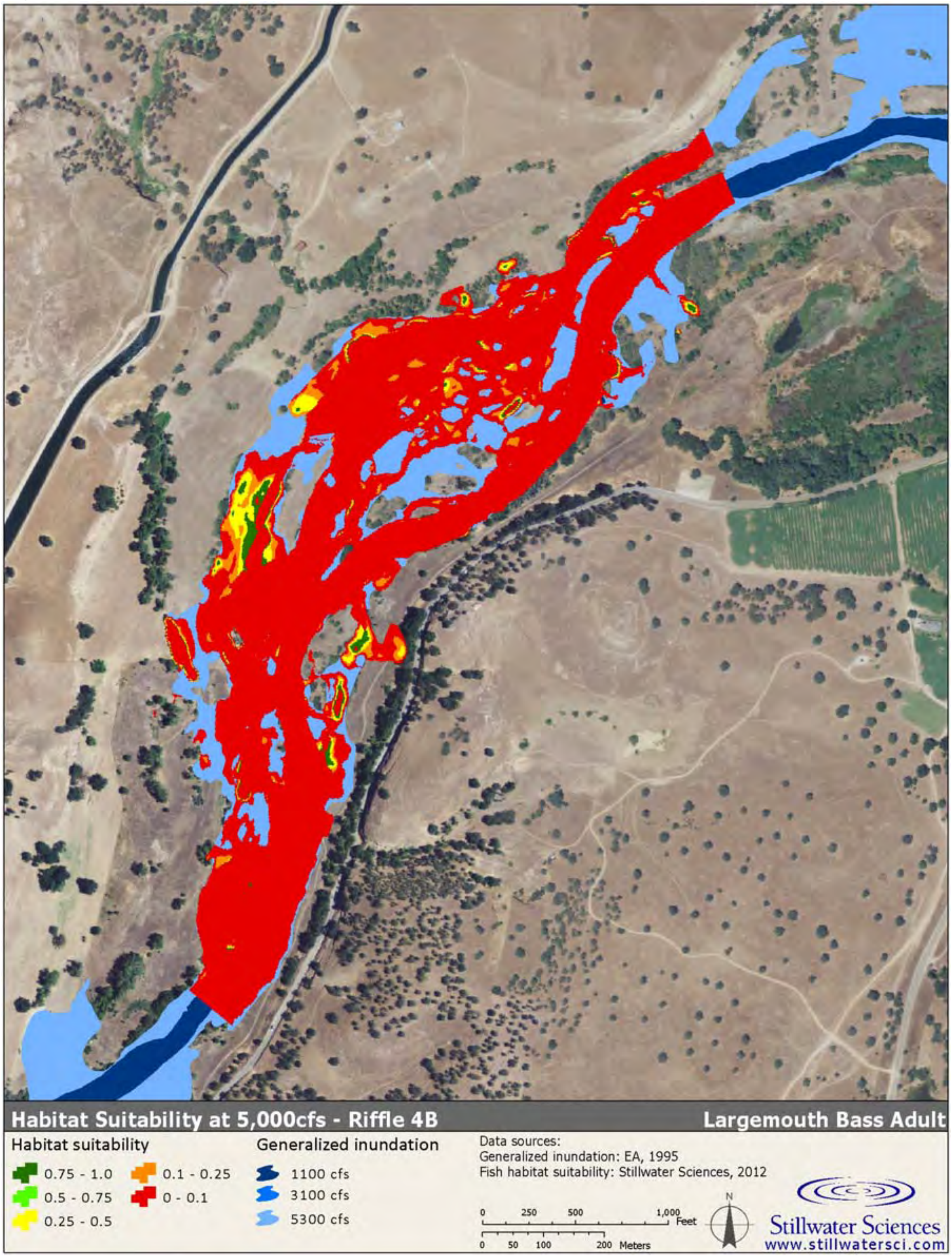


Figure C-39. Riffle 4B results at 5,000 cfs for Sacramento pikeminnow adults.

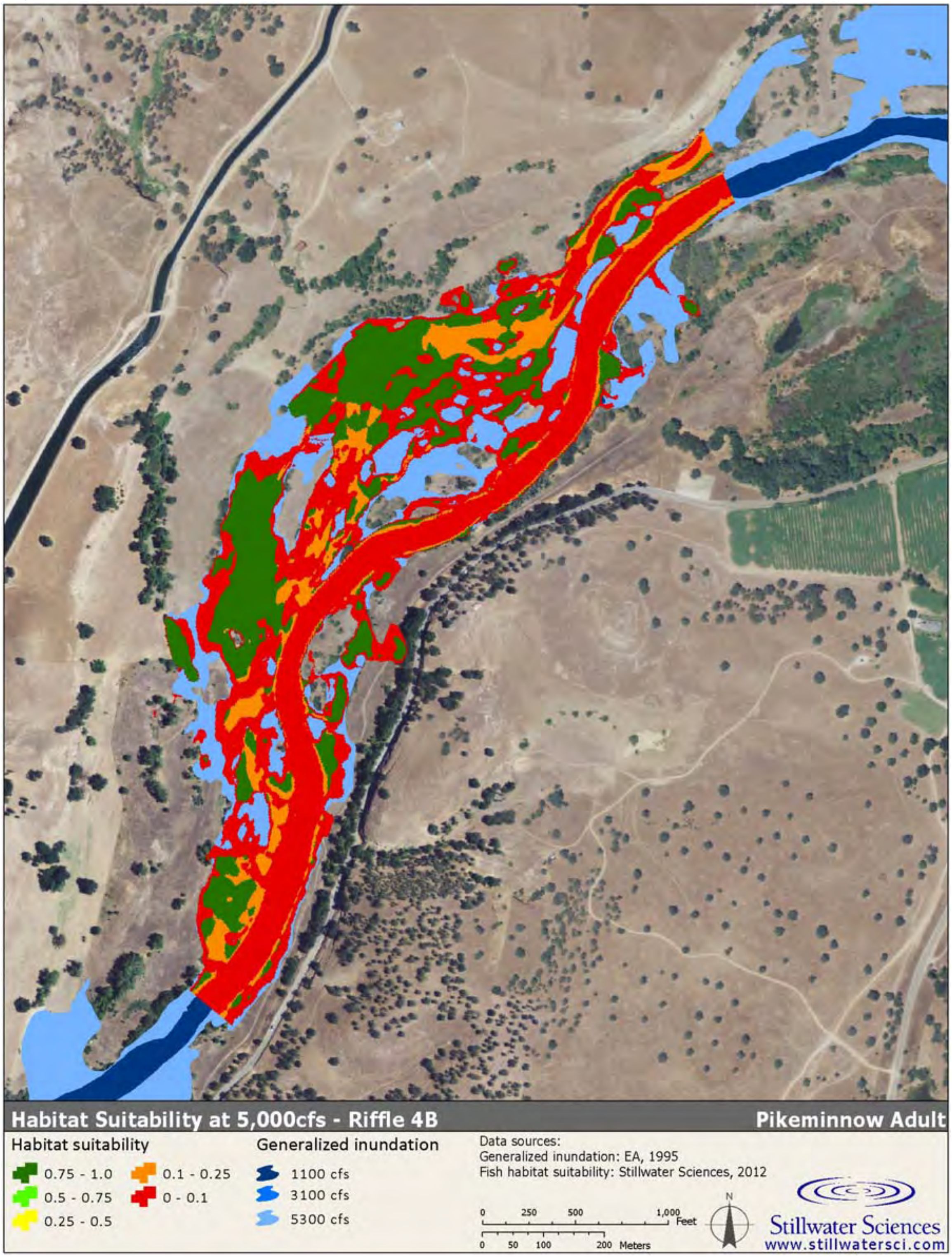


Figure C-40. Riffle 4B results at 5,000 cfs for striped bass adults.

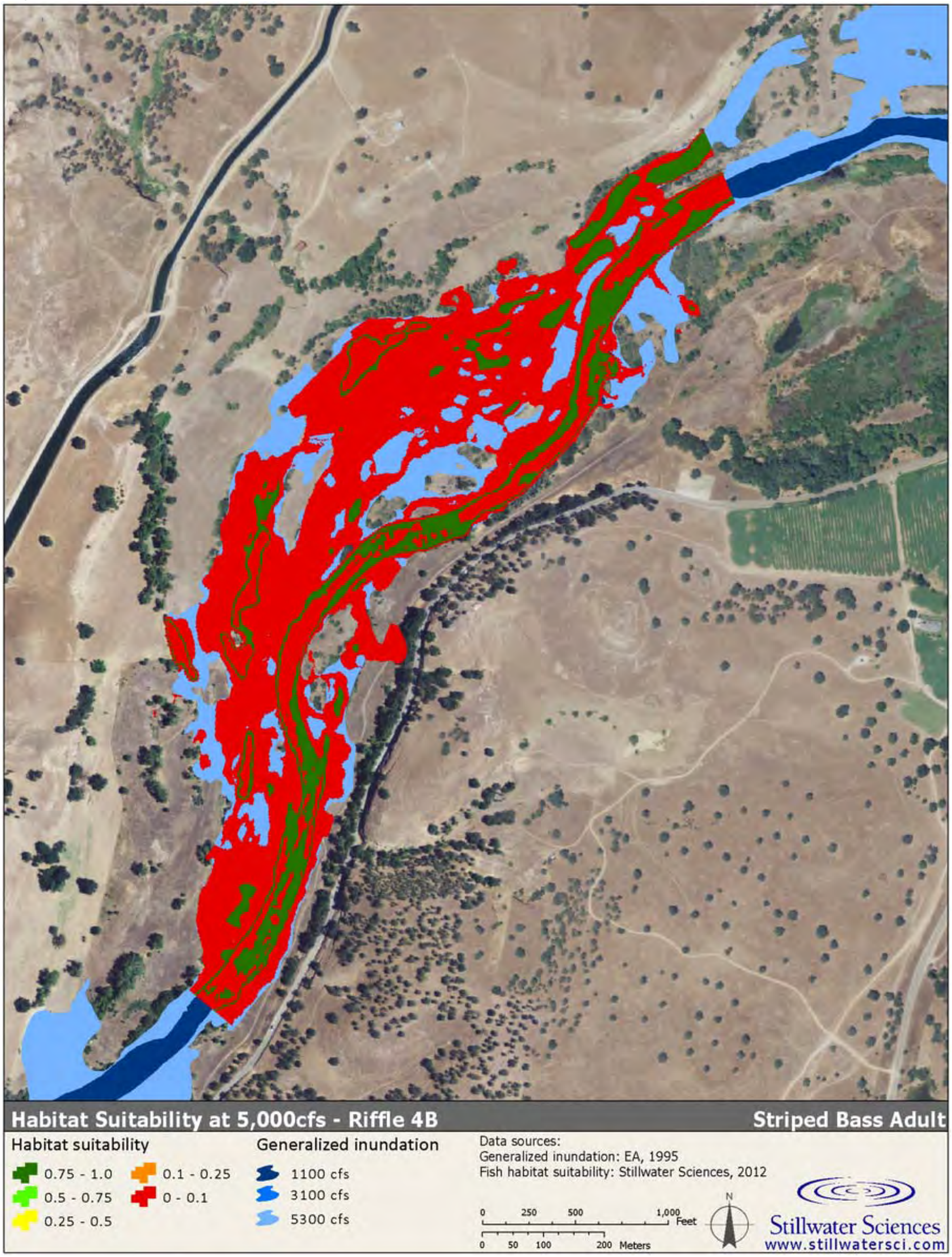


Figure C-41. Riffle 5A (Basso Br.) results at 1,000 cfs for Chinook salmon fry.

Figure C-42. Riffle 5A (Basso Br.) results at 1,000 cfs for *O. mykiss* fry.

Figure C-43. Riffle 5A (Basso Br.) results at 1,000 cfs for Chinook salmon juveniles.

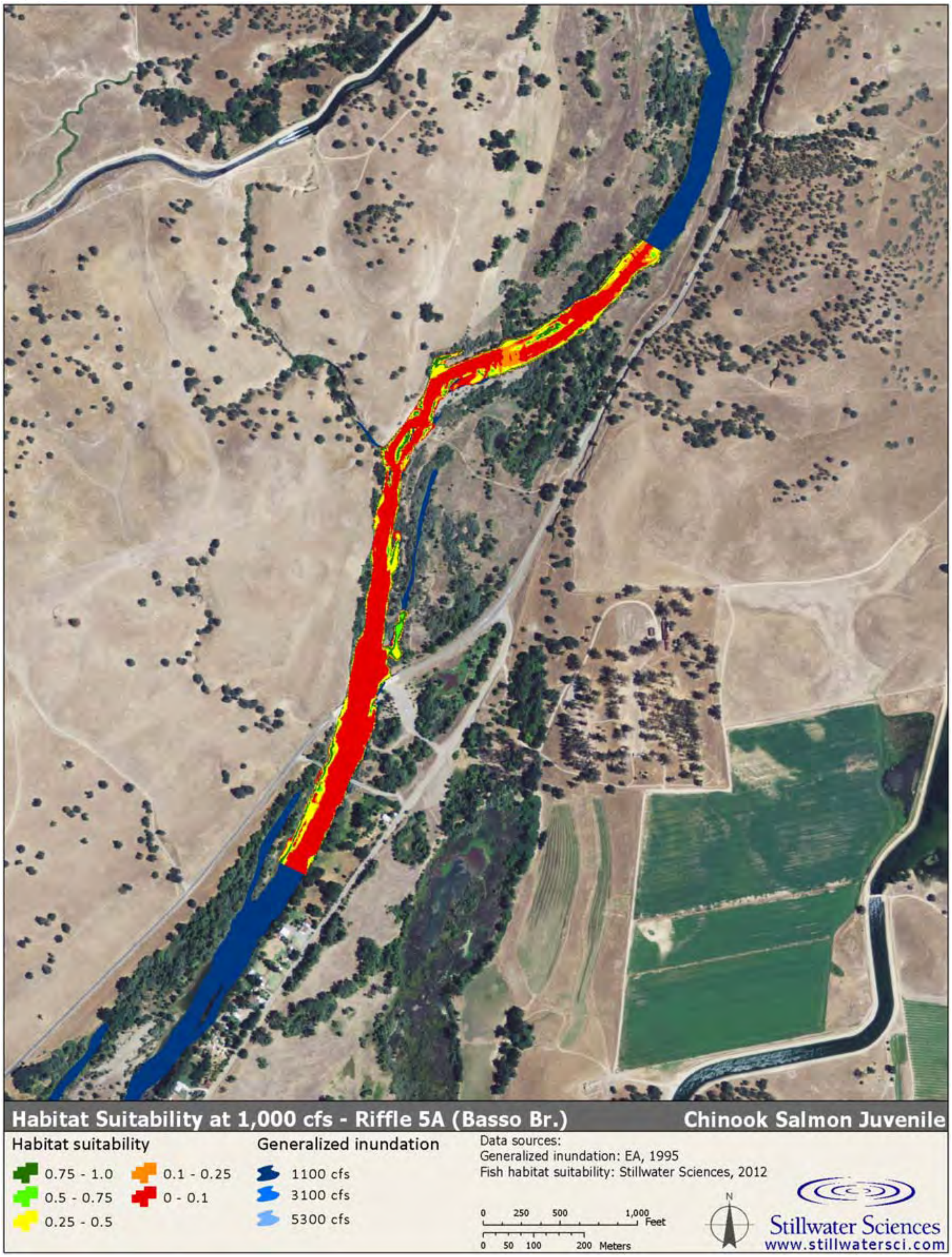


Figure C-44. Riffle 5A (Basso Br.) results at 1,000 cfs for *O. mykiss* juveniles.

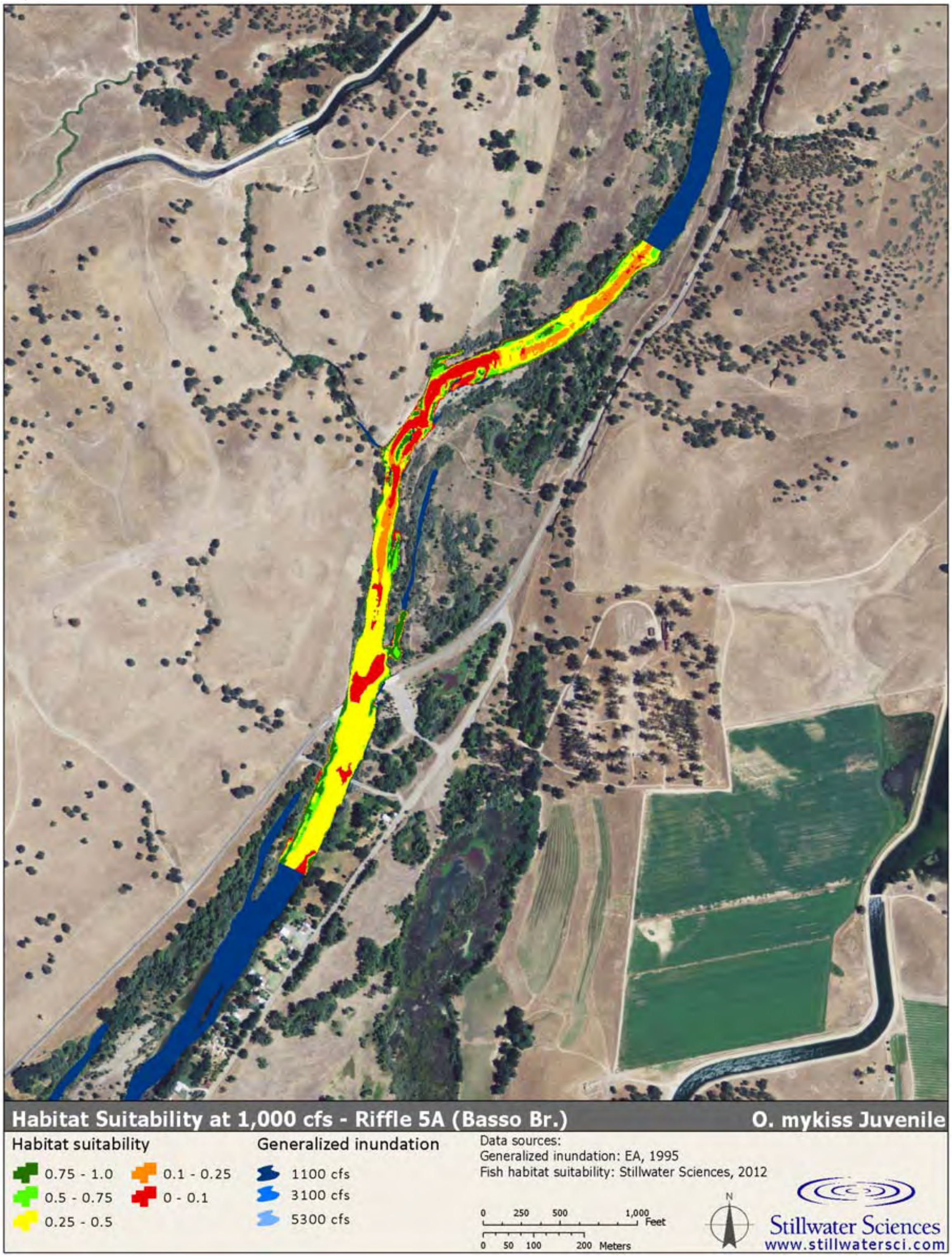


Figure C-45. Riffle 5A (Basso Br.) results at 1,000 cfs for smallmouth bass adults.

Figure C-46. Riffle 5A (Basso Br.) results at 1,000 cfs for largemouth bass adults.

Figure C-47. Riffle 5A (Basso Br.) results at 1,000 cfs for Sacramento pikeminnow adults.

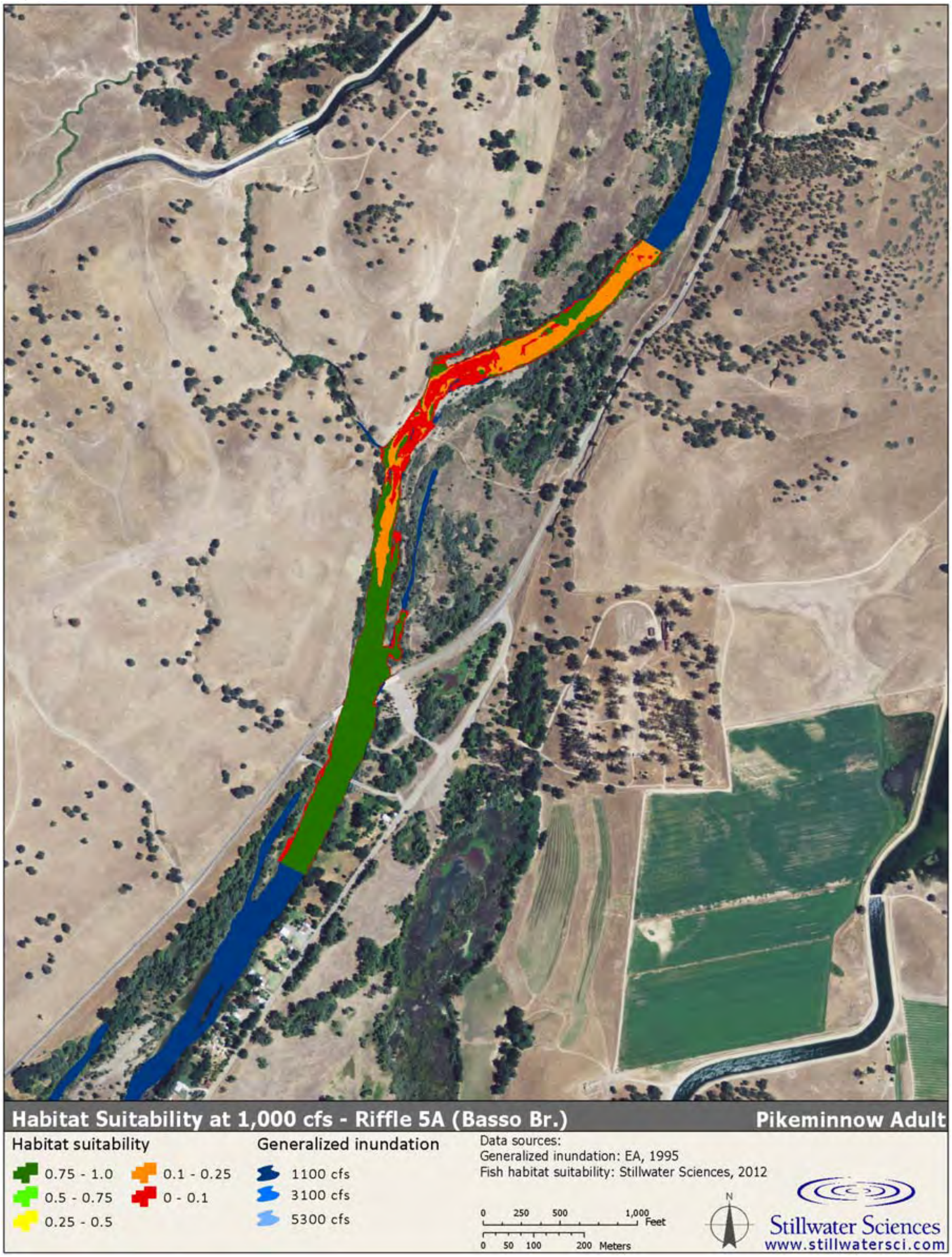


Figure C-48. Riffle 5A (Basso Br.) results at 1,000 cfs for striped bass adults.

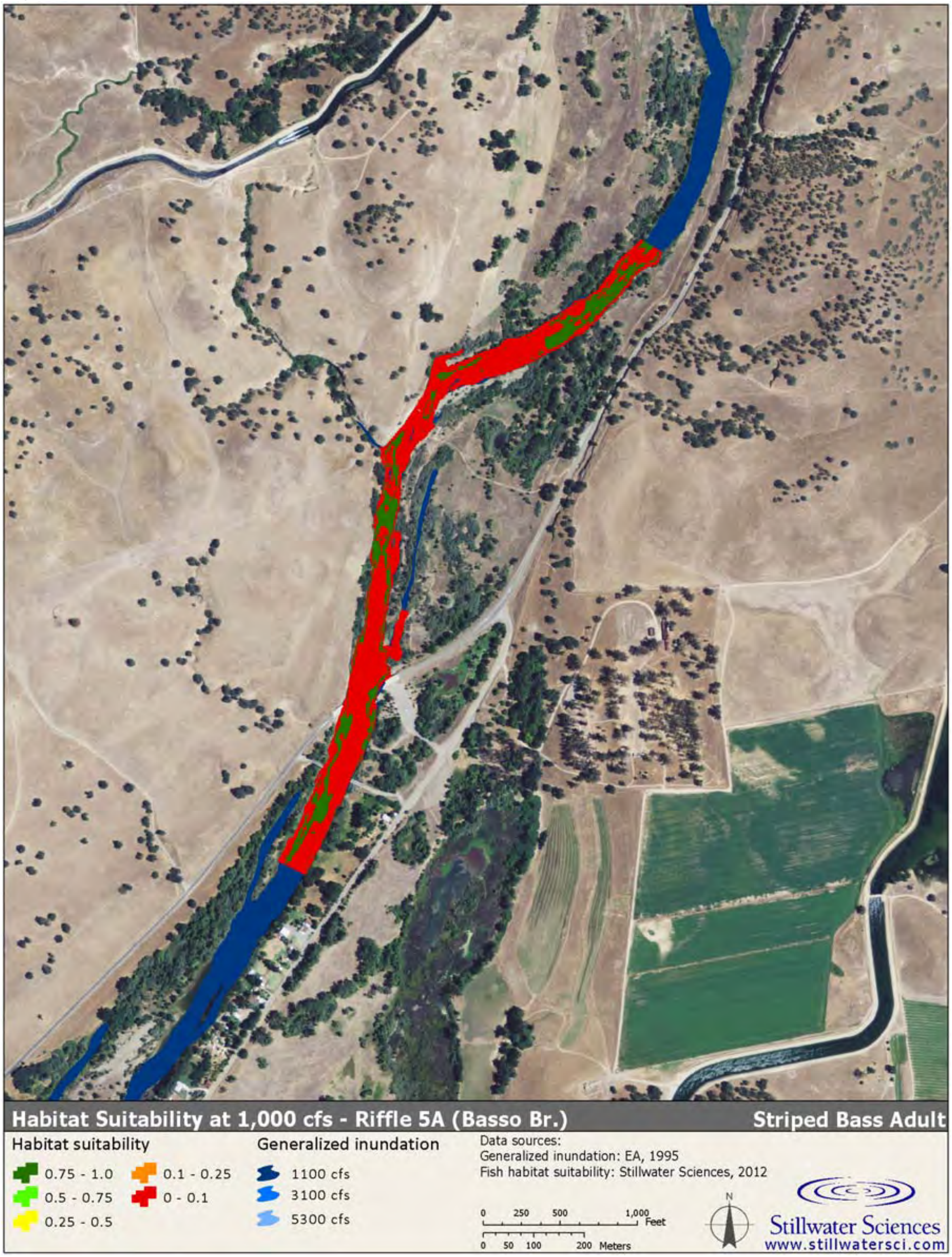


Figure C-49. Riffle 5A (Basso Br.) results at 1,600 cfs for Chinook salmon fry.

Figure C-50. Riffle 5A (Basso Br.) results at 1,600 cfs for *O. mykiss* fry.

Figure C-51. Riffle 5A (Basso Br.) results at 1,600 cfs for Chinook salmon juveniles.

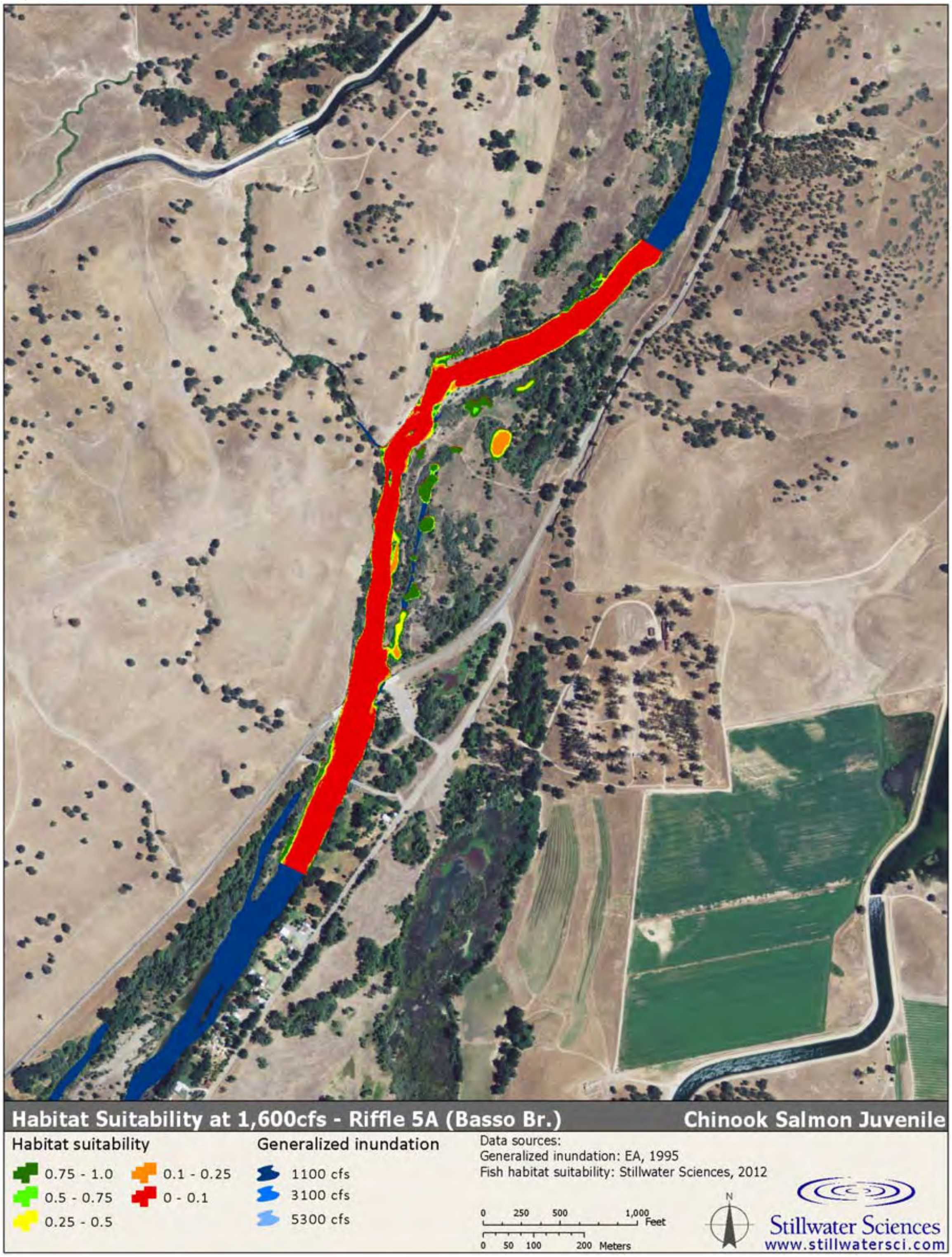


Figure C-52. Riffle 5A (Basso Br.) results at 1,600 cfs for *O. mykiss* juveniles.

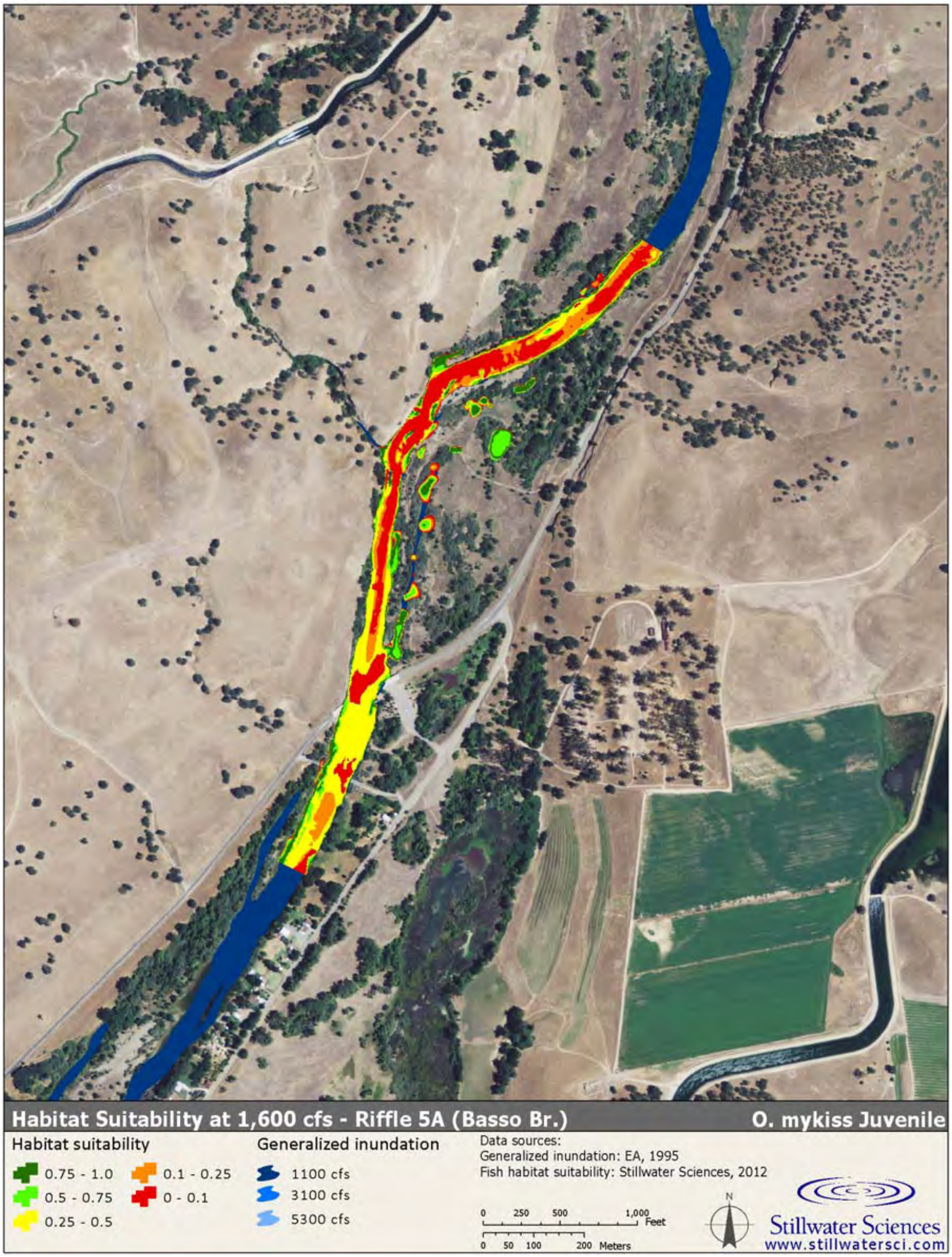


Figure C-53. Riffle 5A (Basso Br.) results at 1,600 cfs for smallmouth bass adults.

Figure C-54. Riffle 5A (Basso Br.) results at 1,600 cfs for largemouth bass adults.

Figure C-55. Riffle 5A (Basso Br.) results at 1,600 cfs for Sacramento pikeminnow adults.

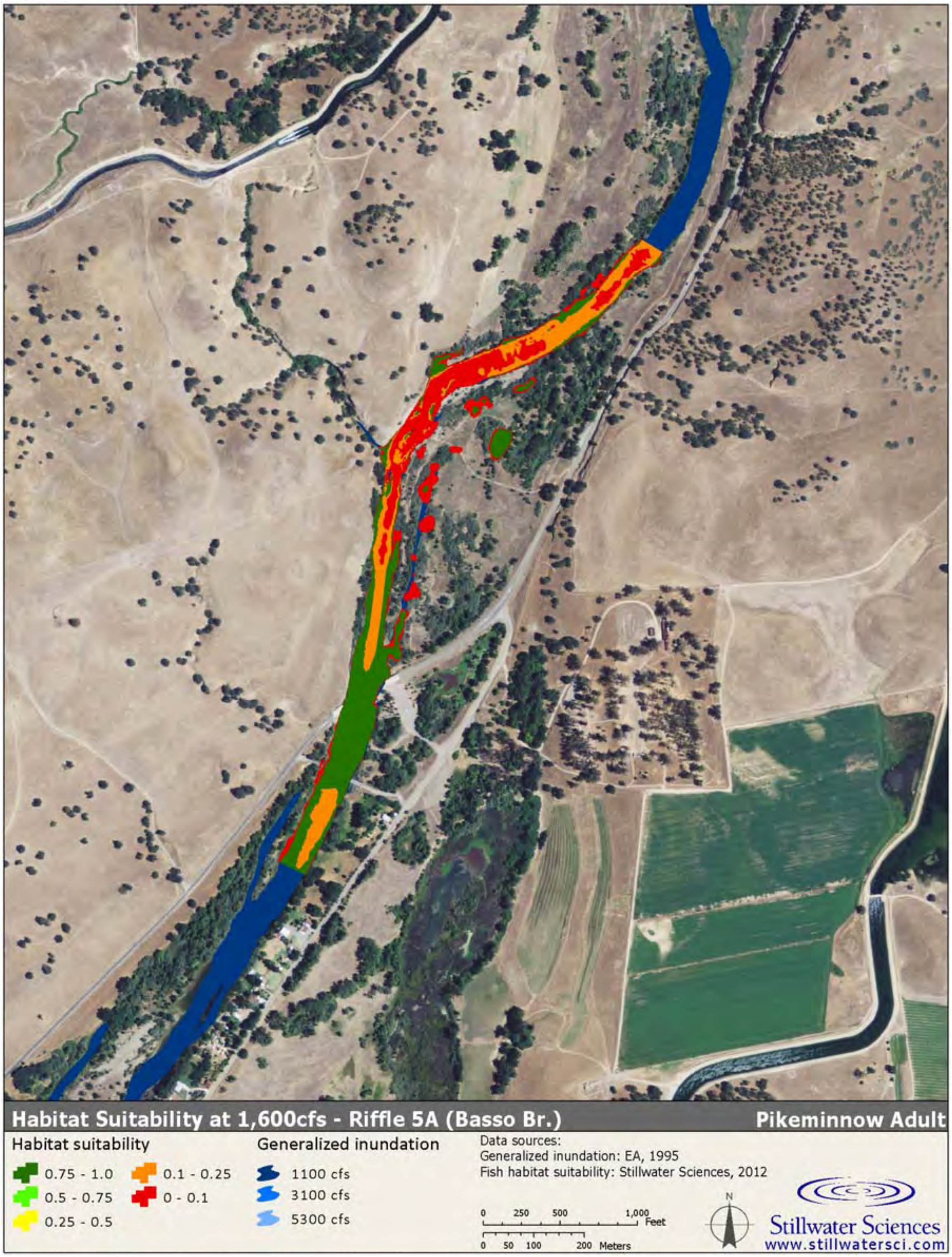


Figure C-56. Riffle 5A (Basso Br.) results at 1,600 cfs for striped bass adults.

