26.0 Water Quality and Fish

26.1 Introduction

Water quality results have been reported in a previous SJRRP ATRs, but little attention has been given to interpreting these results in terms of possible effects on salmon and other native fish species that live within the San Joaquin River. The purpose of this report is to summarize and assess water quality data collected along the river between Friant Dam and the Merced River for the SJRRP during 2009 through 2011. This summary and assessment considers sampling frequency for adequate characterization of variability, sampling locations for sufficient characterization of the sampling reach, and sampling methods for appropriate media (water, sediment, tissue) and detection levels. A discussion of the water quality data and how it compares to available criteria and thresholds for salmonids, native fishes, and other aquatic organisms is also included.

26.2 Water Quality Methods

As described in Appendix C of the 2009 ATR (SJRRP, 2010), water and sediment samples were collected by Reclamation personnel. All collection was done in accordance with Section 22 of the SWRCB Division of Water Rights Order WR 2009-0058-DWR and corrected WR 2010-0029-DWR.

Samples were collected, preserved, and handled according to Reclamation QA practices, which included the incorporation of blank, reference, duplicate, and spiked samples to verify laboratory and field measurements. Bacteria, chlorophyll A, DO carbon, total organic carbon, nitrates, and total suspended solids samples were shipped from the field directly to laboratories. Grab samples were collected from the stream bank in a churn-splitter and then deposited directly into sample bottles. Water samples were collected from the surface at each location. Sediment samples were collected from the top 5 cm at each location.

To summarize and assess the accumulated water quality data for this report, data were first compiled and organized by location and date so that meaningful comparisons could be made. The results were compared to thresholds and criteria obtained from literature sources for effects of water quality on aquatic organisms. This report specifically discusses the results of the SJRRP's water quality monitoring and how those results might affect the fish community within the SJRRP's Restoration reach. Detailed information about each sample's constituent results, location, and collection date is available in Appendix D of the ATR. Constituents that were not detected during SJRRP sampling were not discussed unless recommendations were made to lower current reporting detection limits.

26.3 Results

All available water quality data beginning with interim flows in October 2009 through November 2011 were used in this summary and analysis. Samples are not collected in December.

26.3.1 Sampling Frequency

During fall 2009, 44 water samples (from 11 sites) and 12 sediment samples (from 10 sites) were collected for analysis. Baseline water quality was measured in samples collected before the arrival of Interim Flows at each site. Sediment was collected at four sites before the arrival of Interim Flow water, and at seven sites in December upon completion of Interim Flows (Figure A-26-1).

During 2010, 55 water samples and 7 sediment samples were collected from 7 sampling sites. Water samples were collected once per week in February and March, twice in April, and once per month from June through December. No samples were collected in May and November 2010 due to staff limitations. Sediment samples were collected once in April from seven monitoring sites.

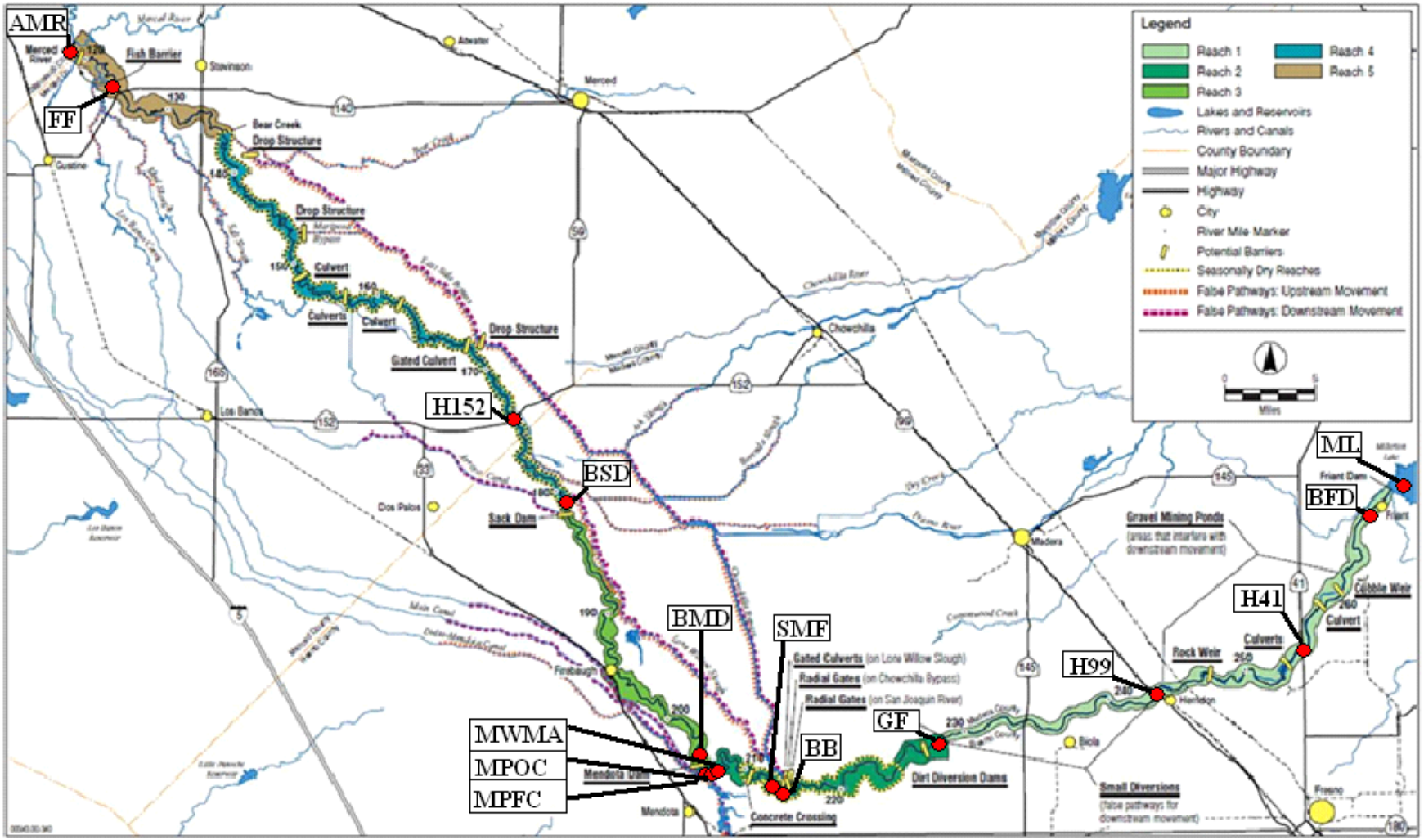
During 2011, water quality samples were collected once per month from February through November. For the year, a total of 66 water samples were collected from 8 sites. Sediment was not collected in 2011.

More than 160 water samples have been collected for the SJRRP water quality monitoring program during 2009 through 2011. Each water sample was analyzed for 153 different constituents. During the same period, 19 sediment samples were collected (from 10 sites), with each sample being measured for 54 constituents.

26.3.2 Sampling Locations

In 2009, water samples were taken from three locations in reach 1A, one location in Reaches 2A, 2B, 3, 4A, and 4B, and two locations in Reach 5 (Table A-26-1, Figure A-26-1). Sediment samples were taken from two locations in Reach 1A, one location in Reaches 2A, 3, and 4B, and four locations in Reach 2B.

In 2010, water samples were taken from two locations each in Reaches 1A, 2A, and 5, and from one location in Reaches 3 and 4B. Sediment samples were taken from two locations in Reach 1A and one location in Reaches 2A, 2B, 3, 4B, and 5. Water samples were collected from each reach in 2011.



Note: Refer to Table A-26-1 for site codes and descriptions.

Figure A-26-1.
Water Quality and Sediment Sampling Site Locations

Table A-26-1.
Water Quality and Sediment Monitoring Site Locations

River Mile	Site code	Monitoring Site	Reach	Media	Year Collected
268	ML	Millerton Lake		wq	09
266	BFD	San Joaquin River below Friant Dam (Lost Lake Park)	1A	wq/s	09/10/11
255	H41	San Joaquin River at Highway 41	1A	wq	09
243	H99	San Joaquin River near Highway 99 (Camp Pashayan)	1A	wq/s	09/10/11
227	GF	San Joaquin River at Gravelly Ford	2A	wq/s	09/10/11
213	BB	San Joaquin River below Bifurcation	2B	wq	09
211.9	SMF	San Joaquin River at San Mateo Ford	2B	s	09
206	MWMA	Mendota Wildlife Management Area	2B	s	09/10/11
205.5	MPOC	Mendota Pool (Contra Costa Irrigation District Outside Canal)	2B	s	09
205.2	MPFC	Mendota Pool (Firebaμgh Canal Water District Intake Canal)	2B	s	09
205	BMD	San Joaquin River below Mendota Dam	3	wq/s	09/10/11
182	BSD	San Joaquin River below Sack Dam	4A	wq	09
174	H152	San Joaquin River at Highway 152	4AB	wq/s	09/10/11
125	FF	San Joaquin River at Fremont Ford	5	wq	09/10/11
118	AMR	San Joaquin River above Merced River (Hills Ferry)	5	wq/s	09/10/11

Key:
Media
s= sediment sites
wq = water quality sites
wq/s= both water quality and sediment sites

26.3.3 Sample Media

Water and bed sediment are the types of media currently being sampled as part of the SJRRP's water quality monitoring.

26.3.4 Detection Limits

Water quality goals for the SJRRP were defined using the water quality objectives for beneficial uses as defined by the Central Valley Regional Water Quality Control Board. Where no goals currently exist, minimum laboratory detection limits were used (Tables A-26-2 and A-26-3). These detection limits may not detect sub-lethal concentrations (discussed further below) and some are above recommendations for detection of biological effects on fishes (Table A-26-3).

26.3.5 Concentrations Found and Comparisons to Criteria – 2009 – 2010 Samples

Approximately 75 percent of the laboratory analyses of water and sediment samples were below minimum lab detection limits. Results for constituent samples above laboratory detection limits are listed Table A-26-4 (water) and Table A-26-5 (sediment). A complete list of constituents measured in water and the laboratory reporting limits is provided in Table A-26-2. A complete list of constituents measured in sediment and the laboratory reporting limits is provided in Table A-26-3.

Of results that were above reporting limits, high sediment concentrations of bifenthrin and lambda-cyhalothrin, both pyrethroid pesticides, are of concern. Both of these samples come from the sampling site "San Joaquin River at San Mateo" on October 1, 2009. The collected sediment sample contained a bifenthrin concentration of 23 micrograms per kilogram (µg/kg) (parts per billion (ppb)). A study on the effects of sediment bound bifenthrin on gizzard shad (*Dorosoma cepedianum*) found that an 8-day exposure to a bifenthrin concentration of 7.75 ppb induced complete mortality. Partial mortality and stress behaviors occurred at concentrations between 0.185 and 1.55 ppb. The gizzard shad is of the same family (Clupeidae) as the threadfin shad (*Dorosoma petenense*), which is a member of the "deep-bodied" fish assemblage, including Sacramento perch (*archoplites interruptus*), hitch (*Lavinia exilicauda*), and Sacramento blackfish (*Orthodon microlepidotus*) (FWUA and NRDC, 2002). The gizzard shad is a filter feeder on zooplankton similar to threadfin shad, Sacramento blackfish, and hitch. Therefore, although the gizzard shad does not exist on the San Joaquin River, comparable fishes do. This example is meant to illustrate the potential effects of bifenthrin on fishes and as few such studies currently exist, information must be drawn from available sources. In the same study, copepod nauplii experienced significant mortality across concentrations (0.090 ppb to 7.75 ppb) on Days 4 and 7 of exposure (Drenner et al., 1992). Copepods are a group of zooplankton that are likely food for zooplankton-consuming fishes. Also, the larvae of almost all fishes consume zooplankton, including copepods, for at least a short time as they grow. These results highlight the fact that bifenthrin readily binds to sediment and is of particular concern for organisms that feed on organic matter, as do some aquatic invertebrates, thus contaminating food sources for organisms that feed on invertebrates, such as salmon. The lambda-cyhalothrin sediment concentration was 21

µg/kg, a sediment-bound concentration harmful to aquatic invertebrates (Amweg et al., 2005; Weston et al., 2004).

Copper levels in water were above laboratory reporting limits (Table A-26-4) in approximately 70 samples. Results for dissolved copper ranged from 0.5 to less than 7.0 micrograms per liter (µg/L). A total of 42 water samples had copper concentrations greater than 1.11 µg/L, which is EPA's Office of Pesticide Programs (OPP) aquatic-life chronic benchmark for invertebrates. Thirty samples were above the acute benchmark for invertebrates (1.8 µg/L) (EPA, 2011). Aquatic life benchmarks are extracted from the most current publicly available risk assessment data, which is based on the most sensitive toxicity data for each aquatic taxa. Each benchmark is an estimate of the concentration below which pesticides are not expected to harm the organism. The highest copper samples come from the San Joaquin River above Merced River, San Joaquin River below Mendota Dam, and San Joaquin River at Fremont Ford.

Dissolved copper naturally occurs in the environment, but elevated ambient levels can cause negative effects on the food web that salmon and other fish depend on as well as lethal and sub-lethal effects to the fish themselves. Sources of copper that can elevate ambient background levels include fertilizers, herbicides, acid mine drainage, and urban runoff. Sub-lethal effect of copper have been shown to impair olfaction, interfere with migration, reduce response to predators, depress immune response, and interfere with brain function of salmonids (Lorz and McPherson, 1977; Baker et al., 1983). For example, Baldwin et al. (2003) found that a 2.3 to 3.0 µg/L increase in copper levels above background levels, for 30 to 60 minutes, affected olfactory related behaviors in juvenile coho salmon regardless of water hardness levels. All other constituents sampled in water and sediment were below EPA's available water quality criteria standards for surface water (EPA, 2009; EPA, 2001; EPA, 1986).

Table A-26-2.
Summary of All Constituents Measured in Water with Laboratory Reporting Limits

Pesticides	Reporting Limit	Carbamates	Reporting Limit		Reporting Limit
Organochlorine scan		3-hydroxycarbofuran	0.5 µg/L	Total Suspended Solids	1.0 mg/L
2,4'-DDD	0.002 µg/L	Aldicarb	0.005 µg/L	Total Organic Carbon	0.3 µg/L
2,4'-DDE	0.002 µg/L	Aldicarb sulfone	0.5 µg/L	Dissolved Organic Carbon	0.3 µg/L
2,4'-DDT	0.002 µg/L	Aldicarb sulfoxide	0.5 µg/L	Nutrients	
2,4,5-T	0.1 µg/L	Baygon	0.5 µg/L	Ammonia as N	0.05 mg/L
2,4,5-TP	0.2 µg/L	Captan	0.005 µg/L	Chlorophyll A	2.0 µg/L
2,4-D	0.1 µg/L	Carbaryl	0.2 µg/L	Nitrate and nitrite as N	0.05 µg/L
2,4-DB	2.0 µg/L	Carbofuran	0.001 µg/L	Nitrate as N	0.05 mg/L
3,5-Dichlorobenzoic Acid	0.5 µg/L	Diuron	0.005 µg/L	Nitrite as N	0.05 mg/L
4,4'-DDD	0.002 µg/L	Linuron	0.005 µg/L	Phosphorus, total as P	0.05 mg/L
4,4'-DDE	0.002 µg/L	Methiocarb	0.005 µg/L		
4,4'-DDMU	0.002 µg/L	Methomyl	0.001 µg/L	Bacteria	
4,4'-DDT	0.005 µg/L	Oxamyl	0.5 µg/L	E. Coli	1.0 MPN/100mL
Acifluorfen	0.2 µg/L	Organophosphates		Fecal coliform	2.0 MPN/100mL
Aldrin	0.002 µg/L	Aspon	0.05 µg/L	Total coliform	2.0 #/100ml
Bentazon	0.5 µg/L	Azinphosmethyl	0.02 µg/L	Trace elements, cations	
Chlordane	0.05 µg/L	Azinphos ethyl	0.05 µg/L	Calcium	1.0 mg/L
Chlordane-alpha	0.002 µg/L	Bolstar	0.05 µg/L	Magnesium	1.0 mg/L
Chlordane-gamma	0.002 µg/L	Carbophenthion	0.05 µg/L	Potassium	1.0 mg/L
Dachtal	0.002 µg/L	Chlorfenvinphos	0.05 µg/L	Sodium	1.0 mg/L
Dalapon	1.0 µg/L	Chlorpyrifos	0.005 µg/L	Trace elements, anions	
Dicamba	0.1 µg/L	Chlorpyrifos, methyl	0.05 µg/L	Alkalinity	5.0 mg/L
Dichlorprop	0.5 µg/L	Ciodrin	0.05 µg/L	Bicarbonate alkalinity	5.0 mg/L
Dieldrin	0.002 µg/L	Coumaphos	0.05 µg/L	Carbonate alkalinity	5.0 mg/L
Dinoseb	0.2 µg/L	Demeton	3.0 µg/L	Chloride	0.2 mg/L
Endosulfan I	0.002 µg/L	Demeton-o	1.0 µg/L	Hydroxide	5000 µg/L

Table A-26-2.
Summary of All Constituents Measured in Water with Laboratory Reporting Limits (contd.)

Pesticides	Reporting Limit	Carbamates	Reporting Limit		Reporting Limit
Endosulfan II	0.002 µg/L	Demeton-s	0.05 µg/L	Sulfate	0.4 mg/L
Endosulfan sulfate	0.002 µg/L	Diazinon	0.005 µg/L	Trace elements, total	
Endrin	0.002 µg/L	Dichlorfenthion	0.05 µg/L	Arsenic	0.5 µg/L
Endrin aldehyde	0.005 µg/L	Dichlorvos	0.05 µg/L	Boron	10.0 µg/L
Endrin ketone	0.005 µg/L	Dicrotophos	0.05 µg/L	Chromium	0.5 µg/L
Gamma-bhc	0.002 µg/L	Dimethoate	0.03 µg/L	Copper	0.5 µg/L
HCH-Alpha	0.002 µg/L	Dioxathion	0.05 µg/L	Lead	0.5 µg/L
HCH-Beta	0.002 µg/L	Disulfoton	0.02 µg/L	Mercury	2.0 ng/L
HCH-Delta	0.002 µg/L	Epn	1.2 µg/L	Molybdenum	0.5 µg/L
Heptachlor	0.002 µg/L	Ethion	0.05 µg/L	Nickel	1.0 µg/L
Heptachlor epoxide	0.002 µg/L	Ethoprop	0.05 µg/L	Selenium	0.4 µg/L
Hexachlorobenzene	0.001 µg/L	Famphur	0.05 µg/L	Zinc	2.0 µg/L
Methoxychlor	0.002 µg/L	Fenitrothion	0.05 µg/L		
Mirex	0.002 µg/L	Fensulfothion	0.05 µg/L		
Nonachlor, cis	0.002 µg/L	Fenthion	0.05 µg/L		
Nonachlor, trans	0.002 µg/L	Fonophos	0.05 µg/L		
Oxadiazon	0.002 µg/L	Glyphosate	6.0 µg/L		
Oxychlordane	0.002 µg/L	Leptophos	0.05 µg/L		
Pentachlorophenol	0.04 µg/L	Malathion	0.02 µg/L		
Picloram	0.1 µg/L	Merphos	0.05 µg/L		
Tedion	0.002 µg/L	Methidathion	0.02 µg/L		
Total DCPA Mono and Diacid Degradates	0.1 µg/L	Mevinphos	0.05 µg/L		
Toxaphene	0.5 µg/L	Naled	0.05 µg/L		
Trichloronate	0.05 µg/L	O,O,O-Triethylphosphorothioate	0.5 µg/L		
		Parathion, ethyl	1.0 µg/L		

Table A-26-2.
Summary of All Constituents Measured in Water with Laboratory Reporting Limits (contd.)

Pesticides	Reporting Limit	Carbamates	Reporting Limit		Reporting Limit
Pyrethroid scan		Parathion, methyl	4.0 µg/L		
Bifenthrin	0.001 µg/L	Phorate	0.02 µg/L		
Cyfluthrin	0.002 µg/L	Phosmet	0.02 µg/L		
Cypermethrin	0.002 µg/L	Phosphamadon	0.05 µg/L		
Deltamethrin	0.5 µg/L	Ronnel	0.05 µg/L		
Esfenvalerate	0.5 µg/L	Sulfotep	0.05 µg/L		
Fenpropathrin	0.002 µg/L	Terbufos	0.05 µg/L		
Lambda-cyhalothrin	0.5 and 0.0005 µg/L	Tetrachlorvinphos	0.05 µg/L		
Permethrin (total)	0.5 µg/L	Thionazin	0.05 µg/L		
Permethrin, cis	0.003 µg/L	Tokuthion	0.05 µg/L		
Permethrin, trans	0.003 µg/L	Trichlorfon	0.05 µg/L		

Key:
µg/L = micrograms per liter
mg/L = milligrams per liter
mL = milliliter
MPN = most probable number

Table A-26-3.
Summary of All Constituents Measured in sediment with Laboratory Reporting Limits

Pesticides	Reporting Limit	Pyrethroid Scan	Reporting Limit
Organochlorine scan		Bifenthrin	1.2-17.0 ng/g
2,4'-DDD	1.1-3.3 ng/g	Cyfluthrin	4.7-17.0 ng/g
2,4'-DDE	2.2-3.3 ng/g	Cypermethrin	4.7 ng/g
4,4'-DDD	0.65-1.1 ng/g	Esfenvalerate	13-17 ng/g
4,4'-DDE	2.2-3.3 ng/g	Fenpropathrin	4.7 ng/g
4,4'-DDMU	3.4 ng/g	Lambda-cyhalothrin	2.3-17.0 ng/g
4,4'-DDT	0.65-5.6 ng/g	Permethrin (total)	13-17 ng/g
Aldrin	1.1 ng/g	Permethrin, Cis	5.8 ng/g
Chlordane, technical	3.3 ng/g	Permethrin, Trans	5.8 ng/g
Chlordane-Alpha	1.1 ng/g	Organophosphates	
Chlordane-Gamma	1.1 ng/g	Chlorpyrifos	0.46 ng/g
Dachtal	1.1 ng/g	Trace elements, total	
Dieldrin	0.56-0.65 ng/g	Arsenic	0.5-1.0 µg/g
Endosulfan I	2.2 ng/g	Chromium	0.5-1.0 µg/g
Endosulfan II	6.8 ng/g	Copper	0.5-1.0 µg/g
Endosulfan sulfate	5.5 ng/g	Lead	0.5-1.0 µg/g
Endrin	0.65-2.2 ng/g	Mercury	0.0117-0.3 µg/g
Gamma-BHC	0.56-13 ng/g	Nickel	1.0 µg/g
HCH-alpha	0.56 ng/g	Selenium	2.5 µg/g
HCH-beta	1.1 ng/g	Zinc	1.5-2.0 µg/g
Heptachlor	1.1 ng/g	Total Organic Carbon	100-2500 µg/g
Heptachlor epoxide	0.65-1.1 ng/g	Dissolved Organic Carbon	2000 µg/g
Hexachlorobenzene	0.77 ng/g	Percent solids	
Methoxychlor	3.4 ng/g	Percent moisture	
Mirex	1.7 ng/g	H. azteca survival	
Nonachlor, Cis	1.1 ng/g	H. azteca dry weight	
Nonachlor, Trans	1.1 ng/g		
Oxadiazon	1.1 ng/g		
Oxychlordane	1.1 ng/g		

Key:
µg/g = micrograms per gram
ng/g = nanograms per gram

Table A-26-4.
2009 – 2010 Results of Water Quality Constituents Above Lab Reporting Limits

Constituent				
General Water Quality	**Max**	**Min**	**Reporting Limit**	**Units**
Alkalinity	200	12	5.0	mg/L
Bicarbonate	190	15	5.0	mg/L
Bicarbonate alkalinity	200	12	5.0	mg/l
E.coli	240	2	1.0	MPN/100mL
Fecal coliform	300	2	2.0	MPN/100mL
Ph	7.8	7.1	0.1	PH
Total coliform	1600	13	2.0	#/100ml
Metals				
Arsenic	6.2	0.5	0.5	µg/L
Boron	790	10	10	µg/L
Chromium	5.3	0.5	0.5	µg/L
Copper	7.0	0.5	0.5	µg/L
Lead	56	0.5	0.5	µg/L
Magnesium	37	1	1.0	mg/L
Mercury	.017	.0022	2.0	µg/L
Molybdenum	9.2	0.8	0.5	µg/L
Nickel	16	1	1.0	µg/L
Selenium	2.3	0.4	0.4	µg/L
Zinc	640	2	2.0	µg/L
Ions				
Calcium	68	2	1.0	mg/L
Carbonate	7	7	5.0	mg/L
Chloride	230	1.1	0.2	mg/L
Potassium	6.6	1	1.0	mg/L
Sodium	170	2	1.0	mg/L
Sulfate	240	0.72	0.4	mg/L
Biological				
Chlorophyll A	6.5	2.4	2.0	µg/L
DOC	8	2	0.3	mg/L
TKN	1.6	0.2	0.2	mg/L
TOC	8.2	2	0.3	mg/L
TSS	85	1.1	1.0	mg/L
Pesticides				
Dacthal	0.014	0.013	0.002	µg/L
Diuron	0.024	0.024	0.005	µg/L

Table A-26-4.
2009 – 2010 Results of Water Quality Constituents Above Lab Reporting Limits (contd.)

Constituent				
General Water Quality	**Max**	**Min**	**Reporting Limit**	**Units**
Nutrients				
Ammonia as N	3.5	0.05	0.05	mg/L
Nitrate + Nitrite as N	1.4	0.055	0.05	mg/L
Nitrate as N	1.5	0.05	0.05	mg/L
Nitrite as N	0.04	0.03	0.03	mg/L
Phosphorus, Total as P	0.39	0.05	0.05	mg/L

Key:
mg/L = milligrams per liter

Table A-26-5.
Results of Sediment Sample Constituents Above Lab Detection Limits

Constituent	Max	Min	Reporting Limit	Units
Metals				
Chromium	15	1.2	0.5-1.0	µg/g
Copper	23	1.2	0.5-1.0	µg/g
Lead	53	0.98	0.5-1.0	µg/g
Nickel	34	1.3	1.0	µg/g
Zinc	62	5.5	1.5-2.0	µg/g
Pesticides				
Bifenthrin	23	<0.013	1.2-17.0	µg/g
Lambda-cyhalothrin	21	<0.013	2.3-17.0	µg/g

Key:
µg/g = micrograms per gram

26.3.6 Concentrations Found and Comparisons to Criteria – 2011 Samples

Approximately 45 percent of the laboratory analyses of water samples were below minimum laboratory detection limits. Results for constituent samples above lab detection limits are listed in Table A-26-5. A complete list of constituents measured in water and the laboratory reporting limits is provided in Table A-26-6. Overall, water quality results for 2011 were lower than previous years.

Copper levels in water were above laboratory reporting limits in approximately 40 samples (Table A-26-5). Results for dissolved copper ranged from 0.5 to 5.0 µg/L. A total of 29 water samples had copper concentrations greater than 1.11 µg/L, which is

EPA's OPP aquatic-life chronic benchmark for invertebrates. Twenty-four samples were above the acute benchmark for invertebrates (1.8 µg/L) (EPA, 2011). Aquatic life benchmarks are extracted from the most current publicly available risk assessment data, which is based on the most sensitive toxicity data for each aquatic taxa. Each benchmark is an estimate of the concentration below which pesticides are not expected to harm the organism. The highest copper samples come from the San Joaquin River above Merced River, San Joaquin River at Highway 152, and San Joaquin River at Fremont Ford.

Table A-26-6.
2011 Results of Water Quality Constituents Above Laboratory Reporting Limits

Constituent				
General Water Quality	**Max**	**Min**	**Reporting Limit**	**Units**
Alkalinity	160.0	7.0	5.0	mg/L
Bicarbonate alkalinity	200.0	8.0	5.0	mg/L
Fecal coliform	500.0	8.0	2.0	MPN/100mL
Total coliform	900.0	2.0	2.0	#/100ml
Metals				
Arsenic	4.3	0.7	0.5	µg/L
Boron	700.0	12.0	10	µg/L
Chromium	3.6	0.5	0.5	µg/L
Copper	5.0	0.5	0.5	µg/L
Lead	1.0	0.5	0.5	µg/L
Magnesium	34.0	1.0	1.0	mg/L
Molybdenum	7.3	0.7	0.5	µg/L
Nickel	5.3	1.4	1.0	µg/L
Selenium	1.8	0.4	0.4	µg/L
Zinc	12.0	2.0	2.0	µg/L
Ions				
Calcium	61.0	2.0	1.0	mg/L
Chloride	250.0	1.0	0.2	mg/L
Potassium	4.3	1.0	1.0	mg/L
Sodium	180.0	2.0	1.0	mg/L
Sulfate	200.0	1.0	0.4	mg/L
Biological				
Chlorophyll A	40.0	2.0	2.0	µg/L
DOC	7.0	1.8	0.3	mg/L
TKN	1.0	0.2	0.2	mg/L
TOC	7.1	1.8	0.3	mg/L
TSS	83.0	10.0	1.0	mg/L
Pesticides				
HCH-Alpha	0.004	0.002	0.002	µg/L
Nutrients				
Ammonia as N	0.1	0.1	0.05	mg/L
Nitrate as N	2.7	0.1	0.05	mg/L
Nitrite as N	0.1	0.0	0.03	mg/L
Phosphorus, Total as P	0.3	0.1	0.05	mg/L

Key:
µg/L = micrograms per liter
mg/L = milligrams per liter

26.4 Discussion and Recommendations

26.4.1 Sampling Frequency

Water quality sampling during 2010 generally occurred once per month for water, and once per year for sediment, in different months. No samples were collected in May and November 2010 due to limited availability of staff. Water quality sampling during 2011 occurred once per month February through November. Sediment samples were not collected in 2011. Continuation of monthly water sampling is recommended so that a thorough understanding of the effects of Interim Flows can be developed. Routine sediment sampling should be considered, meaning that sediment sampling should be collected at the same time each year, ideally before increases in fall flow releases.

Storm sampling should be considered to determine if there are pulses of sampled constituents in the Restoration Area during storm events. In-stream concentrations of constituents that come primarily from surface runoff, such as pesticides, can increase dramatically during a storm event and may have toxic effects on aquatic organisms. A study by Kratzer (1999) found that concentrations of the pesticide diazinon are highly variable during winter storms, with some pulses high enough to be acutely toxic to aquatic invertebrates. Thus, water quality during both base-flow and high-flow events is sampled in order to accurately monitor the water quality of the river (Hladik et al., 2009; Weston et al., 2004; Orlando et al., 2003). Storm sampling is labor intensive and requires careful planning. A recommendation and design for a storm sampling study should be developed separately from this report by experts in the field.

26.4.2 Sampling Locations

Sampling is occurring in at least two locations in every reach, with the exception of Reaches 3 and 4, where access to the river is restricted. Distribution of sampling locations is fairly even, with the exception of Reach 4. To help remedy this, it is recommended that water and sediment sampling sites be added above and below the confluence of Bear Creek with the San Joaquin River. Even distribution of sampling locations helps develop an accurate representation of the water quality throughout the restoration reach.

26.4.3 Sample Media

Tissue samples of resident fish species would be a very valuable asset to the SJRRP. Tissue samples can help address questions regarding bioaccumulation and food web transfer of contaminates as such questions are difficult to address with only data from water and sediment. Tissue sampling has been conducted on the San Joaquin River as part of the Graslands Bypass Project for selenium and boron (Reach 5) and for mercury (Davis et al., 2008).

Another method for addressing the bioavailability of hydrophobic organic chemicals to aquatic organisms involves the use of semipermeable membrane devices (SPMD). This passive sampling technique can mimic the uptake of contaminates through biological membranes (Kot et al., 2000). They have been used to passively sample organochlorine pesticides in aquatic environments and can be used as a surrogate tissue sample to evaluate bioconcentration from water in aquatic organisms (Esteve-Turrillas et al., 2008).

Bioaccumulation of contaminants through the food web cannot be addressed with SPMDs.

Bioassays conducted on aquatic invertebrates can indicate if crucial food web organisms are affected by the presence of contaminates in the sediment or water column. Previous bioassay studies have identified pesticide related toxicity in invertebrates in the San Joaquin River (Kuivila and Foe, 1995; Foe and Connor, 1991). It is recommended that the SJRRP consider conducting bioassays on sediment with benthic invertebrates (e.g., *Hyallela sp*., *Chironomus sp*.) and on water with water column-oriented invertebrates (e.g., *Ceriodaphnia sp*.) as food web surrogates to better understand the possible lethal and sub-lethal effects of contaminates on food web organisms in the Restoration Area. Bioassays have been conducted on invertebrates, fish, and algae as part of the Grasslands Bypass Project, but none of these tests were conducted at locations within the San Joaquin River. These bioassays were conducted in Mud Slough and Salt Slough, both inputs to the San Joaquin River in Reach 5 of the SJRRP.

26.4.4 Sample Processing

2009-2010: Approximately 3 percent of constituent analyses from both sampling years exceeded their holding times for laboratory processing, which can reduce the accuracy of the results. Holding times exceedances ranged from 24 hours to 40 days, with the majority of samples exceeding either their 24-hour (47 percent) or 14-day holding times (44 percent). Samples that exceeded 24-hour hold times were primarily bacteria (coliform and *E.coli*), while those that exceeded 14-day hold times consisted of a variety of constituents, including pesticides and general water quality parameters. Seven dissolved organic carbon (DOC) and one total organic carbon (TOC) samples were not preserved correctly upon collection. Forty-five chlorophyll A samples were not filtered within the correct amount of time following collection. It is recommended that sample processing protocols, including holding times, be improved upon and applied to the current sampling effort.