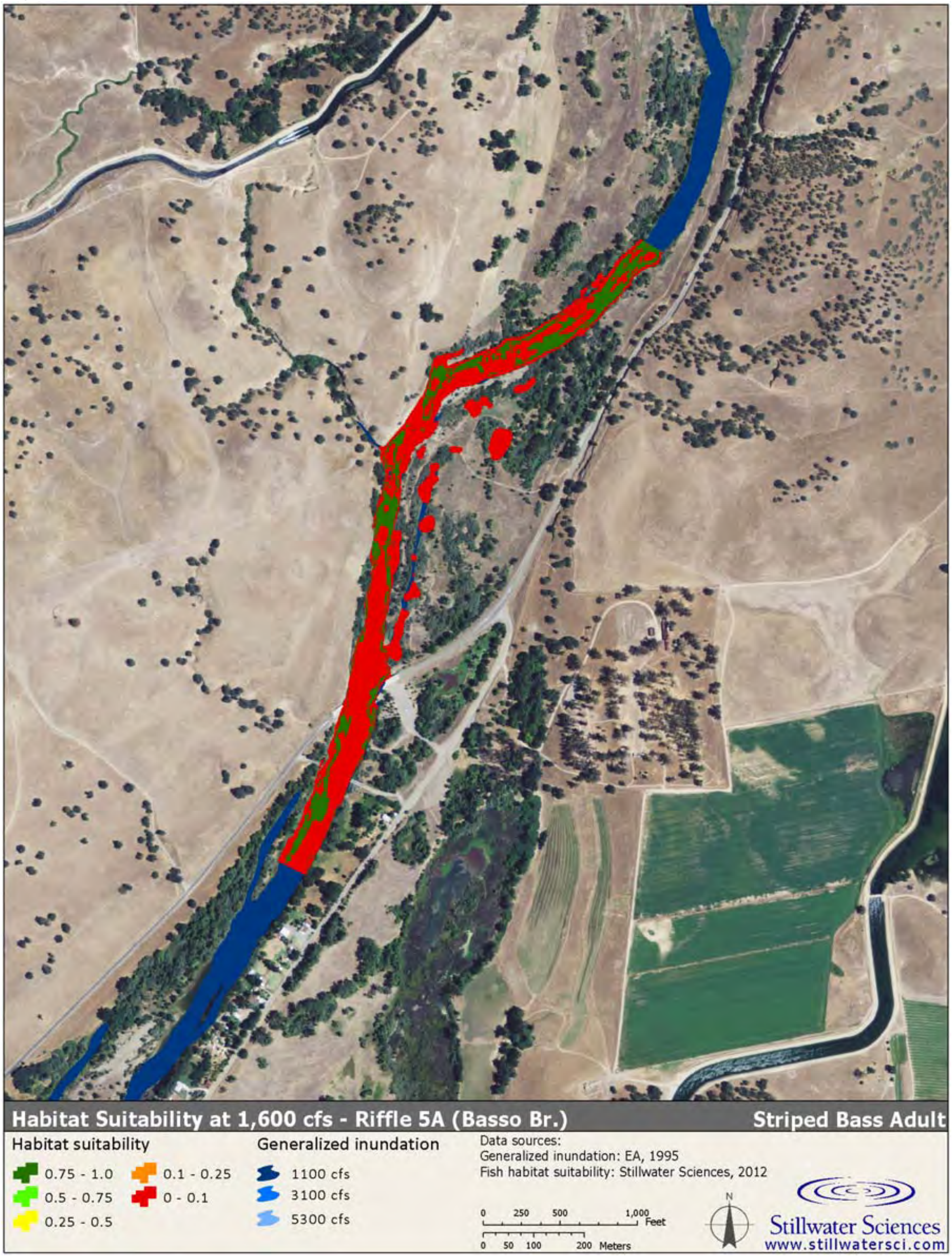


Figure C-57. Riffle 5A (Basso Br.) results at 2,600 cfs for Chinook salmon fry.

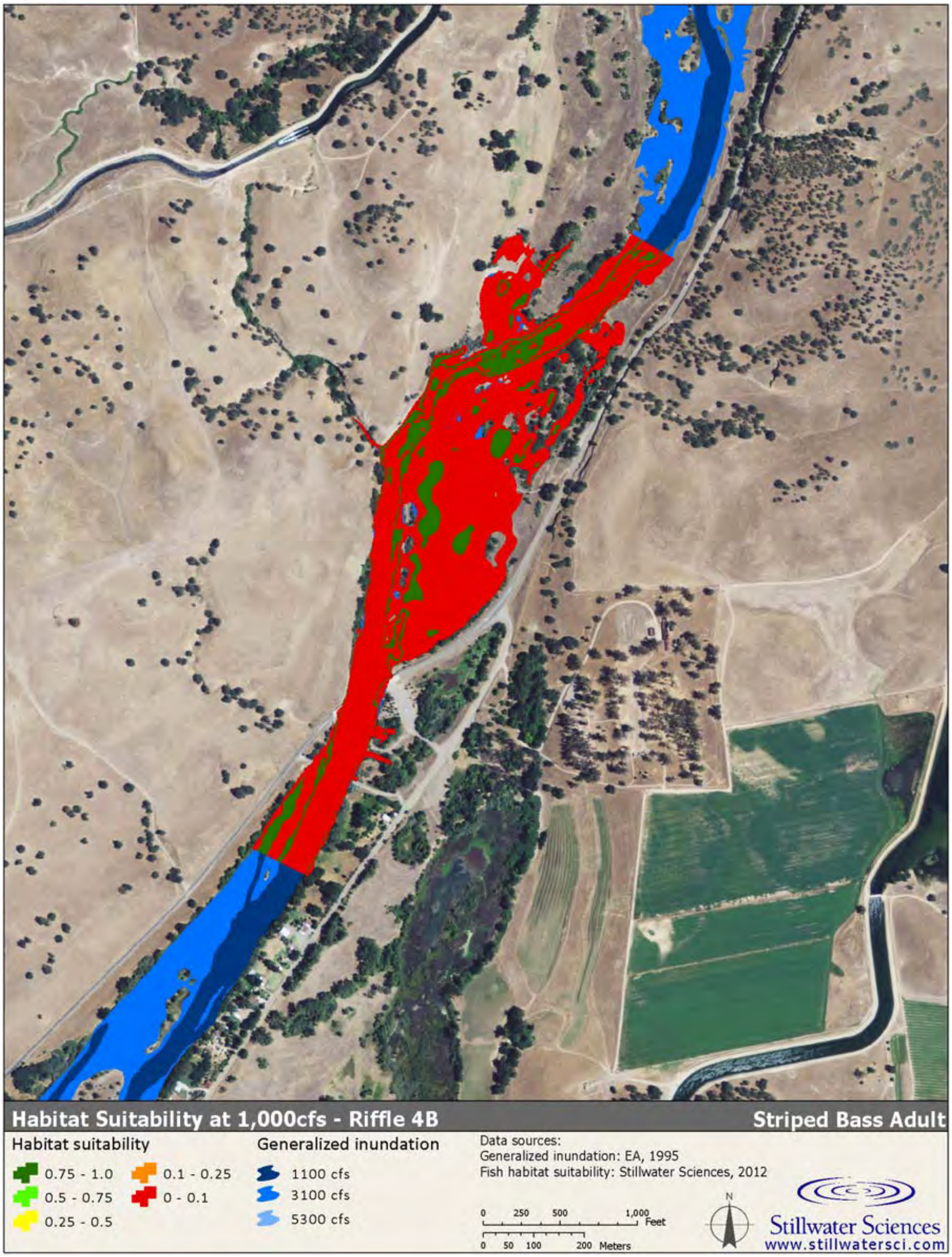


Figure C-58. Riffle 5A (Basso Br.) results at 2,600 cfs for *O. mykiss* fry.

Figure C-59. Riffle 5A (Basso Br.) results at 2,600 cfs for Chinook salmon juveniles.

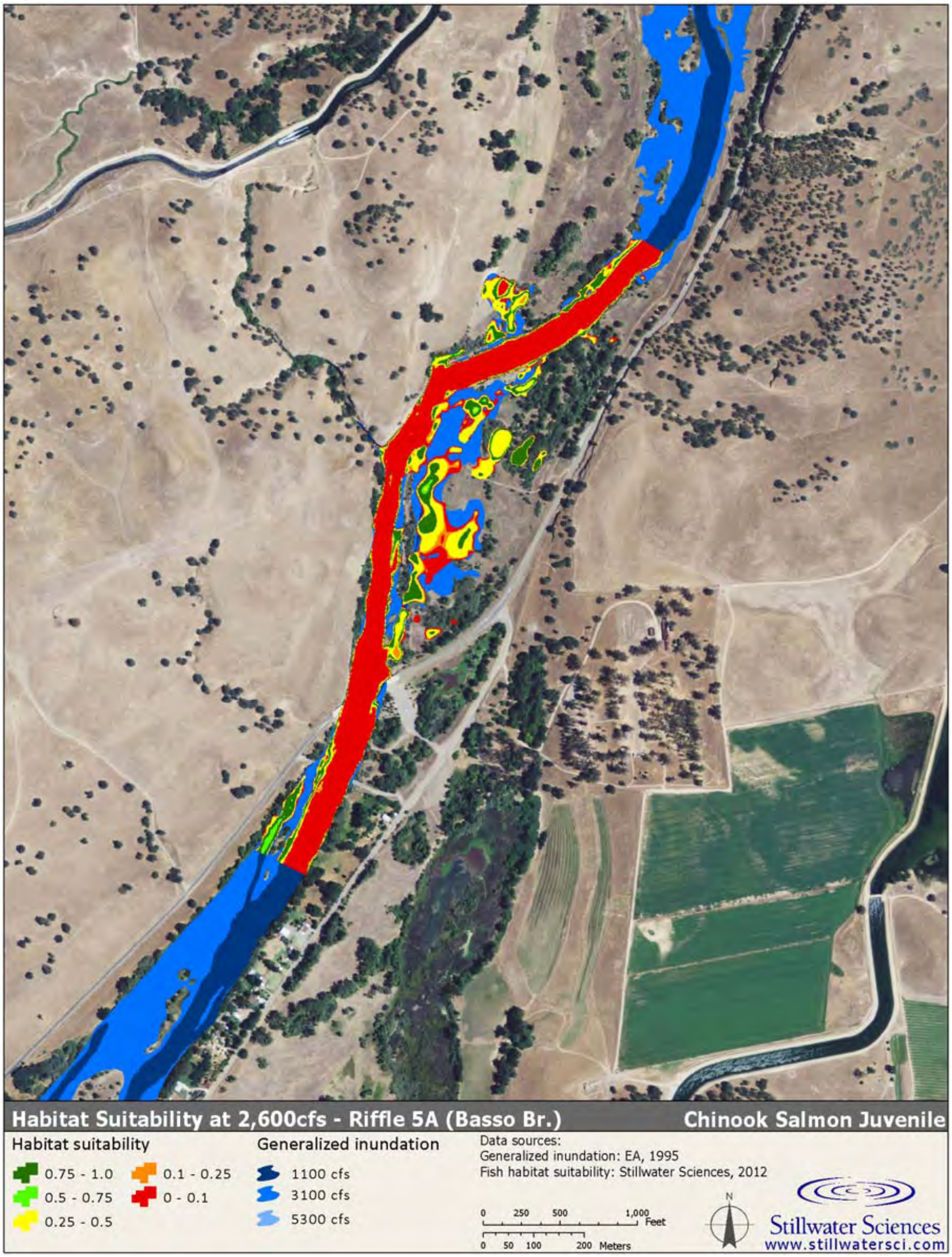


Figure C-60. Riffle 5A (Basso Br.) results at 2,600 cfs for *O. mykiss* juveniles.

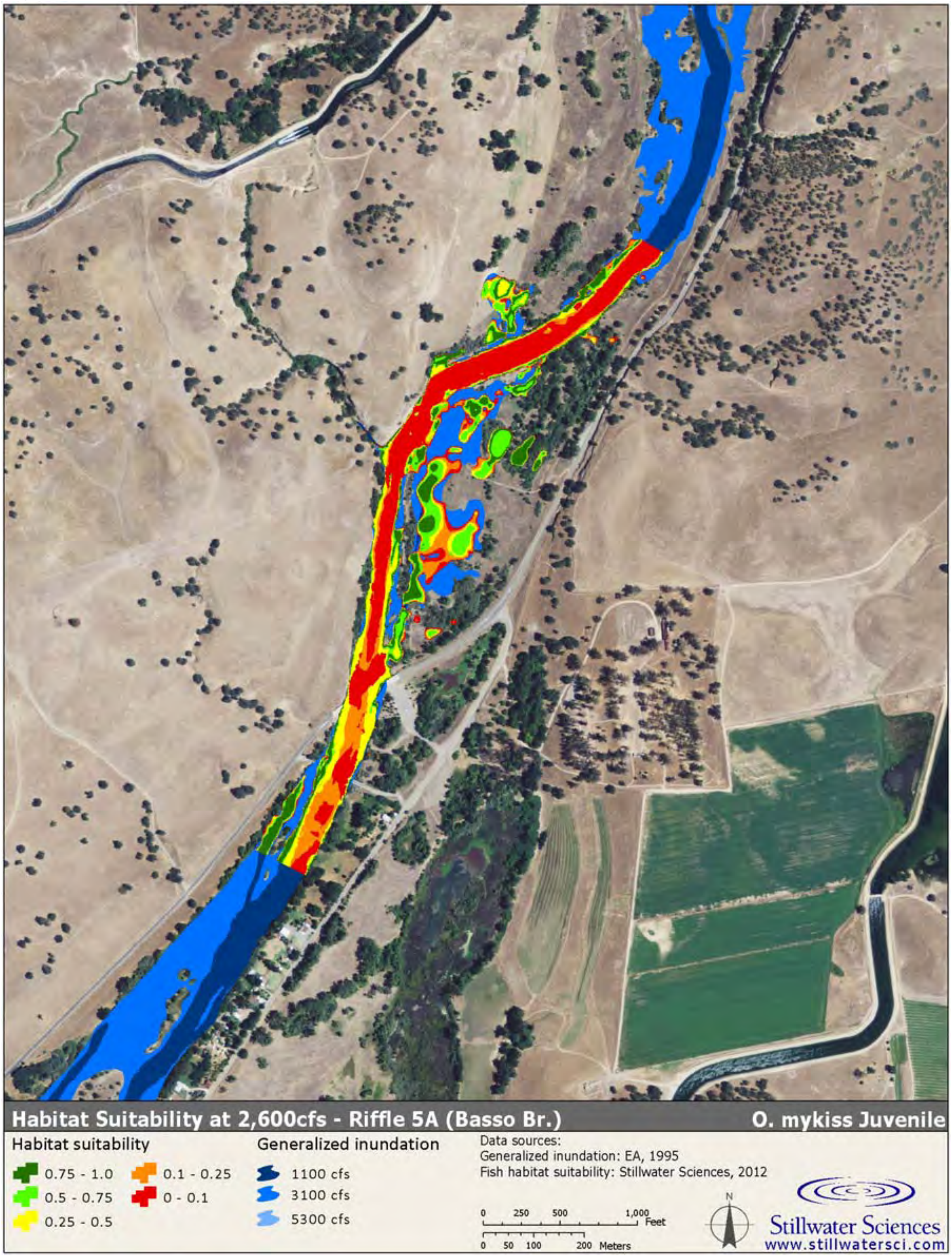


Figure C-61. Riffle 5A (Basso Br.) results at 2,600 cfs for smallmouth bass adults.

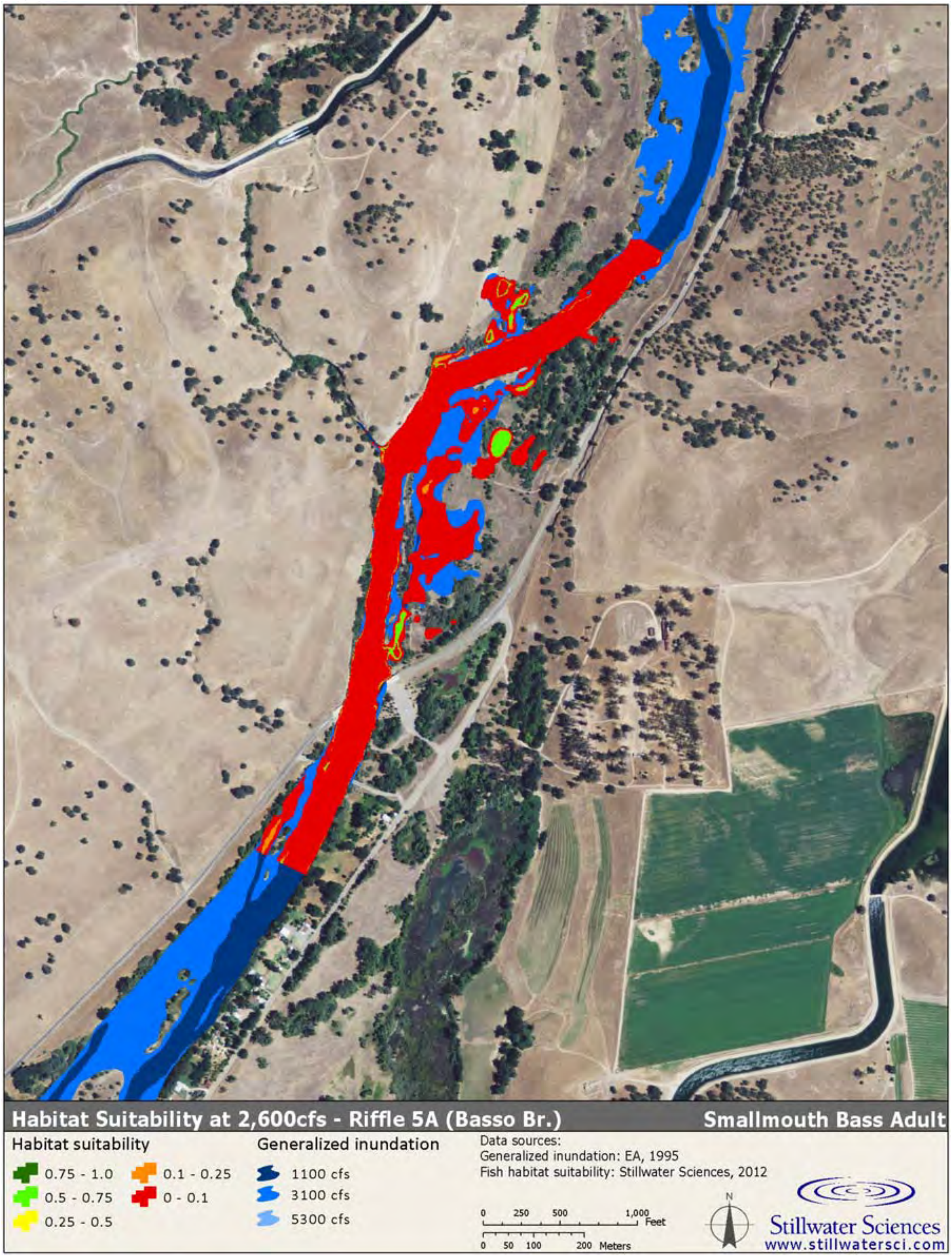


Figure C-62. Riffle 5A (Basso Br.) results at 2,600 cfs for largemouth bass adults.

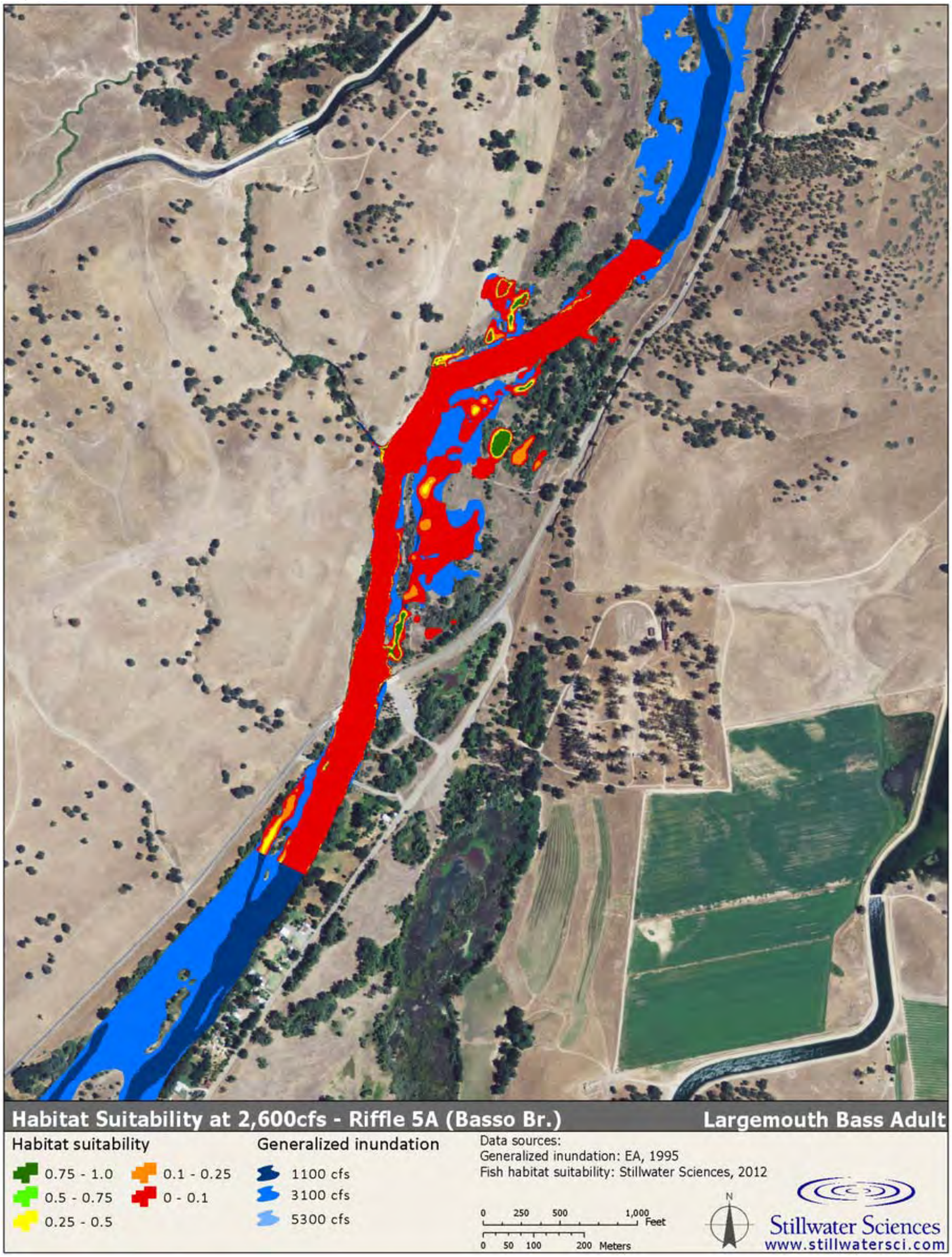


Figure C-63. Riffle 5A (Basso Br.) results at 2,600 cfs for Sacramento pikeminnow adults.

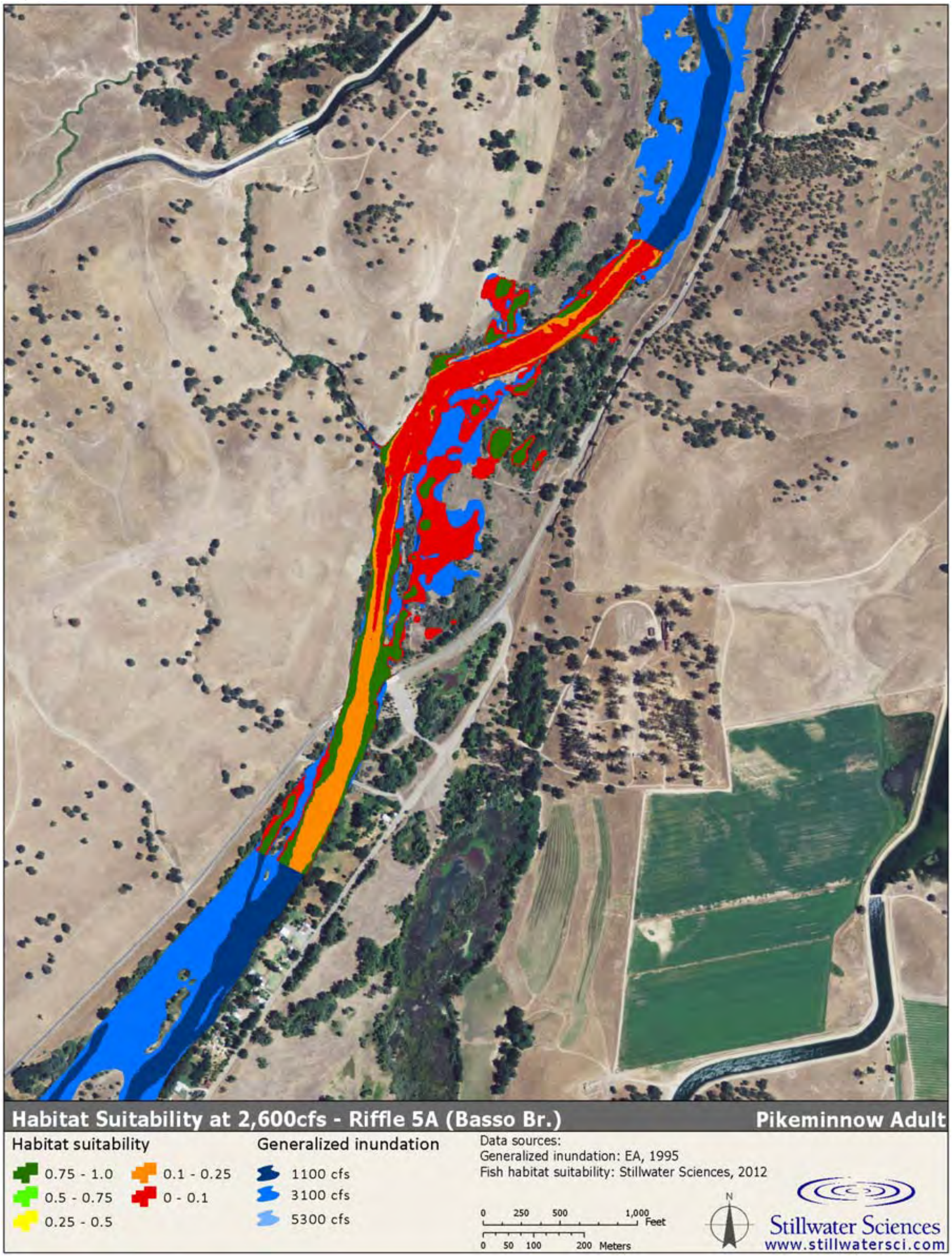


Figure C-64. Riffle 5A (Basso Br.) results at 2,600 cfs for striped bass adults.

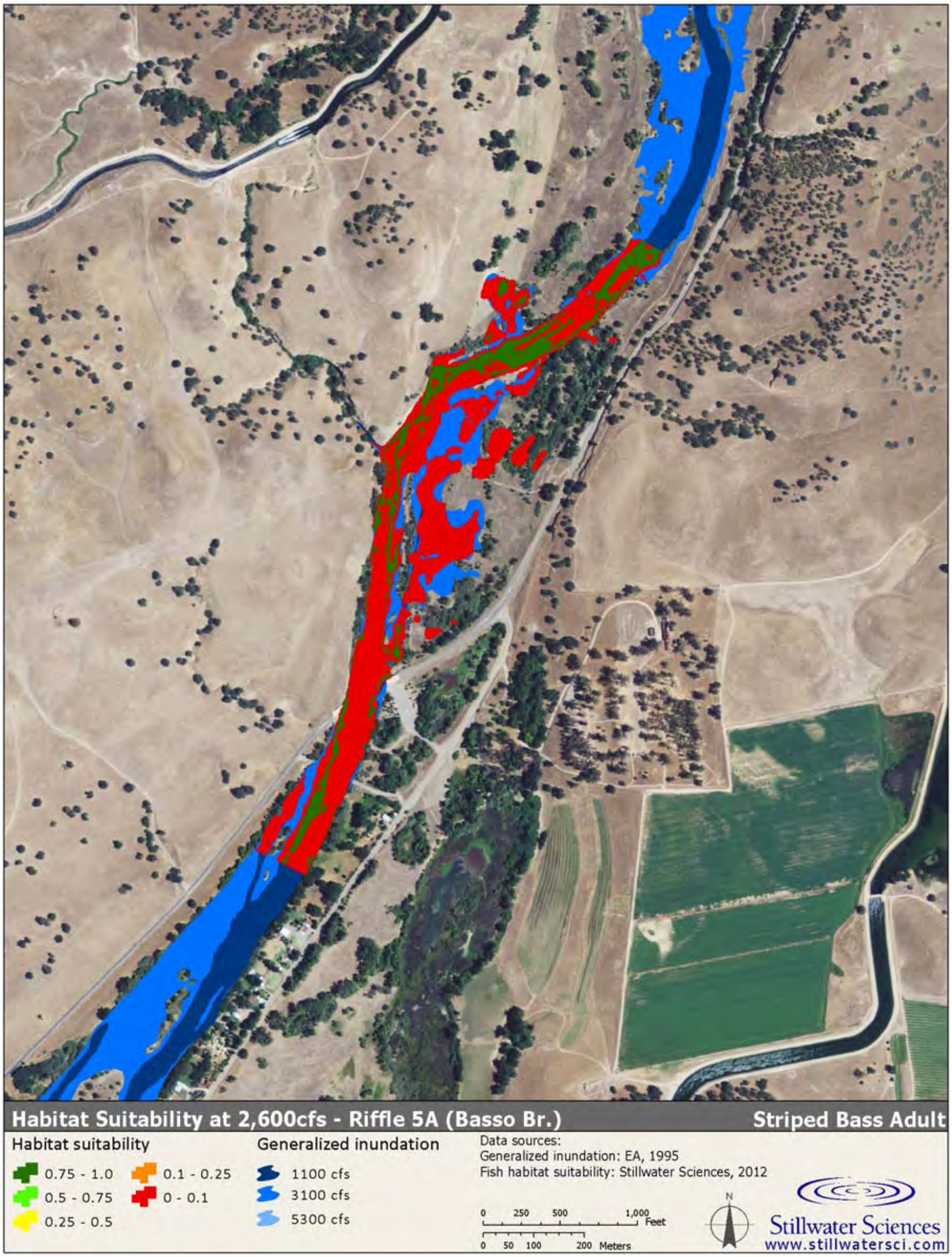


Figure C-65. Riffle 5A (Basso Br.) results at 3,000 cfs for Chinook salmon fry.

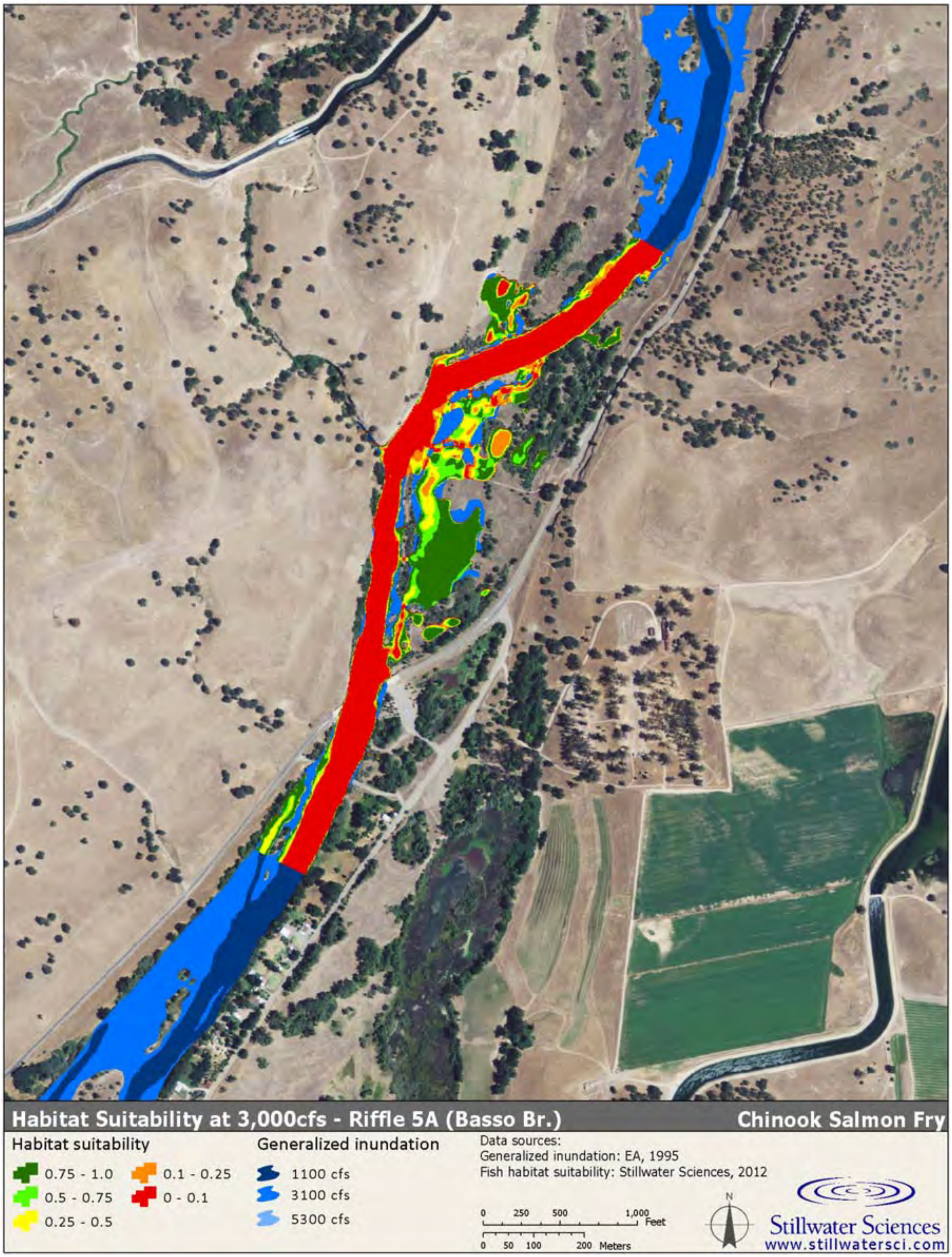


Figure C-66. Riffle 5A (Basso Br.) results at 3,000 cfs for *O. mykiss* fry.

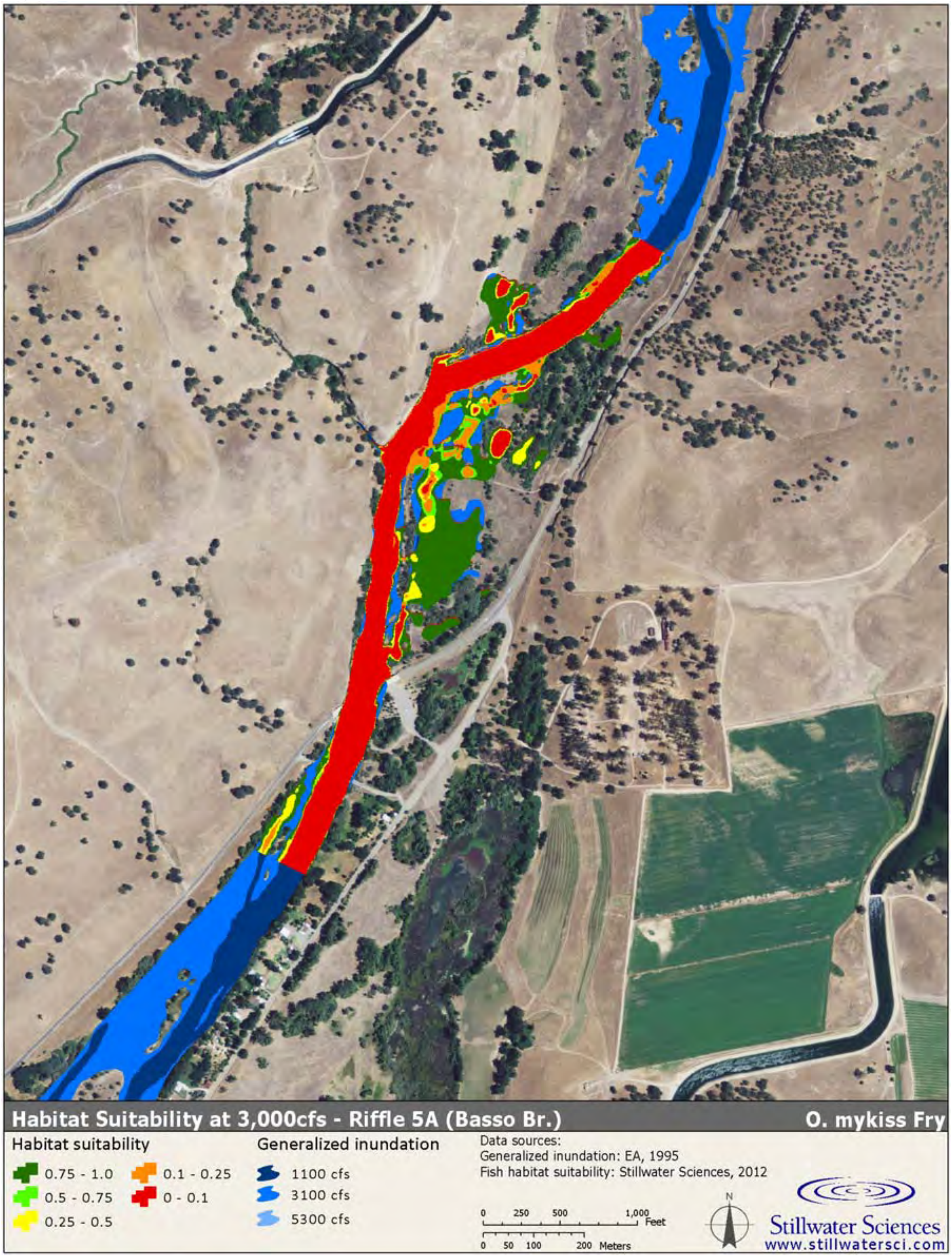


Figure C-67. Riffle 5A (Basso Br.) results at 3,000 cfs for Chinook salmon juveniles.