2011: Approximately 5 percent of constituent analyses exceeded their 24-hour filtration hold time. Samples that exceeded this hold time included chlorophyll A, *E. coli*, and coliform.

26.4.5 Detection Limits

Detection limits are mostly sufficient for detecting concentrations potentially toxic to aquatic biota, with some acceptations. It is recommended that arsenic, boron, chlordane, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), and dichlorodiphenyltrichloroethane (DDT) be tested with lower detection limits than currently used (Table A-26-7). Note that some pesticides such as chlorpyrifos, diazinon, malathion, and bifenthrin can be detected at lower concentrations than possible with laboratory analyses presently being used by the SJRRP. Detection of toxic constituents at low levels can help identify and investigate sub-lethal effects of both salmon and resident native fishes (discussed further below). A review of existing literature indicates that the detection levels currently being used by the SJRRP appear to be sufficient for monitoring

biological effects of harmful constituents within the river, with the exception of those present at a sub-lethal concentration.

Table A-26-7.
Recommended Detection Limits for Biological Effects on Fishes from the 2009 SJRRP Water Quality Monitoring Plan

Constituent	Current Detection Limit	Recommended Detection Limit
Arsenic	0.5 µg/L	0.014 µg/L
Boron	10.0 µg/L	0.8 µg/L
Chlordane	0.05 µg/L	0.0043 µg/L
DDD	0.002 µg/L	0.00031 µg/L
DDE	0.002 µg/L	0.00022 µg/L
DDT	0.005 µg/L	0.001 µg/L

Key:
µg/L = micrograms per liter

26.4.6 Thresholds

Review of the water quality data collected to date for the SJRRP shows few constituents present at concentrations that exceed aquatic life thresholds. However, other water quality studies conducted on the San Joaquin River have found elevated levels of constituents, such as selenium and methyl-mercury in the system that may pose threat to aquatic organisms. Thus, regular and consistent sampling should be maintained in the Restoration Area to understand possible changes associated with natural factors, such as seasonal differences, storm events, as well as anthropogenic factors, such as changes in restoration flows, restoration of floodplain, and changes in agricultural practices. Monitoring results should be evaluated in the context of current research on the effects of pollutants in surface waters on aquatic biota. Such evaluation can guide refinements in the water quality monitoring program.

The SJRRP manages for Chinook salmon and other native fish that are linked through a food web. The water quality program will not adequately used existing results until the translation of water quality effects up the food web is investigated and better understood. This investigation should rely on conclusions from existing studies and address these information gaps. For example, there is little information about toxic effects of pesticides on aquatic invertebrates and how such effects translate up the food web (Macneale et al., 2010). Of the work that has been done in this area, results show that applications of pesticides can have a strong negative effect on the food web. In a study done by Relyea and Diecks (2008) that looked at food web effects of the insecticide malathion, findings showed that all levels of application (10 to 250 µg/L) over short periods of time (1 to 4 days) caused a decline in zooplankton, which caused a cascading decline in all other species in the study. They also found that repeated applications of low doses caused a greater negative response than a single application of a high dose. These and other studies highlight the importance of quantifying pesticide exposure in aquatic habitats due to

pesticide-use patterns, combined effects of multiple pesticides, and how the fate of various pesticides change in relation to degradation times, uptake rates and binding ability of soils (Laetz et al., 2009; Oros and Werner, 2005; Nowell et al., 1999).

A variety of research has been done on pesticides and their various effects on fish. Organophosphates and carbamates are two classes of pesticides that are of particular concern as both target the nervous system (Fulton and Key, 2001). For example, a 2-hour exposure to the organophosphate insecticide diazinon has been found to decrease olfactory-mediated alarm responses in Chinook salmon at concentrations of 1.0 µg/L. A 24-hour exposure to diazinon at concentrations ranging from 0.1 to 10.0 µg/L disrupts homing in Chinook salmon males (Scholz et al., 2000). Another currently used pesticide that is commonly applied in the San Joaquin Valley, chlorpyrifos, has been shown to inhibit acetylcholinesterase (AChE), a chemical in the transmission of nerve impulses, in the nervous system and muscles of juvenile steelhead and coho salmon at concentrations of 510.0 mg/L. Reduction in AChE activity has been linked to decreased swimming behavior and prey consumption by juvenile salmon (Sandahl et al., 2005; Sandahl and Jenkins, 2002). The presence of these and other pesticides are well documented on the San Joaquin River and its tributaries (Domagalski et al., 2010; Orlando et al., 2004) and SJRRP monitoring should continue.

Sub-lethal effects of pesticides, such as those discussed above, are of particular concern for aquatic organisms in the San Joaquin River. Sub-lethal effects include reductions in growth, swimming behavior, reproductive success, and immune system response in aquatic fish and invertebrates, often at much lower than lethal concentrations (Oros and Werner, 2005). The pesticide carbofuran is thought to have sub-lethal effects on reproduction in Atlantic salmon (Waring and Moore, 1997). To date, the results from the SJRRP's water quality sampling show few exceedances, yet it is possible that aquatic organisms within the river are exposed to concentrations of both pesticides and other potentially harmful constituents that are sufficient to cause sub-lethal effects. It may be valuable to test for some of the most toxic constituents, particularly pesticides, at the lowest available detection limits so that a sub-lethal baseline can be established. If sub-lethal effects occur with exposures in the part per trillion range, then they are not currently being detected since the SJRRP's laboratories' detection levels are in the parts per million or ppb range. This type of testing may lead to a better understanding of how present persistent pollutants affect the San Joaquin River fish fauna.

Summary of Recommendations

- Continue monthly water quality sampling throughout the year
- Consider sampling sediment at the same time each year, before increases in flow releases (i.e., September).
- Evaluate desirability of storm sampling
- Add sample site above and below Bear Creek confluence
- Evaluate desirability of tissue sampling

- Consider using SPMDs for passive pesticide sampling
- Consider conducting bioassays above Reach 5
- Change detection limits to those listed in Table A-40-6
- Evaluate the likelihood of sub-lethal effects based on existing data and literature review

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27.0 Water Temperature Monitoring

27.1 Introduction

Water temperature substantially influences the abundance, growth, and survival of fishes and is critical to the timing of life-history events, especially reproduction (Fry, 1971). High temperatures result in physiological stress and increased metabolic demand on fishes, which may result in slower growth, susceptibility to disease, and lower survival rates. Understanding the longitudinal distribution of water temperatures in relation to the Restoration Flows on the San Joaquin River is critical to our ability to successfully prepare the system for reintroduction of Chinook salmon (i.e., evaluate site-specific alternatives, assess habitat availability and needs, recommend water allocations, and recommend stock selection and reintroduction strategies). Exhibit A of the SJRRP FMP, Conceptual Models of Stressors and Limiting Factors for San Joaquin River Chinook Salmon, presents the acceptable temperature ranges at each life stage of Chinook salmon and discusses why suitable temperatures affect salmonids at an individual and population level (FMWG, 2009). The DFG began collecting water temperatures during the fall 2009 Interim Flow period. The purpose of this report is to summarize the methods, data collected, and preliminary results of temperature monitoring during the 2011 Interim Flow period.

27.2 Methods

Temperature data loggers (HOBO Water Temperature Pro v2) were programmed to record temperature hourly and placed at various locations beneath the water surface, in a longitudinal array throughout the Restoration Area. Loggers were arrayed so that migration pathways and potentially suitable holding, rearing, and spawning habitats could also be evaluated (see Appendix A, Temperature Monitoring Locations Maps). The location of loggers were dependent on legal access to the site, an appropriate anchor point, and the ability to conceal the loggers to reduce vandalism. Where possible, placement was made within the thalweg of the stream, or in an area with adequate year-round flow and water depth to avoid measurement bias from the warmer stream edges or thermal stratification. Most loggers were deployed in runs, riffles, and glides along the right and left banks in the San Joaquin River. Typically, loggers were cabled to trees, root wads, or permanent structures and would be located approximately 2 feet below the water surface in continuous flow. Loggers in depths less than 2 feet are located approximately 6 inches from the river bottom in continuous flow.

Temperature loggers were also deployed in pools and off-channel mining pits that have connectivity to the San Joaquin River. These sites contain loggers mid-channel on vertical profiling stringers with a weight and float. Pools and mining pits with depths less than 8 feet have one logger attached to the stringer approximately 1 foot below the water

surface, and those with depths greater than 8 feet have two loggers attached to the stringer. One logger is attached to the stringer approximately 1 foot below the water surface and the other logger is attached approximately 18 inches from the substrate. Each mining pit site initially had two locations with vertical stringers (one stringer at the entrance of the pit and one stringer approximately in the center of the pit); however, locations at the entrance of pits are no longer used as monitoring stations due to high vandalism.

A Microsoft Access database is used for the temperature monitoring study. It is the responsibility of DFG staff to ensure valid data; additionally, the database is equipped with a quality assurance/quality control (QA/QC) Utility to detect questionable data. The QA/QC Utility is designed to flag any data points that have a value in excess of a certain tolerance when compared with adjacent points. To minimize the possibility that erroneous data will migrate to other applications, the database will not allow the user to generate any reports or graphs until a QA/QC check is performed and all data points tagged with QA/QC codes are cleared. Once processed, the data can be used for temperature model application purposes as well as to generate graphs and reports

27.3 Data Collected

Overall, 59 monitoring areas were operational before the 2012 Interim Flow period. All vertical stringers located at the entrance of the gravel pits were lost during the 2010 Interim Flow period. Several other monitoring sites had missing loggers due to vandalism and/or high flows. A more complete analysis and report is in progress and can be expected in June 2012. A description of monitoring sites and status of loggers is provided in Appendix B, Temperature Logger Summary and Status. Raw temperature data for each monitoring location are located in Appendix C, Temperature Data. These data are preliminary and subject to revision.

27.4 Discussion

DFG will continue the current program of monitoring temperature in the San Joaquin River, which has been ongoing since 2009. New temperature loggers will also be deployed in potential spawning and holding habitats during micro-habitat evaluations during the 2012 Interim Flow period. As access becomes available, DFG intends to expand the temperature logger array by deploying loggers in Reach 4 and in the bypass system (Appendix D, Proposed Logger Locations). Additionally, we will continue to monitor longitudinal temperatures patterns during future Interim Flow periods to identify the annual variability in water temperatures throughout the Restoration Area. The FMWG will continue to assess water temperatures during the spawning and incubation period and adjust the limiting factors analyses as appropriate.

Temperature monitoring data will be used to validate the Conceptual Models of Stressors and Limiting Factors for San Joaquin River Chinook Salmon and will be prepared for inclusion into the EDT model and potentially other models used by the SJRRP. Analysis

of temperature monitoring will be used to evaluate the relative importance of the various factors affecting stream temperatures, and to evaluate what impact changes in solar radiation (e.g., shade from riparian vegetation), channel form (geometry and morphology), and flow (magnitude and timing) may have on the stream temperature regime. Temperature monitoring evaluation will assist the SJRRP in developing Total Maximum Daily Load (TMDL) standards and assist in making recommendations on specific actions relating to adaptive management of the SJRRP.

27.5 References

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28.0 Adult Passage Report

28.1 Introduction

This document describes the Task 2 data collection and evaluation of potential fish passage barriers on the main-stem of the San Joaquin River and bypass system, from Friant Dam to the Merced River confluence. DWR is performing this work as part of its fish passage evaluation that is being performed for the SJRRP to identify and prioritize fish passage barriers in the Restoration Area in an effort to minimize migration delays, stranding, and mortality of juvenile and adult salmon and other native fish. The fish passage evaluation plan follows a phased approach separated in three main tasks. Task 1, deemed first pass, was presented in the 2011 ATR in Appendix B, Section 20 and identifies the potential passage impediments to migration of juvenile and adult salmon and other native fish. Task 2, deemed second pass, which is currently underway, includes data collection and hydraulic evaluation of the potential fish passage barriers that were identified for further study in Task 28-1. Task 3 may be completed after Task 2 to recommend modifications to structures that were identified as barriers.

28.2 Methods

Table A-28-1 lists the 13 structures ranked as potential barriers (gray) during Task 1 that will be analyzed during Task 2. In addition, the Eastside Bypass and Mariposa Bypass control structures that are known barriers (red) will be analyzed during Task 2 to determine if there are any flows when it is not a barrier (assuming the gates are fully open). The beaver dams will be represented as a single typical structure for this evaluation since these are natural structures and are constantly changing and new dams being constructed. Task 1 did not identify structures on the Chowchilla or Eastside Bypass system upstream from Sand Slough since the Chowchilla Bypassis not identified as a migration pathway by the SJRRP. The evaluation of the Eastside Bypass system below Sand Slough will focus on a few known and potential barriers. Two weirs in the Eastside Bypass were identified by Reclamation in August 2011, as part of the sufficient flow study, as potential fish passage barriers. These structures were added for Task 2 since these structures were not identified as potential barriers during Task 1. This evaluation will not identify off-channel structures like diversions or gravel mining pits that have the potential for fish entrainment. In addition, tributaries to the San Joaquin River that could cause fish straying or structures that are potential barriers on the tributaries are not going to be included in this evaluation.

Field surveys have been conducted and hydraulic models are being developed to determine the hydraulic constraints of each structure. The analysis will allow the SJRRP to compare the model results with refined fish passage criteria that will be provided by the fisheries agencies to determine the suitable flows for passage and prioritize structures

for modification to improve passage. The hydraulic model results will be presented in tables and charts to display the structures' physical and hydraulic parameters to compare to defined fish passage criteria.

Table A-28-1.
Second Pass Locations

Identification Number	Reach	Description
4	1A	Lost Lake Rock Weir #1
5	1A	Lost Lake Rock Weir #2
17	1B	Donny Bridge
23	2A	San Mateo Avenue
29	4B1	Sand Slough Connector
36	4B2	Beaver Dam #5
37	4B2	Beaver Dam #4
38	4B2	Refuge Low Flow Crossing
39	4B2	Beaver Dam #3
40	4B2	Beaver Dam #2
41	4B2	Beaver Dam #1
48	4B1	Eastside Bypass Control Structure
49	4B1	Mariposa Bypass Control Structure
51	4A	Dan McNamara Road
69	4B2	Eastside Bypass Rock Weir
70	4B1	Refuge Weir #2
71	4B1	Refuge Weir #1

Current efforts have focused on collection of hydraulic data and topography at each structure identified in Table A-28-1 for further study. Hydraulic data are needed to evaluate passage conditions at the structures for various flow depths, velocities, and discharges and compared with the fish capabilities to determine the fish passage success.

High floodflows that were present during this study, fall 2010 through spring 2011, limited the access to many locations to safely collect hydrologic data. DWR staff was able to collect intermediate flow data in the late spring of 2011. Table A-28-2 lists the location, date and flow for each structure that was monitored during Task 2. These flows were typically out of the main channel and in the overbank at most structures. These data were able to supplement the Interim Flow calibration data collected in 2010, which were used for calibration of the Tetra Tech HEC-RAS hydraulic model. Flows less than 50 cfs were not collected due to the absence of these flows in most of the reaches, except Reach 4B2, during the study. Calibration on average was completed for one to two flow measurements over a broad range of flows. This means that for very low flows and very high flows the model, on average, has not been calibrated.

Table A-28-2.
DWR Discharge and WSE Details

Reach	Location	Monitoring Date	Recorded Flow (cfs)
1A	Lost Lake Weir #1	05/12/2011	3,110
1A	Lost Lake Weir #2	05/13/2011	2,870
1B	Donny Bridge	05/19/2011	3,040
2B	San Mateo Avenue	05/19/2011	1,160
4B2	Beaver Dam #4	07/07/2011	36.1
4B1	Eastside Bypass Control Structure	05/23/2011	1,720
4B2	Refuge Low Flow Crossing	05/24/2011	32.5
4B2	Beaver Dam #1 & #2	05/24/2011	41.0
4A	Dan McNamara Road	05/10/2011	1,860
4B2	Eastside Bypass Rock Weir	07/07/2011	1,840

Key:
cfs = cubic foot per second
WSE = water-surface elevations

Additional topographic information that was collected during the second pass included elevations of the structures and channel at model cross sections. These data were either collected by Total Station, survey-grade GPS, or bathymetry collected during flow measurements with an ADCP. Topographic data was compared with previous elevation data from the 1998 Ayres and 2008 LiDAR mapping for reasonableness. Topographic data collected during this effort superseded any existing topography in the model. Table A-28-3 lists the dates and locations of structures that were surveyed.

Table A-28-3.
Location of Second Pass Topographic Surveys

Reach	Location	Survey Date
4A	Dan McNamara Road	09/28/2011
4B2	Eastside Bypass Control	11/29/2011
4B2	Mariposa Bypass Control	11/29/2011
4B2	Refuge Low Flow Crossing	11/17/2011
4B2	Bypass Rock Weir	10/04/2011

28.3 Results

These results will help validate draft conceptual models of stressors and limiting factors for Chinook salmon (FMWG, 2009a), and help build the ecosystem diagnosis and treatment model framework. In addition, these results will be critical to the decision-making loop of adaptive management, as described in the FMP (FMWG, 2009b). At the completion of these analyses, it is expected that a priority list of structures to replace or modify will be developed with coordination from fisheries agencies. These priorities will then be recommended to the SJRRP for inclusion as a Paragraph 12 action in the Settlement.

28.4 Discussion

Task 2 results in a guide for making management decisions to minimize the risk of entrainment, stranding, and death from structures on the river and bypass system. These results generally depict the hydraulic conditions at each structure but should be followed up with actual fish passage monitoring during the experimental salmon runs to support the model findings before constructing permanent fish passage facilities. It is further recommended that those structures that were not identified as barriers be closely monitored for changes in the structural or channel conditions. The draft report for Task 2 is scheduled to be released in spring 2012. All data collected will be provided in the appendices of the Task 2 report.

28.5 References

Fisheries Management Work Group (FMWG). San Joaquin River Restoration Program (SJRRP). 2009a. Conceptual models of stressors and limiting factors for San Joaquin River Chinook salmon. 178 pp. June.

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29.0 Observations on the Hyporheic Environment Along the San Joaquin River Below Friant Dam

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Observations on the Hyporheic Environment along the San Joaquin River below Friant Dam

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ABSTRACT

The intragravel environment of the San Joaquin River from 4.8 to 14.0 km below Friant Dam was studied using hyporheic samplers. These samplers allowed for collection of water quality, sediment, and macroinvertebrates associated with this portion of the river environment. The goal was to characterize the substrate environment in the context of salmon egg/alevin survival in Reach 1A of the Restoration Area. Results suggest that poor hyporheic water quality, along with sand, in the redd environment may impact survival of early life history stages of salmon. It appeared that the macroinvertebrate community was composed of taxa that were largely tolerant of fine-sediment. Invertebrates that might affect survival of eggs or alevins were largely absent from hyporheic samples.

INTRODUCTION

Hyporheic samplers were used to assess spawning gravel, water quality, and invertebrate communities in the San Joaquin River within 14.0 km of Friant Dam in California. This assessment was a component of the San Joaquin River Restoration Program which is directed towards flow restoration and developing a self sustaining population of Chinook salmon (*Oncorhynchus tshawystcha*) (Fisheries Management Work Group 2010). During spawning activity and redd construction, Chinook eggs are buried in the substrate, at depths from ca. 30 cm (e.g., DeVries 1997) to 45 cm (Geist 2000). This relatively deep substrate region is often in the zone of surfacewater and groundwater interaction, typically referred to as the hyporheic zone. Hyporheic conditions within the redd may differ markedly from those found at the surface (e.g., Soulsby et al. 2001) and may differ spatially within the river channel because of variation in channel morphology, groundwater connectivity, and substrate permeability (Arntzen et al. 2006). Conditions for suitable egg incubation in the hyporheic environment may be negatively altered in regulated systems (Calles et al. 2007) that have relatively constant, diminished flows and altered substrates.

Factors that influence eggs during incubation include: quantity of sand in the redd (Kondolf 2000), quantity of flood-delivered sediment (Bowen and Nelson 2003), pH (Lacroix 1985), dissolved oxygen (DO) concentration in the redd (Ingendahl 2001), and amount of upwelling (Garrett et al. 1998). Upstream reservoirs may also alter water temperatures in receiving streams, and large efforts may be expended on managing these systems for cold-water fishes (e.g. Yates et al. 2008). Upwelling source is also important because of differences in water quality between upwelling due to phreatic (upland-derived) groundwater sources and upwelling driven by surface-water flow and redd morphology (Malcolm et al. 2009). Geist (2000) showed that Chinook salmon were less likely to spawn in areas dominated by groundwater upwelling zones with associated low DO, a parameter known to be important to salmon larval survival (Chapman 1988). Dissolved oxygen may be affected by proportions of surface/groundwater in the hyporheic zone and, in turn, influence salmon egg/alevin survival and/or growth.

Along with abiotic factors, biotic factors also influence survival of eggs within the redd environment (Meyer 2003). For example, Sparkman (2003) found that presence of an egg-eating oligochaete, *Haplotaxis ichthyophagous*, was negatively correlated with fry emerging from coho salmon redds. Benthic assemblages could impact salmon eggs and fry via predation (McDonald, 1960; Brown and Diamond, 1984) or cause changes in food availability and alterations in fry development while still within the redd (e.g., Heming et al., 1981, Field-Dodgson 1988). Organisms such as *Hydra*, which have caused large alevin mortalities in hatchery situations (Eisler and Simon 1961) are often common below dams (Armitage 1976, Nelson and Roline 2003). Studies of hyporheic zone utilization by invertebrates associated with salmon spawning runs are a recognized need (Peterson and Foote 2000). Aquatic invertebrates may also provide a biotic measure of habitat and water quality as part of projects aimed towards the reintroduction of salmon.

The present study was designed to collect information on several of these environmental variables that might affect the ability of Chinook salmon to successfully utilize potential spawning environments in the San Joaquin River. Hyporheic samplers were installed at several locations along the San Joaquin River below Friant Dam for depiction of Chinook salmon redd ecology related to water quality, sediment, and macroinvertebrate assemblages.

METHODS

Site locations—Sites are presented in Figure 1 and were at increasing distance downstream of Friant Dam. Site A was 4.8 km below the dam; B, 9.6 km; C, 10.9 km; and D, 14.0 km. Initially 8 samplers were placed at each of Sites B and C in July 2010. Site C was vandalized between installation in July and a return visit in September, and the majority of samplers were disturbed, leaving two in place. A single sampler was also disturbed at Site B. Three samplers were then placed at each of two sites, A and D, in September of 2010. Samplers were placed at riffle/run areas believed to be appropriate for Chinook salmon spawning. The portion of the river that was studied was believed, because of cool water from the dam, to have the highest likelihood for appropriate water temperatures for egg and alevin survival and development.

Sampling methods— Hyporheic samplers were constructed of 10-cm inside diameter polyvinyl choloride (PVC) piping with numerous 20-mm-diameter holes drilled in the sides (20% of surface area perforated) and covered on the bottom end with a PVC cap (Figure 2). Samplers extended approximately 32-cm into the substrate and were placed inside a 15- cm inside diameter PVC hole-drilled-sleeve (30% of surface area was holes). To install samplers, a 19-L bottomless bucket was placed at the selected spot in the stream and substrate material was then removed and placed into the sampler. As material was removed, the bucket was lowered in the resulting hole to stabilize the sides. Once sufficient depth had been achieved, the sampler and sleeve were placed in the hole. The hole was then filled with streambed substrate, and the bucket was removed. Larger river rock was placed on top of installed samplers to help prevent loss from high flows and to conceal samplers from vandals. The sleeve allowed for removal and then replacement of the sampler without reconstructing the hole in the river bed. Hyporheic samplers that

were replaced were filled with sediment collected from nearby sources. Minimum macroinvertebrate colonization time was 70 days. As hyporheic samplers were removed from the stream bed for collection of invertebrates and sediment, a 63-micron mesh screen was slipped below the sampler to reduce losses of organisms and substrate through the perforations. Because capture biases vary with type of hyporheic sampler (Fraser and Williams, 1997) our data are procedurally-defined.

Surber samples (0.09 m^2, 5 cm depth, 500 micron mesh size) were also obtained adjacent to collected hyporheic samplers in September, December, and February of 2011 (three Surber samples were collected on each date). We used these data to compare surface fauna collected with Surbers to the hyporheic fauna in the nearby hyporheic samplers. Contents of individual samples from both hyporheic samplers and Surber collection methods were placed into separate containers and macroinvertebrates preserved in propanol. In the laboratory, samples were washed in a 600-micron mesh sieve to remove alcohol, organisms were picked from the substrate under 10X magnification, and invertebrates identified to lowest practical taxon under a binocular dissecting scope. During washing a 63-micron mesh sieve was nested below the larger mesh sieve to retain finer sediment. All other sediment was also kept for size analyses (see Habitat assessment section).

Water samples--Hyporheic pore water samples were collected via a fused glass air stone attached inside the bottom of each hyporheic sampler. Plastic tubing, connected to the air stone, led to the surface and allowed for collection of pore water *in situ*. The air stone was used to prevent clogging of the tubing by sand or other particles during collection. A 60- ml plastic syringe was connected to tubing to withdraw pore water samples and was also used to collect surface water samples associated with each hyporheic sampler. The tubing was initially cleared by withdrawing and discarding 10-mls of fluid, followed by collecting 15-ml for DO determination. A final volume of 60-mls was collected for measurement of temperature (^oC) and conductivity (µS/cm). The same procedure was followed for collection of surface water samples. The collection of small volumes is suggested as important for clearly delineating environmental conditions at a given substrate depth (e.g., Malcolm et al., 2009).

A spectrophotometric method (Chemetrics, Inc.) was used for measurement of DO. The Rhodazine-D™ colorimetric method minimizes atmospheric interaction with the water sampled (White et al., 1990). The sampling system uses partially evacuated oxygen-free glass ampules containing Rhodazine-D™ that are broken along a prescored capillary tip while they are submerged in the water to be analyzed. A portable spectrophotometer which accepts the glass ampule is then used to measure DO after the spectrophotometer has been zeroed using a blank. Water temperature and conductivity were measured with a hand-held meter with a probe that requires a very minimal immersion depth (WTW Multiline P4).

Habitat assessment--Information on particle size of substrate material was obtained from size gradations of dried mineral samples from hyporheic samplers. Samples were oven dried for 24 hrs at 105^o C. A set of sieves placed in a mechanical shaker for 15 min was used to sift each diameter class, which were then weighed separately. Flow (discharge)

was obtained from on-line data from the U.S. Geological Survey station just below Friant Dam. Water velocity at 10 cm above the substrate was measured at each hyporheic sampler in October, December, and February. Coarse-particulate-organic-matter (CPOM) was collected from each hyporheic sample during macroinvertebrate processing. This material was dried for 48 hrs at 60^{o}C and then weighed.

Piezometers were used to measure the difference between piezometric water level and river water level, to identify areas of upwelling and downwelling. Piezometers, made of PVC pipe (15 mm i.d.), were attached to the outside of each hyporheic sampler sleeve (Figure 2) to a substrate depth of 32 cm. Piezometers were in sections, with a short 0.4-m section with a threaded top (capped when not in use) permanently installed in the substrate, while longer 1.2-m sections were temporarily attached just prior to measurements. Before measurements, piezometers were bailed using a short section of plastic tubing and allowed to equilibrate for 15-30 min. A bottomless bucket was placed over the hyporheic sampler and used as a stilling basin during measurements. Hydraulic head, the difference between water height in hyporheic zone piezometers and ambient stream water surface, was measured manually with a graduated electric tape. Water depth (water surface to substrate) was also determined at this time. Positive hydraulic head readings suggest hyporheic discharge or upwelling, where hyporheic water enters the stream channel. Negative values indicate downwelling or recharge from the stream channel into the hyporheic zone.

Data analyses--Paired *t* -tests were used to test for differences in DO, conductivity, and water temperature between surface and hyporheic water samples in the San Joaquin River. The difference in measurements between surface water conductivity and temperature and hyporheic conductivity (C_s-C_h) and temperature (T_s-T_h) were calculated and used as an index of exchange between these zones. Negative values indicate higher values in the hyporheic zone.

Dissolved oxygen in the hyporheic zone was considered the most important variable for determining survival potential for salmon eggs and alevins. Correlation analysis (Pearson product-moment) was used to describe relationships between hyporheic DO and other environmental variables. Correlation analysis was also used to examine relationships between benthic organisms and environmental variables. A *P*-value between 0.05 and $\leq$ 0.10 was considered to provide marginal evidence against the null hypothesis, while values < 0.05 provided moderate evidence against the null hypothesis.

Analysis of variance (ANOVA) followed by Tukey's test for comparisons were used to compare means of environmental variables between months.

Multiple regression was used to predict hyporheic DO from regressors. In some cases selection of a particular regressor was based on importance identified from correlation analysis. Velocity and hydraulic head were not used in the model because they were measured on a limited number of occasions and would have drastically decreased the number of observations. Dummy variables were constructed for temporal (monthly) variation for use in analysis.

Multivariate analysis (CANOCO 4.0) and invertebrate abundance were used to analyze invertebrate assemblages. We also examined taxa tolerance to fine sediment using indicator values derived by Carlisle et al. (2007). Ordination techniques were used to examine patterns in the macroinvertebrate data and to identify physical and chemical variables that were most closely associated with invertebrate distributions. To compare different types of samples (Surber surface sampler and hyporheic sampler), data were transformed to numbers per cubic meter. These data were analyzed with detrended correspondence analysis (DCA) and with a paired *t*-test.

Initial analysis of just the hyporheic macroinvertebrate data set used DCA, and revealed that the data set had a gradient length of 2.0 suggesting that a linear model [redundancy analysis (RDA)] was appropriate for direct ordination analysis. Infrequent taxa (taxa contributing <0.05% of total number counted) were deleted and faunal data transformed (square root) before analysis. Wilk-Shapiro/-Rankit plots were used to test for normality of environmental variables. If needed, variables were transformed with ln (X+1). If environmental variables were strongly positively correlated ($r \geq 0.60$), only a single variable was selected for use in the RDA to avoid problems with multicollinearity. Partial RDA was used to eliminate effects of variables that expressed seasonal differences and relate variation instead to other measured variables. Forward selection of environmental variables and Monte Carlo permutations (1000 permutations) were used to determine whether variables exerted a significant effect ($P < 0.05$) on invertebrate distributions. In the ordination diagram, taxa and sites are represented by points and the environmental variables by arrows. The arrows roughly orient in the direction of maximum variation in value of the given variable.

RESULTS

Water chemistry/habitat assessment--potential impacts to salmon eggs/alevins

Spatial variation--Dissolved oxygen, conductivity, and water temperature differed significantly between hyporheic pore water and surface water (n=51or 52, $P \leq 0.0007$, for all 3 paired *t* -tests) in the study area. Conductivity and temperature were typically higher in the hyporheic zone while DO was lower (Figure 3).

Only four of the hyporheic sampler locations consistently had hyporheic DO measurements $\geq$ 6 mg/L (see Figure 3a). The relationship between these samplers and other measurements are presented in Figure 3. Figure 3a includes high DO concentrations measured in September after samplers had been harvested and then refilled with gravel and returned to the river. Dissolved oxygen concentrations increased on average 4.9 $\pm$ 1.0 SE mg DO/L from this disturbance that might be similar to salmon spawning activities. Correlation analyses comparing DO concentrations and other environmental variables used measured concentrations prior to disturbance.

Weight of sand (diameter < 2mm) in hyporheic samplers (n=31) varied from 11.3 to 458 g/sampler. The overall average was 142.6 g. Presented as % sand, values ranged from 1.4 to 14.1 % sand, with a mean value of 7.4 % sand. Ten of the 31 samples had % sand values greater than 9%. Sand in hyporheic samplers varied with sites, with mean values higher at the furthest upstream locations (Figure 4).

Correlations between hyporheic DO and other environmental variables--Hyporheic DO concentrations were marginally correlated with surface water DO concentrations (r=0.2594, P=0.0660, n=52). Hyporheic DO concentrations were significantly correlated with conductivity (r=-0.3539, P=0.0108) and C_s-C_h (r=0.4628, P=0.0006) (n=51) but not correlated to temperature ($P \geq 0.5387$). Examination of scatterplots suggested that some of the more extreme conductivity exchange index values were having an undue influence on correlations. The metric C_s-C_h was even more correlated with hyporheic DO when the 5 extreme values (<-50) were omitted (r=0.6814, P <0.0001, n=46) (Figure 5). Hyporheic DO was marginally correlated with the weight of sand (particles < 2 mm in diameter) in hyporheic samplers (r=-0.3302, P=0.0748, n=30) (Figure 6) but was not correlated with % sand (P=0.9781). Hyporheic DO was marginally correlated with velocity (r=0.2546, P=0.0994, n=43) (Figure 7). Correlation of velocity with hyporheic DO varied seasonally with a significant relationship in October (r=0.5574, P=0.0309, n=15) and no statistical significance in December or February (P>0.15). The correlation of hyporheic DO with depth also varied seasonally, with significance detected in September (r=0.8412, P=0.0089, n=8) and December (r=0.5887, P=0.268, n=14) but not in October or February (P>0.84). Hydraulic head was not correlated with hyporheic DO (P=0.2387, n=28) but was marginally correlated with conductivity (r=0.3174, P=0.0998). Measures of hydraulic head varied with locations (Figure 8). Hydraulic head measurements from September and October were omitted from analysis because of difficulties in measuring piezometer water height with an electric tape that was relatively insensitive to low conductivities at that time of the year. There was no significant correlation between hyporheic DO and CPOM (square-root transformation, P=0.7526).