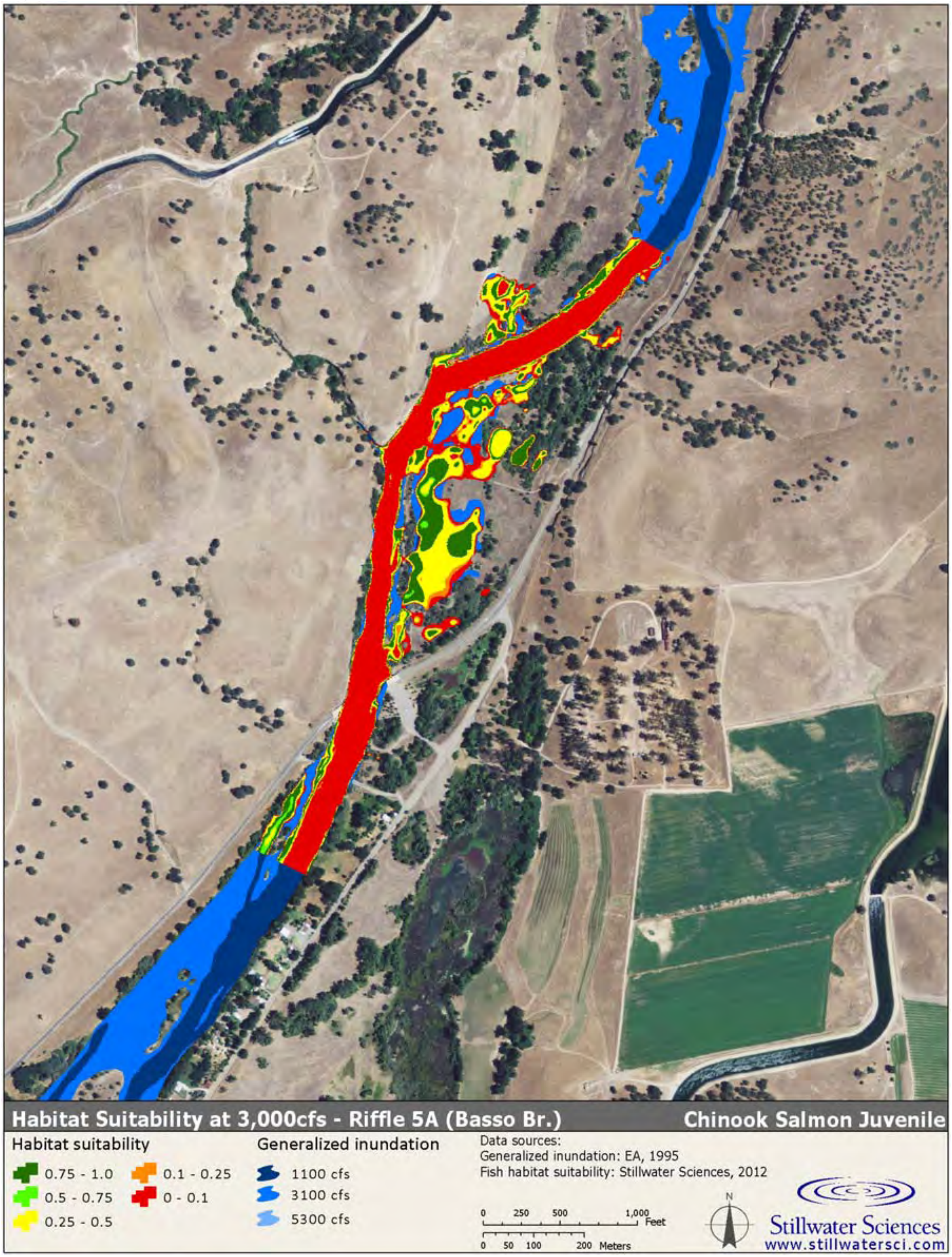


Figure C-68. Riffle 5A (Basso Br.) results at 3,000 cfs for *O. mykiss* juveniles.

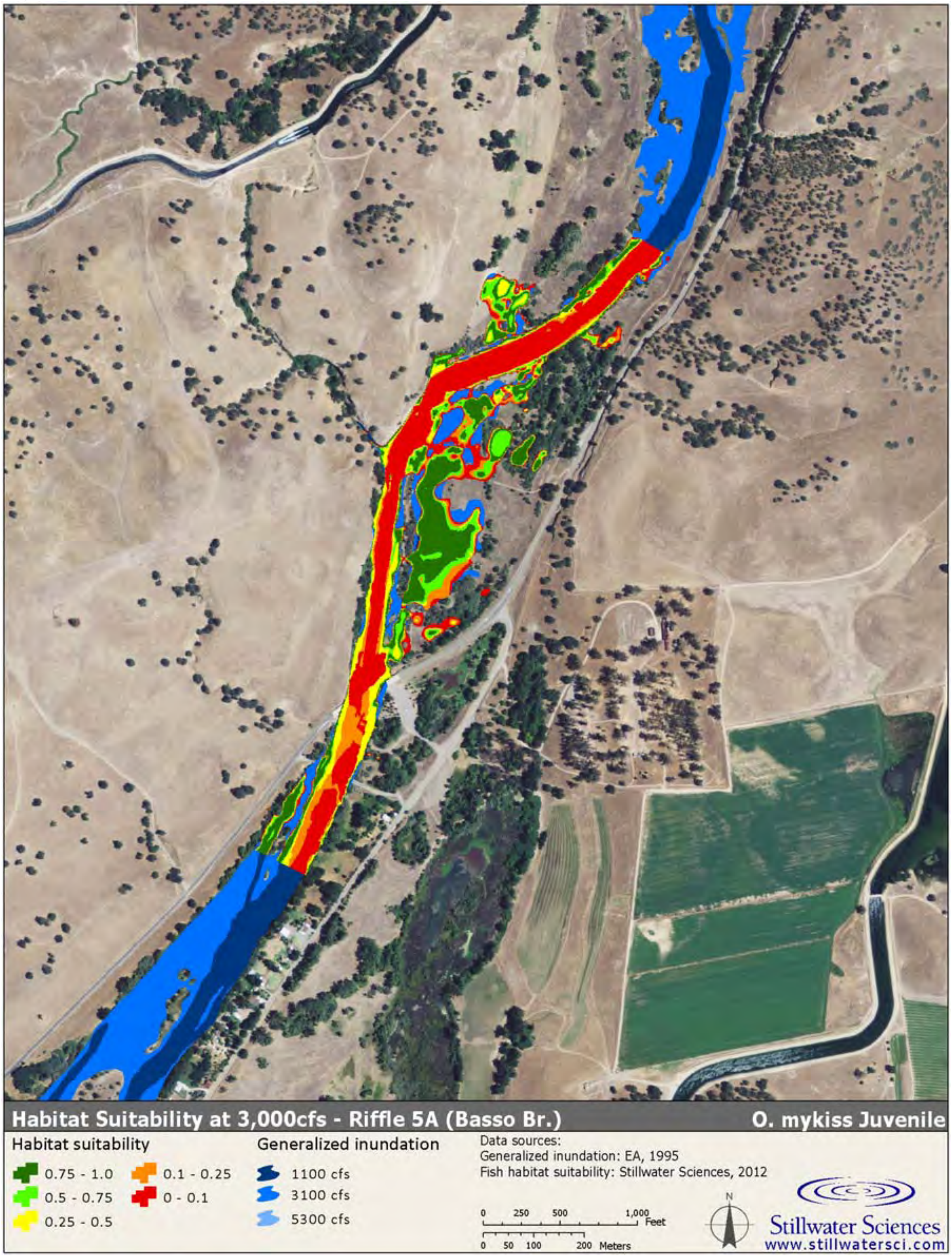


Figure C-69. Riffle 5A (Basso Br.) results at 3,000 cfs for smallmouth bass adults.

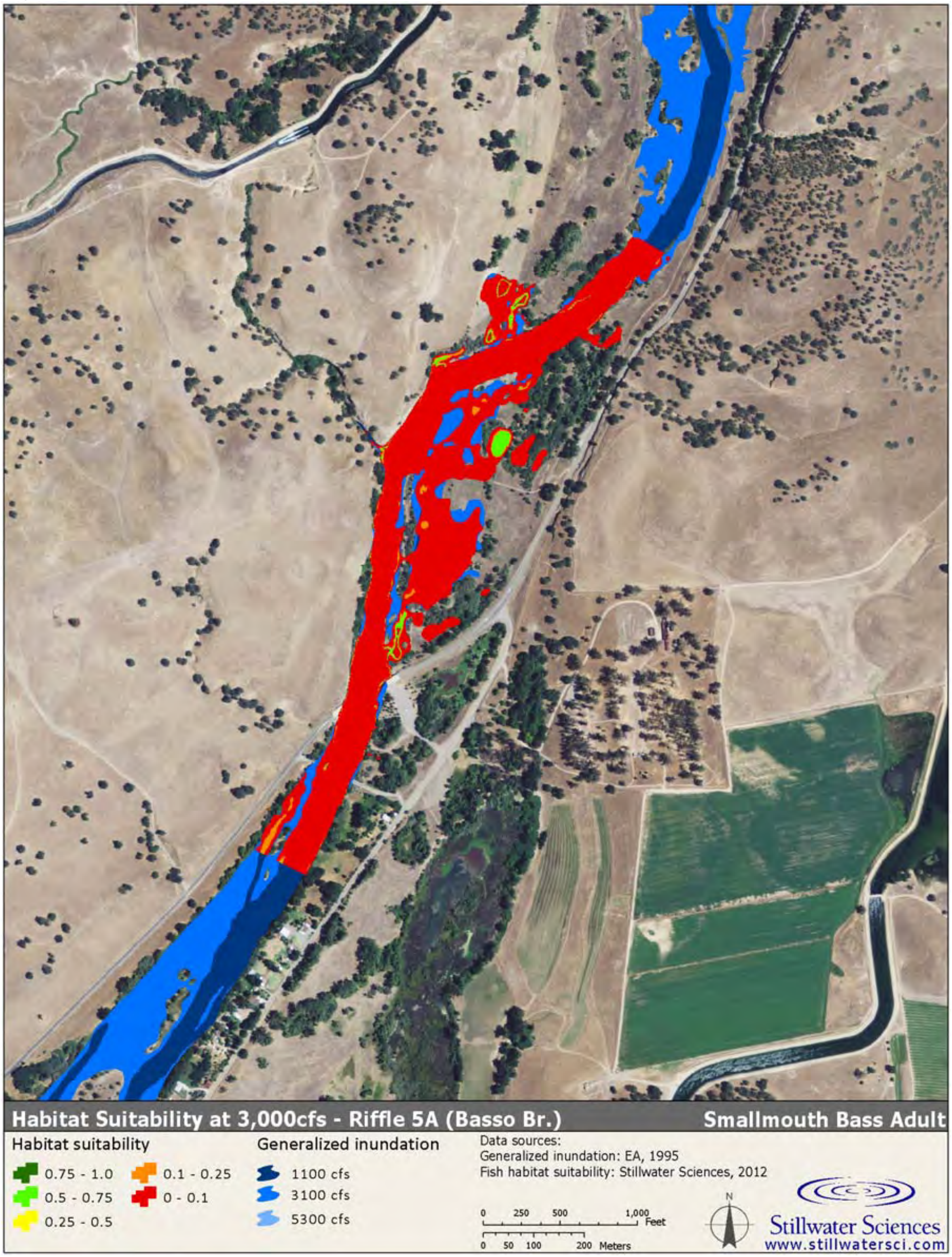


Figure C-70. Riffle 5A (Basso Br.) results at 3,000 cfs for largemouth bass adults.

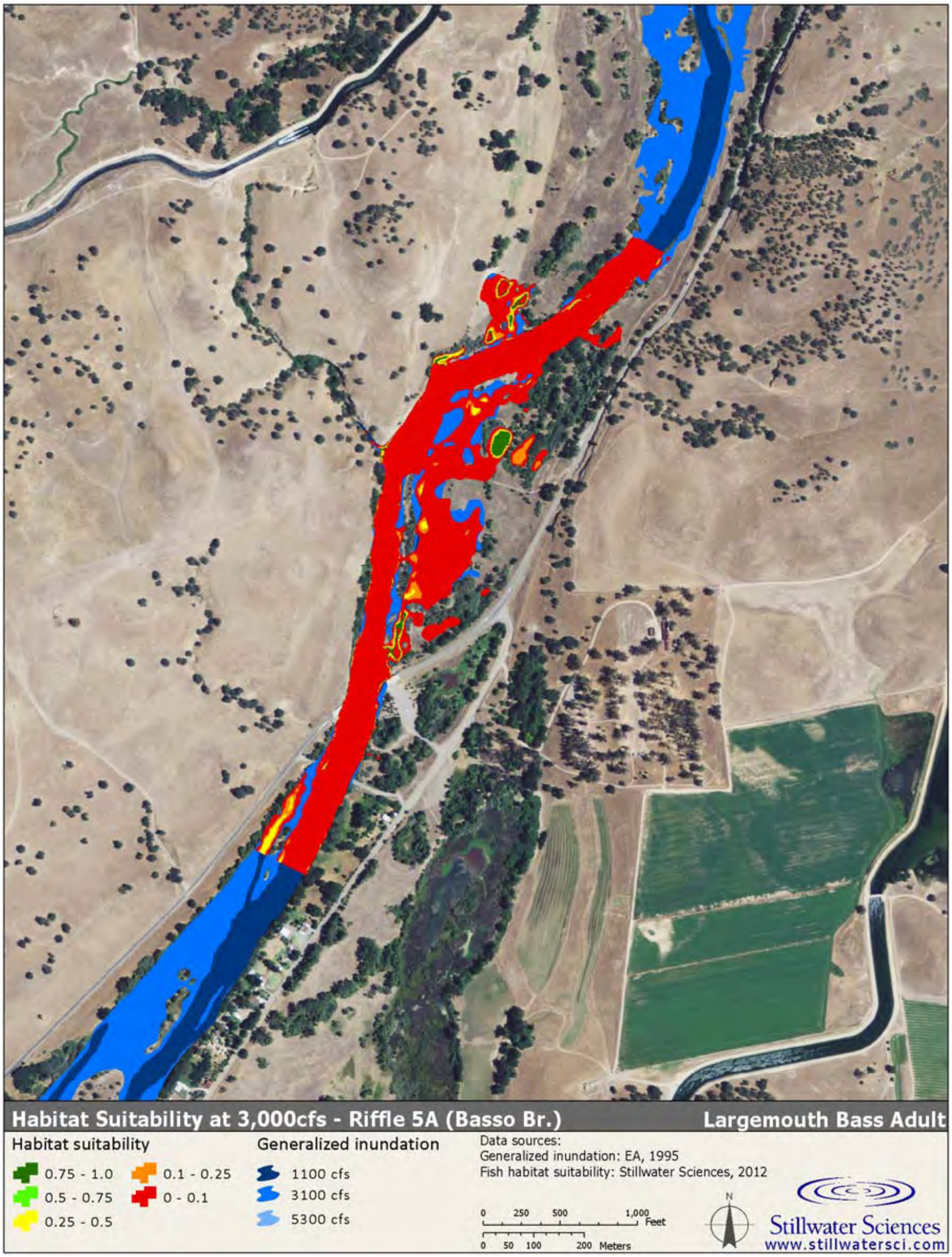


Figure C-71. Riffle 5A (Basso Br.) results at 3,000 cfs for Sacramento pikeminnow adults.

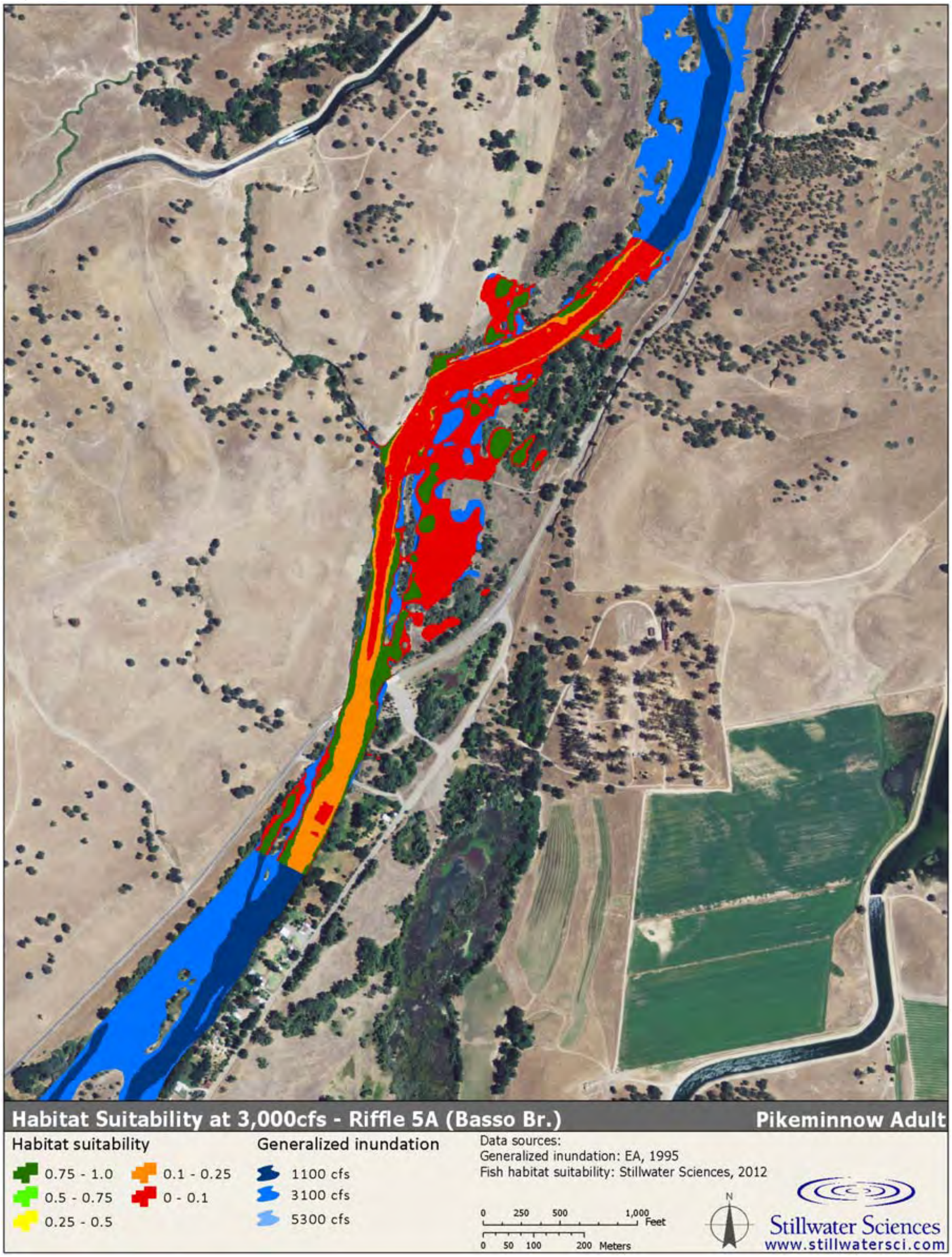


Figure C-72. Riffle 5A (Basso Br.) results at 3,000 cfs for striped bass adults.

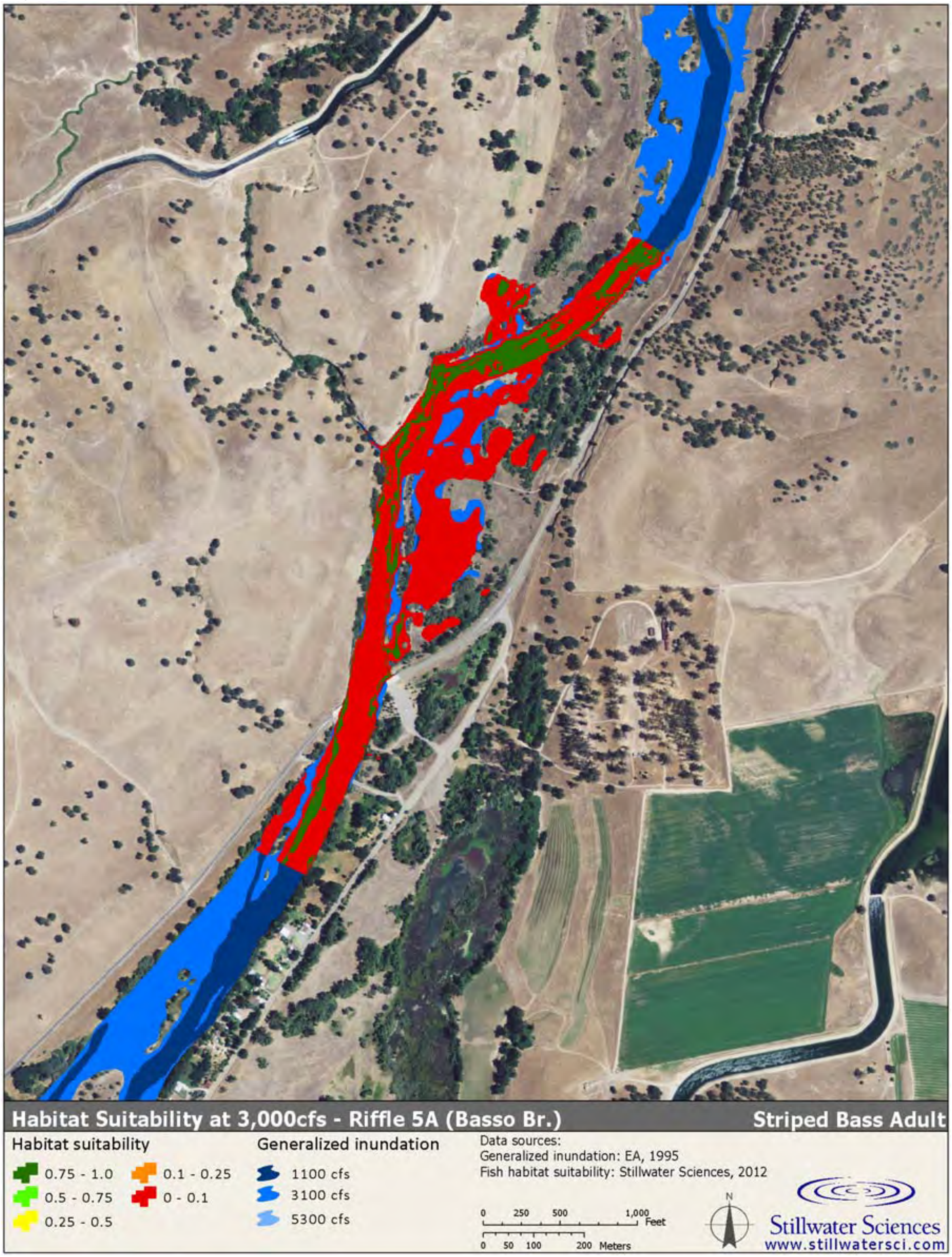


Figure C-73. Riffle 5A (Basso Br.) results at 5,000 cfs for Chinook salmon fry.

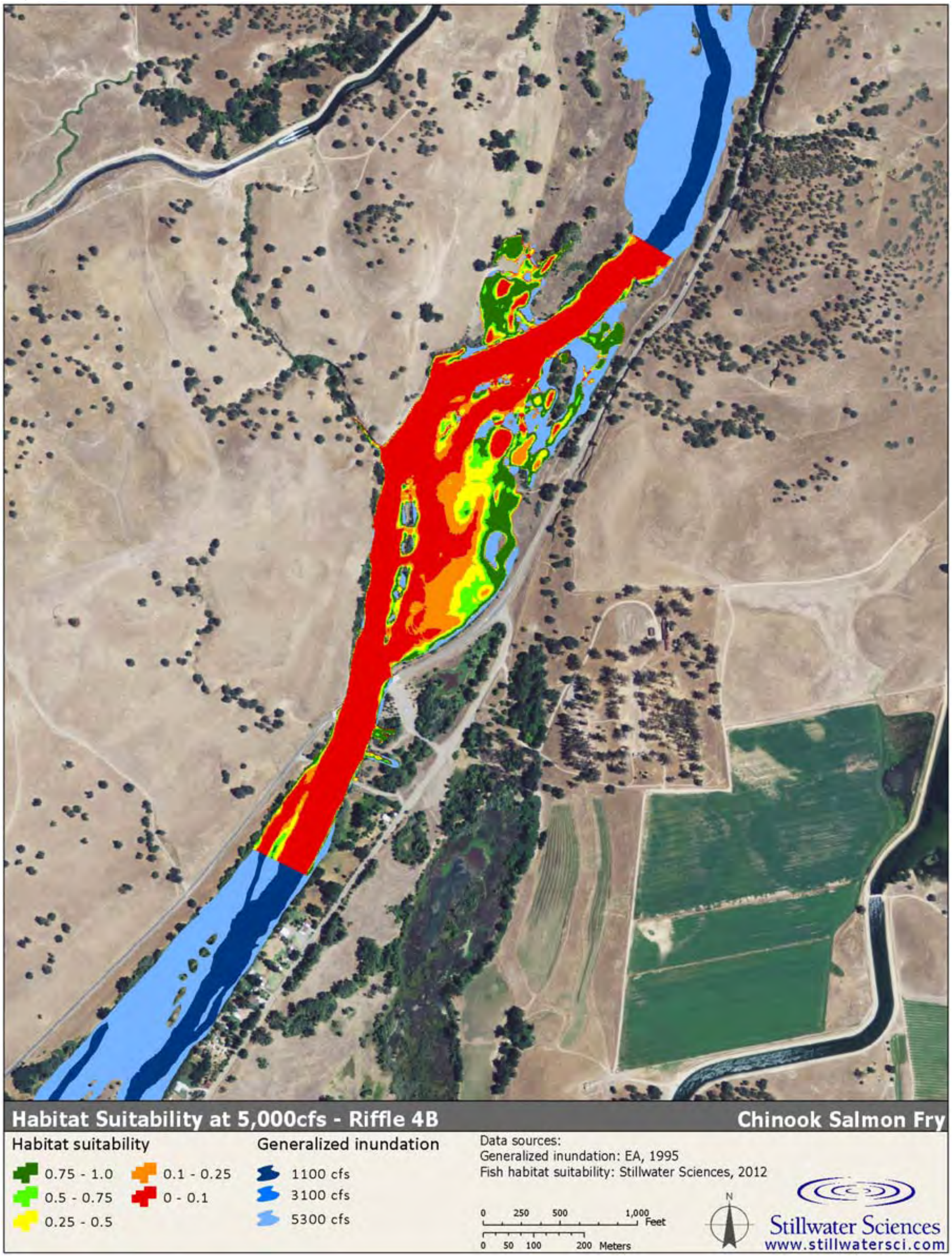


Figure C-74. Riffle 5A (Basso Br.) results at 5,000 cfs for *O. mykiss* fry.

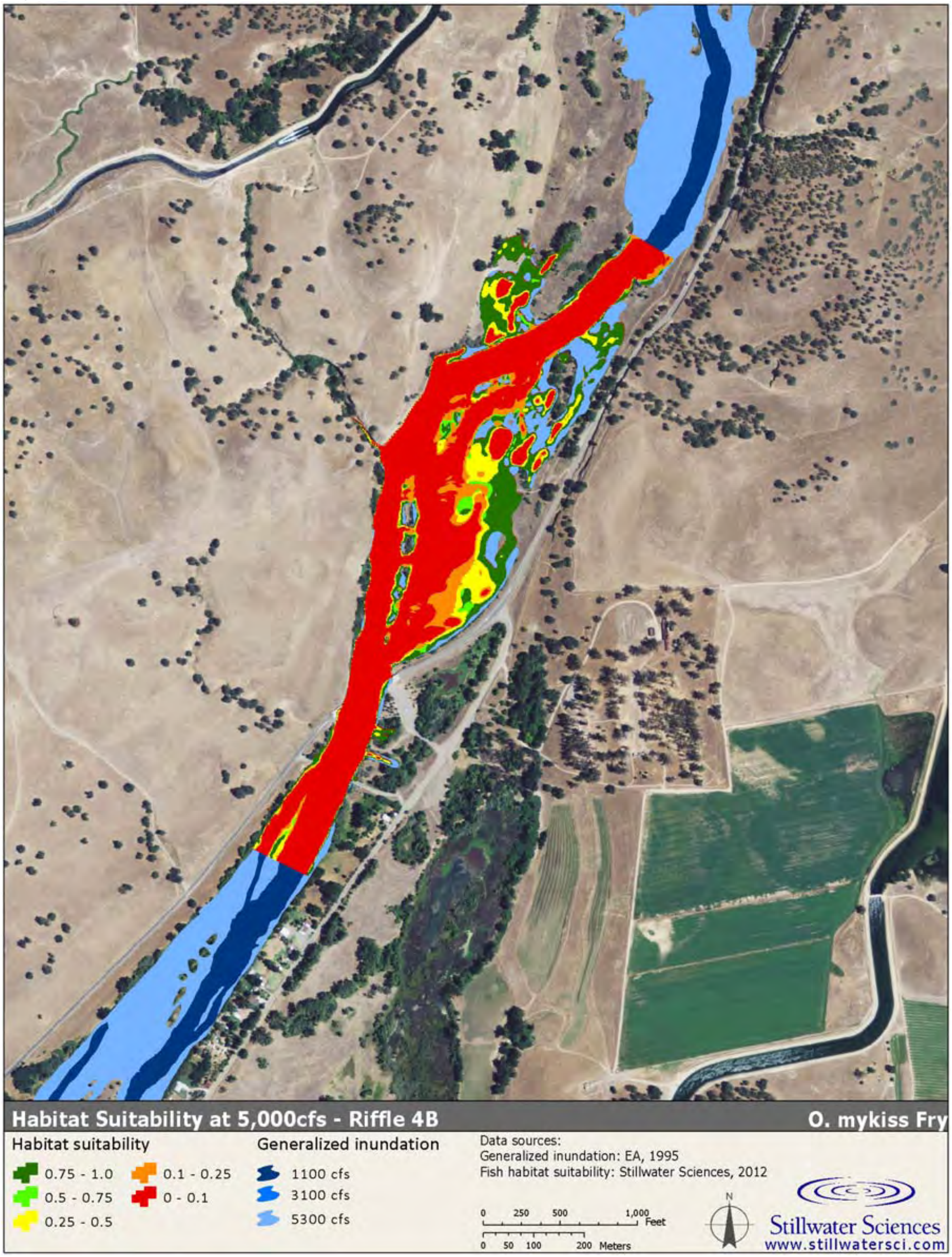


Figure C-75. Riffle 5A (Basso Br.) results at 5,000 cfs for Chinook salmon juveniles.

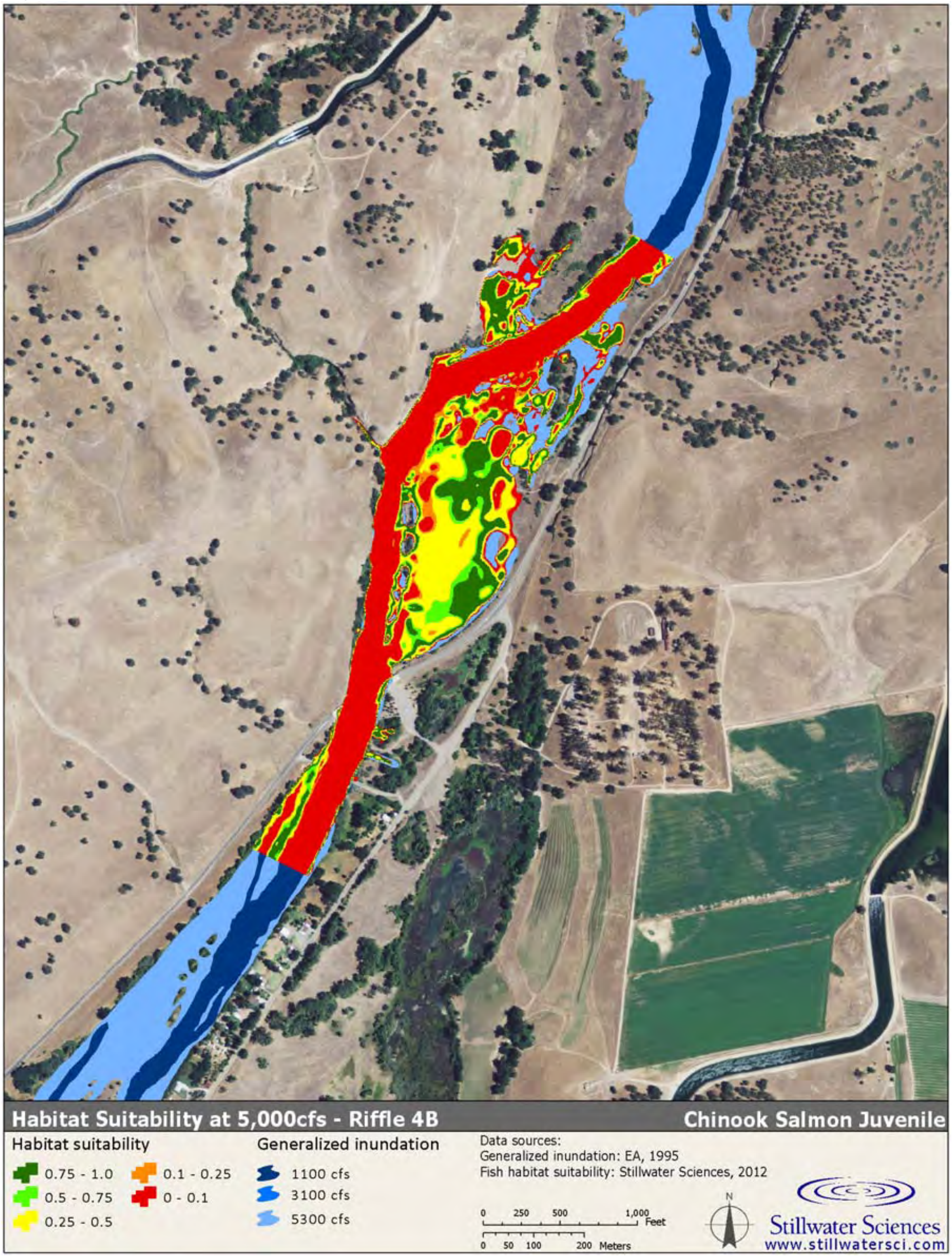


Figure C-76. Riffle 5A (Basso Br.) results at 5,000 cfs for *O. mykiss* juveniles.

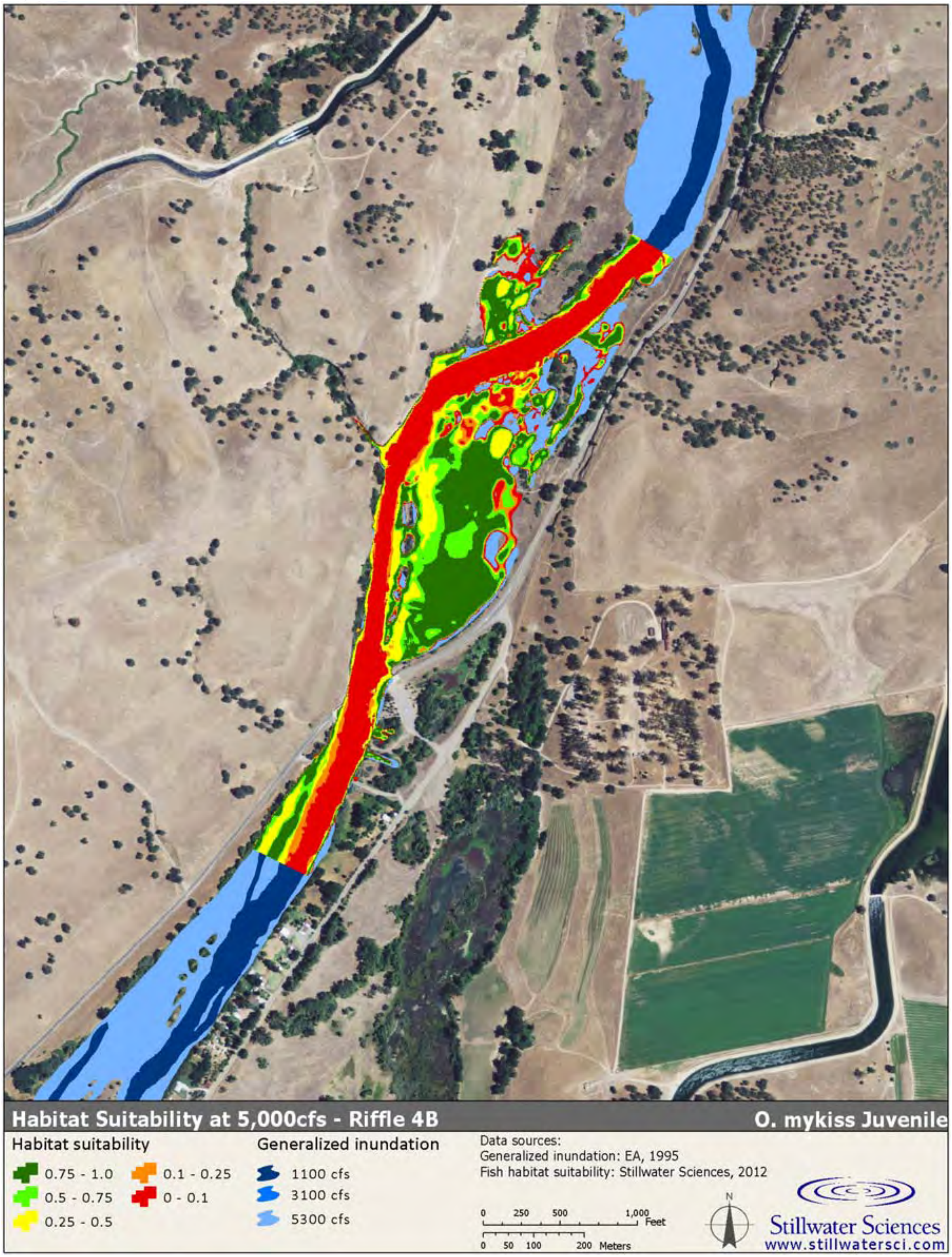


Figure C-77. Riffle 5A (Basso Br.) results at 5,000 cfs for smallmouth bass adults.

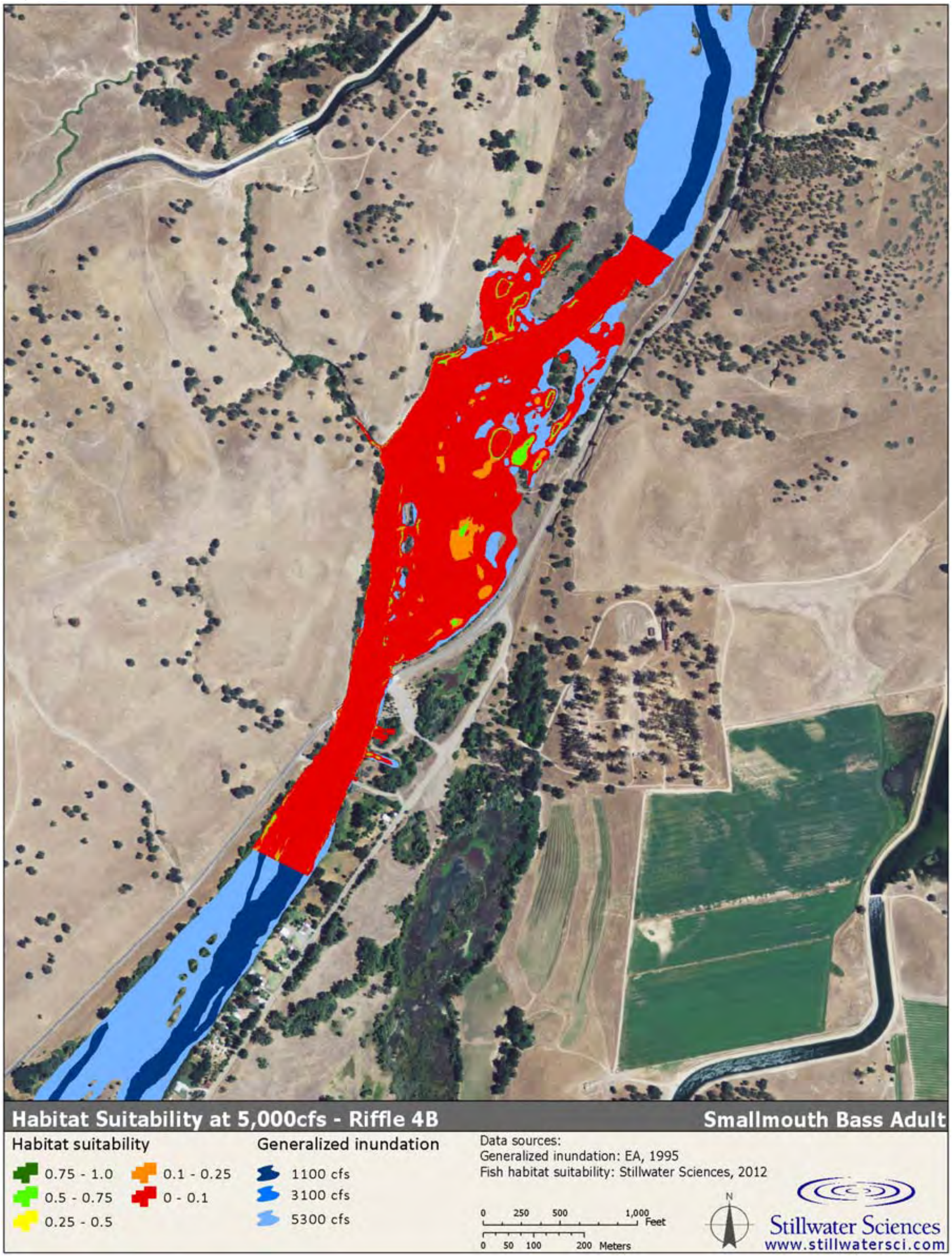


Figure C-78. Riffle 5A (Basso Br.) results at 5,000 cfs for largemouth bass adults.

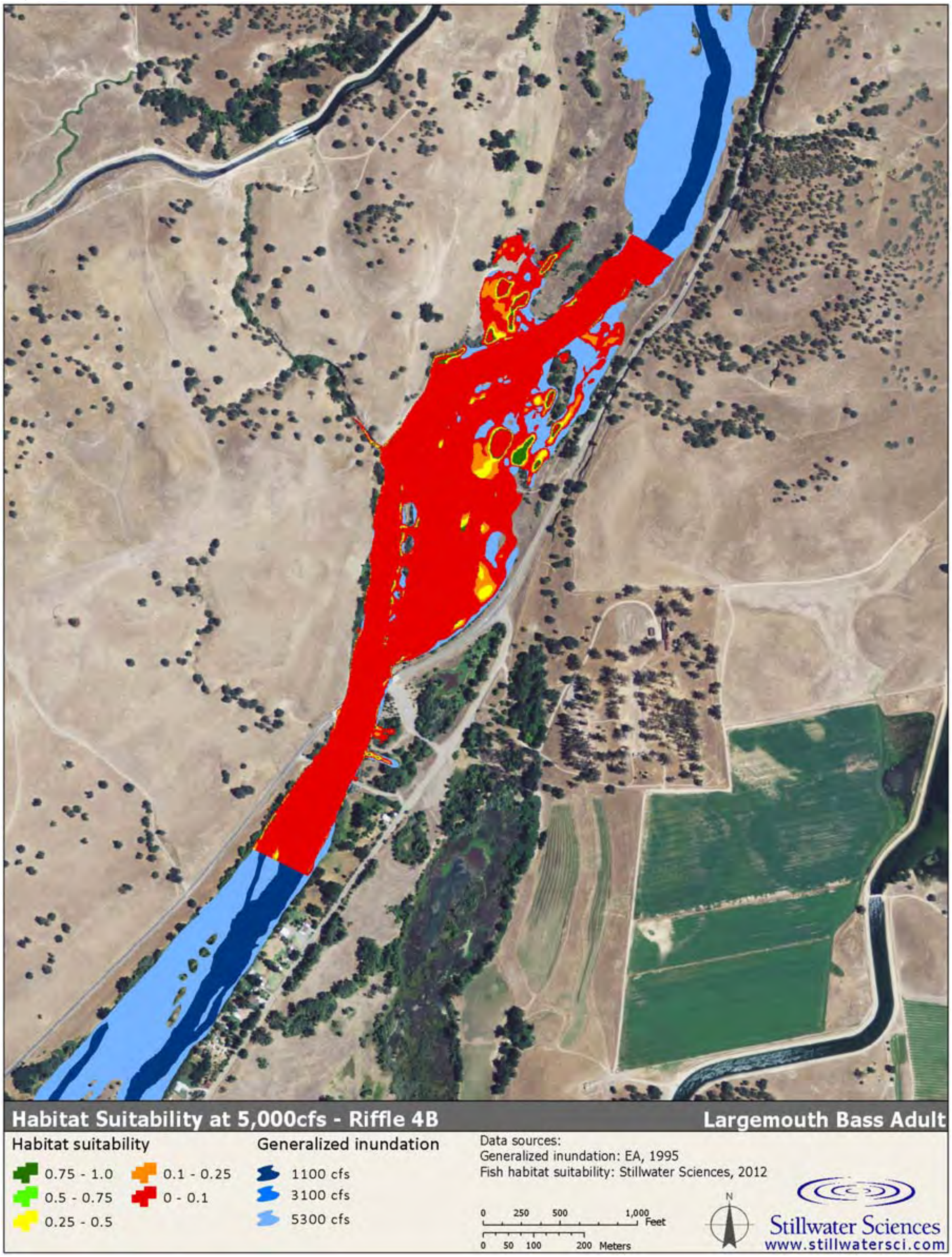


Figure C-79. Riffle 5A (Basso Br.) results at 5,000 cfs for Sacramento pikeminnow adults.

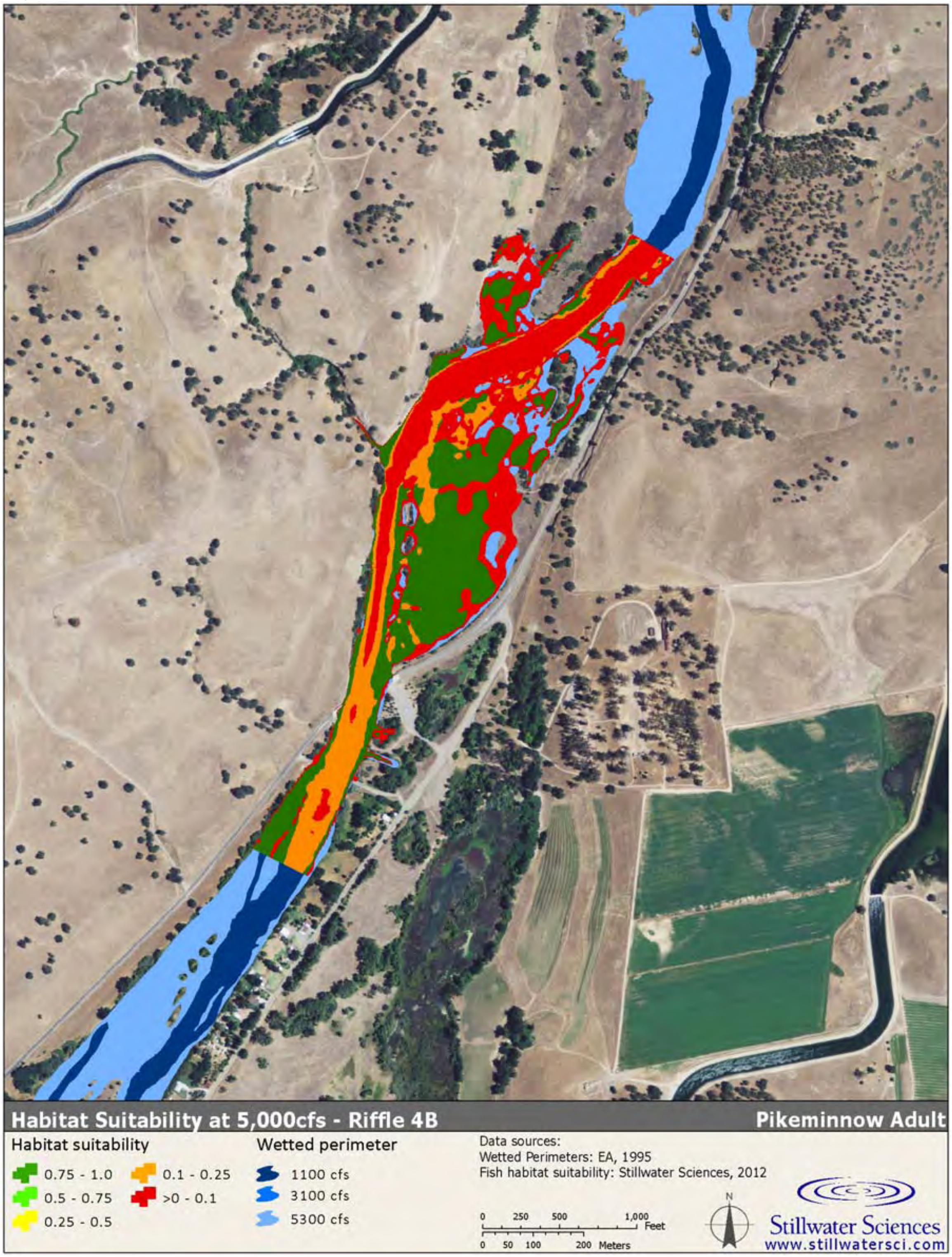


Figure C-80. Riffle 5A (Basso Br.) results at 5,000 cfs for striped bass adults.

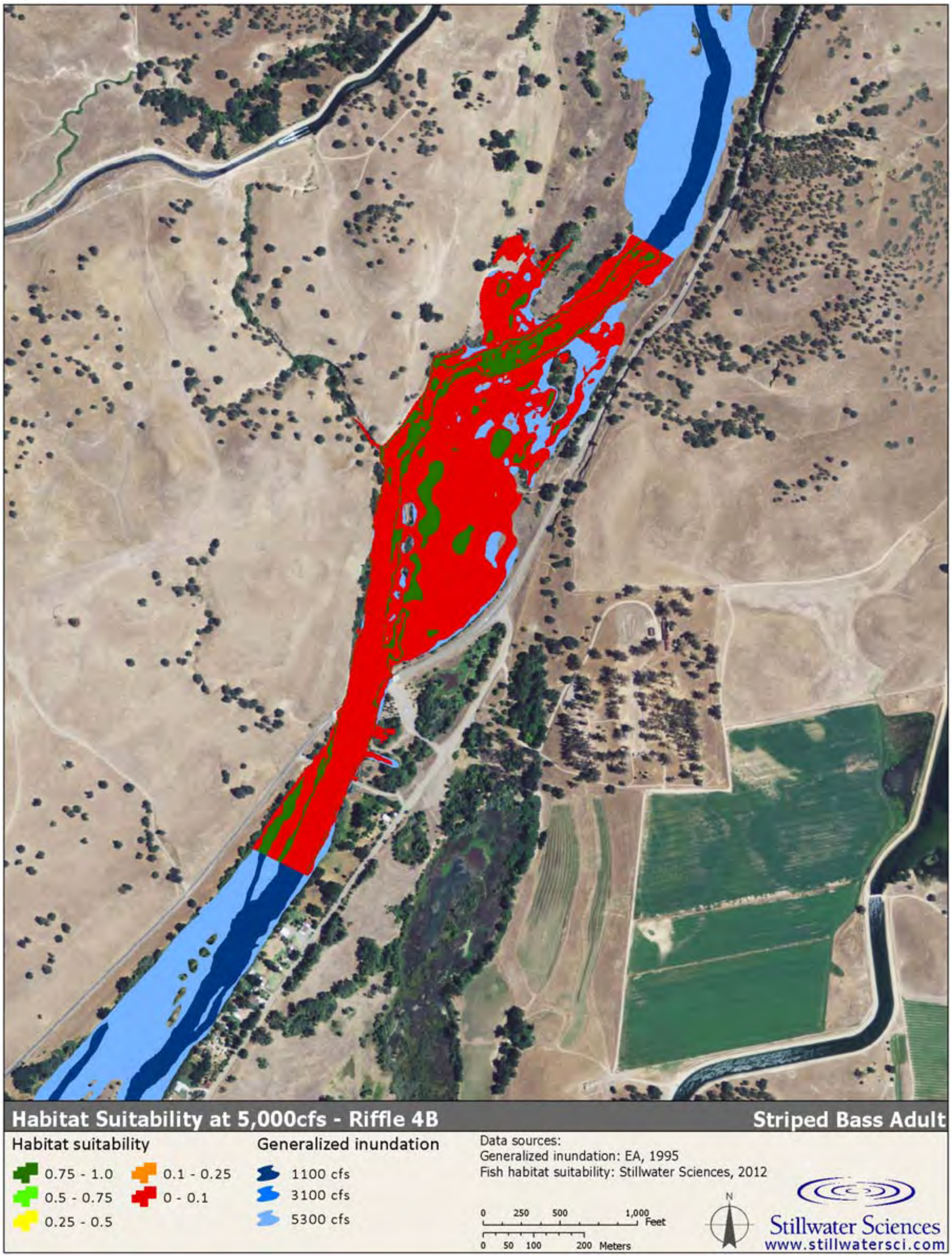


Figure C-81. Bobcat Flat/Zanker property results 1,000 cfs for Chinook salmon fry.

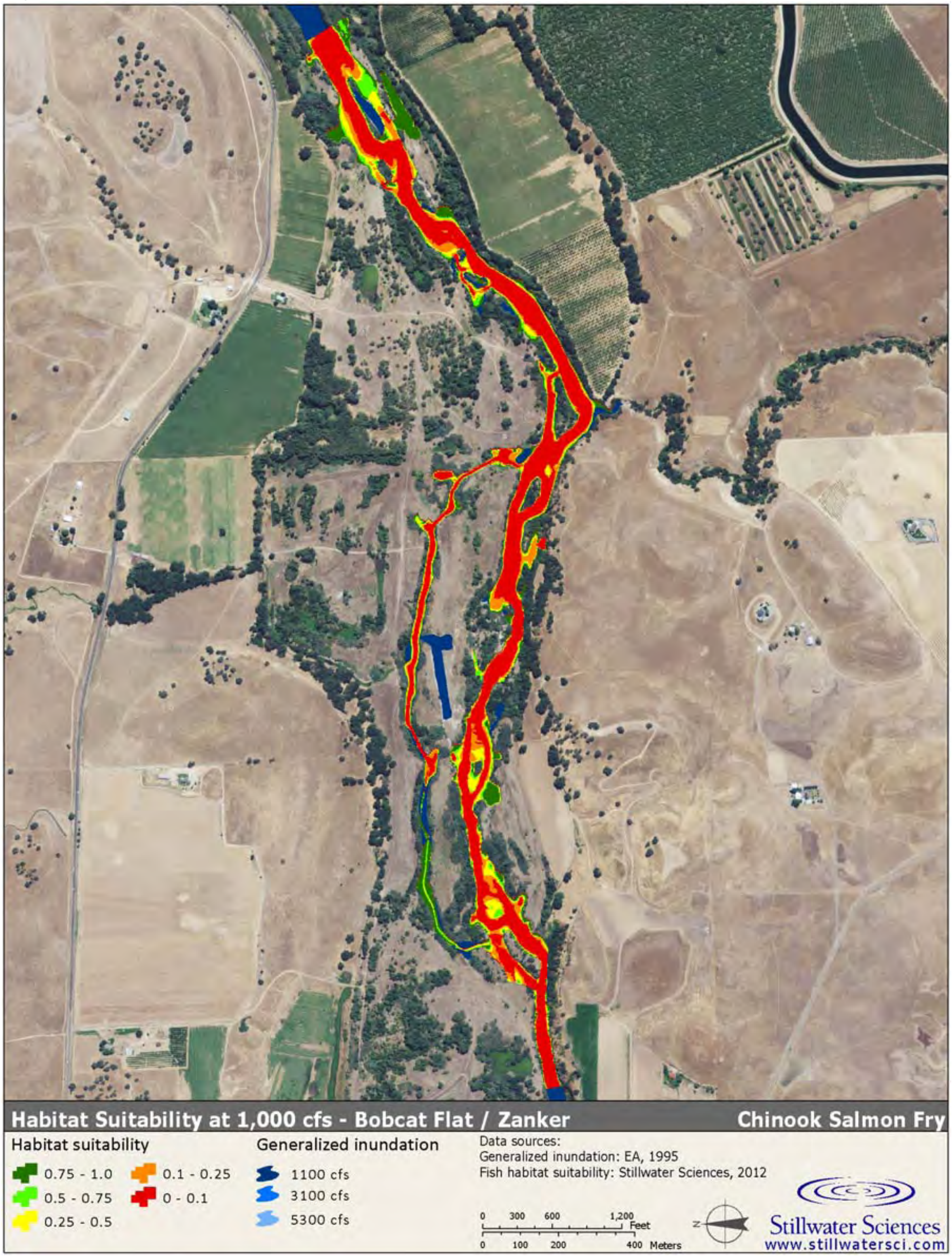


Figure C-82. Bobcat Flat/Zanker property results 1,000 cfs for *O. mykiss* fry.

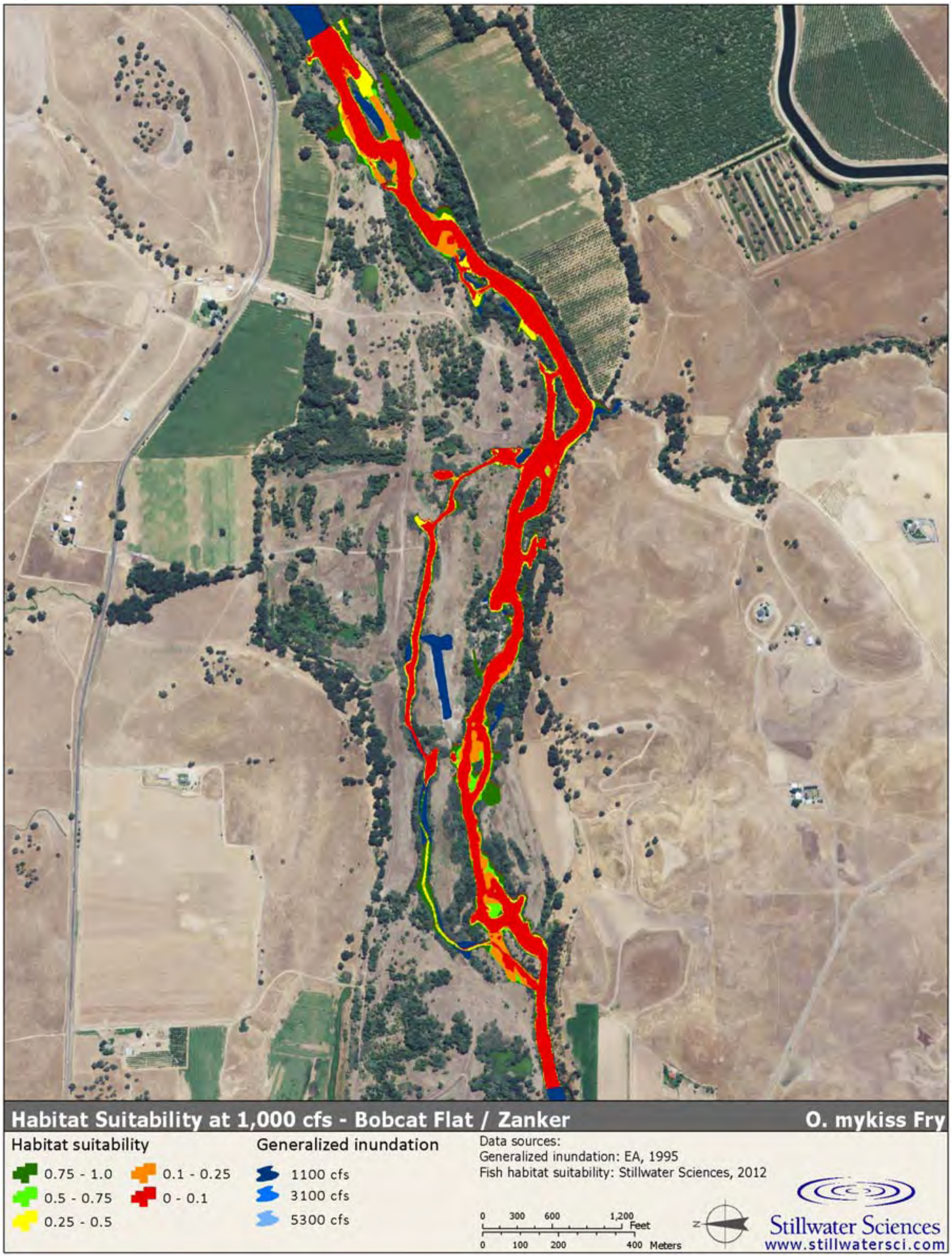


Figure C-83. Bobcat Flat/Zanker property results 1,000 cfs for Chinook salmon juveniles.

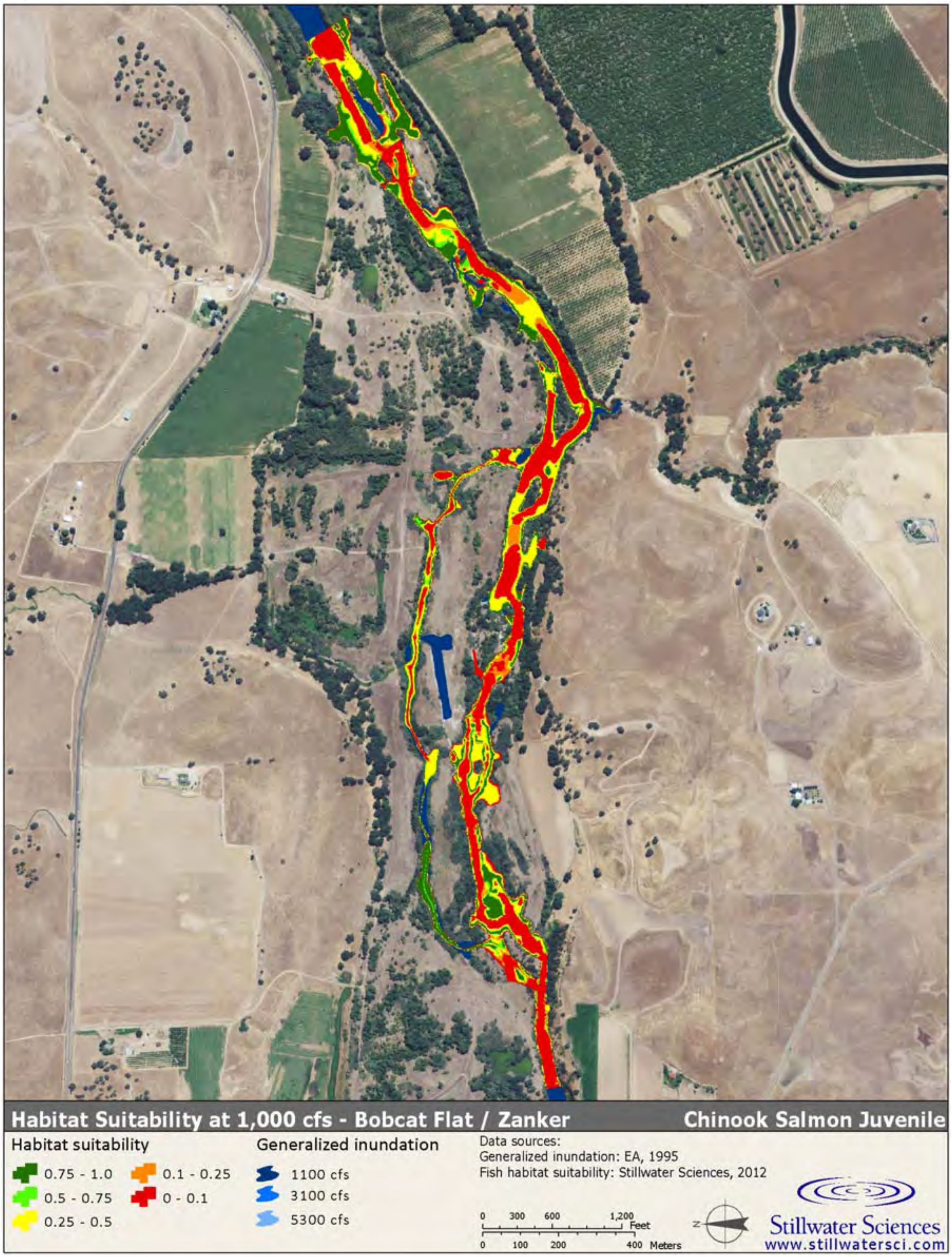


Figure C-84. Bobcat Flat/Zanker property results 1,000 cfs for *O. mykiss* juveniles.

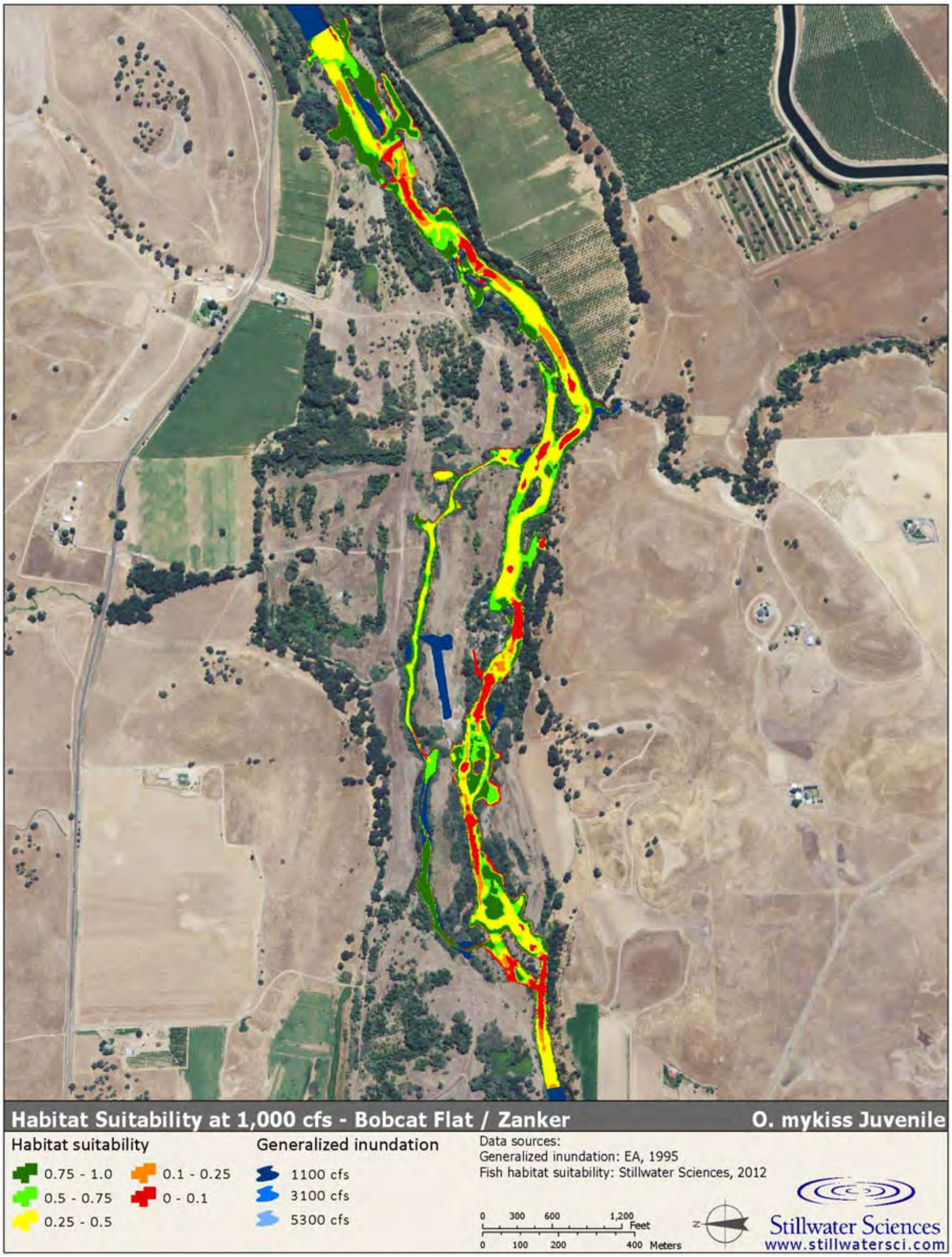


Figure C-85. Bobcat Flat/Zanker property results 1,000 cfs for smallmouth bass adults.

Figure C-86. Bobcat Flat/Zanker property results 1,000 cfs for largemouth bass adults.

Figure C-87. Bobcat Flat/Zanker property results 1,000 cfs for Sacramento pikeminnow adults.

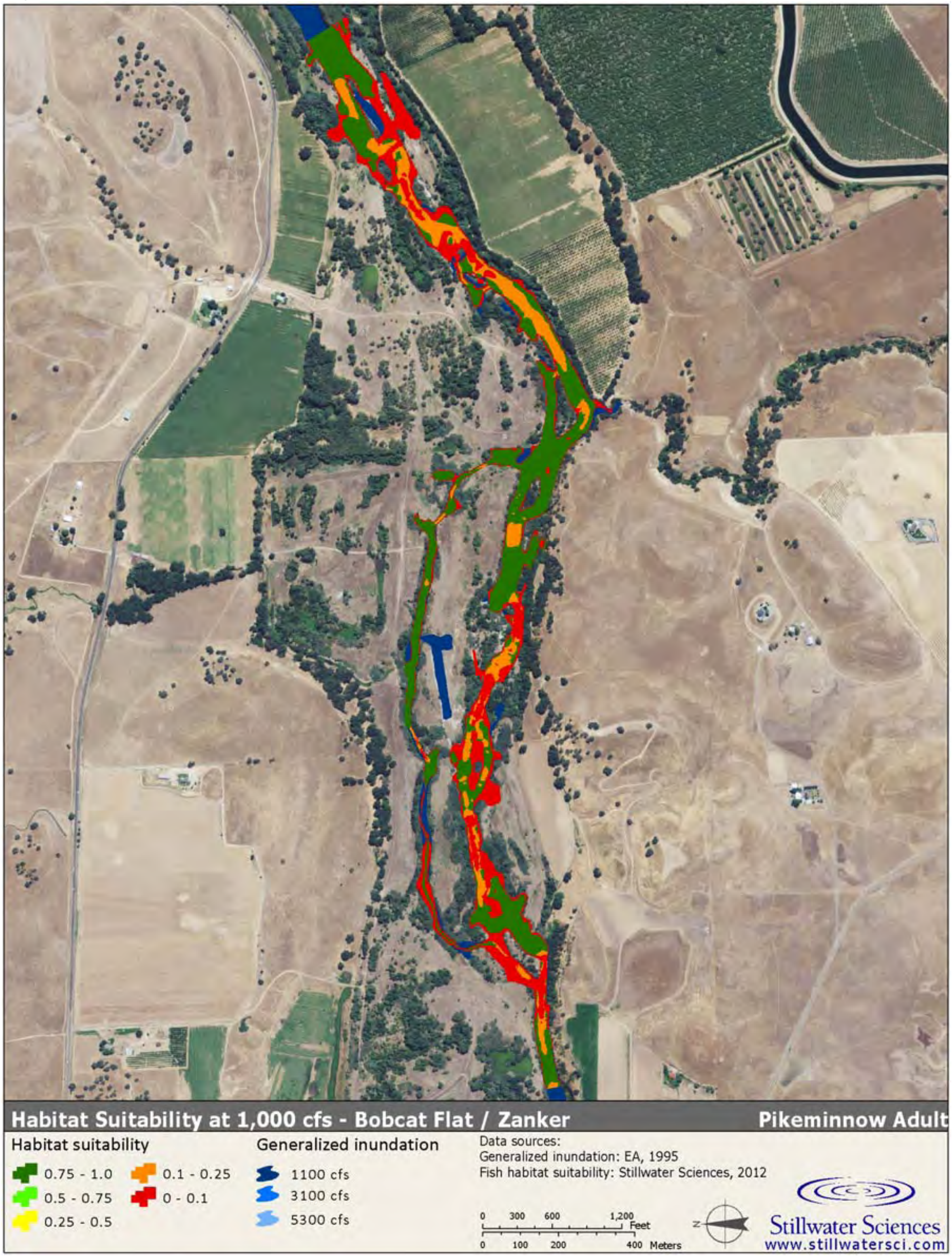


Figure C-88. Bobcat Flat/Zanker property results 1,000 cfs for striped bass adults.

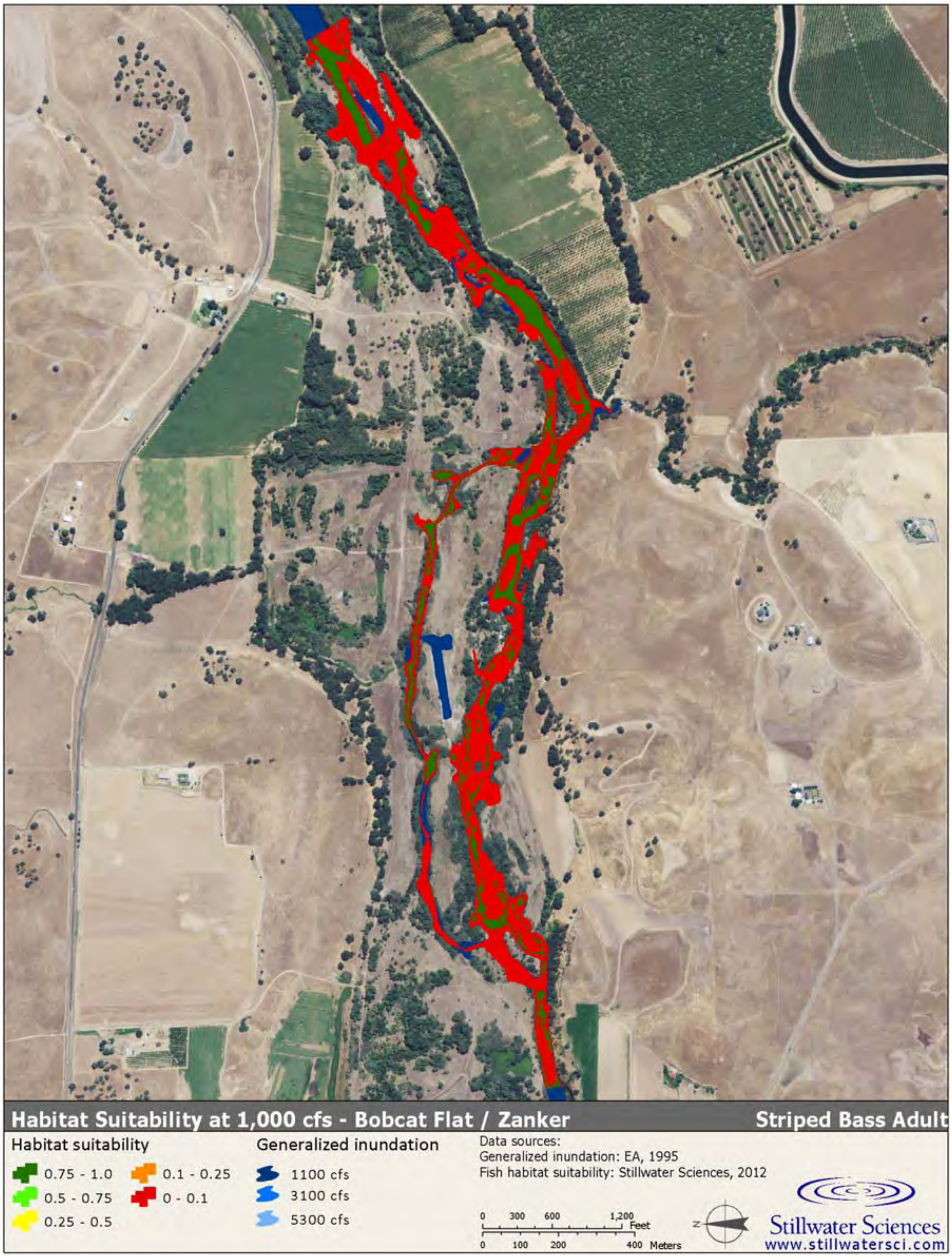


Figure C-89. Bobcat Flat/Zanker property results 1,600 cfs for Chinook salmon fry.

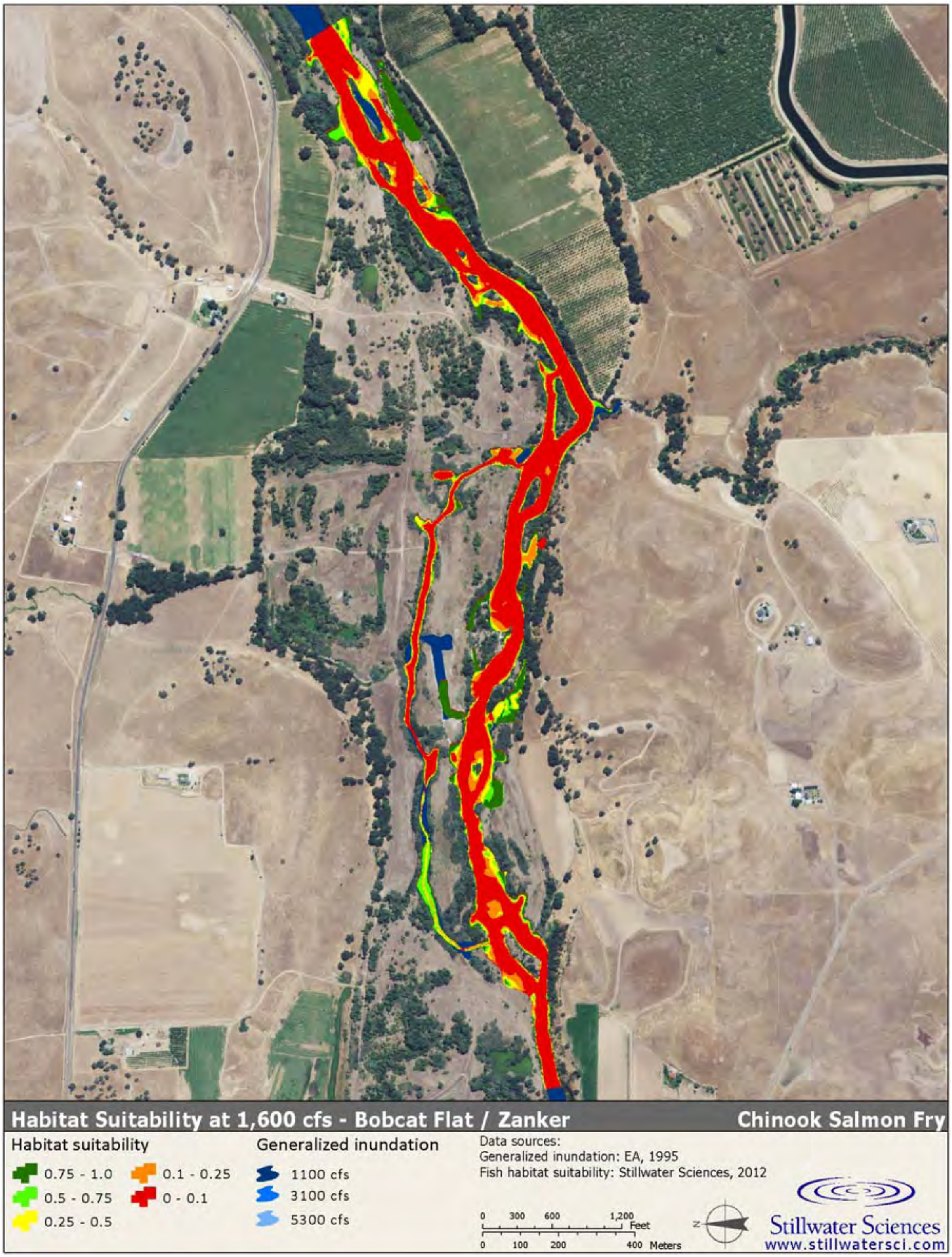


Figure C-90. Bobcat Flat/Zanker property results 1,600 cfs for *O. mykiss* fry.