Temporal variation—Hyporheic DO did not vary significantly between seasons (P=0.5617) (Figure 9) even though mean values were lower in September. Hyporheic conductivity, however, did exhibit a seasonal effect (P=0.0032, Figure 10) although the variable C_s-C_h did not (P=0.7761). Mean weight of sand per sampler also did not differ significantly by season (P=0.1262, Figure 11). Hyporheic temperature differed between seasons (P<0.0001, Figure 12), as did T_s-T_h (P<0.0001). Sampling only occurred during periods of low flow (Figure 13) when samplers could be physically accessed. Water quality samples collected during high flows may have been very different. Depths were significantly lower in December (ANOVA, P<0.0001) (Figure 14) with the tops of some samplers out of the water. Depths in December ranged from -75 to 125 mm and were lower than the minimum depth criteria of 183 mm from meaurements of Oregon Chinook salmon redds (Smith 1973). This depth criteria was derived for spawning activity but may also indicate values associated with natural redds.

Potential drivers of hyporheic dissolved oxygen—Correlation analyses indicated that hyporheic DO was correlated with conductivity and amount of sand in the environment.

It also appeared that velocity played a role, with higher velocities associated with increased hyporheic DO. Stream depth also appeared to play a role during September when temperatures were highest and December when depths were lowest. Hydraulic head may have also influenced DO to some extent through the influence on conductivity; which was correlated with hyporheic DO.

Multiple regression for the dependent variable, hyporheic DO, was initially used with the regressors: C_s-C_h, weight of sand per sampler, surface DO, T_s-T_h, and the months September, December, and February. Only C_s-C_h, weight of sand per sampler, and September were significant in the model and the final model was constructed using those three variables (Table 1). Table 2 presents hyporheic DO predictions from the regression equation for each sampling location using the worst-case values at the various locations. The regressor September had a major impact on prediction results (Table 2) but may not be especially important since salmon redd building disturbance will likely increase hyporheic DO for at least a short time (see section *Spatial variation*). The absence of September information for sites A and D also impacts the data set. Interaction between the conductivity exchange index, C_s-C_h and weight of sand per sampler are likely key to hyporheic DO in the system.

Water temperatures—Water temperatures presented in Figure 3c show that, in general, hyporheic temperatures were higher than surface water temperatures. The average temperature difference was close to 1^{o}C in October and February. Minimal average differences in temperature were detected in December (-0.08) and maximum differences were found in September when hyporheic temperatures were close to 2 ^{o}C higher in the hyporheic samples.

Mean hyporheic water temperatures were highest in September (mean=15.1 ^{o}C) and October (mean=14.7 ^{o}C) (Figure 12) and ranged from 13.9 to 17.0 ^{o}C in September and 13.7 to 16.4 ^{o}C in October. Of the 23 measurements made in September and October, none were at the optimal temperature ($\leq$ 13^{o}C, from Table 3-1, San Joaquin River Restoration Program 2010) for incubation, 11 were in the critical range of 14.4 to 15.6 ^{o}C, and 5 were at or above the lethal temperature of > 15.6 ^{o}C (Table 3). Temperatures in December and February were much more amenable to egg survival (see Figure 12 and Table 3). Temperatures at the four locations that had suitable DO concentrations (see Figure 3) for egg development all had maximum hyporheic temperatures that were above the optimal temperature. At two of the locations maximum temperatures were within the critical range, while the other two locations had maximum temperatures just below this range. Surface water temperatures were highly correlated with hyporheic water temperatures (r=0.9198, P<0.0001). Surface water temperatures measured in September and October averaged 13.8 ^{o} C and ranged from 13.0-16.1 ^{o} C (n=24). There did not appear to be a longitudinal change in hyporheic water temperature (Figure 15) that might suggest more suitable temperature conditions closer to the dam. Figure 15 has data from September omitted so that all sites represent the same collection periods.

Data used in analyses are presented in Appendices A and B.

Macroinvertebrates

Hyporheic vs. surface—A paired *t*-test indicated that abundance (ln transformed) differed between hyporheic and surface environments (P=0.0169). Organisms collected with hyporheic samplers (n=9) averaged 118,311± 29,336 (SE) individuals/m^3 while those collected with Surber samplers (n=9) averaged 768,611 ± 364,964 (SE) individuals/m^3.

DCA results from comparison of hyporheic and surface collected samples had eigenvalues of 0.304 and 0.155 for the first two axes and explained 27.8% of the species data variation. DCA appeared to demonstrate some differences between communities associated with surface environments vs. those in the shallow hyporheic. Samples appeared to be separated according to sampler type (Figure 16) with surface samples towards the more positive end of Axis I, while hyporheic samples were towards the negative end of Axis I and the positive portion of Axis II. At the positive portion of the diagram along Axis I was the mayfly, *Acentrella insignificans* which was largely associated with surface samples (hyporheic abundance= 88.9 ± 88.9 (SE) individuals/m^3, surface abundance= 5,277.8 ± 3,046.1 (SE) individuals/m^3), while in the negative portion of Axis I and upwards along Axis II the amphipod *Crangonyx* was associated with hyporheic samples. This organism was consistently and only found in hyporheic samplers (hyporheic=1,866.7 ± 721.1 (SE) individuals/m^3). Several of the midges (*Thienemanniella* and *Thienemannimyia*) found in the negative portion of Axis I were found on only a few occasions and may not necessarily be representative of hyporheic environments. However, others like *Tanytarsus* were more consistently found in the hyporheic (hyporheic=1,555.6 ± 734.7 (SE) individuals/m^3, surface=277.8 ± 277.8 (SE) individuals/m^3). The blackfly *Simulium* was detected with both types of samplers but was much more abundant in surface samples (hyporheic=7,022.2 ± 5,694.5 (SE) individuals/m^3, surface=341,111 ± 272,644 (SE) individuals/m^3) and was located to the right along Axis I (Figure 16).

Results of partial RDA for the hyporheic benthos had eigenvalues of 0.167 and 0.058 for the first two axes and explained 26.6% of the species data variation and 88.1% of the species–environment relation. Initial environmental variables used in the model included CPOM (weight in g, (ln (X+1)) transformation), C_s-C_h, sand (weight in g/hyporheic sampler), hyporheic DO, and T_s-T_h. Variables found to be significant (P<0.05) in the model were CPOM, sand, and T_s-T_h (Figure 17). Monte Carlo tests indicated that all canonical axes were significant (P=0.0010).

The gradient that appeared most dominant (Axis I) was sand, with Ephemeroptera such as *Baetis tricaudatus* and *Ephemerella* in the positive portion of Axis I while oligochaetes such asTubificidae, Lumbricidae, and Lumbriculidae were most abundant in the negative portion of Axis I. The genus *Baetis* and *Ephemerella* were among those taxa that were most sensitive to sediment in this portion of the San Joaquin River according to the sediment indicator value (Table 4). The midge *Tvetenia* is also considered sensitive to fine sediment (Table 4) and was found along the positive portion of Axis I. Sand was negatively correlated with overall invertebrate abundance (r=-0.4090, P=0.0276) and also negatively correlated with Ephemeroptera abundance (r=-0.3771, P=0.0437) (Figure 18). However, sand was positively correlated with oligochaeta abundance (r=0.7303,

P<0.0001) (Figure 19). The vast majority of abundant taxa that were collected were highly tolerant of fine sediment (Table 4). A secondary axis was associated with CPOM, and this may be important in hyporheic invertebrate production (Crenshaw et al. 2002). The species list for hyporheic samplers demonstrates that invertebrates, such as predatory stoneflies or *Hydra*, known to impact salmon eggs or alevins were either not present (Table 3), or only found in low numbers such as odonata (total=1) or crayfish (total=1). This could change when eggs are placed in the environment and perhaps attract predatory invertebrates that were otherwise undetected. It is possible that some invertebrates may quickly respond to these new food resources. Continued monitoring of hyporheic invertebrates might be important following implementation of restoration actions.

DISCUSSION

Characteristics of the hyporheic environment in the San Joaquin River were studied using hyporheic samplers. The degree to which these samplers represent natural conditions is uncertain, with Meyer (2003) concluding from a comparison of artificial and natural redds that it was not possible to confirm how representative artificial redds were to natural redds. One of the concerns with hyporheic samplers is that placement in the gravel bed may allow for easier penetration of surface water, along the rigid tubing, into the hyporheic. If this is the case, measures of water quality may be less extreme (e.g., more similar to surface water) than actual. There is also concern with extraction of intermittent samples from the hyporheic, rather than *in situ* continuous measurements. Rapid changes in water quality (including sample warming and changes in DO) may occur upon sample withdrawal from the hyporheic zone. Also, spot sampling of the environment may occur during an atypical moment rather than during a more representative period (e.g., Mesick 2001, Malcolm et al. 2010). There may also be losses of fine sediment during sampler removal.

Hyporheic environmental variables

Hyporheic DO and conductivity--Hyporheic DO at locations sampled in the San Joaquin River were often at concentrations deemed harmful to early life history stages of salmonids and differed significantly from surface water DOs.

The Environmental Protection Agency (USEPA, 1986) sets the average DO value for **no production impairment** of salmonid eggs in gravel at $\geq$ 8 mg/L, and 50 % of all hyporheic measurements in the San Joaquin River were at or above this level. The percent of measurements that were at the **slight to severe production impairment** ($\leq$ 6 mg/L DO) level was 38%. However, it is likely that the most important measurement for DO is that specific to a given sampler location. Of the 15 samplers, only four had DO concentrations that were $\geq$ 6 mg/L on all occasions. The Washington State Department of Ecology (WDOE, 2002) has found that growth is reduced by 25% when eggs are incubated at 6 mg/L DO. Survival may also be reduced at DO concentrations around this value, and Eddy (1971) found that Chinook egg survival ranged from 49-57% when eggs

were maintained at 7.3 mg/L DO. WDOE (2002) notes that field studies on emergence consistently cite intragravel oxygen concentrations of 8 mg/L or greater as being necessary for superior health and survival, oxygen concentrations below 6-7 mg/L result in a 50% reduction in survival through emergence, and oxygen concentrations below 5 mg/L result in negligible survival. Measurements of DO in the San Joaquin River hyporheic indicated that 25% were below 5 mg/L.

Decreased hyporheic zone DO is typically linked to anoxic groundwater and/or fine sediments which decrease porosity, while increased hyporheic zone conductivity may be related to mixing of ground water with surface water (Fraser and Williams 1998). Land use near the San Joaquin River may also affect the hyporheic, with CMARP (1999) suggesting that contaminated groundwater from agricultural or urban areas may increase water temperature and reduce DO within salmon redds.

Dissolved oxygen in the San Joaquin River appeared to be especially related to both conductivity (low DO groundwater) and amount of sand (decreased porosity) in the environment. However, many other factors influence DO in the hyporheic zone. As an example of a factor that could be managed in this regulated system, higher flows in the San Joaquin River may positively impact hyporheic DO. Measures of stream velocity, water depth, and hydraulic head influences on hyporheic chemistry provide evidence that flow could affect hyporheic DO concentrations in the San Joaquin River.

Temperature—Mean water temperatures in the hyporheic were higher than surface water temperatures in this study at most sampled locations. Most critical was the finding that none of the hyporheic zone measurements from September and October were at the optimal temperature for salmon egg incubation. Several measurements were in the critical/lethal range.

Low velocity flows through large, slow moving, in-channel pools may impact hyporheic temperatures. It is also possible that off-channel large open areas of water from gravel mining affect hyporheic river temperatures, especially if there is significant interaction with the river channel. A review by Webb et al. (2008) suggested that land use, irrigation water returning via the subsurface, channel morphology, and hyporheic exchange may all impact stream heat budgets. Flood-plain gravel mines may influence hyporheic processes, perhaps through altering groundwater levels (Norman et al., 1998).

The elevated temperatures, high conductivity, and low DO's may be due to the inflow of anoxic groundwater (e.g., Mesick 2001) into the San Joaquin River at some locations. Temperature differences between surface water and hyporheic indicate that more intense monitoring of the hyporheic is needed. Some element of hyporheic zone temperature may need to be incorporated into temperature models for the San Joaquin River.

Sediment/water depth—Kondolf (2000) suggest difficulties in finding a univerally applicable threshold for fine sediments in redds. Perhaps as a result, different particle sizes have been promulgated as impacting salmon. Particles of less than 6.4 mm are recognized as having the potential to infiltrate redds, forming a layer in the stream

gravels which sometimes prevents emergence of fry (Lisle 1989). Kondolf (2000), in a review of the literature, found that salmonid emergence and survival was decreased by 50% when fine sediments (<6.4 mm) exceeded 30%. Bryce et al. (2010) suggested that hatching success will decline to unsustainable levels when bedded sand and fine sediments (< 2 mm) are between 11% and 18% by volume or mass. A mixture of sizes of fine sediments may also be important to Chinook salmon embryo survival and Tappel and Bjornn (1983) developed equations from incubation studies that used sizes of < 0.85 mm and <9.5 mm to predict survival in gravel mixtures.

Embryo survival fell below 50% when sediment <2 mm composed more than about 9% of the redd substrate and reached zero at around 14% sediment < 2 mm (Heywood and Walling 2007). Approximately a third of the samplers we collected contained fine sediments > 9%. Heywood and Walling (2007) suggested that accumulation of sediment limited the interchange of surface water and intragravel water through the redd surface, reducing the DO supply to the intragravel environment. While salmon have the ability to substantially decrease amounts of fine sediment in the redd pocket during redd construction, if fine sediment levels in the stream bed outside the redd are high, fines may intrude into constructed redds during high flows (Kondolf 2000). Sedimentation of newly constructed redds is very rapid and reflects the efficiency of cleaned redd gravels in trapping fine sediments (Heywood and Walling 2007).

Sediment may impact other salmonid life stages. Suttle et al. (2004) found large effects to juvenile salmonids in streams impacted by fine sediments (particles with diameter <2 mm). As sand increased, the availability of invertebrate prey items decreased along with fish growth. Suttle et al. (2004) concluded that they found no threshold below which fine-sediment addition is harmless. Suttle et al. (2004) had a low treatment threshold (other than their control which contained 0% sand) of 20% sand by volume. Cover et al. (2008) also found fine sediment (< 4 mm) impacts to macroinvertebrates at relatively low percent fines in the range of 4-16%. They suggest that negative impacts were to specific taxa that are more available as salmonid prey and would thus negatively impact fish populations. Information from hyporheic samplers also demonstrate this phenomenon with Ephemeroptera, a more available salmon food, declining while burrowing organisms, such as oligochaetes (largely unavailable to salmonids), increase with increasing fine sediment.

Water depth during observed lower flows in December may negatively impact Chinook salmon survival if alevins are present. While Reiser and White (1981) found no significant effects on survival to hatching of chinook salmon embryos exposed to 1-5 weeks of continuous redd dewatering (if eggs were kept moist), alevins expire quickly (Williams 2006). Reiser and White (1981) also make the point that complete dewatering of eggs may be preferable to the situation where low DO standing water covers the eggs. There may also be concerns with eggs freezing if redds are dewatered during times of cold temperatures (Reiser and White 1981).

Macroinvertebrates

Hyporheic invertebrate communities differed to some degree from those collected from surface sediments. However, it appeared that invertebrates documented or suspected of possible impacts to salmon eggs or alevins were absent or only present in limited numbers. Salmon are not presently found in this portion of the San Joaquin River, but benthos provided evidence of a biotic response to varying sand volumes present in the river. The macroinvertebrate community represents one affected by fine sediment, with most taxa highly tolerant of this sort of impact. Much of the lower San Joaquin River macroinvertebrate community has been documented as consisting of psammophilous aquatic invertebrate species (Leland and Fend 1998) and may, at least within recent memory, never have been especially abundant (lowest part of river sampled was near "old" Friant Bridge, Needham and Hanson 1935). The hyporheic community may be especially affected by sand because estimates of abundance appear to be much lower than those collected from surface sediment environments. Other investigators (Richards and Bacon 1994) have concluded that fine sediment may disproportionately impact the hyporheos with major impacts to stream productivity.

Bryce et al. (2010) concluded that streambed areal surficial fine sediment levels of $\leq$13% sand and fines ($\leq$2 mm) would retain habitat potential for sediment-sensitive aquatic vertebrates in mountain streams. Although most of our measurements of fine sediment were below this threshold, we still detected a gradient between various macroinvertebrate biotic measures and amount of sand in the hyporheic. It appears that impacts in the San Joaquin occurred at values deemed protective by Bryce et al. (2010); although it may also be the case that fine sediment was slightly underestimated in the present study, and that the San Joaquin River is not consistent with the types of mountain streams evaluated by Bryce et al. (2010). Cover et al. (2008) findings of impacts at 4-16% fine sediment (< 4 mm, see Appendix B for our sediment measurements of < 4 mm) were more consistent with the findings of this sediment study.

Hyporheic restoration

The findings of low DO, high conductivity, higher amounts of sand, relative high temperatures, and a fine sediment tolerant macroinvertebrate community all suggest that sediments of the shallow hyporheic zone are not conducive to biota that might otherwise occur in this portion of the San Joaquin River. Hester and Gooseff (2010) stated that the hyporheic zone needs to be incorporated into stream restoration activities and describe the importance of several techniques useful in enhancing hyporheic exchange. Some of these include creation of slope breaks, adding channel structures to modify hydraulic conditions, and sediment coarsening to increase permeability. Hester and Doyle (2011), in a review of human impacts on river temperatures, indicate that average temperature increases in the summertime from loss of riparian shading, loss of upland forests, and reduction of groundwater exchange can range from 0.2 to 4.1^{o}C. A variety of factors are important in restoration of groundwater/surfacewater exchanges, and Richie et al. (2009) promulgated the need for integration of physical, hydrological, chemical, and biological restoration techniques. Their Table 10.2 provides a listing of restoration techniques and

possible impacts to abiotic and biotic factors associated with groundwater/surfacewater exchange (Richie et al. 2009).

The most common hyporheic restoration mentioned in the literature appears to be in the form of gravel augmentation to increase the coarseness of substrate. Gravel augmentation increased stream velocities and probably increased hyporheic/surface water exchange in a study on the Mokelumne River in California (Merz and Chan 2005). Gravel cleaning operations were used to decrease fine sediment (< 2 mm size) in a stream in Germany and resulted in improved hyporheic DO at three study sites (Meyer et al. 2008). Spawning-bed enhancements increased Chinook salmon survival and growth in a regulated river in California (Merz et al. 2004). Simulations of a variety of restoration elements on stream-subsurface water exchange indicated that addition of coarse sediments also required re-meandering of the channel to significantly enhance desired downwelling of stream water (Kasahara and Hill 2008).

Along with positive changes in DO, channel complexity and gravel augmentation may increase thermal heterogeneity of rivers. Burkholder et al. (2008) found that water moving through gravel bars can be thermally out of phase with river channel temperatures. Water entering gravel bars during cool times of the day can reenter the river at warmer times and provide some localized cooling effects. Burkholder et al. (2008) suggested that creation of cool patches from hyporheic exchange can offset some thermal degradation. Hester et al. (2009) observed a drop in shallow hyporheic temperature downstream of a test weir and suggest that weirs and other similar structures are much more consistent in decreasing temperatures relative to gravel bars. Weir height was positively associated with cooling of surface water. Seedang et al. (2008) described three general categories of methods used for reducing river temperatures: (1) increase in riparian shade, (2) flow augmentation with cool reservoir water, and (3) adding channel complexity to promote hyporheic exchange. Seedang et al. (2008) used a hyporheic flow model to investigate management actions that alter temperatures and found that surface water cools as it flows through certain channel features. Increasing channel complexity for temperature cooling was deemed more cost effective than water augmentation, riparian planting, or a combination of augmentation and planting. The median hyporheic cooling effect from water flowing through channel features was -2.7 ^{o}C, and this cooled river temperatures by -0.61^{o}C (Seedang et al. 2008). Fernald et al. (2006) suggested that hyporheic temperature cooling was related to conductive loss of heat to the substrate when cool river temperatures are retained by lithic materials and transferred during warmer periods. Gravel structures, after hyporheic passage of water through the structures, resulted in water temperatures 6-10^{o}C cooler than the main channel. It was suggested that stream heating is a result of degraded channel morphology while cooling gradients are caused by hyporheic flows in areas of channel complexity. Fernald (2006) indicated that some hyporheic temperatures had lag times of weeks. It is possible that lag times could result in seasonal changes in hyporheic temperatures relative to river channel temperatures. Seedang et al. (2008) observed such a pattern and found that hyporheic water temperatures were often cooler than river channel temperatures from May to early September (when river water is especially warm), but then changed to where hyporheic water was warmer than surface water after September. Perhaps some of this difference

was caused by thermal lag times. Timing of daily water releases from dams may influence thermal properties of the hyporheic. Gerecht et al. (2011) found that nighttime releases resulted in maximum thermal penetration of cool river water into the hyporheic. This cool water might then be available from the hyporheic for chilling river water during the hottest parts of the day.

Decreased channel complexity may be an issue in the San Joaquin River. Cain et al. (2003) indicates that channel incision, reduction of peak flows, and gravel mining has resulted in a narrower channel and has probably reduced the complexity of channel habitat. Prior to these channel modifications, the channel was characterized by large gravel bars, mid-channel bars, and a complex maze of secondary and high flow channels (Cain et al. 2003). These channel structures may have resulted in greater river thermal heterogeneity in the past.

Our data suggests that increased flows may result in more surface/hyporheic interaction and less dominance by groundwater sources; lowering temperatures, decreasing conductivity, and increasing DO. Information collected on velocity and water depth provides some evidence of these possibilities. Increased flows could serve as a tool for increasing water quality in the San Joaquin hyporheic. It is unclear what specific flows might be suitable or even available for September and October and literature demonstrates that assumed changes in the hyporheic may not necessarily occur. On the Snake River, flux reversals were achieved with altered flows at a few sites, but in most cases hyporheic zone temperatures were largely unaffected by changes in river discharge (Hanrahan 2008). In other studies, DO concentrations changed rapidly in response to hydrological events, but tended to decline during the recession limb when water tables were high (Malcolm et al. 2009). Large woody debris (LWD) may also have effects on hyporheic exchange. Senter and Pasternack (2011) indicate that LWD tends to increase downwelling and intragravel DO concentrations in the riverine environment. These areas of LWD may be focal points for salmon spawning in rivers that are otherwise dominated by suboptimal spawning habitat (Senter and Pasternack 2011).

Albertson et al. (2010) warned that river restoration for enhancement of spawning habitat, including the addition of coarse substrate, may have unintended consequences. Gravel augmentation along the Merced River in California decreased invertebrate abundance and biomass and it was suggested that this could impact juvenile Chinook salmon growth and survival. Riffle restorations in the Trinity River resulted in decreased invertebrate diversity and unstable invertebrate communities which may decrease food availability which in turn may also decrease fish survival (Boles 1981). However, Merz and Chan (2005) observed higher benthic invertebrate densities and biomass at gravel augmentation sites on the Mokelumne River. These disparate responses suggest the need for monitoring of macroinvertebrates if hyporheic restoration occurs in the San Joaquin River.

Overall data from this study provides some limited evidence of the quality of the hyporheic salmon redd environment but must be considered a snapshot of the San Joaquin River hyporheic, which may be quite variable. Important results for salmon egg/alevin survival were the detection of low DO concentrations at some locations,

higher hyporheic water temperatures, and the near absence of egg/alevin predators in the macroinvertebrate community. Sediment and conductivity appeared to be associated with hyporheic DO concentrations in the San Joaquin River. However, it must be recognized that factors affecting oxygen concentration within spawning gravels may vary significantly within river systems (Greig et al. 2007) and that further, more intensive studies would be needed to definitively identify factors impacting San Joaquin River hyporheic DO concentrations. It is suggested that continuous *in situ* monitoring of the hyporheic zone is needed to determine baseline conditions in the section of the San Joaquin River that is most conducive to Chinook salmon spawning.

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Table 1. Results of multiple regression for the dependent variable hyporheic DO (n=29). Variables that were not significant in the model included surface DO, T_s-T_h, and the months December and February. A Durbin-Watson value close to 0 suggests positive autocorrelation, and a value close to 4 suggests negative autocorrelation. In the absence of autocorrelation the value will be close to 2 (Analytical Software 2003).

Variable	Coefficient	Std error	T	P
Constant	12.5512	1.33557	9.40	0.0000
C_s-C_h	0.05338	0.01449	3.68	0.0011
Weight of sand	-0.02351	0.00648	-3.63	0.0013
September	-3.83605	1.31348	-2.92	0.0073
R squared	0.4917			
Adjusted R squared	0.4307			Durbin- Watson Test=1.5448

Table 2. Worst case scenario hyporheic DO's derived from predicted values from multiple regression (see Table 1). This table assumes that the most negative Cs-Ch and the highest amount of sand co-occur at the same time at a given location. It is recognized that negative values for DO are not physically possible; however, these values are presented to give an idea of the magnitude of the prediction. Locations and predicted values that were close to or greater than 6 mg/L for both September and other months are presented in **bold**. Actual measured values are presented for comparison. It should be noted that water quality in samplers from A and D sites were not measured in September.

Sampler location	C_s-C_h (most negative value)	Maximum sand weight per sampler (g)	September hyporheic DO (mg/L) predicted value plus standard error of predicted value	Other months hyporheic DO (mg/L) predicted value plus standard error of predicted value	Measured DO (mg/L) minimum and maximum
A1	-20.0	239.60	2.01 (3.21)	5.85 (2.98)	2.0/9.8
A2	-21.0	457.90	-3.17 (3.89)	0.66 (3.50)	2.0/10.9
A3	-5.0	271.70	2.06 (3.27)	5.89 (3.02)	3.7/10.5
B1	-37.2	222.70	1.49 (3.2)	5.32 (2.98)	3.6/11.8
B2	-55.0	202.42	1.02 (3.22)	4.85 (3.00)	2.6/12.3
B3	-1.0	121.30	**5.81** (3.06)	**9.64** (2.98)	9.9/13.8
B5	-106.0	283.72	-3.61 (3.66)	0.22 (3.33)	4.0/11.1
B6	-1.1	120.20	**5.83** (3.06)	**9.66** (2.98)	10.2/12.7
B7	-6.0	191.95	3.88 (3.12)	7.72 (2.96)	5.8/10.9
B8	-2.6	93.60	**6.37** (3.06)	**10.21** (3.00)	10.0/12.8
C1	-183.0	222.50	-6.28 (4.11)	-2.45 (3.81)	2.1/10.1
C2	-102.0	80.10	1.39 (3.31)	5.22 (3.17)	2.0/10.4
D1	-9.0	107.90	**5.70** (3.06)	**9.53** (2.98)	3.4/9.3
D2	-14.0	133.40	4.83 (3.07)	8.67 (2.96)	6.6/12.9
D3	-9.0	195.90	3.63 (3.13)	7.46 (2.96)	5.5/8.4

Table 3. Spot measurements of temperatures from several locations on the San Joaquin River. Egg incubation categories are from Table 3-1 from San Joaquin River Restoration Program (2010) except for the Marginal category which is identified as measurements between Optimal and Critical.

Month	Location	Egg incubation categories (% measurements in category-number of measurements in parentheses)			
		Optimal $\leq$13.0^{o}C	Marginal 13.1-14.3^{o}C	Critical 14.4-15.6^{o}C	Lethal >15.6^{o}C
September	Surface	22.2% (2)	55.5% (5)	0% (0)	22.2% (2)
	Hyporheic	0% (0)	12.5% (1)	62.5% (5)	25.0% (2)
October	Surface	6.7% (1)	66.6 % (10)	20.0% (3)	6.7% (1)
	Hyporheic	0% (0)	40.0% (6)	40.0% (6)	20.0% (3)
December	Surface	93% (13)	7% (1)	0% (0)	0% (0)
	Hyporheic	92% (12)	8% (1)	0% (0)	0% (0)
February	Surface	100% (15)	0% (0)	0% (0)	0% (0)
	Hyporheic	100% (15)	0% (0)	0% (0)	0% (0)

Table 4. Invertebrate taxa list from hyporheic samplers in the San Joaquin River. Fine sediment indicator values from Carlisle et al. (2007) are based on generic or family level identifications.

TAXA	Total number of individuals from all sampling occasions	Fine sediment indicator value[a]
EPHEMEROPTERA		
Baetidae		
Acentrella insignificans	6	5
Baetis tricaudatus	766	4
Fallceon sp.	6	9
Ephemerellidae		2
Ephemerella sp.	4	
Leptohyphidae		
Tricorythodes explicatus	728	9
ODONATA		
Coenagrionidae	1	7
TRICHOPTERA		
Glossosomatidae		
Glossosoma sp.	15	3
Hydropsychidae		
Hydropsyche sp.	2715	8
Hydroptilidae		
Hydroptila sp.	15	6
Lepidostomatidae		
Lepidostoma sp.	3	1
LEPIDOPTERA		7
Pyralidae		
Petrophila sp.	3	2
COLEOPTERA		
Hydrophilidae		9
Helochares normatus	1	
DIPTERA		
Chironomidae		
Diamesinae		
Potthastia longimana group	13	4
Orthocladiinae		
Brillia sp.	1	7
Corynoneura sp.	4	10
Cricotopus / *Orthocladius* sp.	107	8
Eukiefferiella sp.	27	5
Nanocladius sp.	23	10
Orthocladius (*Euorthocladius*) sp.	68	--
Parakiefferiella sp.	1	10
Parametriocnemus sp.	2	6
Rheocricotopus sp.	12	9
Synorthocladius sp.	3	3
Thienemanniella sp.	9	8

Tvetenia sp.	299	3
Chironomini		
Cryptochironomus sp.	1	9
Dicrotendipes sp.	1	10
Endochironomus sp.	1	--
Paratendipes sp.	1	--
Phaenopsectra sp.	10	7
Polypedilum sp.	17	8
Pseudochironomini		
Pseudochironomus sp.	1	7
Tanytarsini		
Micropsectra sp.	22	5
Rheotanytarsus sp.	103	9
Tanytarsus sp.	79	9
Tanypodinae		
Ablabesmyia sp.	1	9
Pentaneura sp.	3	8
Procladius sp.	17	--
Thienemannimyia group	12	--
Empididae		9
Clinocera sp.	1	
Neoplasta sp.	2	
Trichoclinocera sp.	1	
Simuliidae		
Simulium sp.	371	7
TURBELLARIA		
Dugesiidae		
Dugesia sp.	126	--
NEMERTEA		
Prostoma sp.	8	--
NEMATODA	27	--
OLIGOCHAETA		
Enchytraeidae	57	10
Lumbricidae	42	--
Lumbriculidae	179	4
Naididae	4	10
Tubificidae	30	10
HIRUDINEA		
Glossiphoniidae	14	6
Piscicolidae		
Piscicola sp.	1	--
OSTRACODA	3	--
AMPHIPODA		
Crangonyctidae *Crangonyx*	381	--
Hyalellidae		
Hyalella azteca	3	9
ACARI		

Lebertiidae		
Lebertia sp.	1	--
Sperchonidae		
Sperchon sp.	3	--
DECAPODA		
Cambaridae	1	6
GASTROPODA		
Lymnaeidae	3	--
Physidae	6	10
Planorbidae	3	5
BIVALVIA		
Corbiculidae		6
Corbicula sp.	1	
Sphaeriidae		5
Pisidium sp.	8	

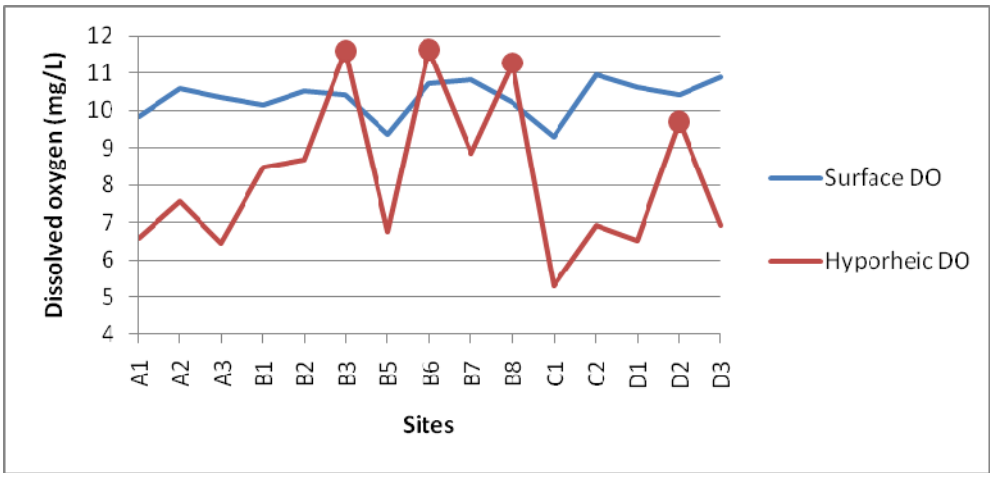
[a]From Carlisle et al. (2007). Values range from 1 to 10 with 1 the least tolerant to fine sediment and 10 the most tolerant. Fine sediment (percent fines < 2 mm) in Carlisle et al. (2007) was visually estimated as the relative proportion of fine-grained sediment within a sampling reach.

Figure 1. Sites used in sampling redd environments in San Joaquin River. Upper right is Millerton Lake retained by Friant Dam.