Figure C-91. Bobcat Flat/Zanker property results 1,600 cfs for Chinook salmon juveniles.

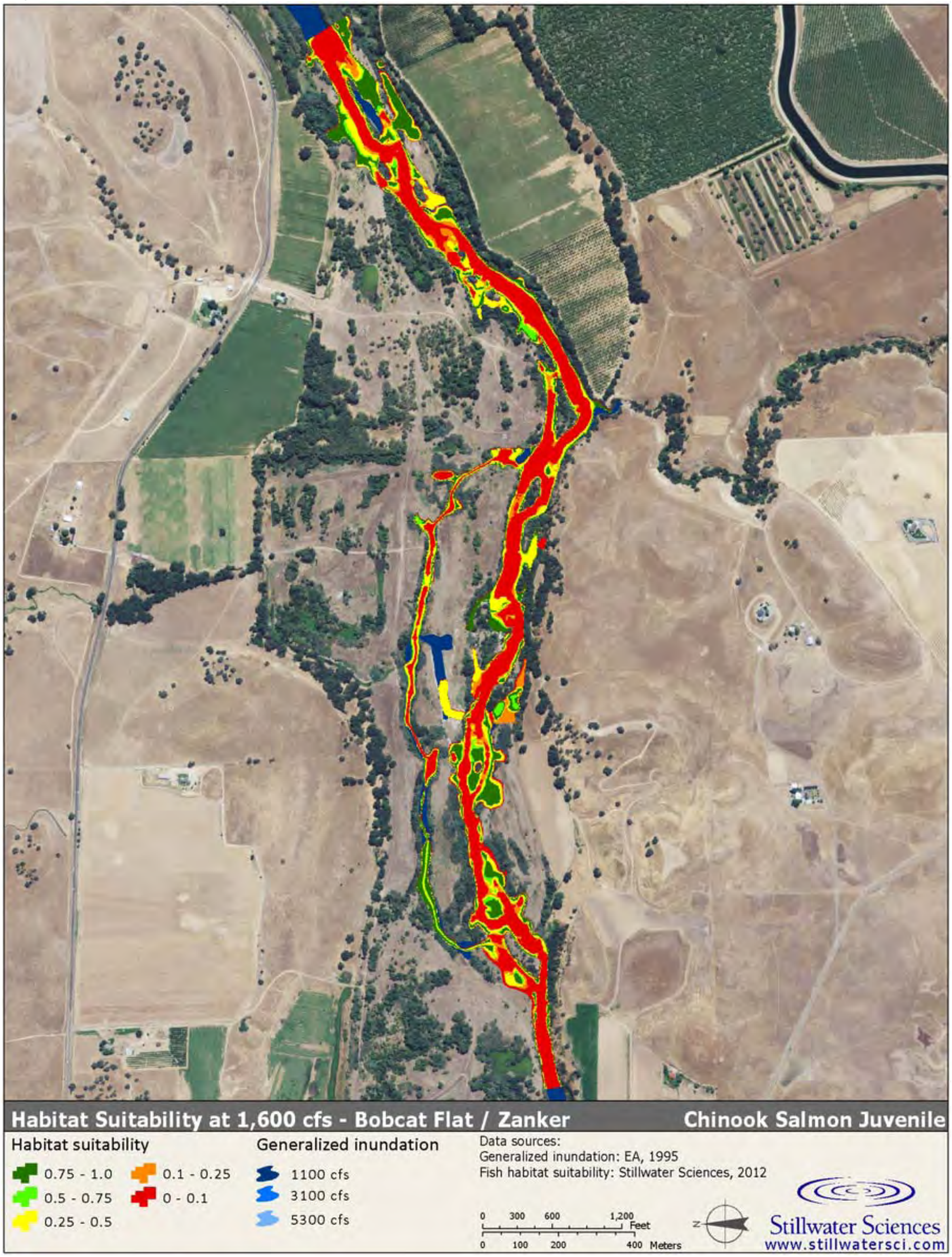


Figure C-92. Bobcat Flat/Zanker property results 1,600 cfs for *O. mykiss* juveniles.

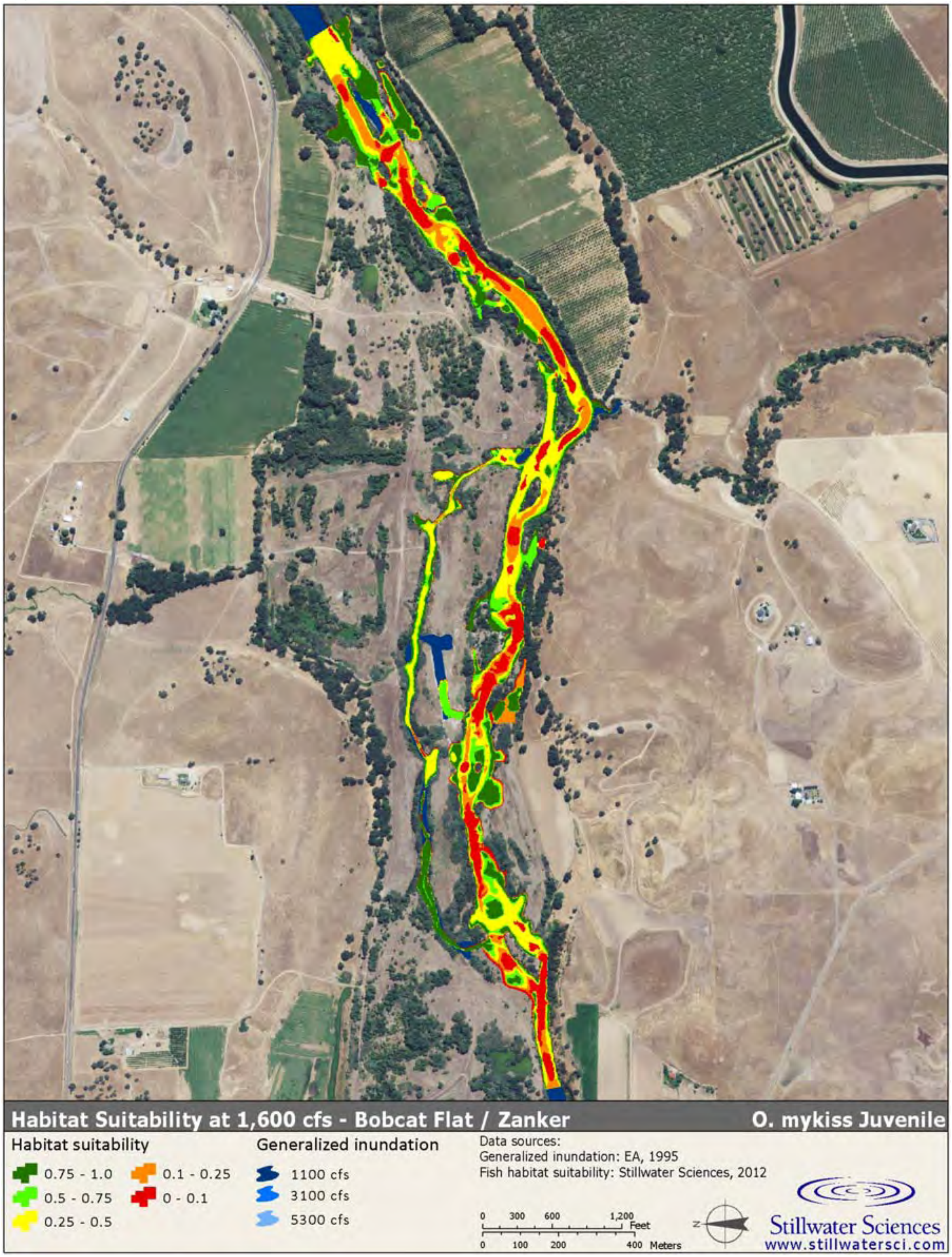


Figure C-93. Bobcat Flat/Zanker property results 1,600 cfs for smallmouth bass adults.

Figure C-94. Bobcat Flat/Zanker property results 1,600 cfs for largemouth bass adults.

Figure C-95. Bobcat Flat/Zanker property results 1,600 cfs for Sacramento pikeminnow adults.

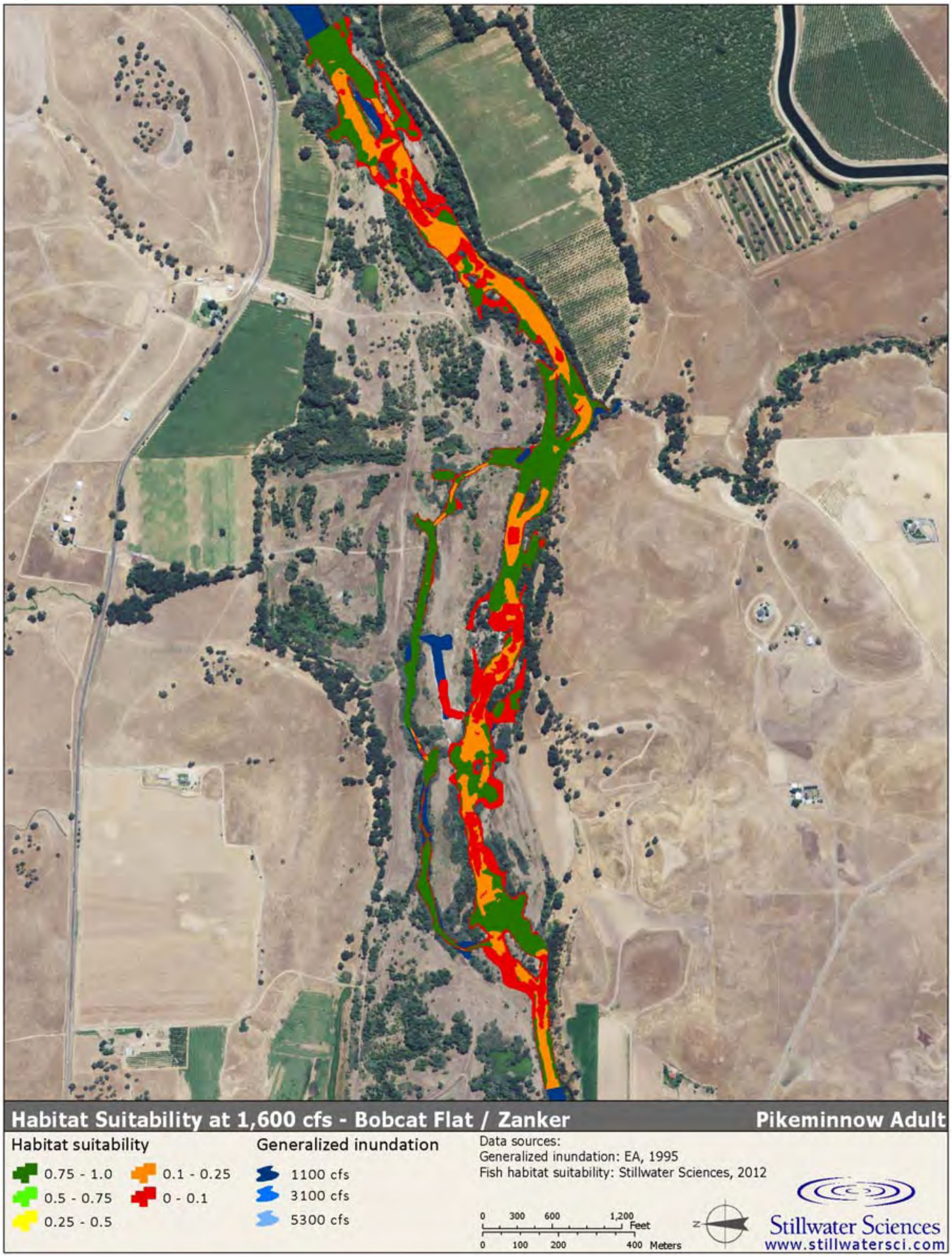


Figure C-96. Bobcat Flat/Zanker property results 1,600 cfs for striped bass adults.

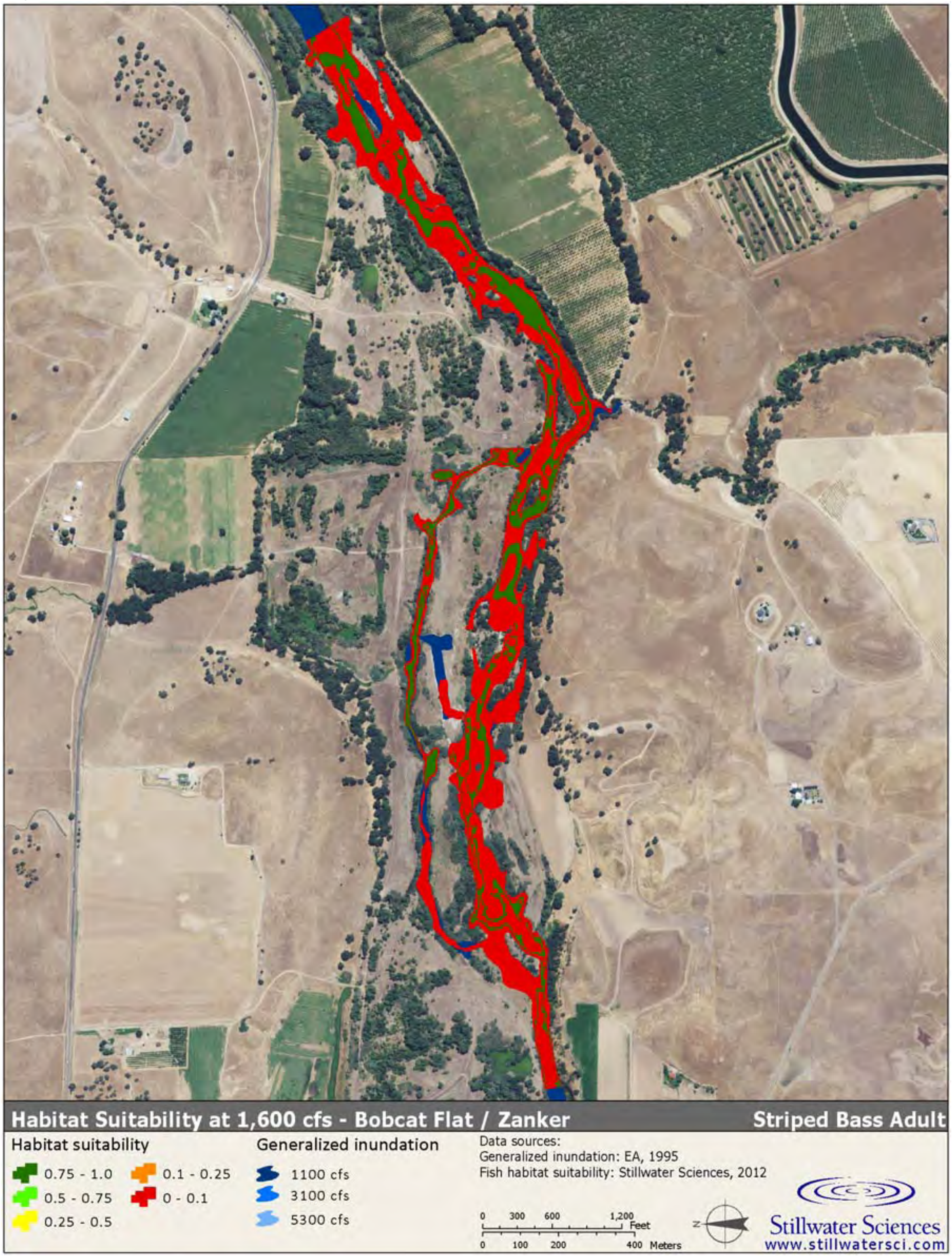


Figure C-97. Bobcat Flat/Zanker property results 2,600 cfs for Chinook salmon fry.

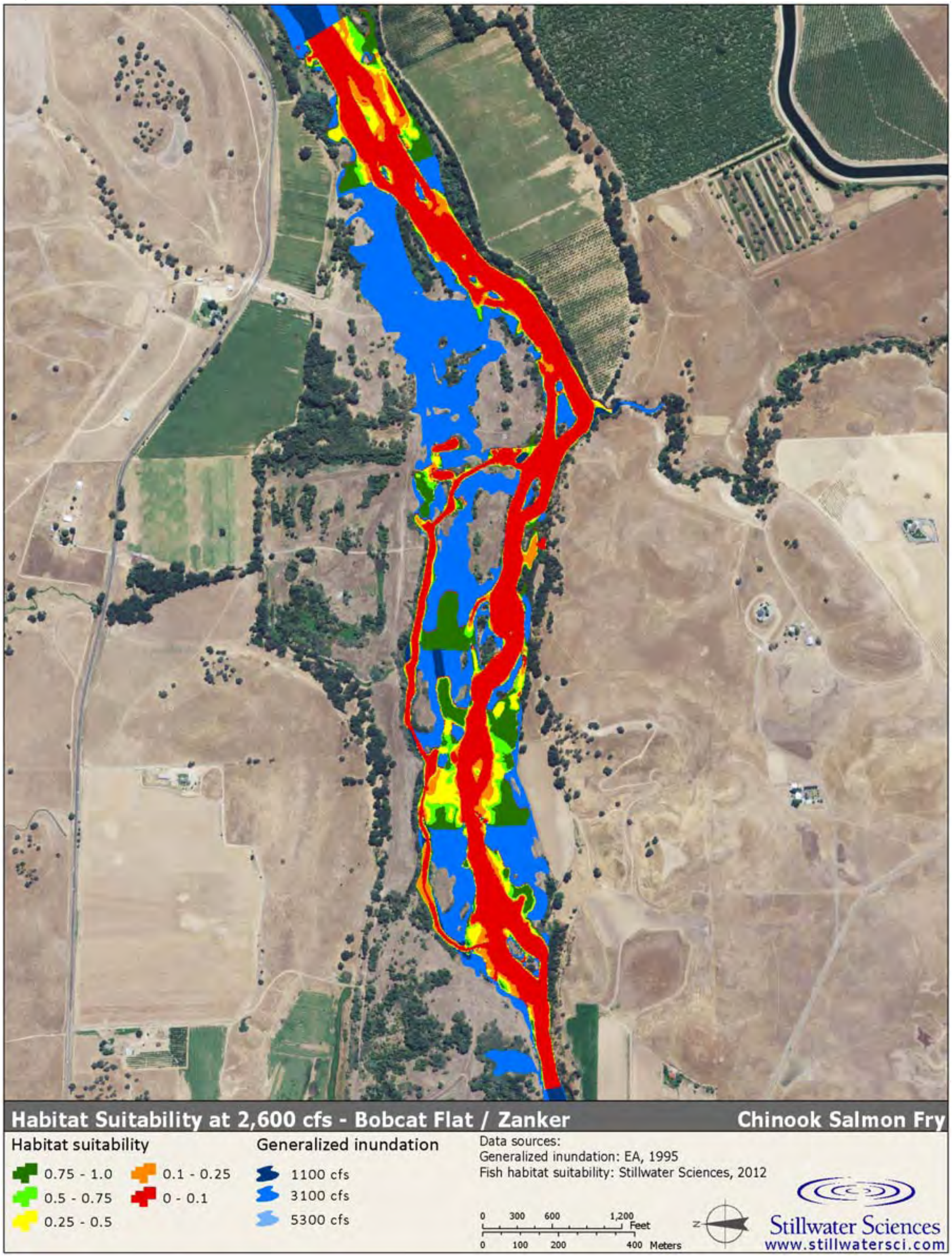


Figure C-98. Bobcat Flat/Zanker property results 2,600 cfs for *O. mykiss* fry.

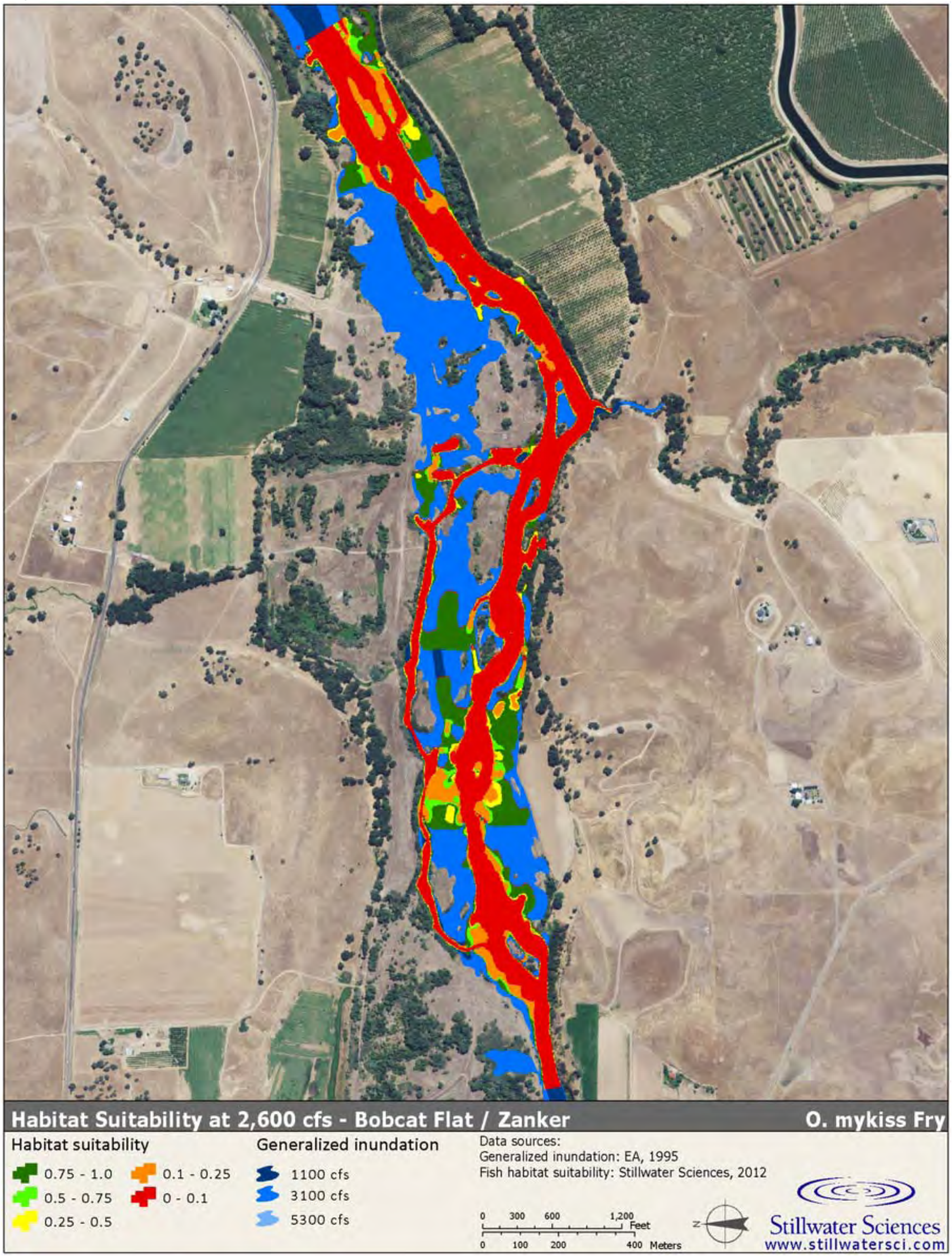


Figure C-99. Bobcat Flat/Zanker property results 2,600 cfs for Chinook salmon juveniles.

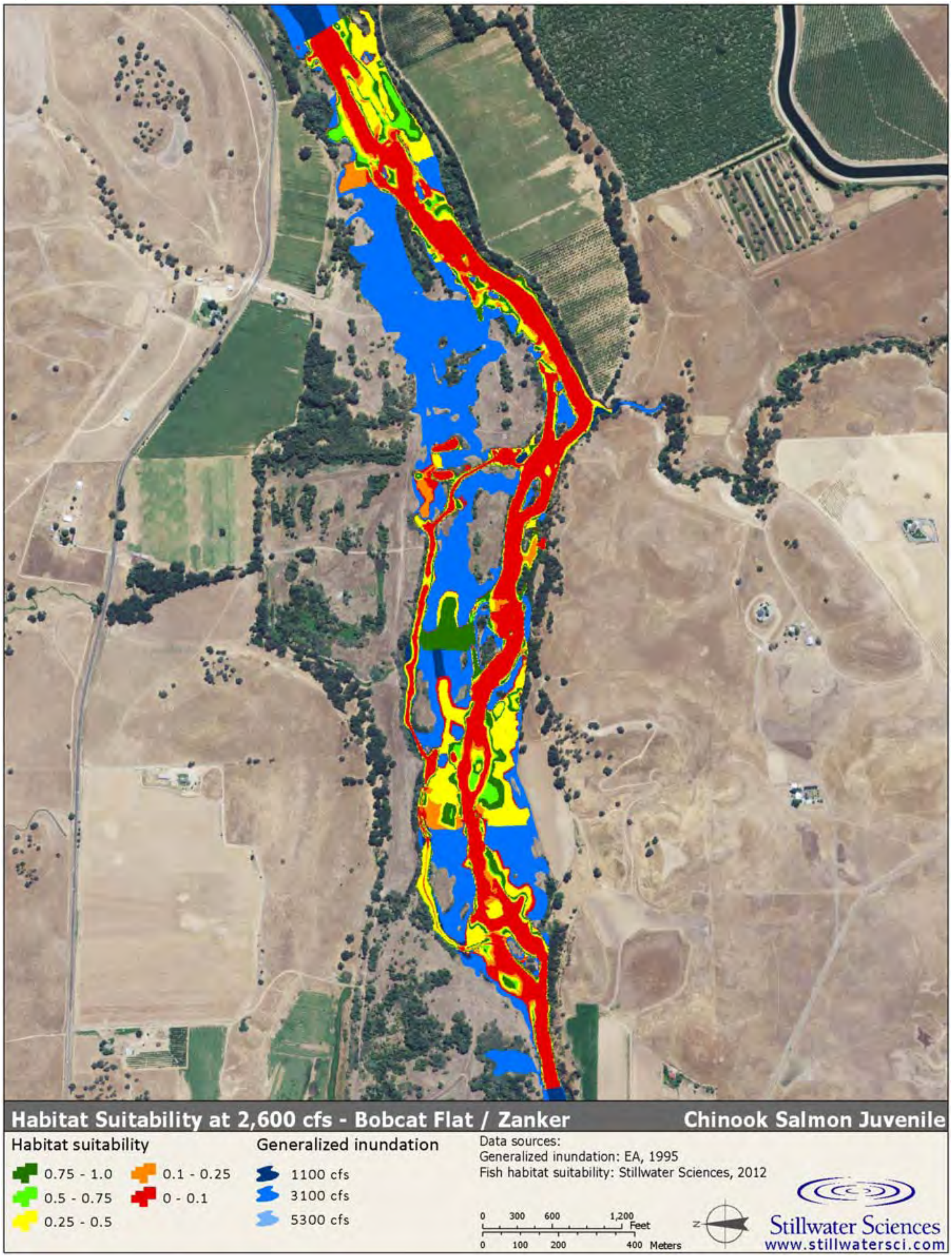


Figure C-100. Bobcat Flat/Zanker property results 2,600 cfs for *O. mykiss* juveniles.

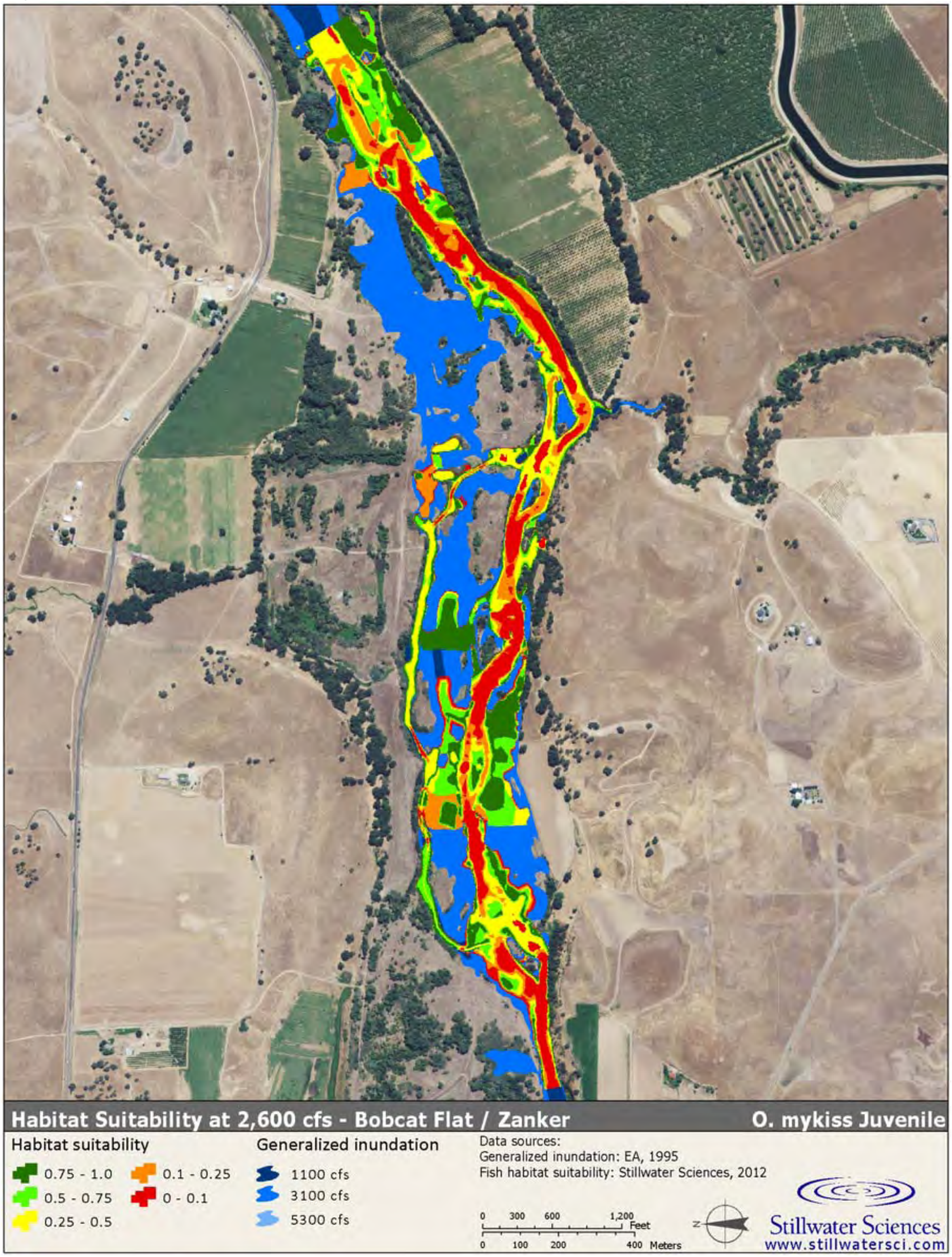


Figure C-101. Bobcat Flat/Zanker property results 2,600 cfs for smallmouth bass adults.

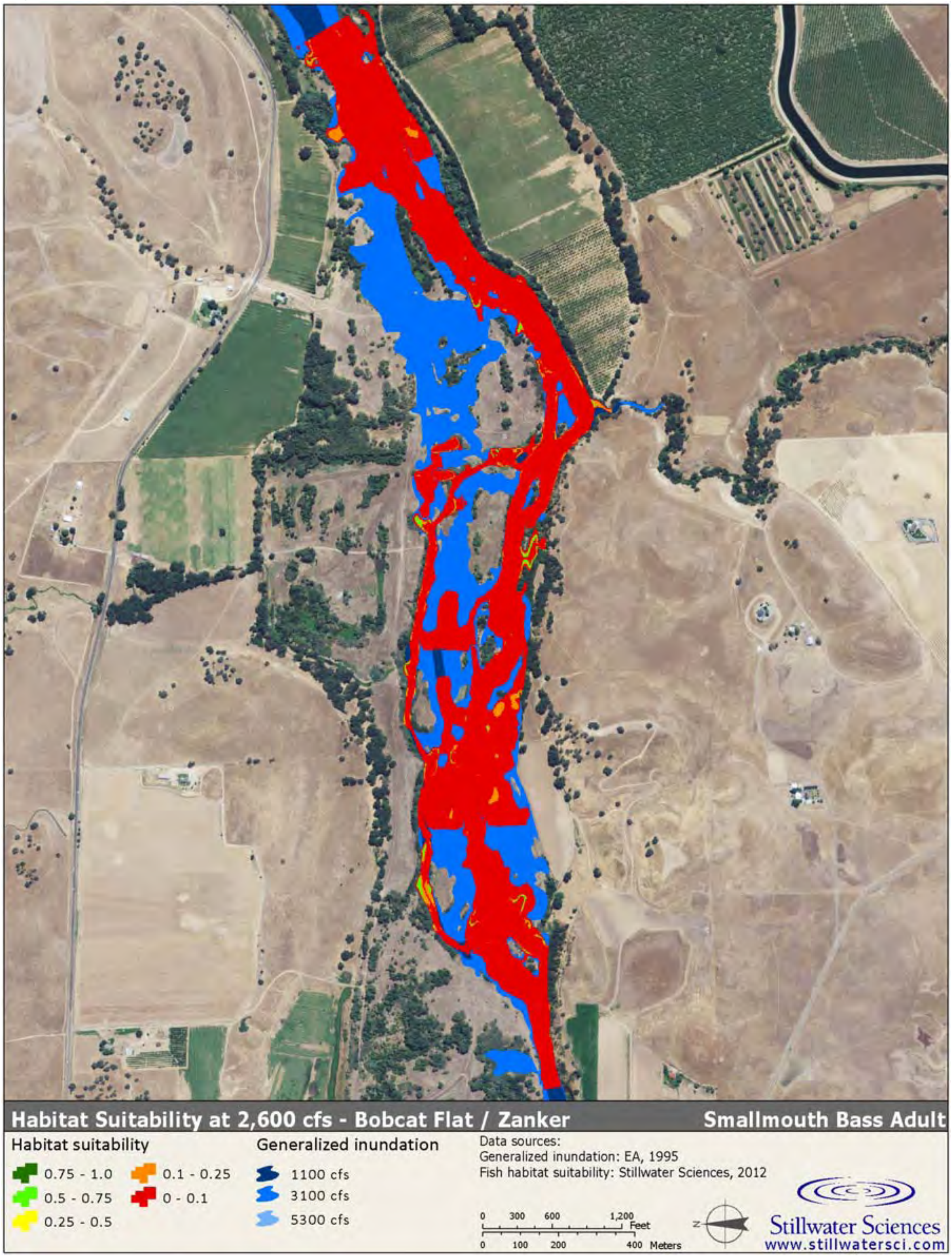


Figure C-102. Bobcat Flat/Zanker property results 2,600 cfs for largemouth bass adults.

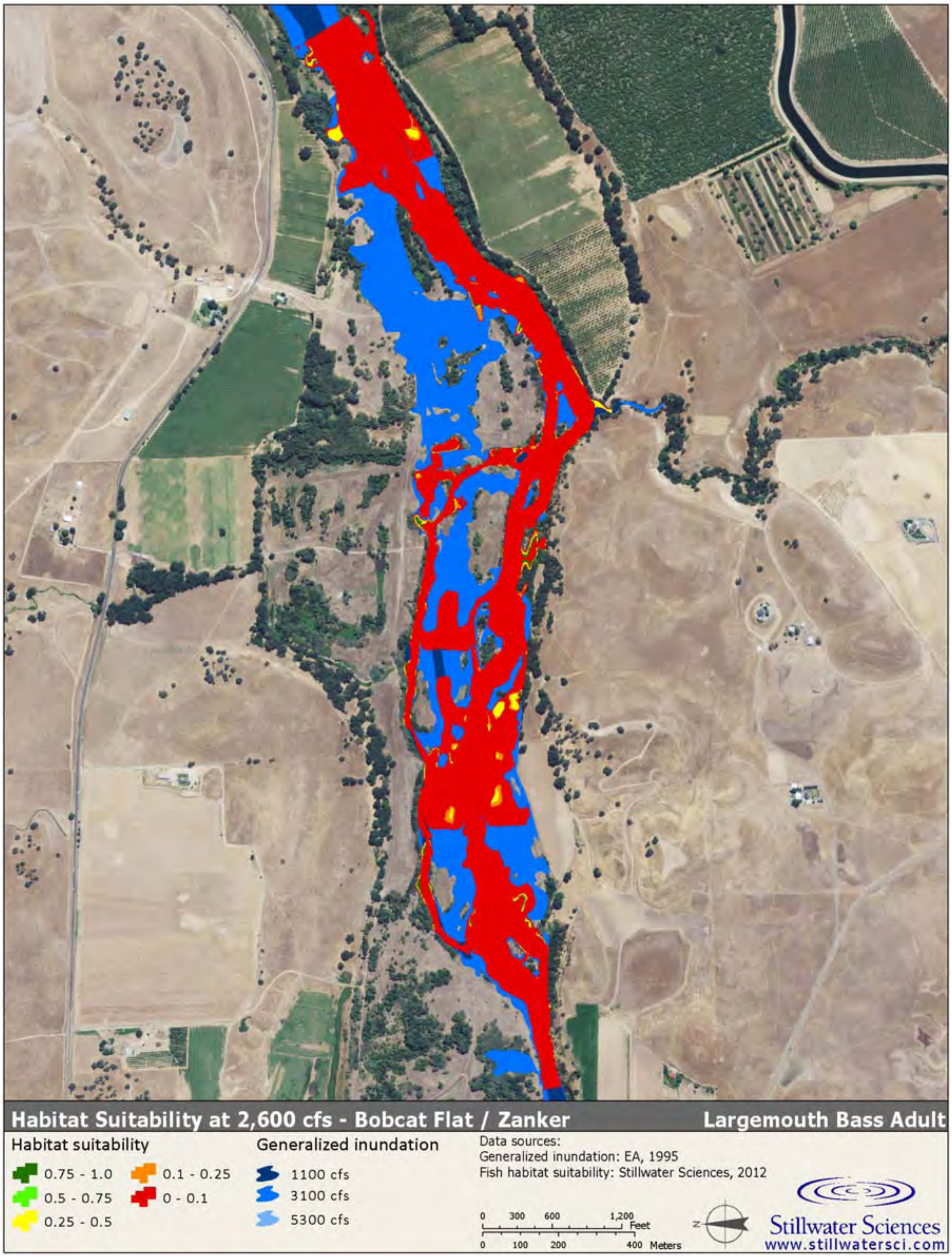


Figure C-103. Bobcat Flat/Zanker property results 2,600 cfs for Sacramento pikeminnow adults.