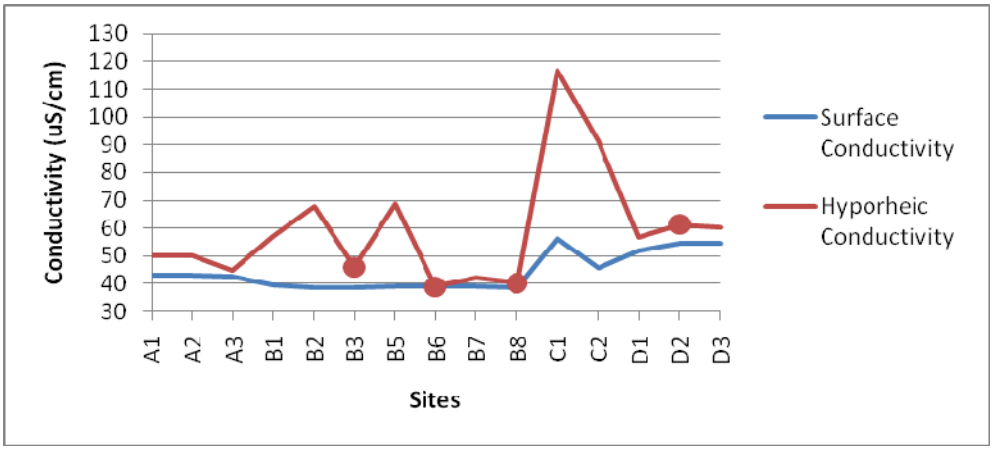
Figure 2. Photo showing hyporheic sampler (left) and sleeve (right) with attached piezometer.

Figure 3. Comparison of mean surface and hyporheic water chemistry variables for DO (a), conductivity (b), and temperature (c) at different locations at four different sites. Locations designated with red-filled circles were those that consistently had DO concentrations > 6 mg/L.

a



b



c

Figure 4. Mean sand per sampler from locations along the San Joaquin River. Error bars are standard error.

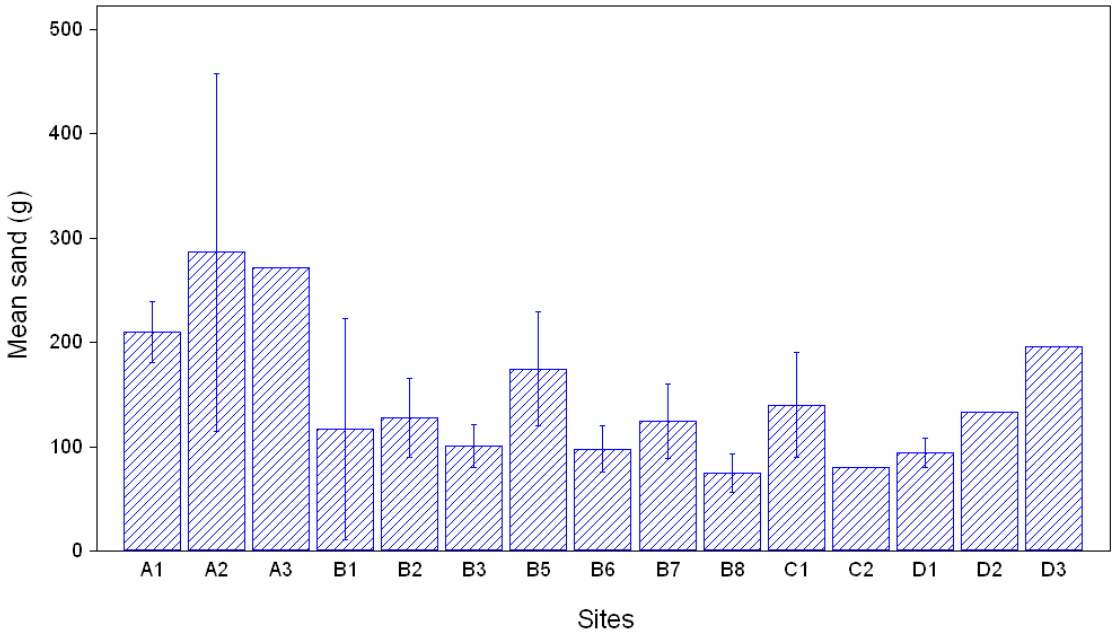


Figure 5. Relationship between the conductivity exchange index, C_s-C_h, and hyporheic DO (r=0.6814, P<0.0001).

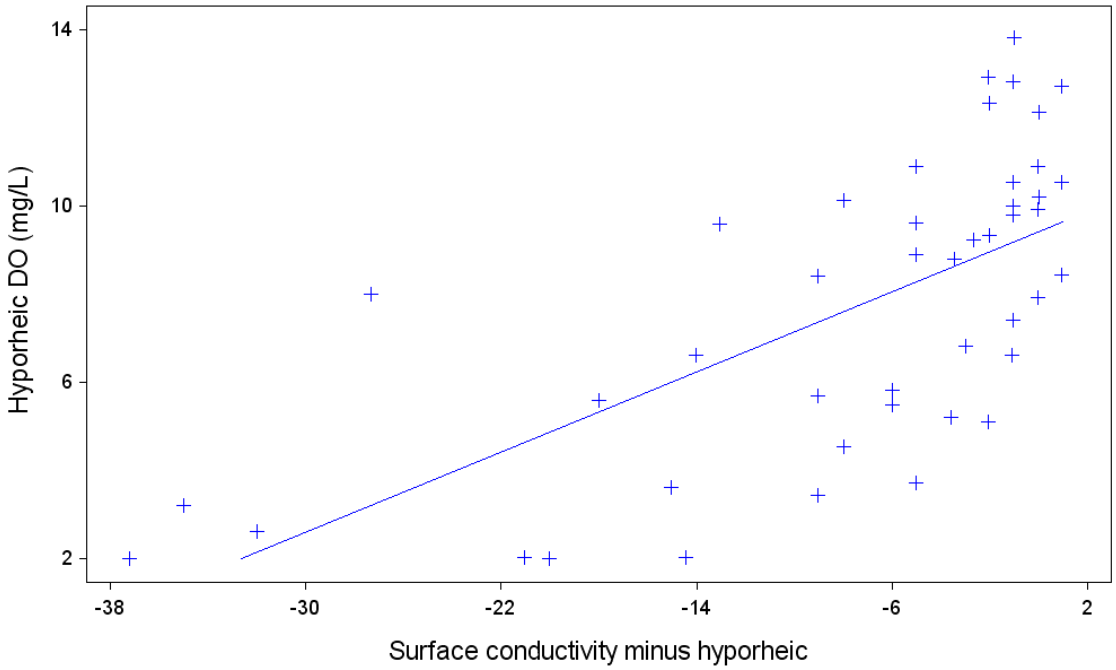


Figure 6. Relationship between sand and hyporheic DO (*r*=-0.3302, *P*=0.0748).

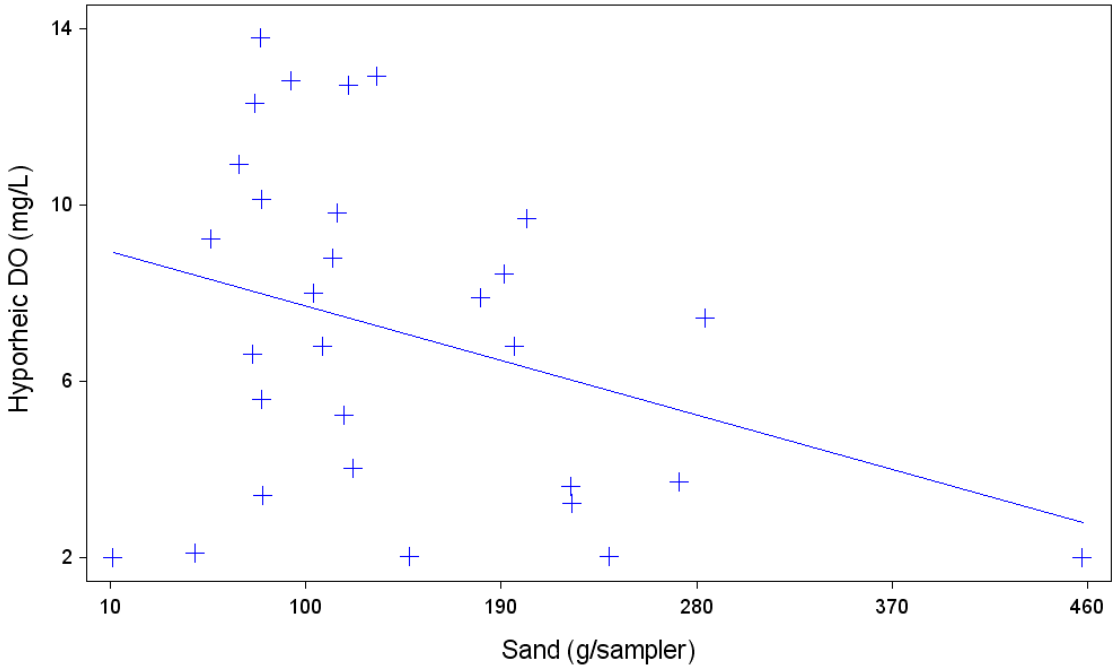


Figure 7. Relationship between velocity and hyporheic DO (*r*=0.2546, *P*=0.0994).

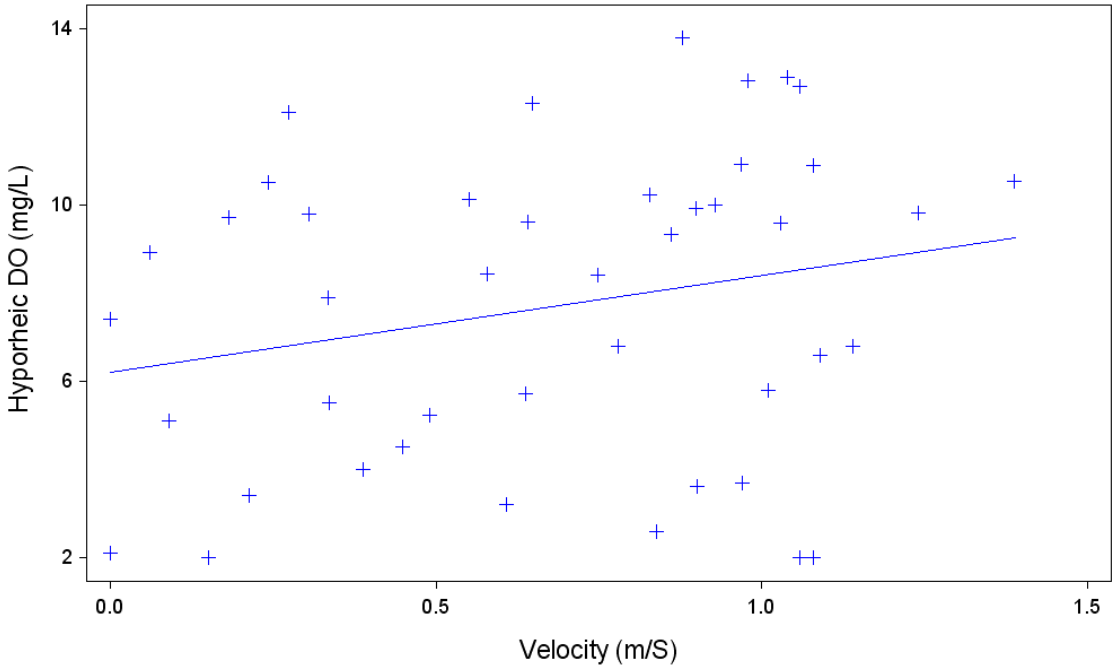


Figure 8. Hydraulic head measurements from locations along the San Joaquin River.

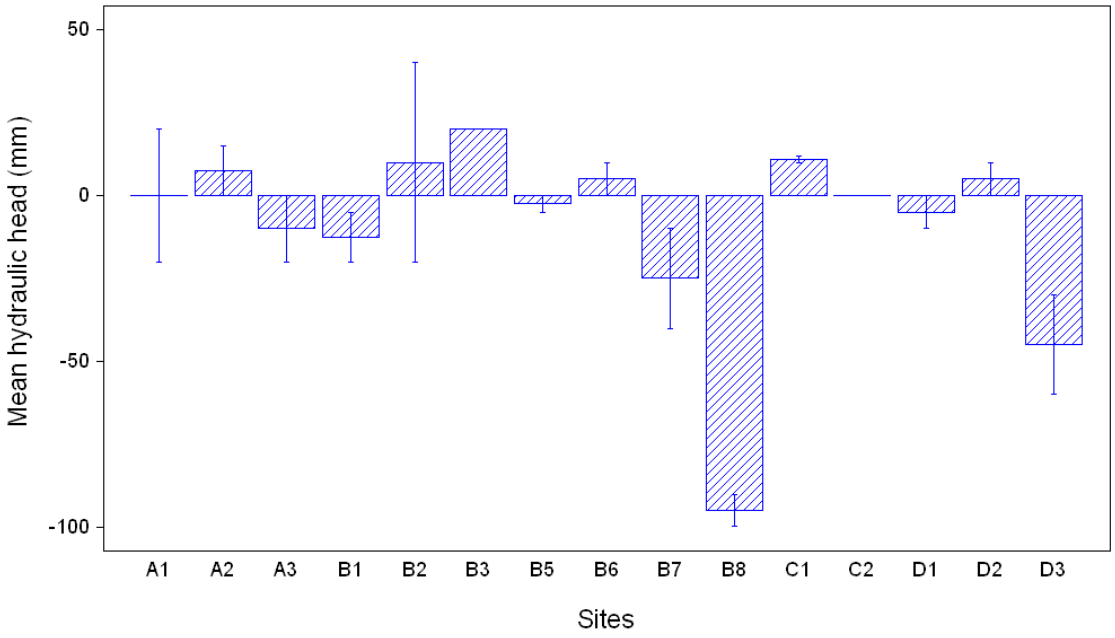


Figure 9. Mean hyporheic DO by season. No significant difference was detected in DO between months.

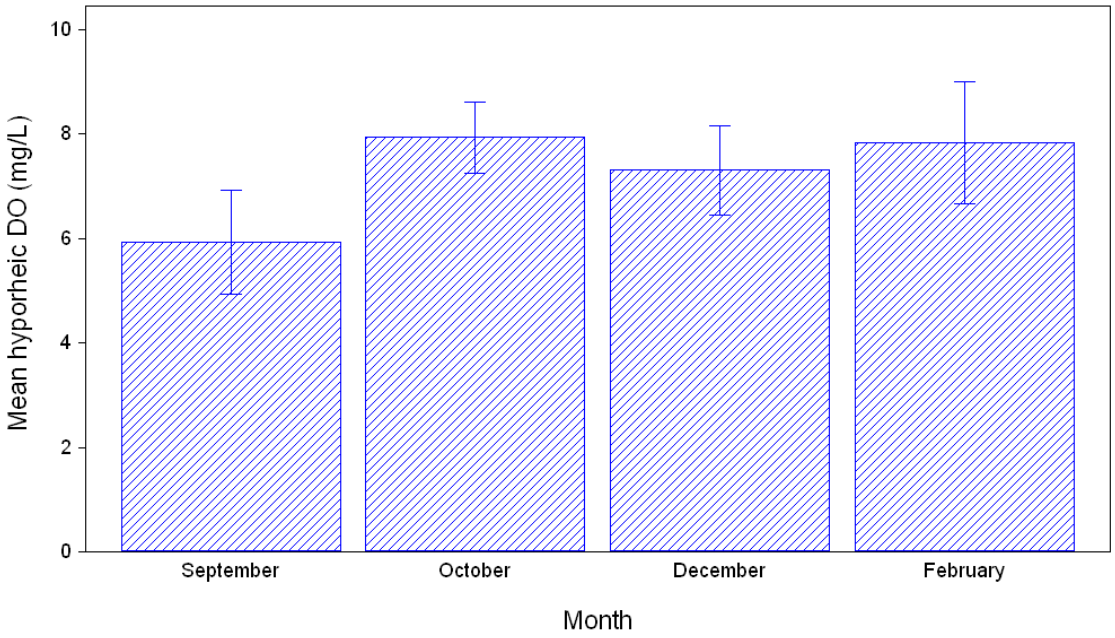


Figure 10. Hyporheic conductivity by season. Months with the same letter do not differ significantly (*P*>0.05).