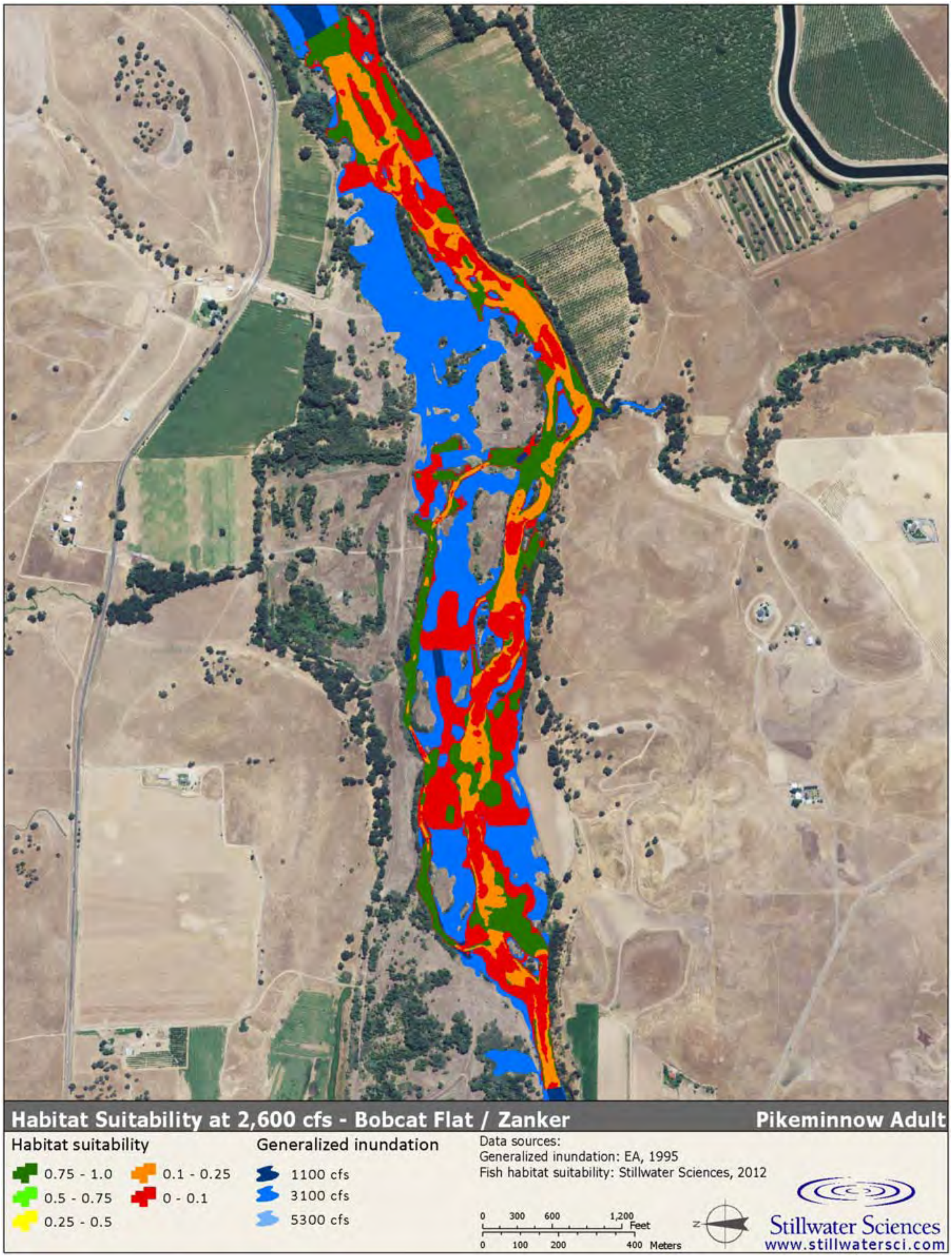


Figure C-104. Bobcat Flat/Zanker property results 2,600 cfs for striped bass adults.

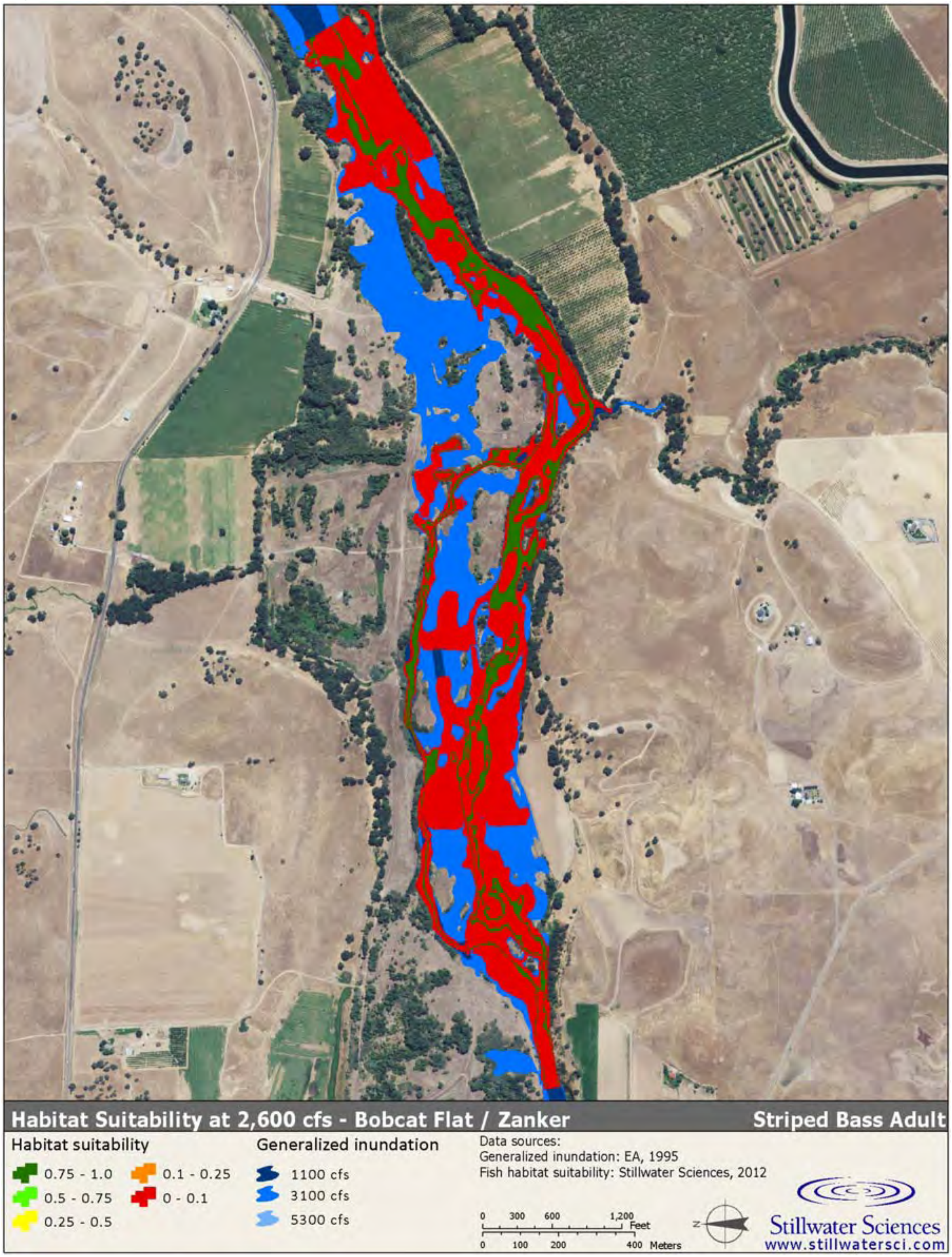


Figure C-105. Bobcat Flat/Zanker property results 3,000 cfs for Chinook salmon fry.

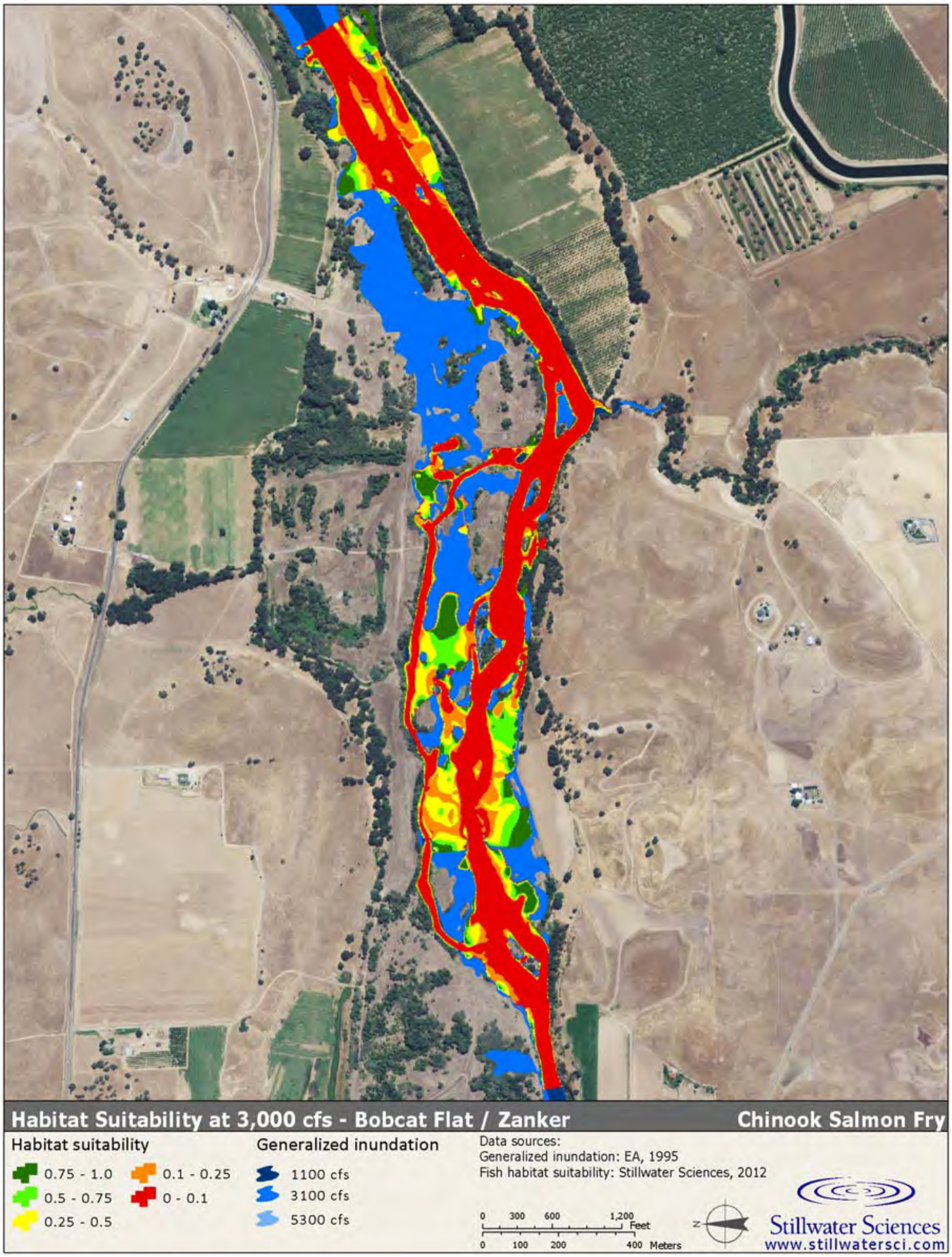


Figure C-106. Bobcat Flat/Zanker property results 3,000 cfs for *O. mykiss* fry.

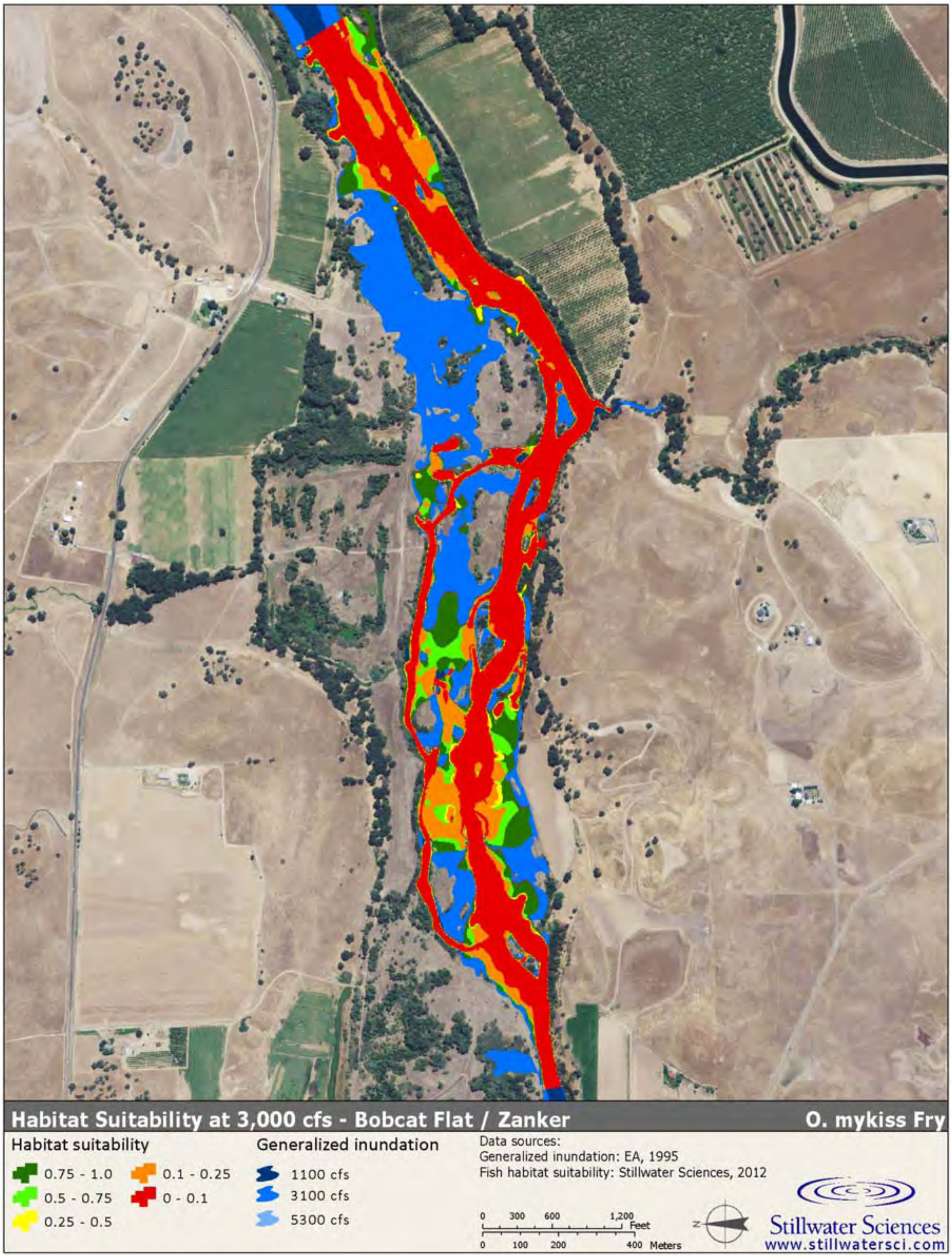


Figure C-107. Bobcat Flat/Zanker property results 3,000 cfs for Chinook salmon juveniles.

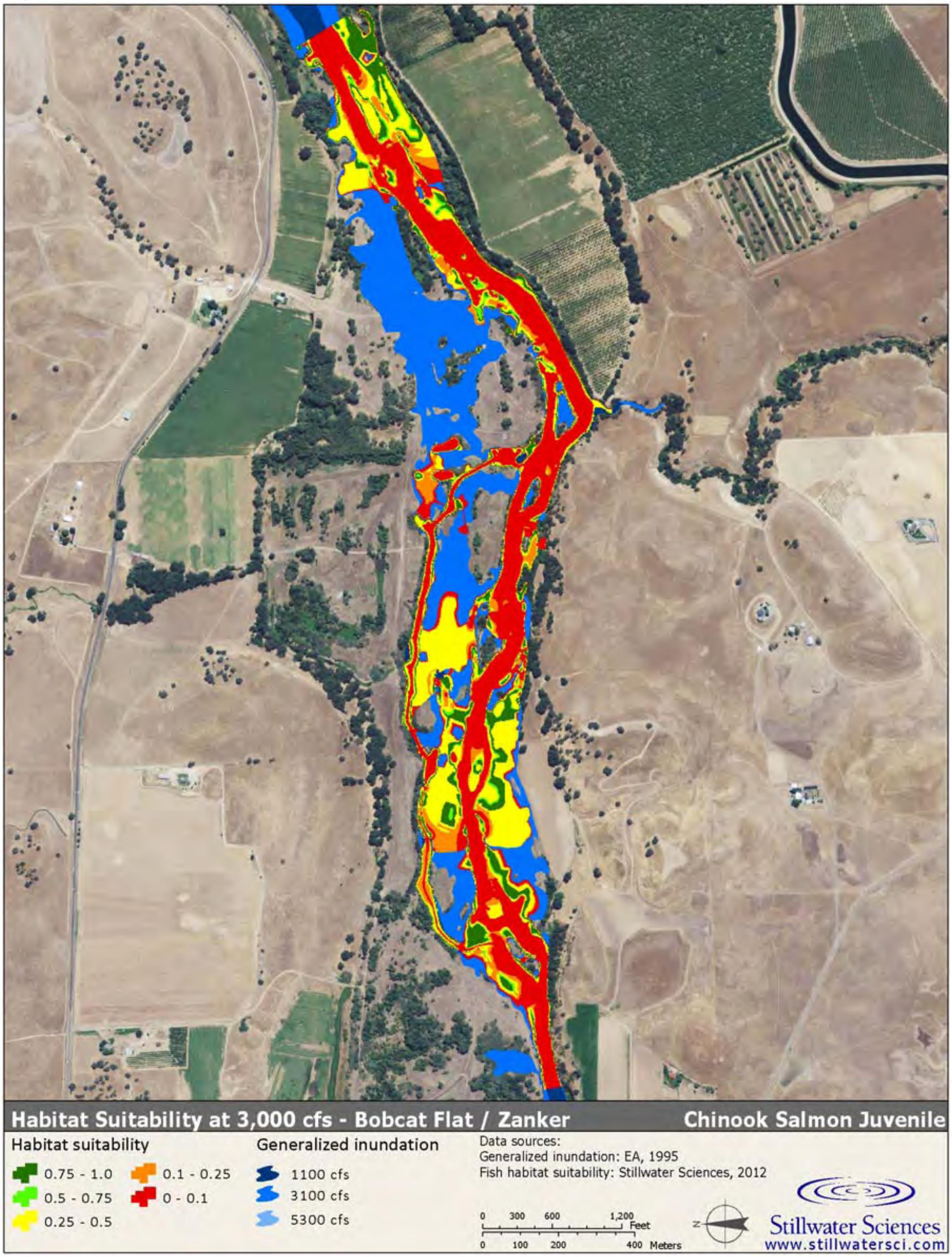


Figure C-108. Bobcat Flat/Zanker property results 3,000 cfs for *O. mykiss* juveniles.

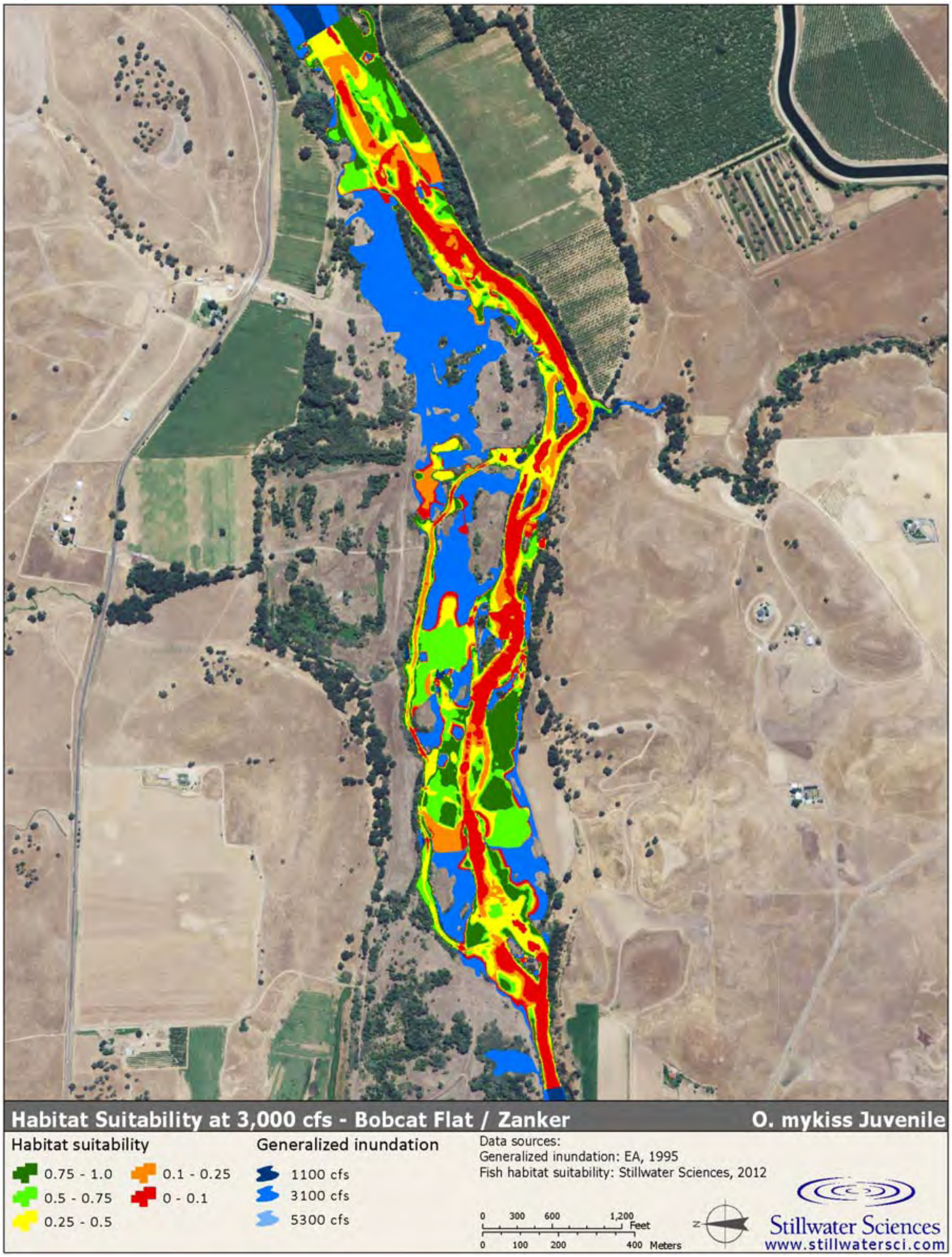


Figure C-109. Bobcat Flat/Zanker property results 3,000 cfs for smallmouth bass adults.

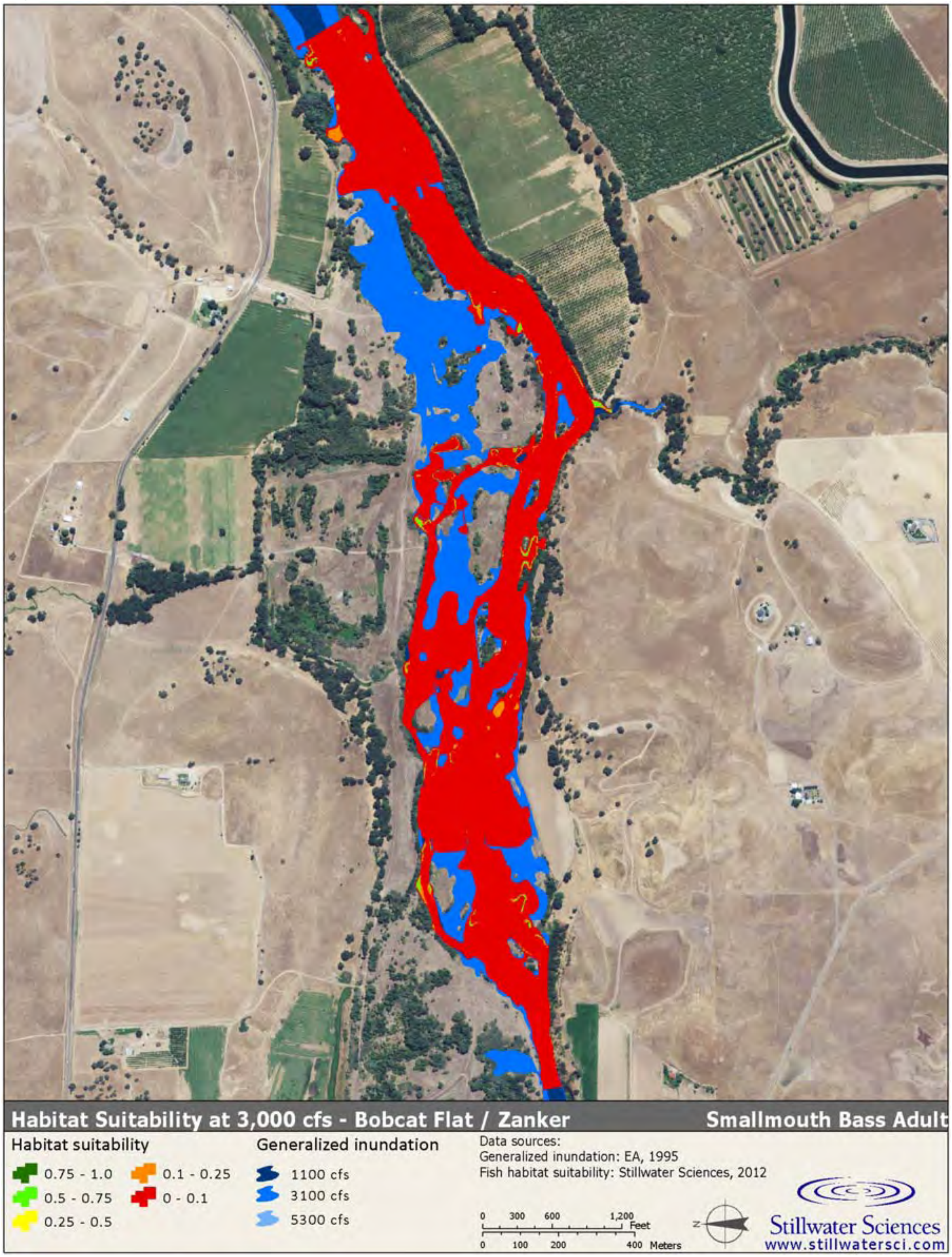


Figure C-110. Bobcat Flat/Zanker property results 3,000 cfs for largemouth bass adults.

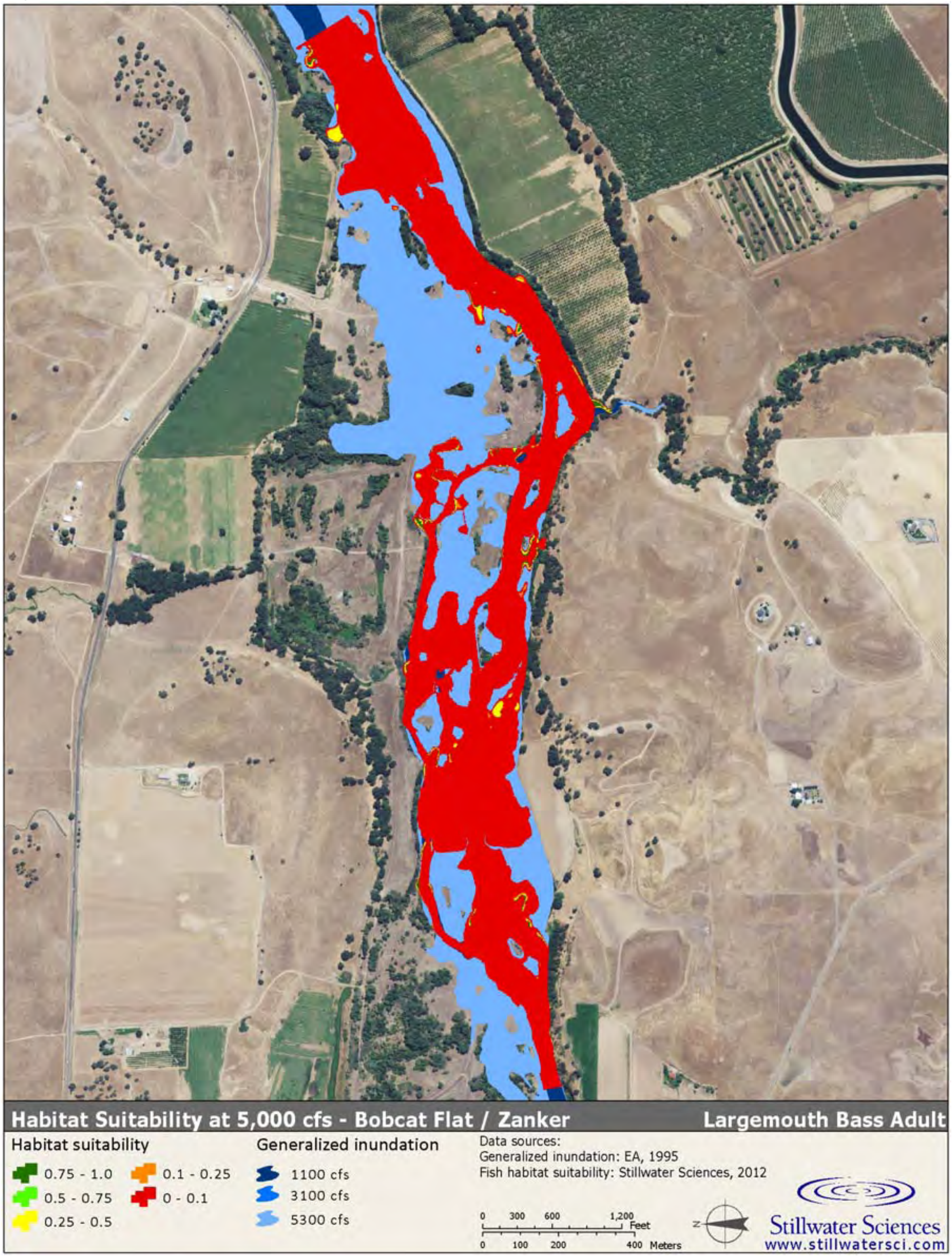


Figure C-111. Bobcat Flat/Zanker property results 3,000 cfs for Sacramento pikeminnow adults.

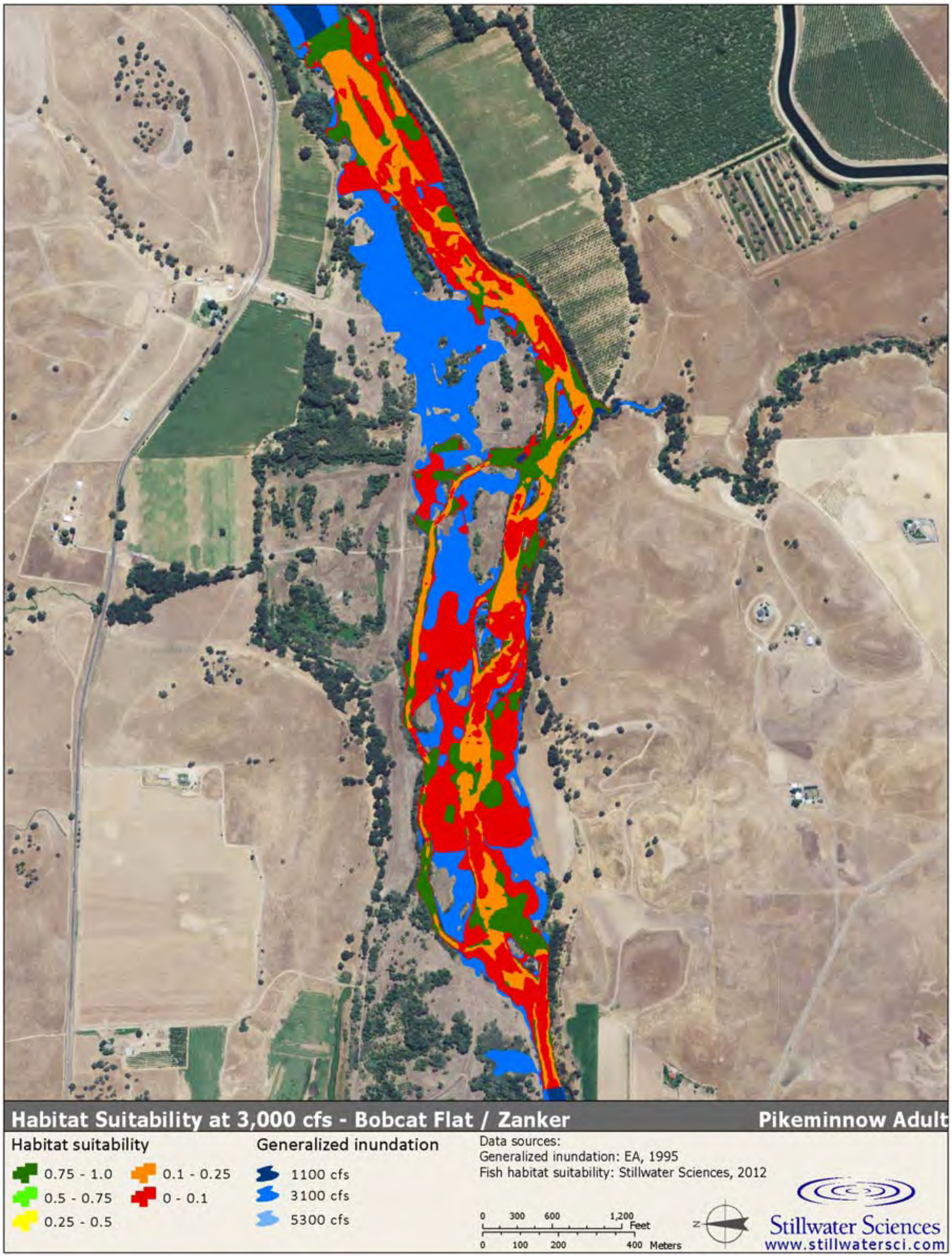


Figure C-112. Bobcat Flat/Zanker property results 3,000 cfs for striped bass adults.

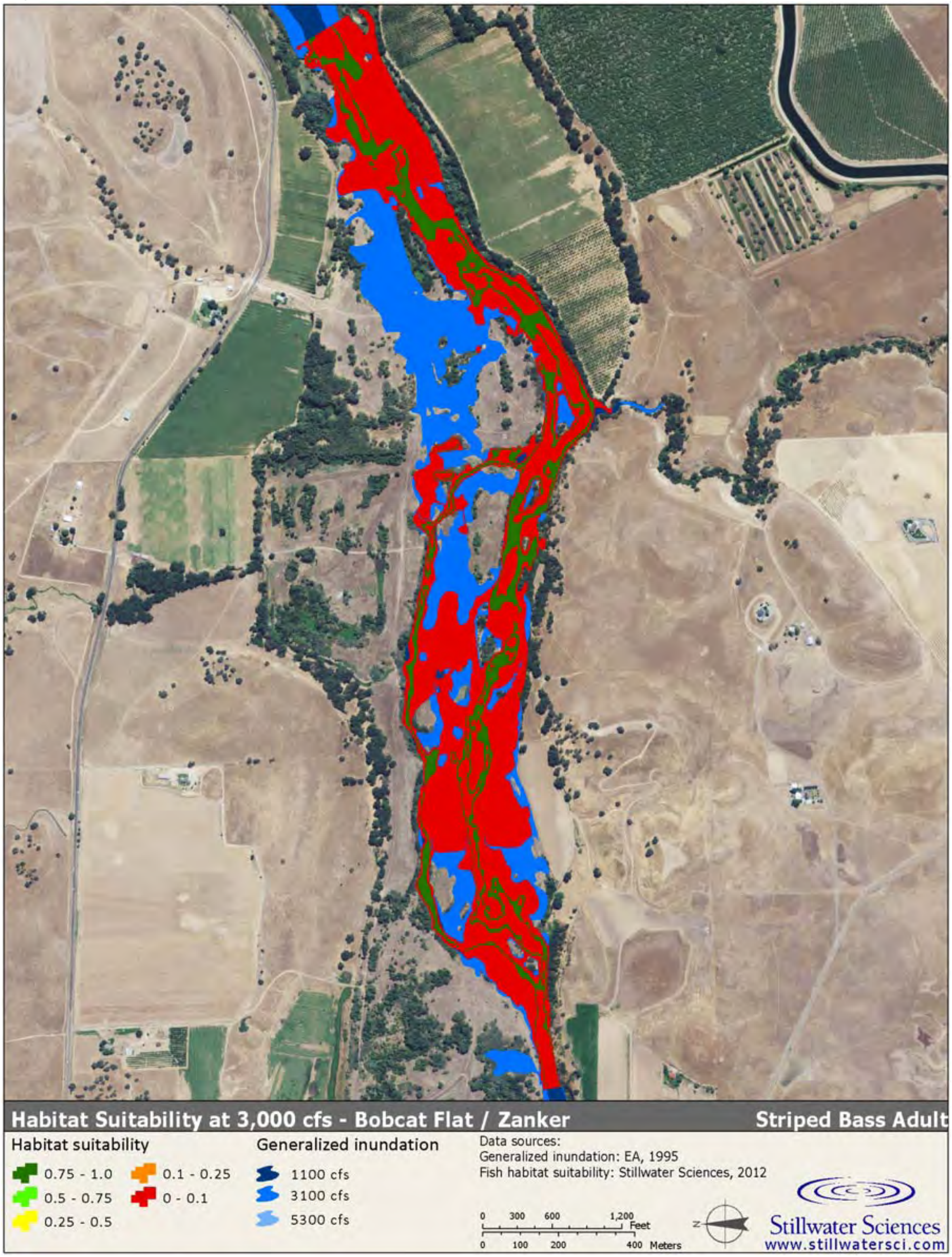


Figure C-113. Bobcat Flat/Zanker property results 5,000 cfs for Chinook salmon fry.

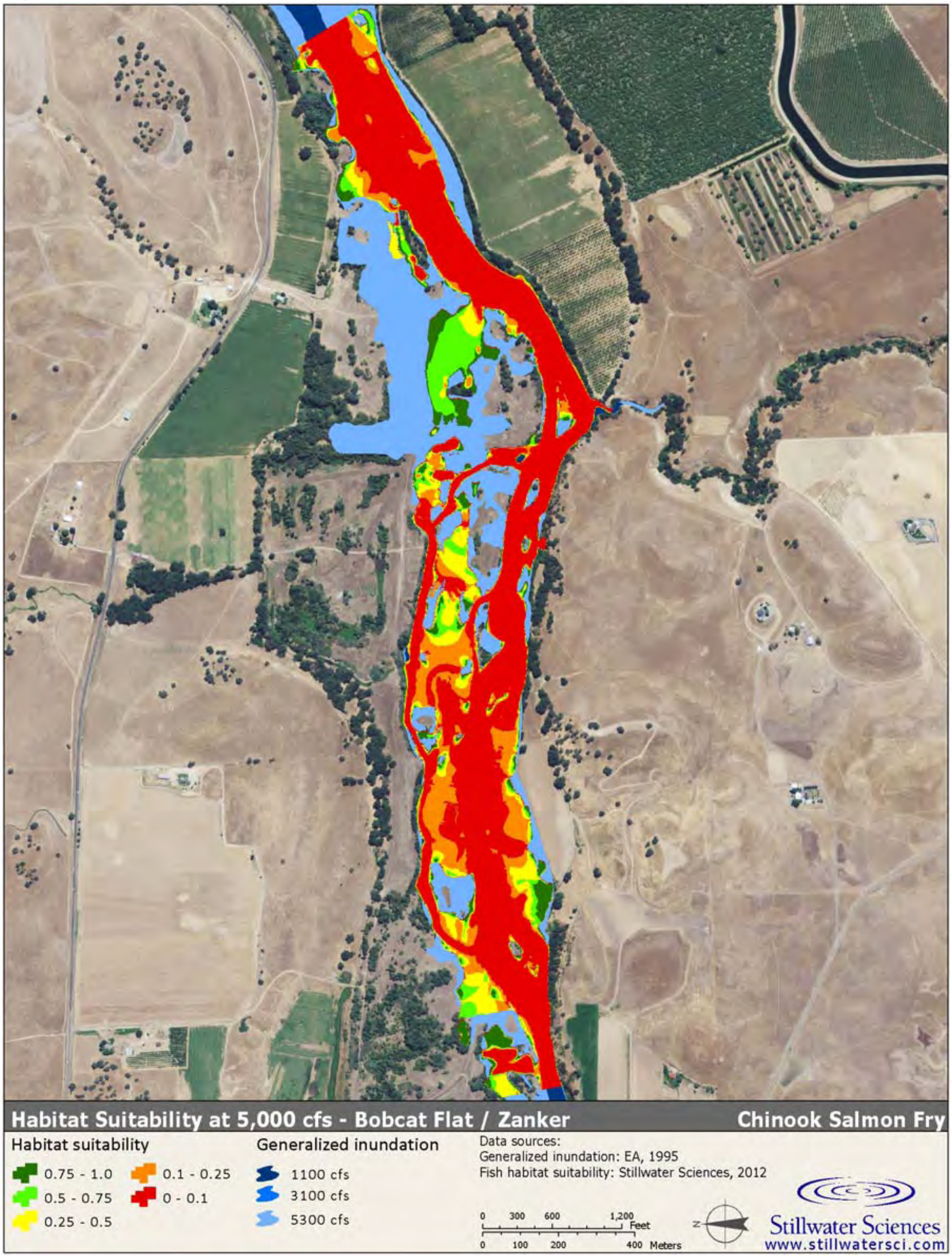


Figure C-114. Bobcat Flat/Zanker property results 5,000 cfs for *O. mykiss* fry.

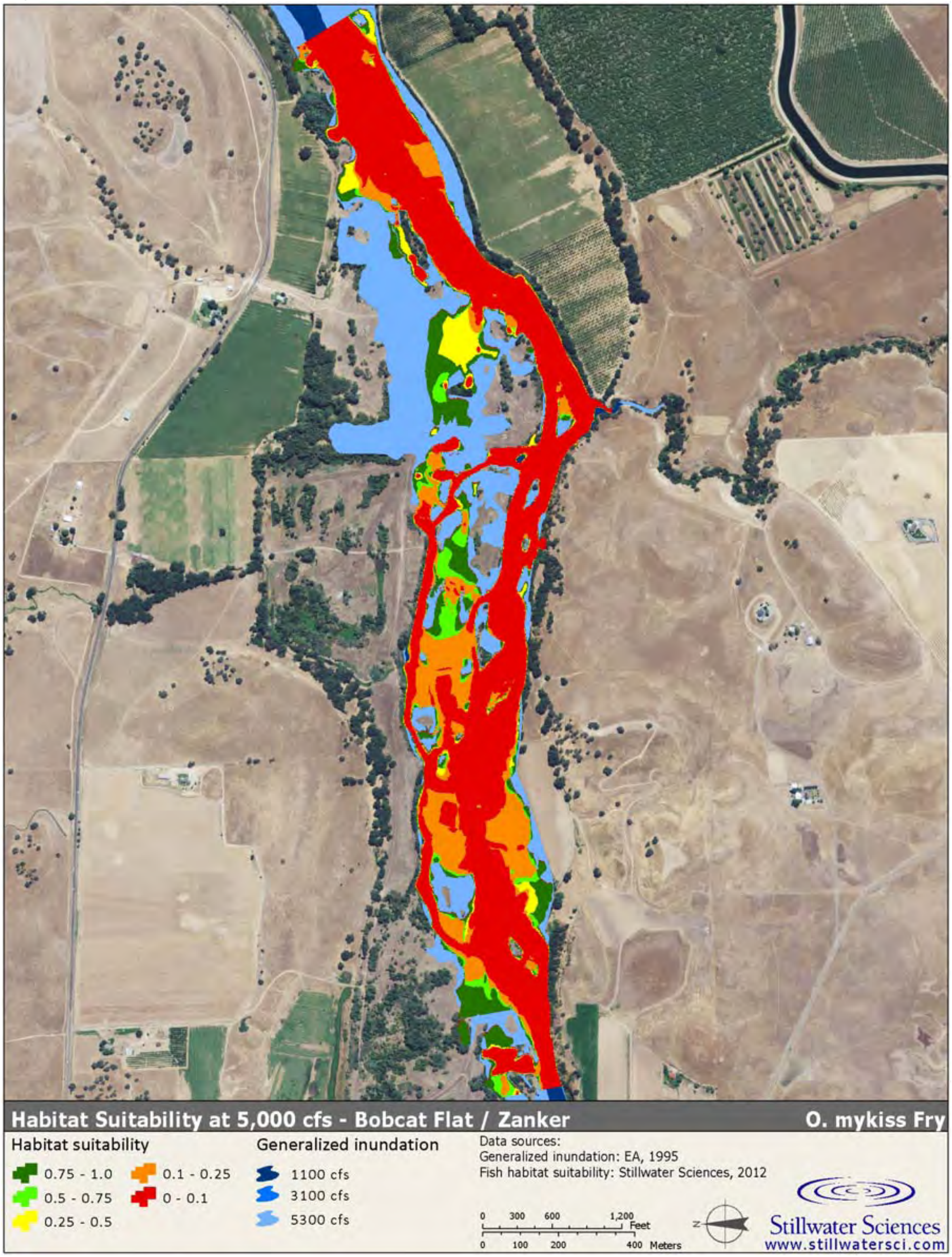


Figure C-115. Bobcat Flat/Zanker property results 5,000 cfs for Chinook salmon juveniles.

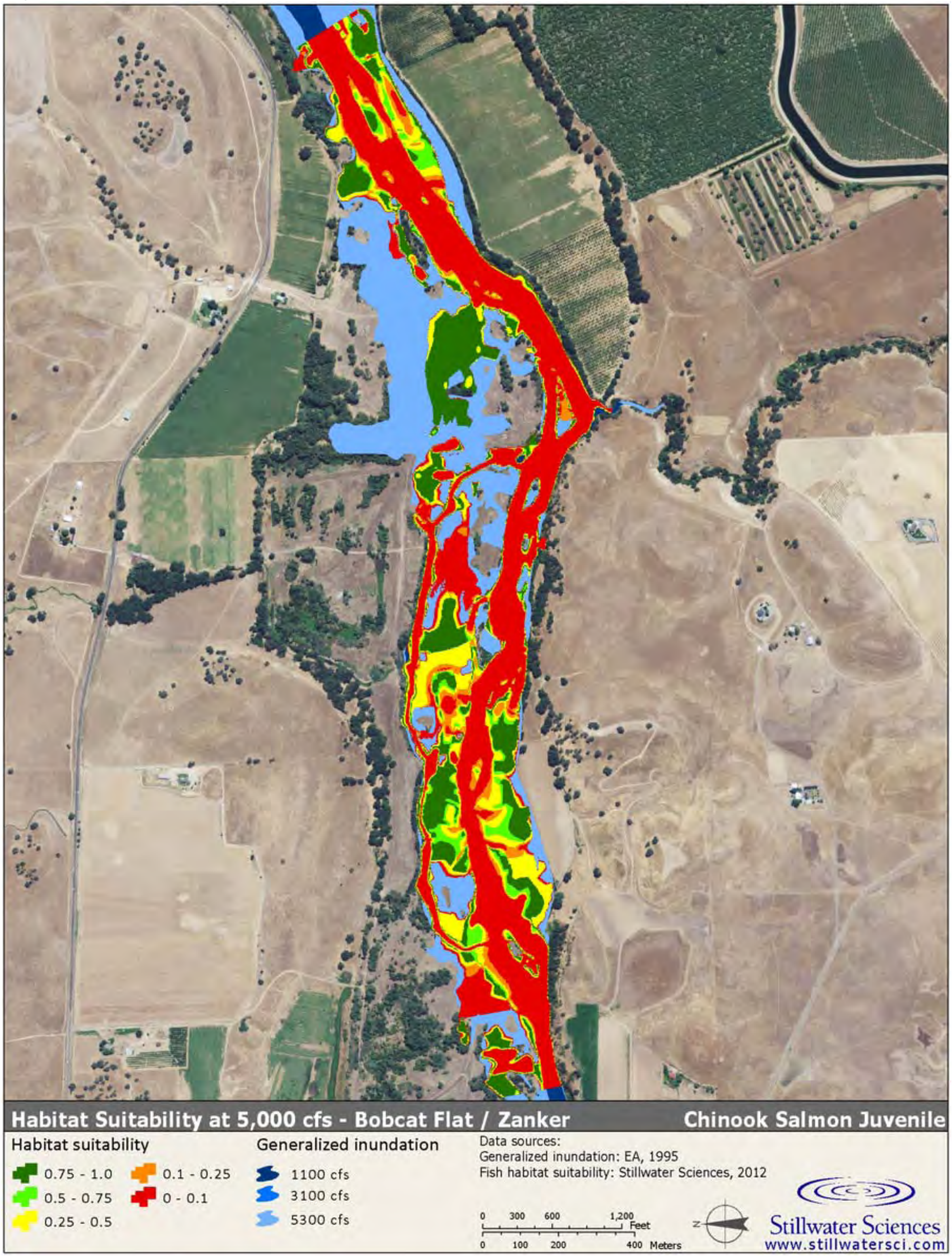


Figure C-116. Bobcat Flat/Zanker property results 5,000 cfs for *O. mykiss* juveniles.

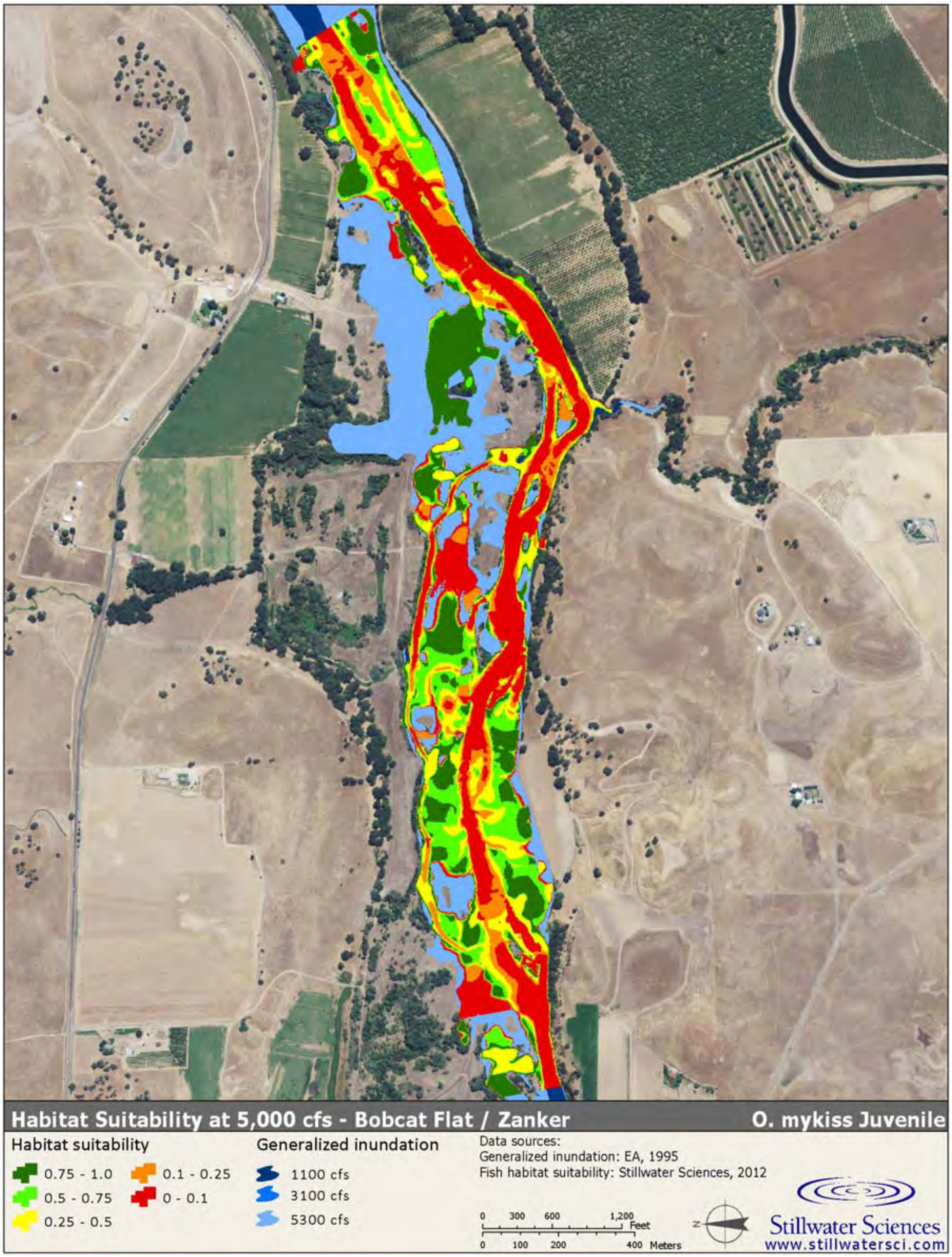


Figure C-117. Bobcat Flat/Zanker property results 5,000 cfs for smallmouth bass adults.

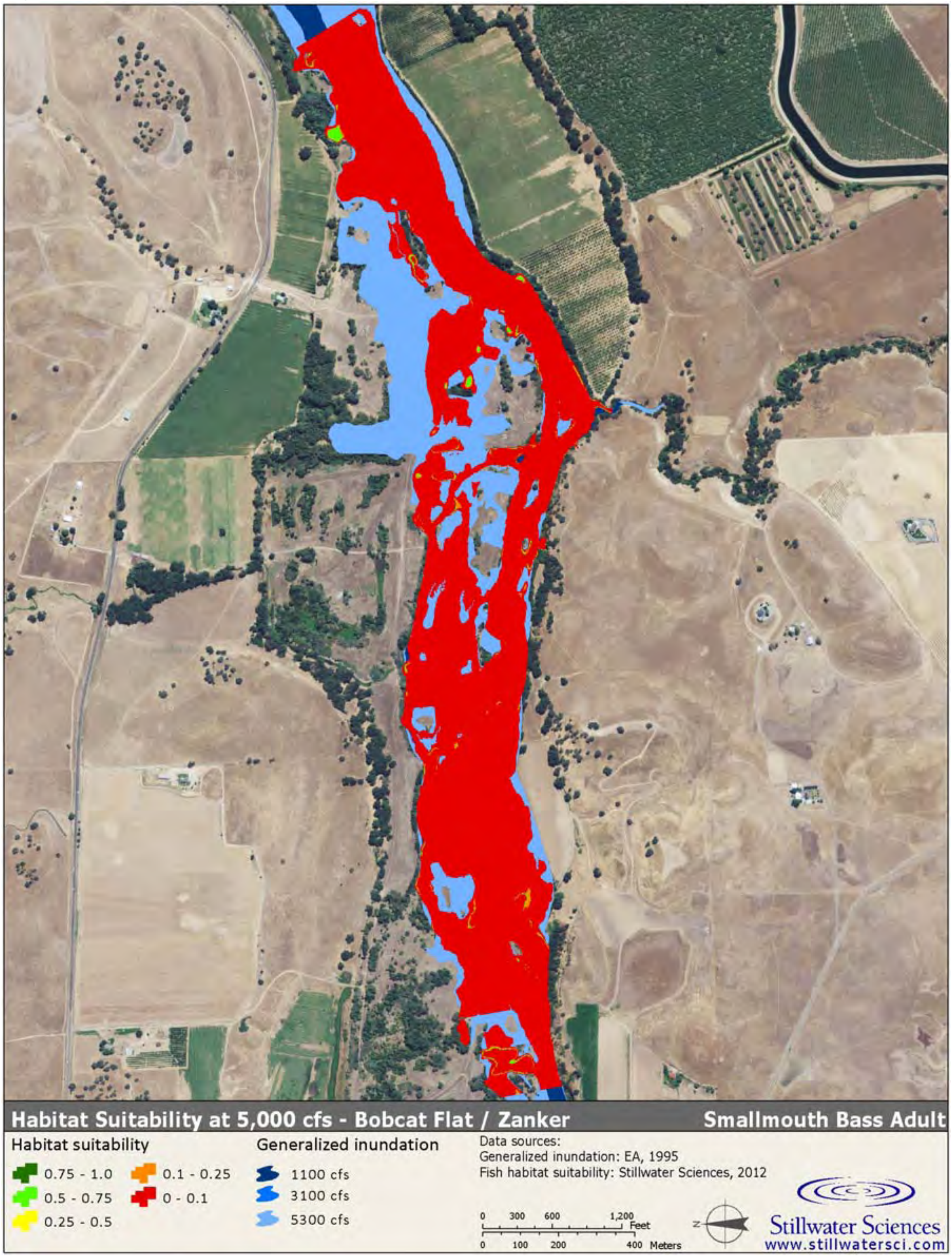


Figure C-118. Bobcat Flat/Zanker property results 5,000 cfs for largemouth bass adults.

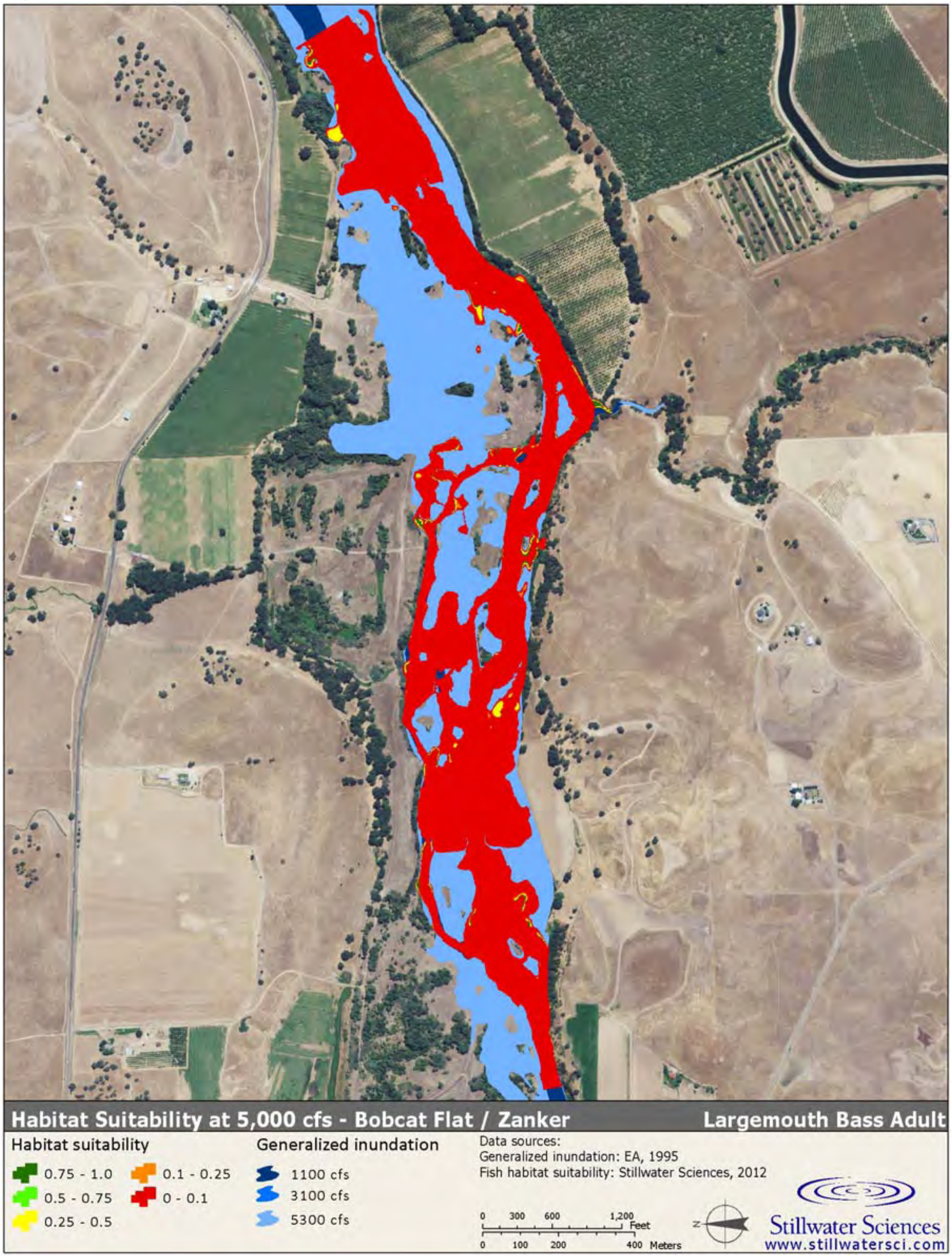


Figure C-119. Bobcat Flat/Zanker property results 5,000 cfs for Sacramento pikeminnow adults.

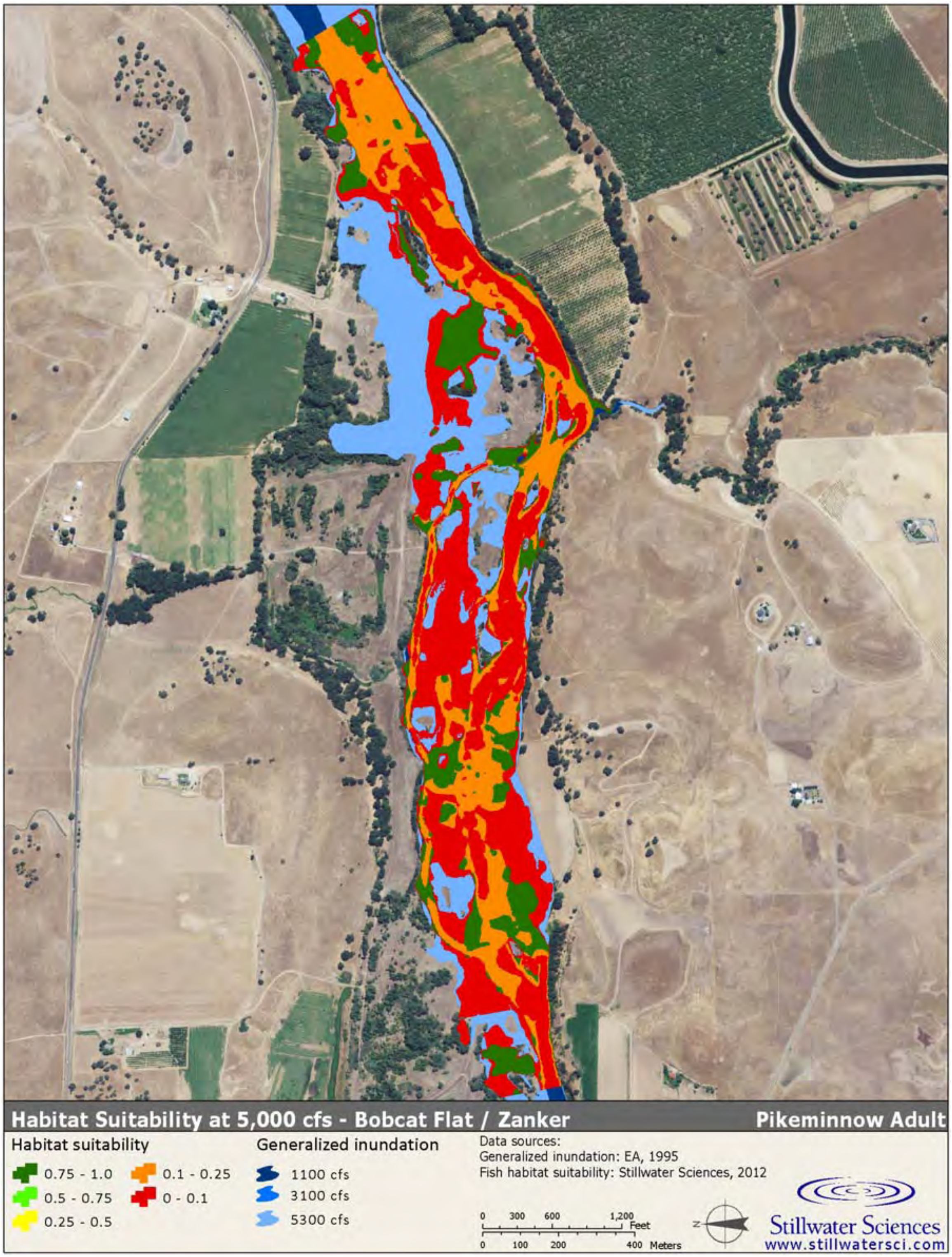
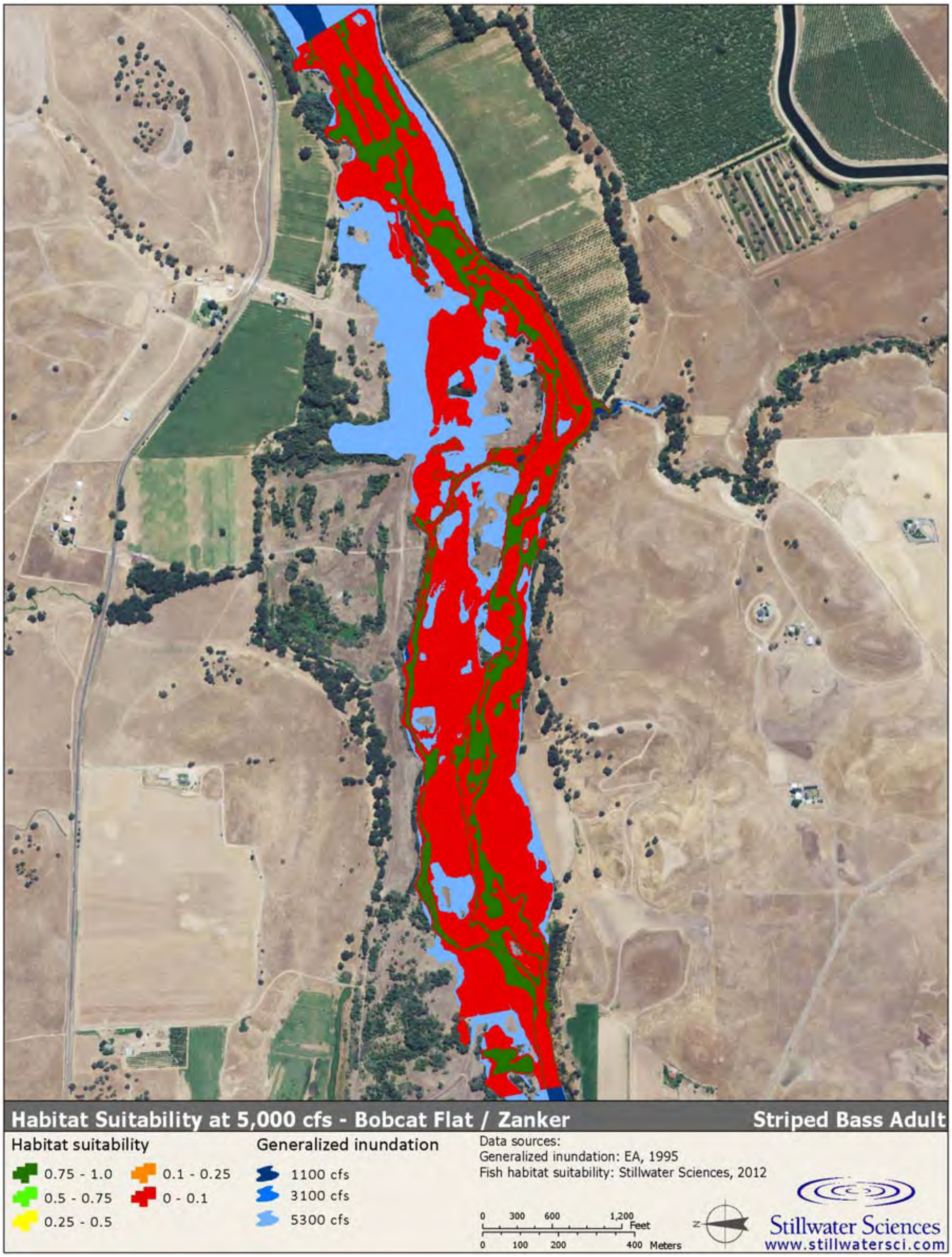


Figure C-120. Bobcat Flat/Zanker property results 5,000 cfs for striped bass adults.



Appendix D

Relationships between in channel water temperature, Spring and Fall Pulse Flows (2001-2011)

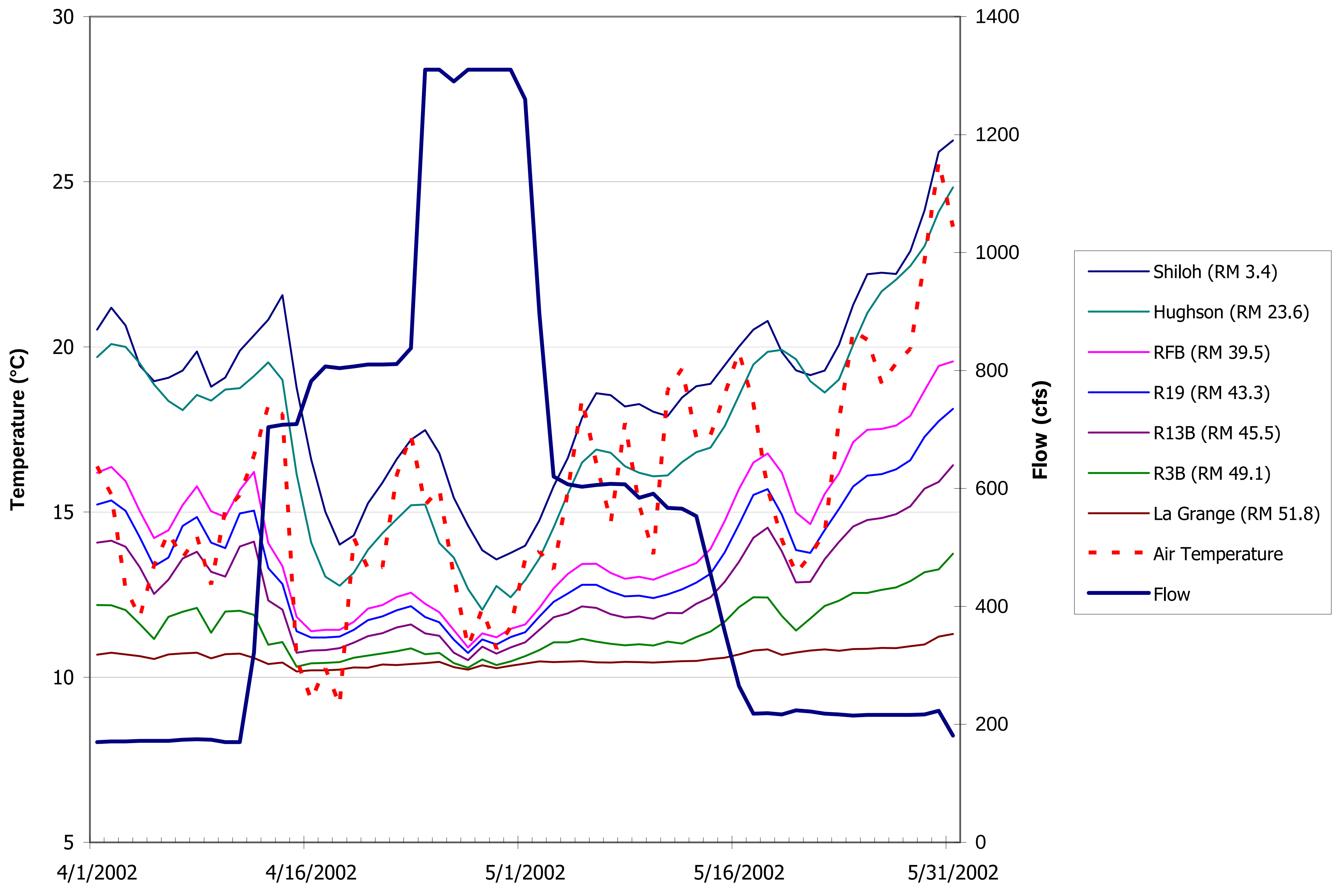


Figure D1. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2002.

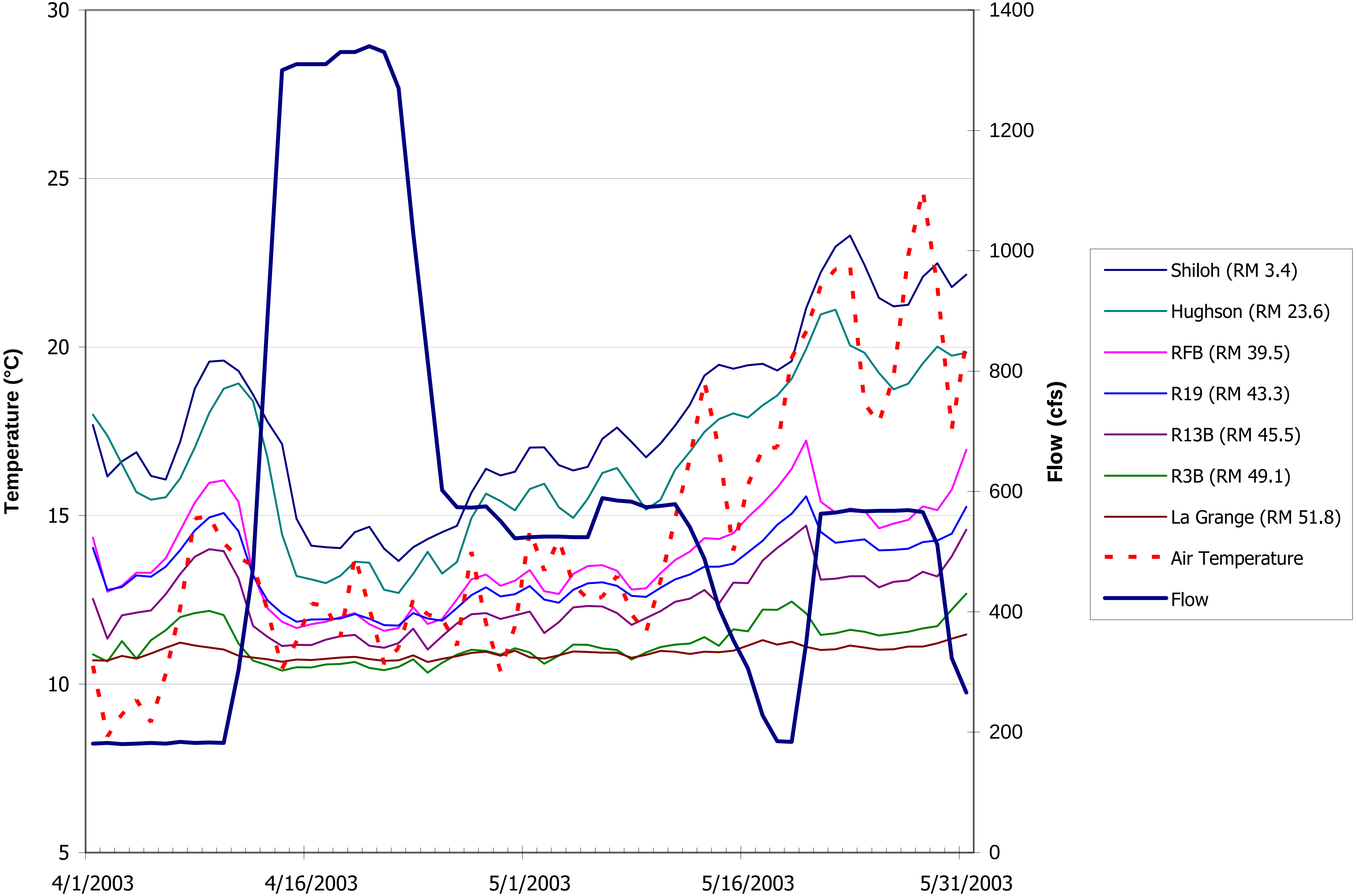


Figure D2. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2003.

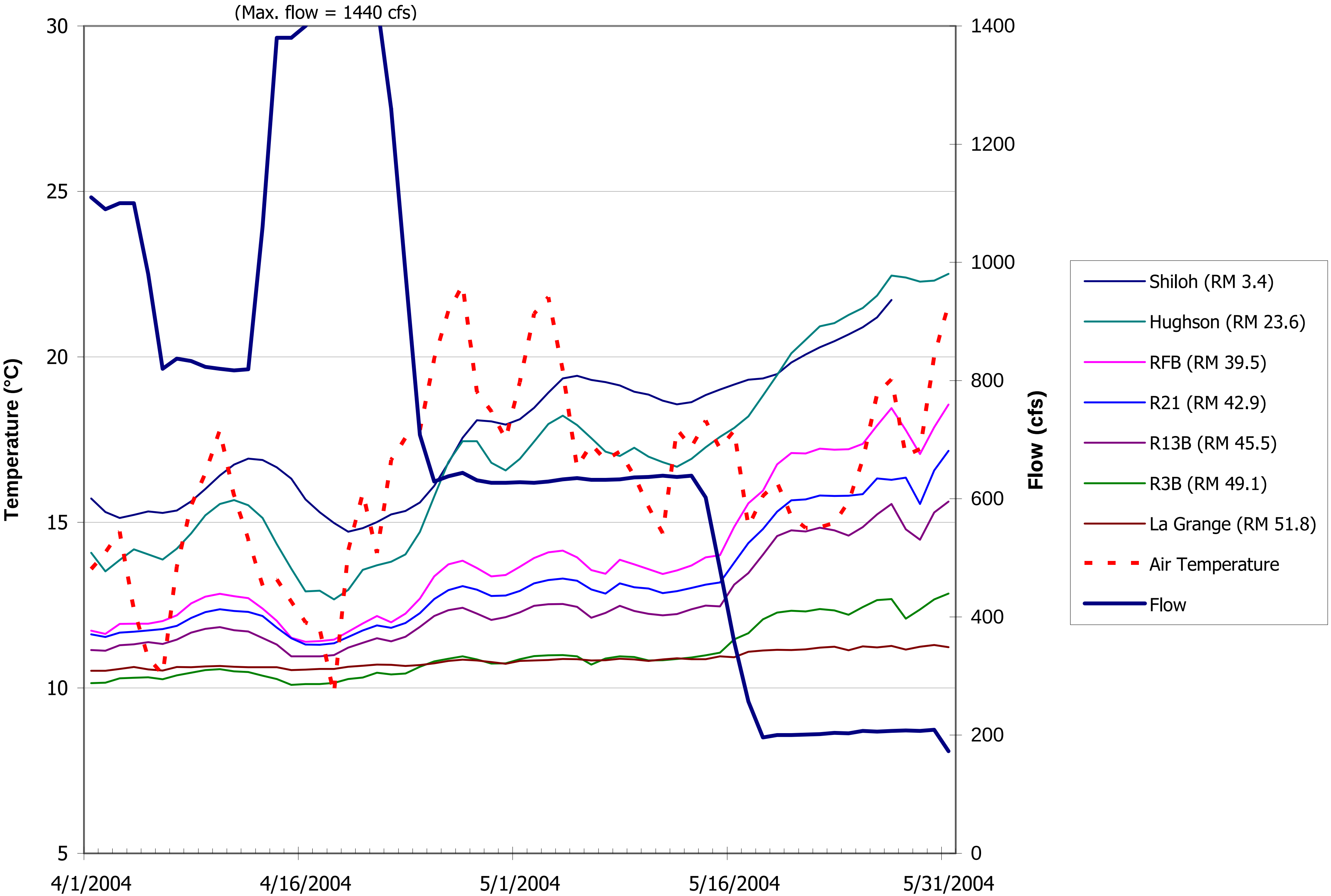


Figure D3. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2004.

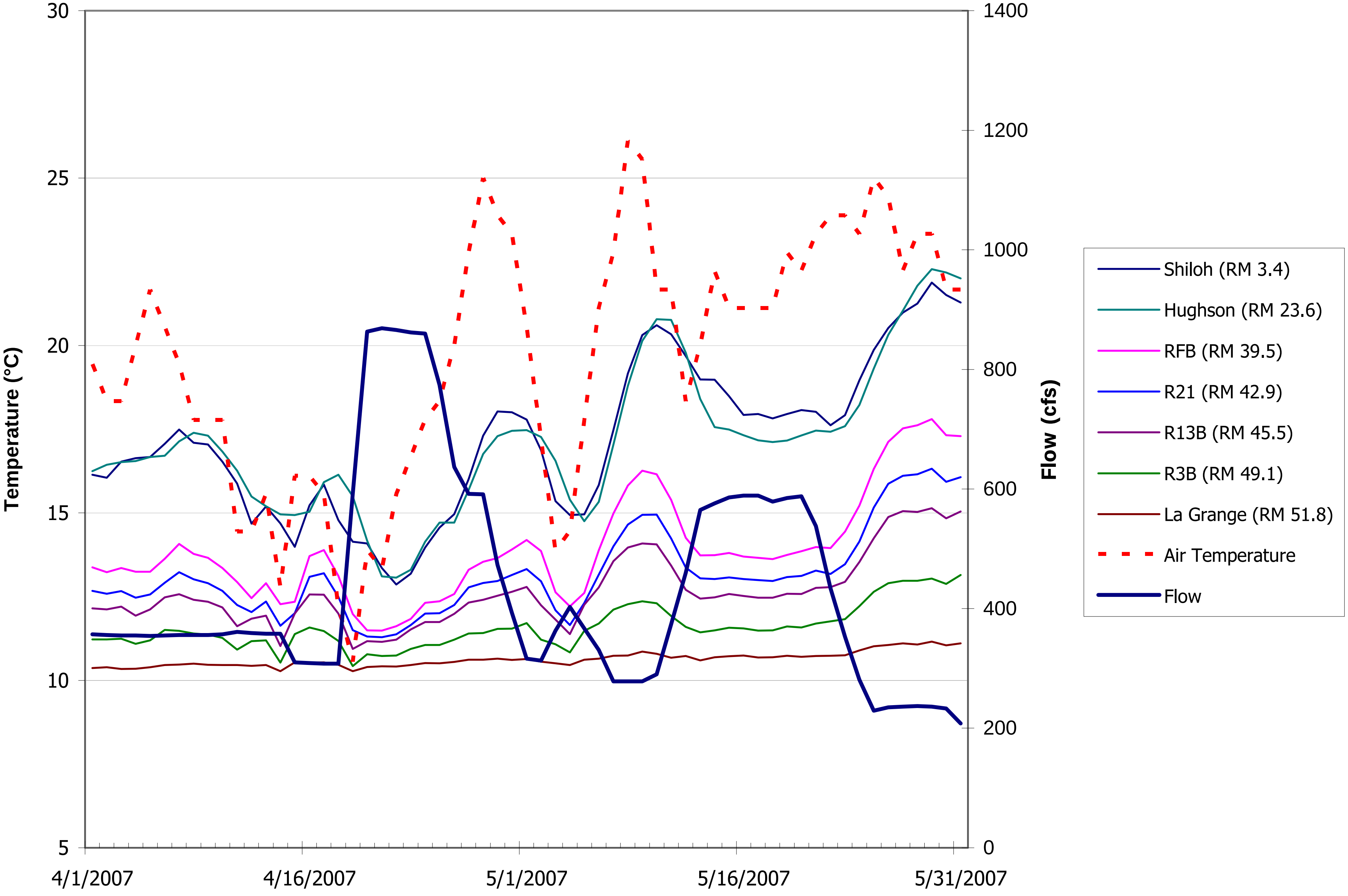


Figure D4. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2007.

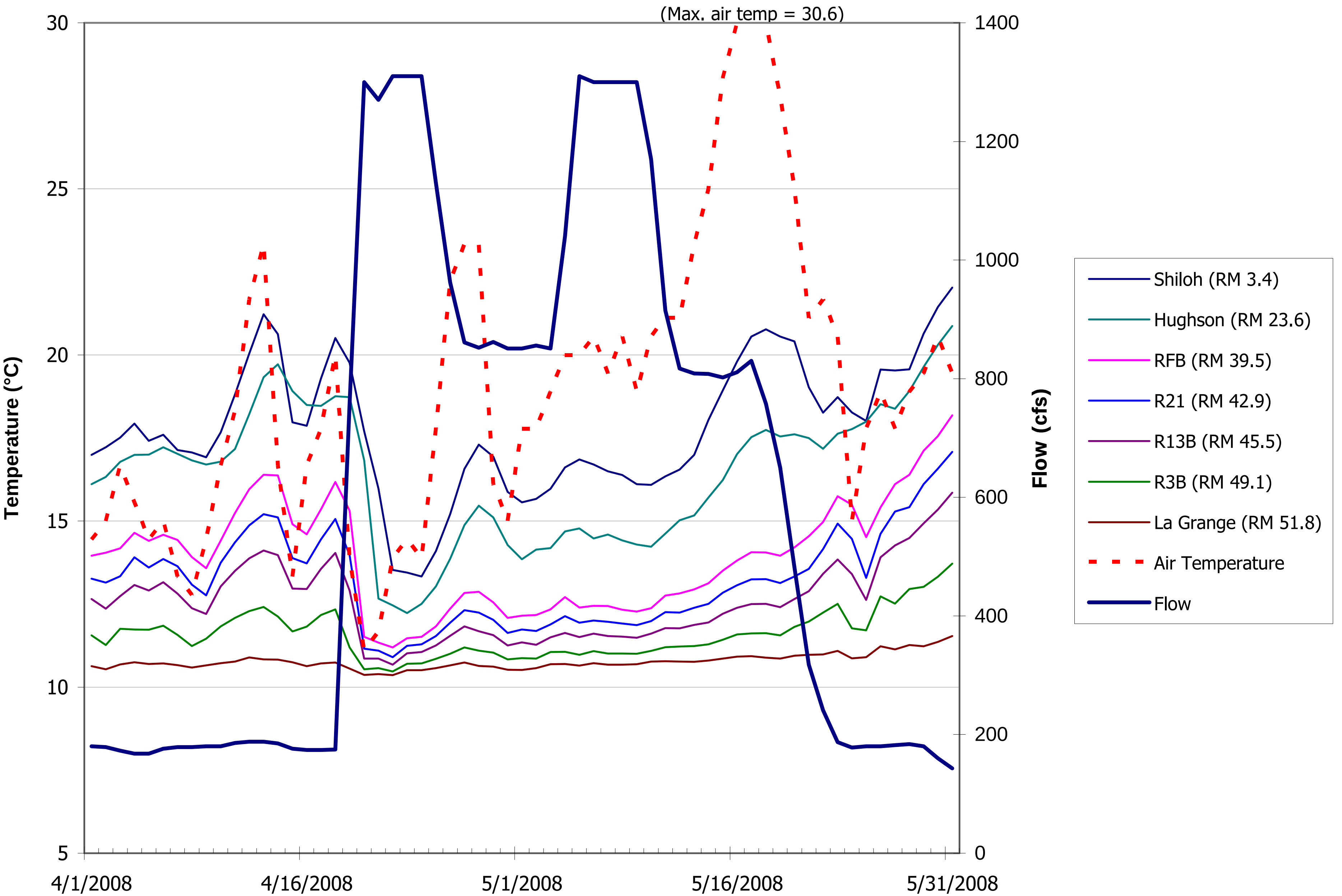


Figure D5. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2008.

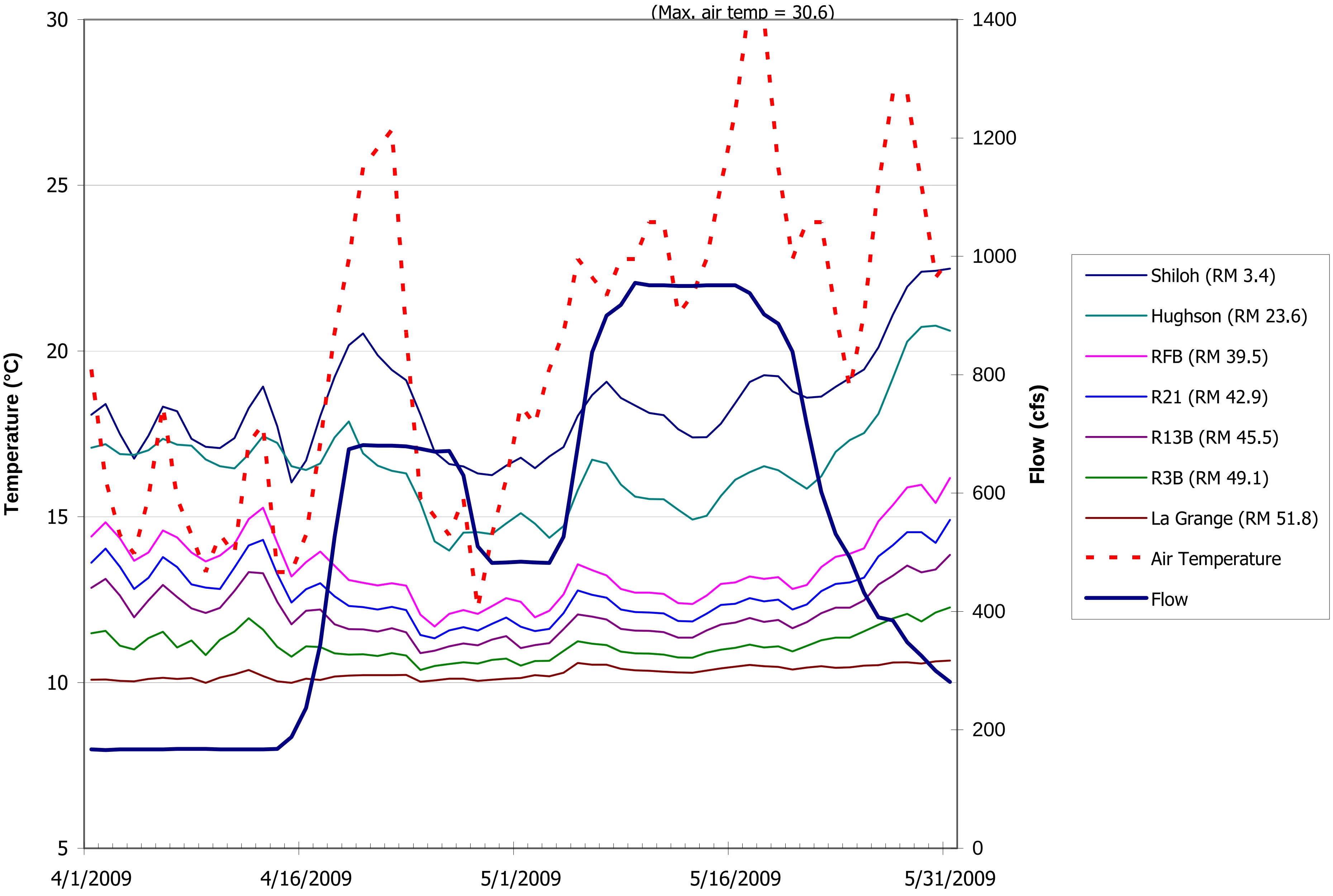


Figure D6. Spring pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in April – May 2009.

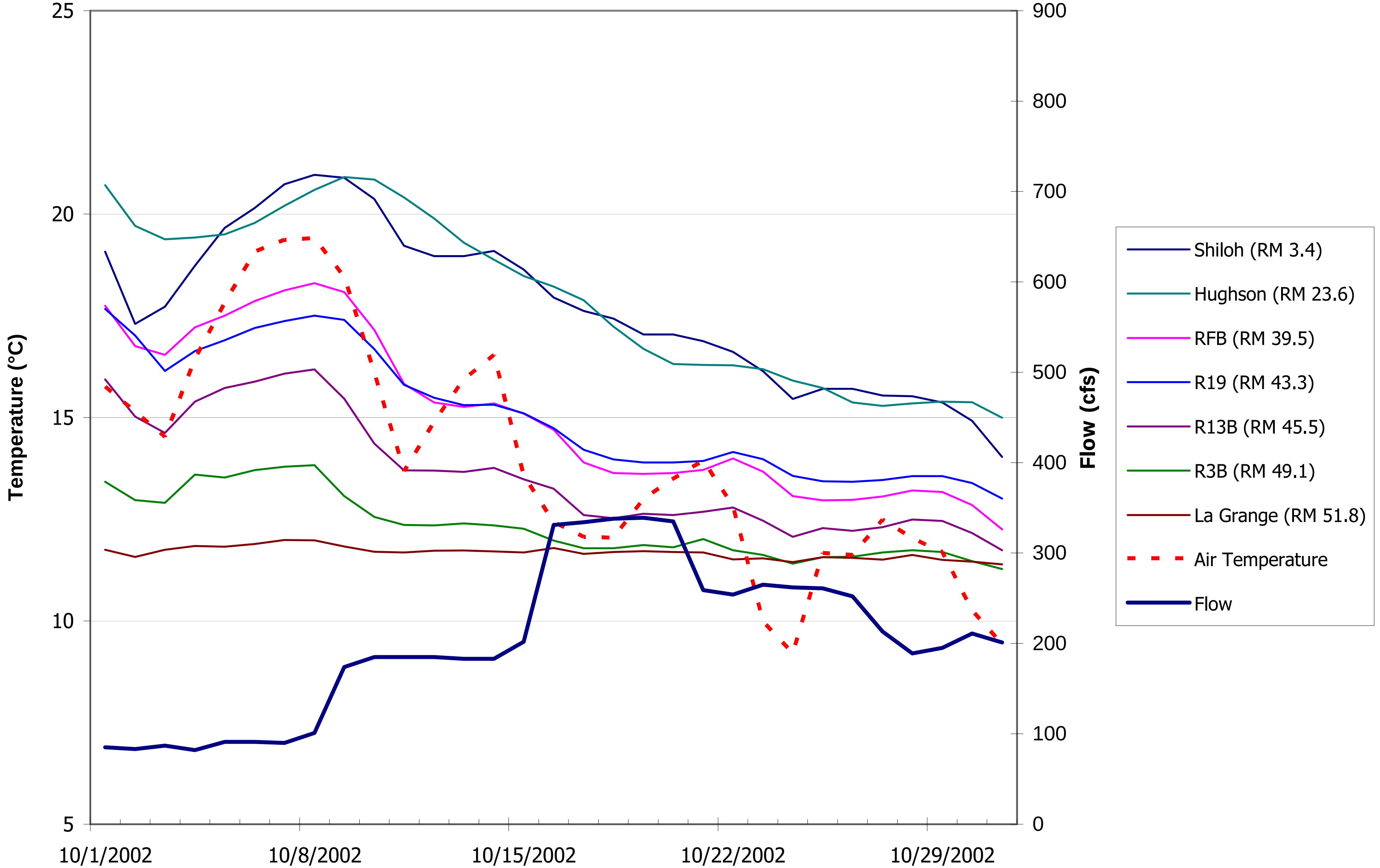


Figure D7. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2002.

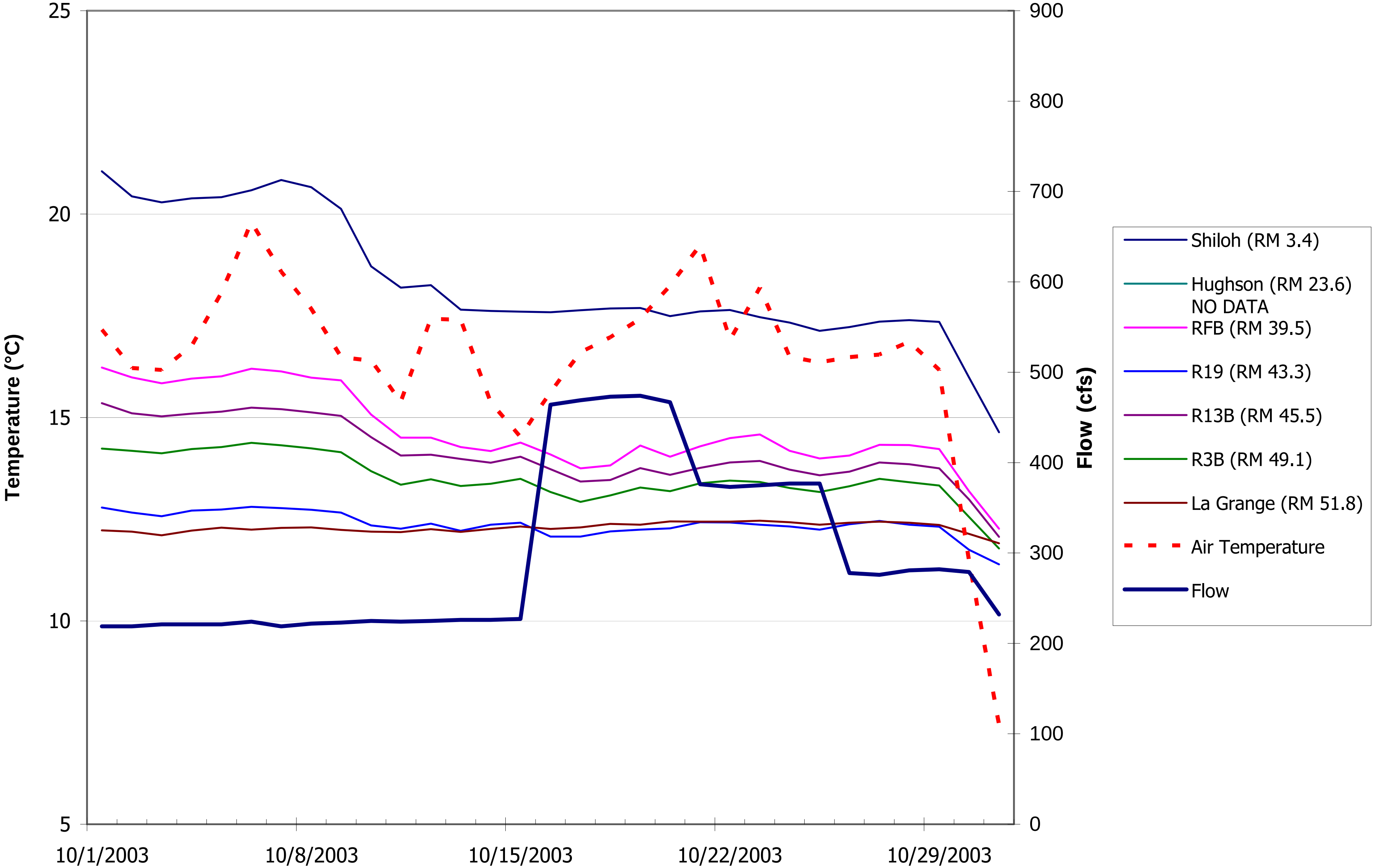


Figure D8. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2003.

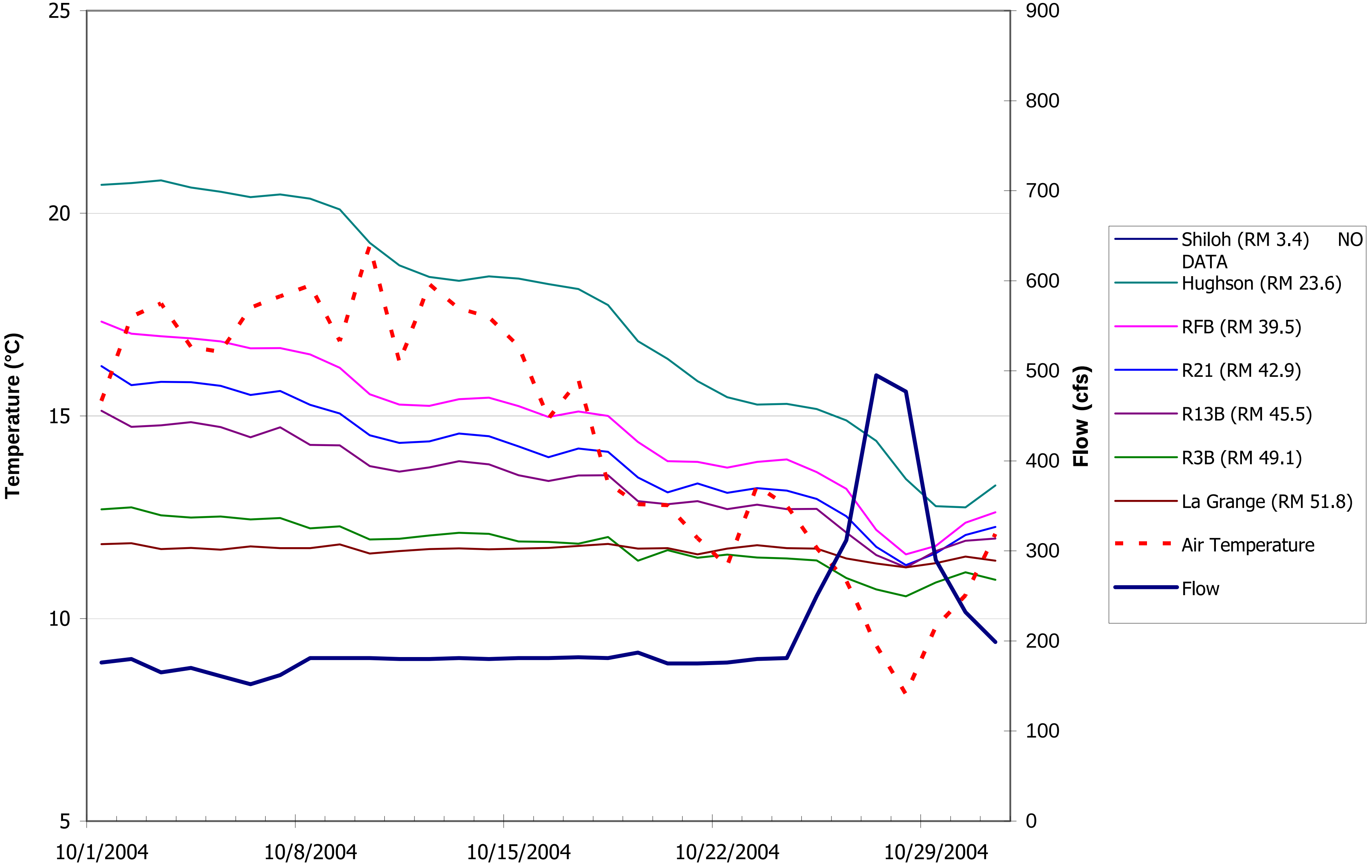


Figure D9. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2004.

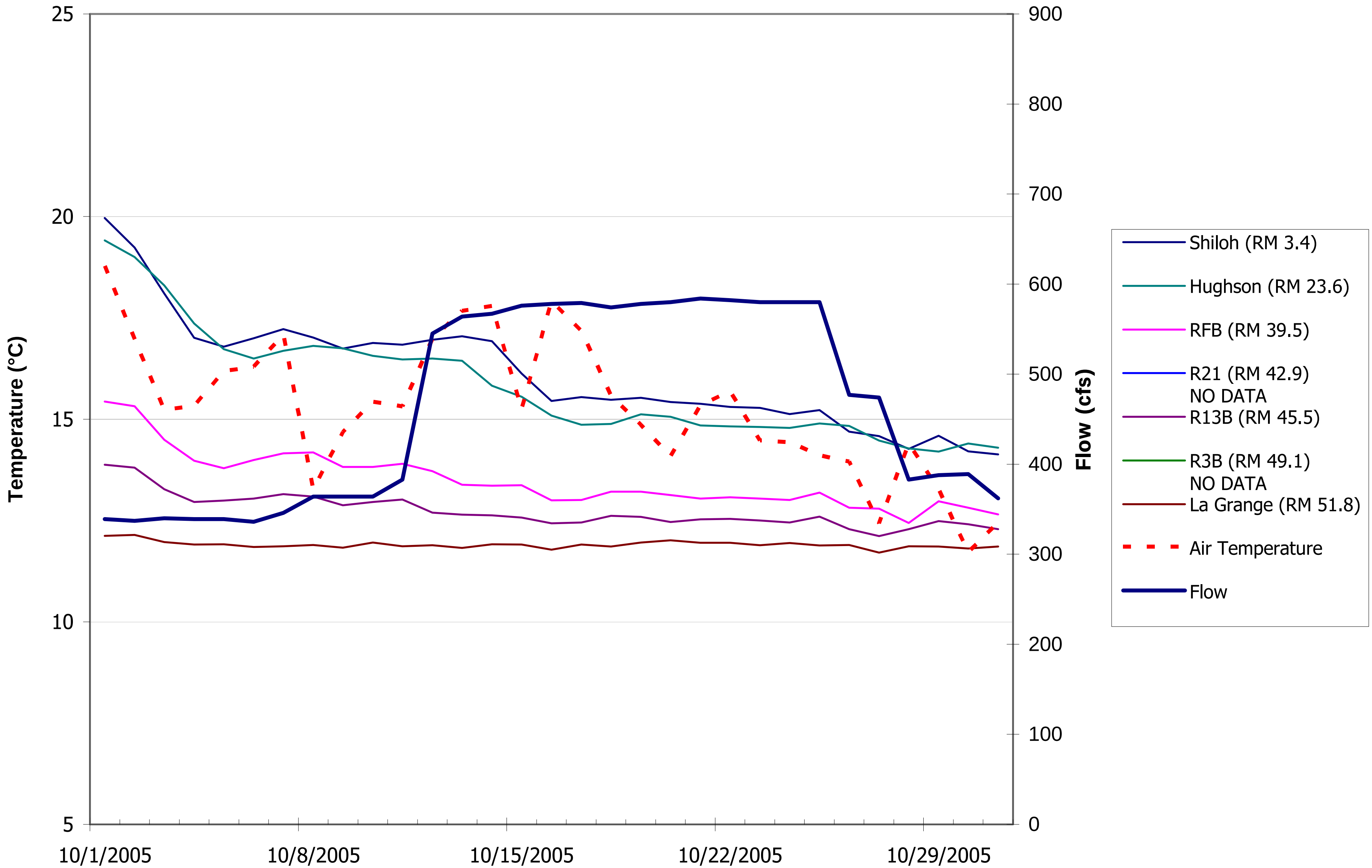


Figure D10. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2005.

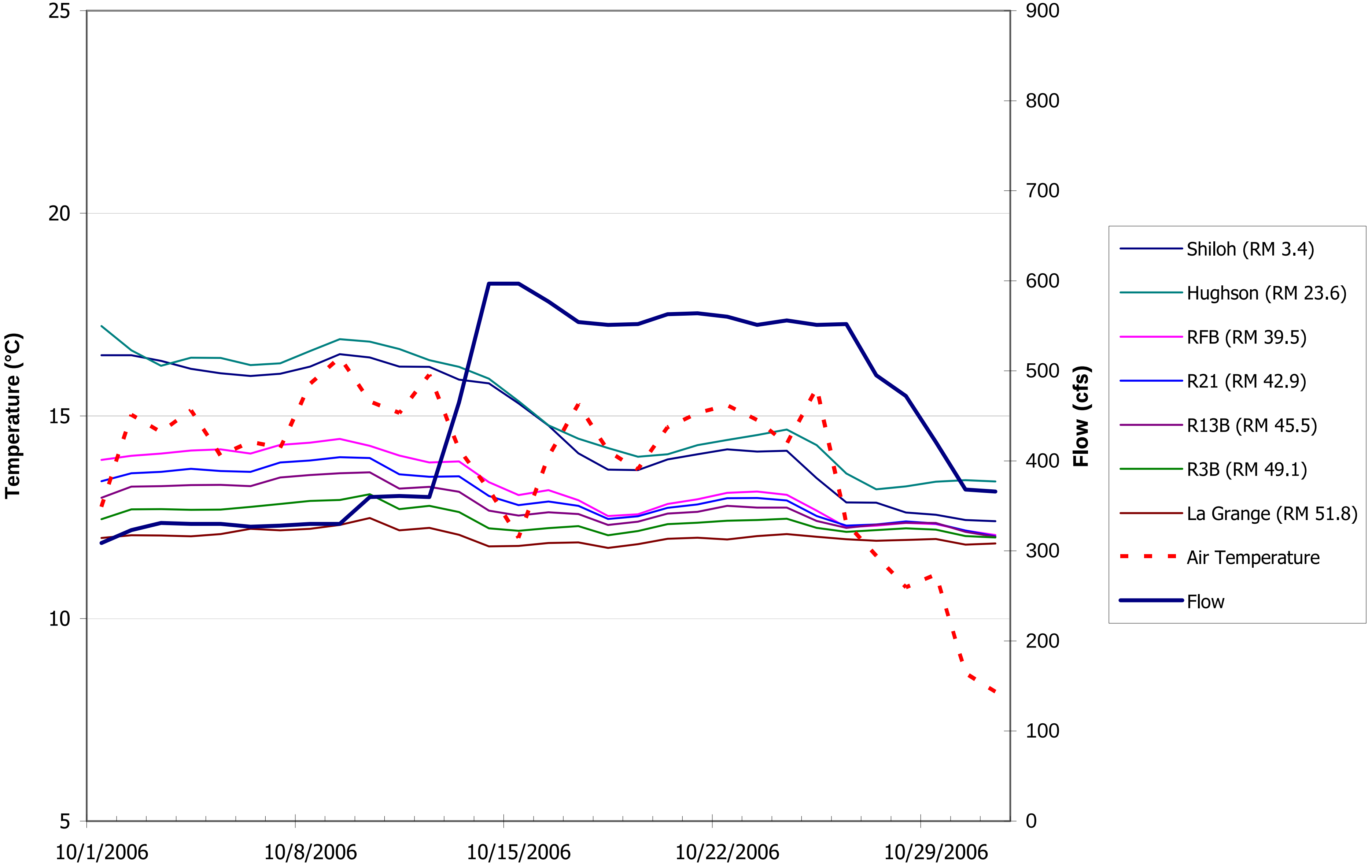


Figure D11. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2006.

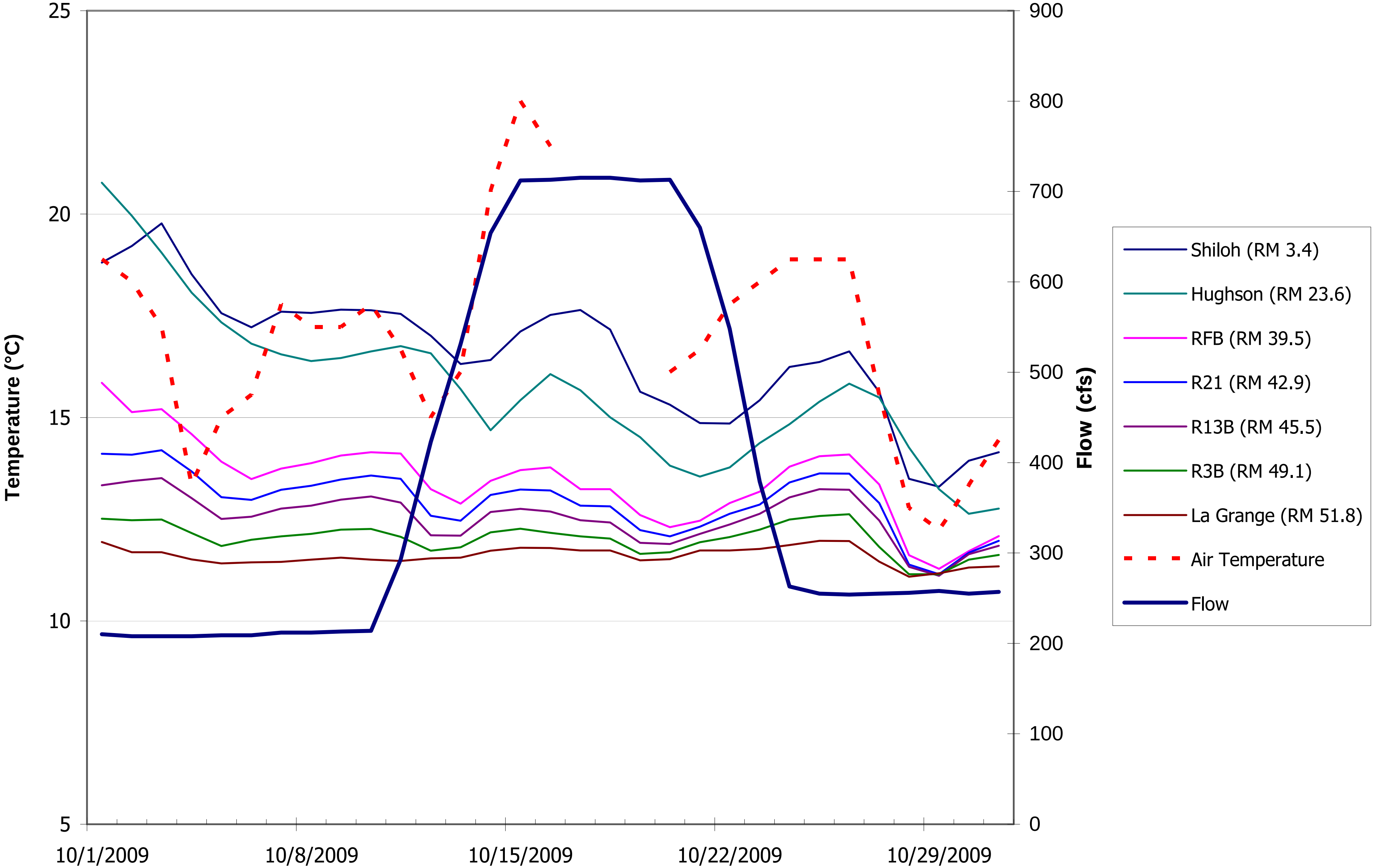


Figure D12. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2009.

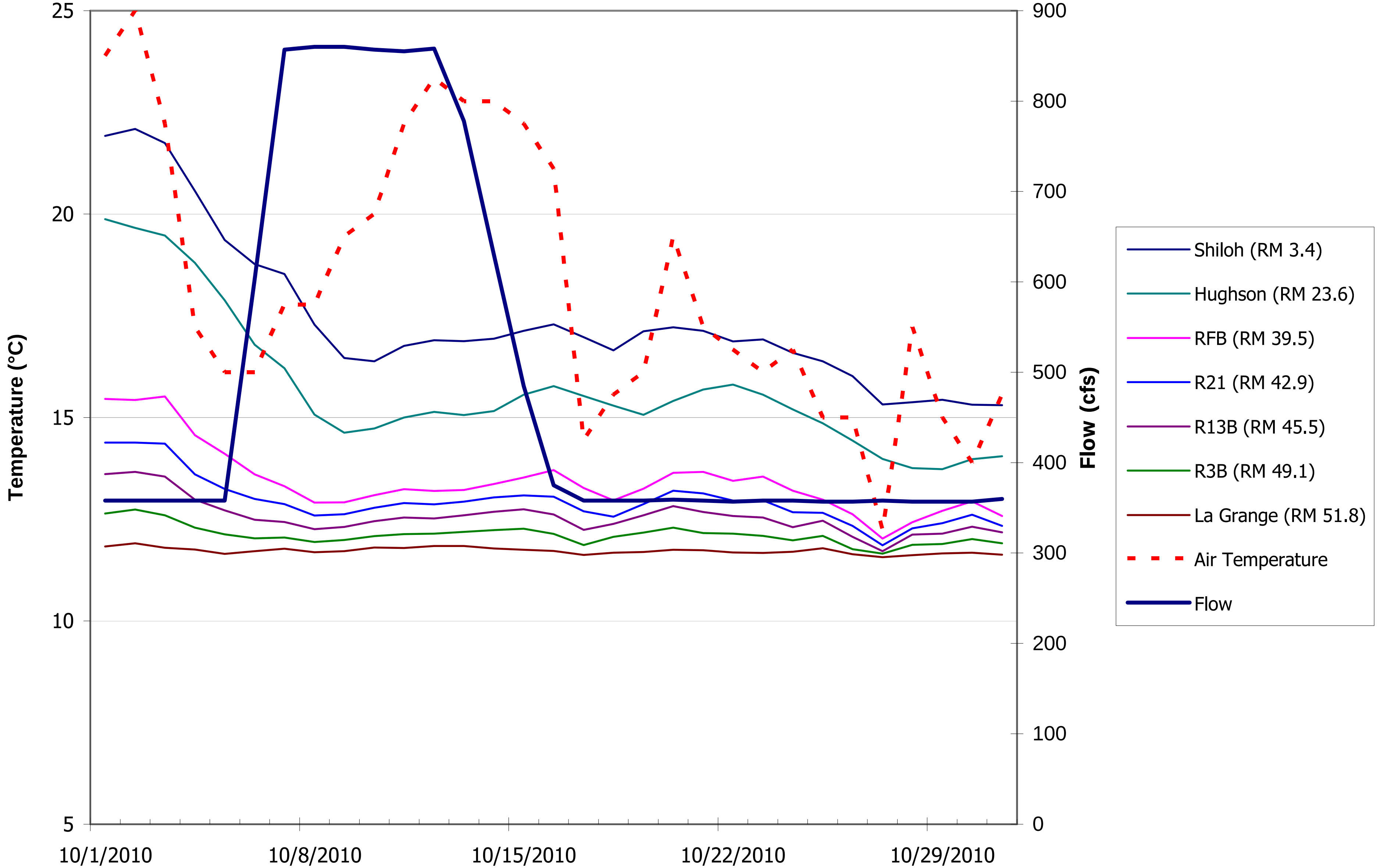


Figure D13. Fall pulse flow release along with main channel water temperatures and air temperature at Modesto, CA in October 2010.