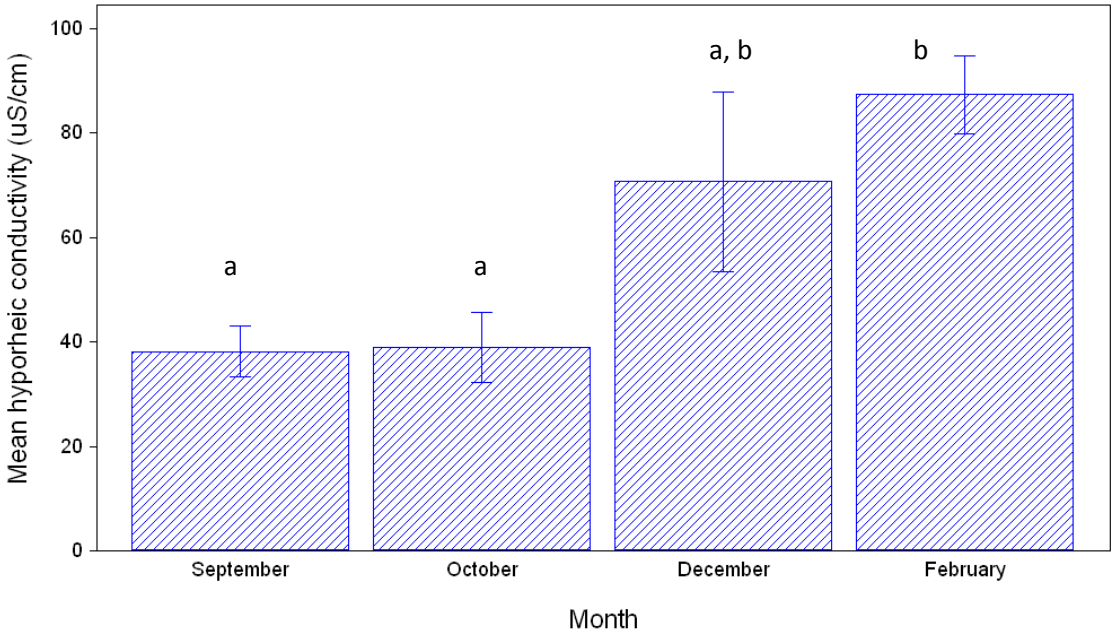


Figure 11. Mean sand in hyporheic samplers by month. No significant differences (*P*>0.05) were detected between months.

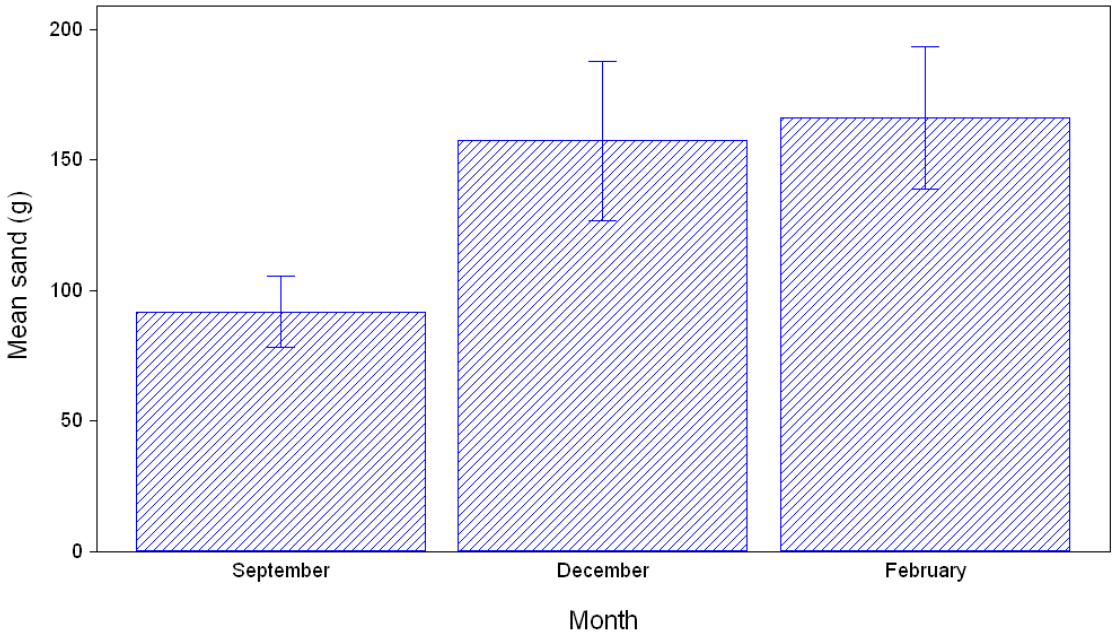


Figure 12. Mean hyporheic temperature derived from all locations by month. Bars with the same letter are not significantly different, while those with different letters differ significantly ($P \leq 0.05$).

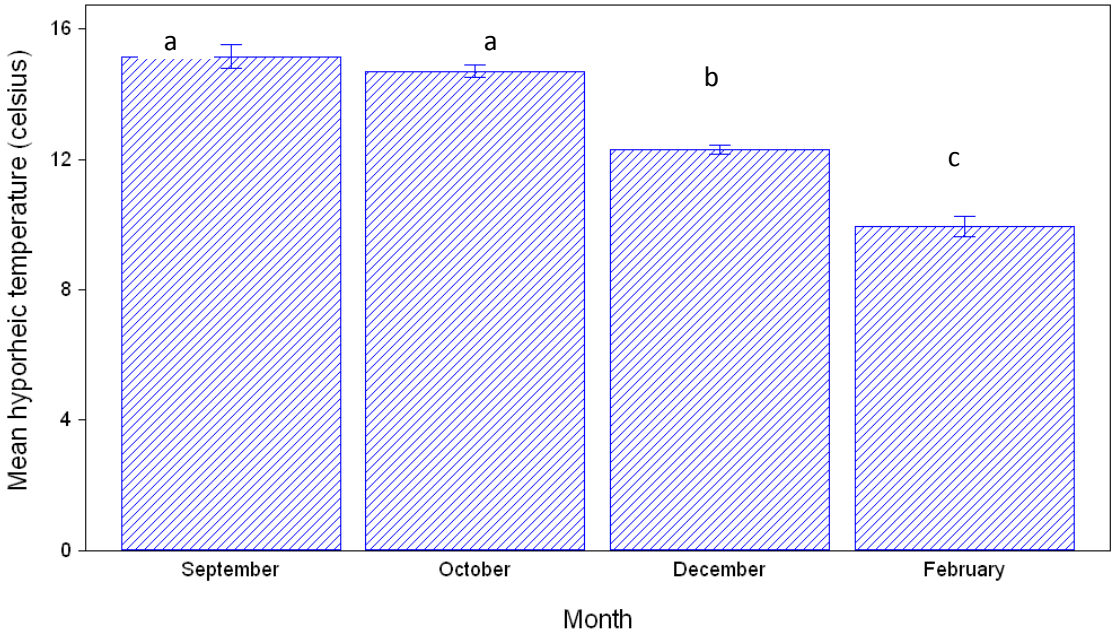


Figure 13. San Joaquin hydrograph from the sampling period. Sampler installation and sample collection dates are represented by filled triangles.

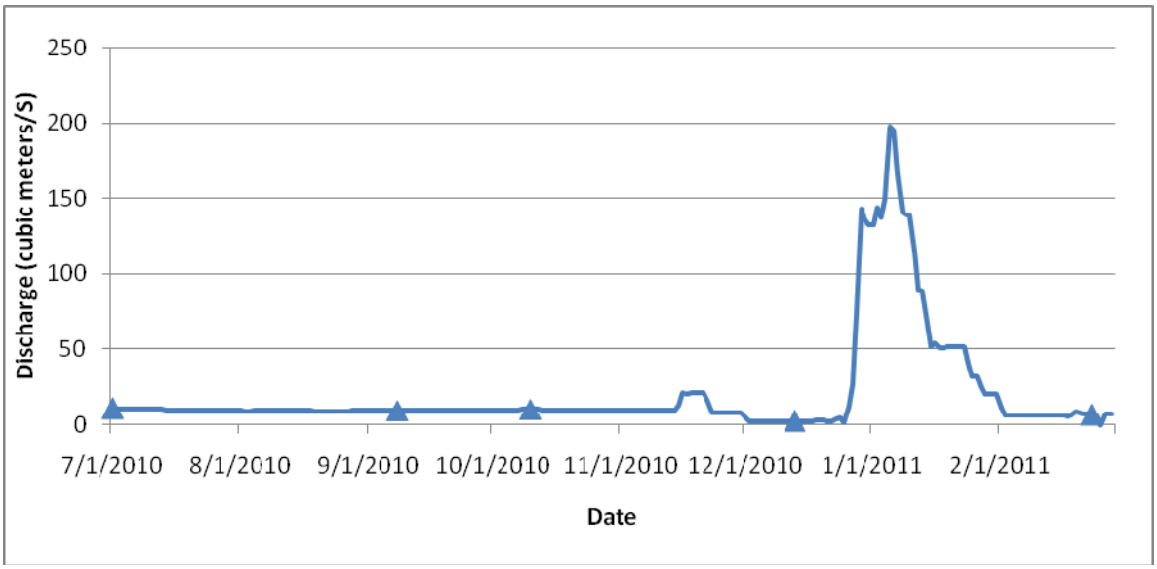


Figure 14. Mean water depth during study months. Water depth in December differed significantly (P<0.05) from that in other months.

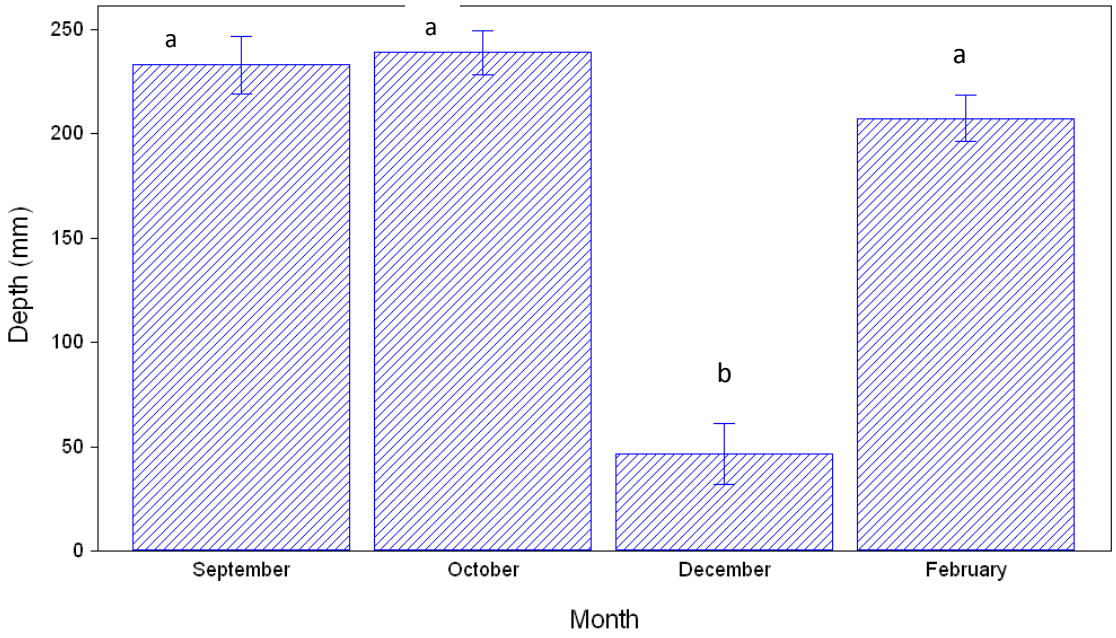


Figure 15. Mean hyporheic zone water temperatures at site locations from upstream (A) to the furthest downstream site (D).

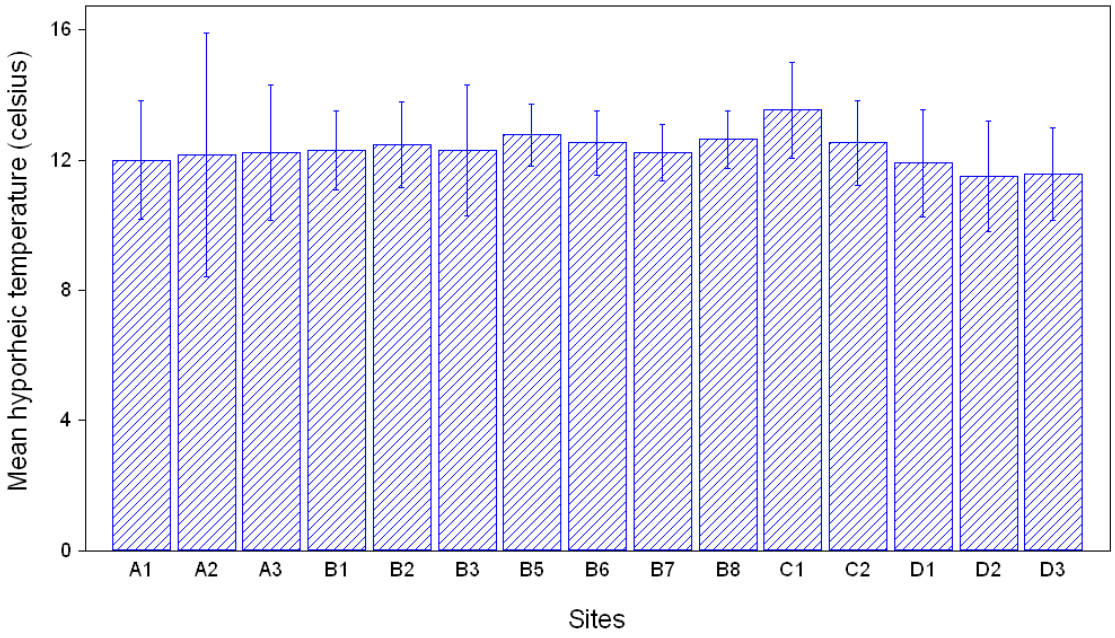


Figure 16. Biplot based on a detrended correspondence analysis (DCA) of paired surface and hyporheic samples. Samples are represented as open circles for those collected with a Surber sampler and filled circles for those collected with hyporheic samplers. All samples were converted to number/m^3 prior to analysis. Only species with a fit and weight of >5% are shown.

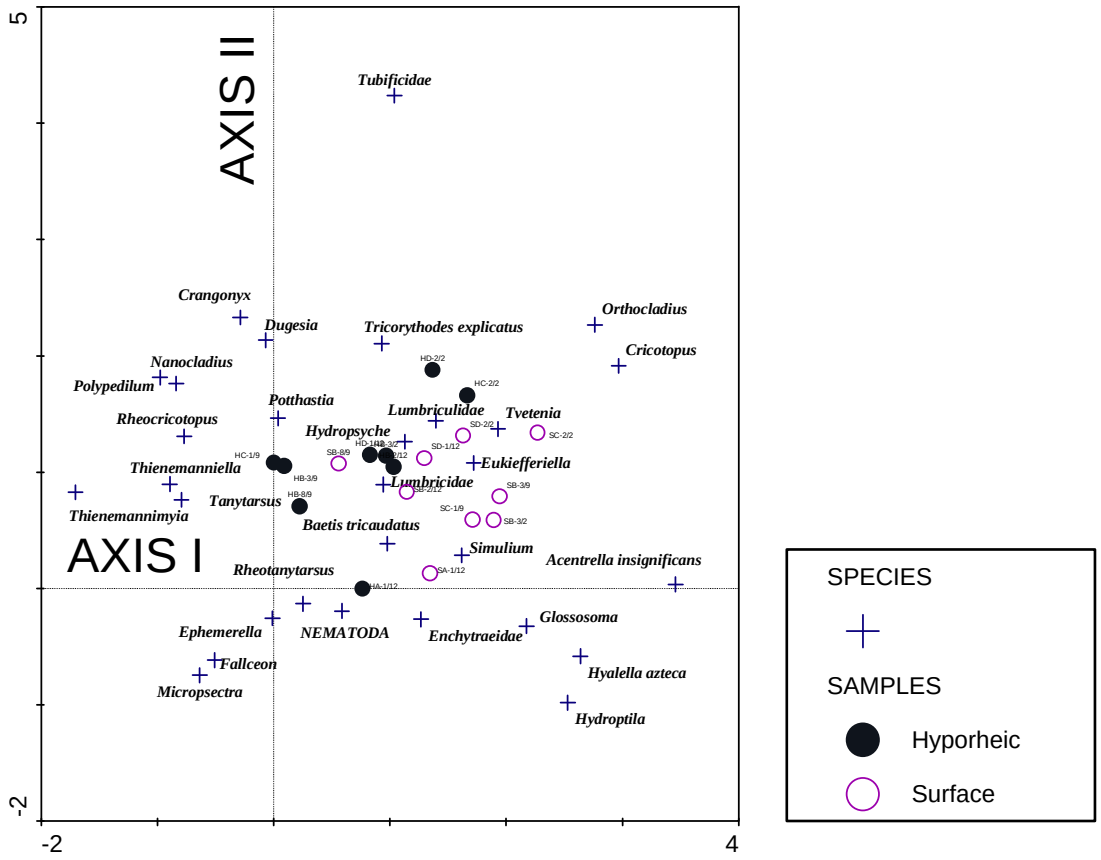


Figure 17. Triplot based on a redundancy analysis (RDA) of sites and taxa with respect to environmental variables. Environmental variables were related to community attributes as shown by arrows. Site samples are represented as geometric shapes as shown in the legend, while species are represented as crosses. Only those species that had a fit >5% are shown in the figure.

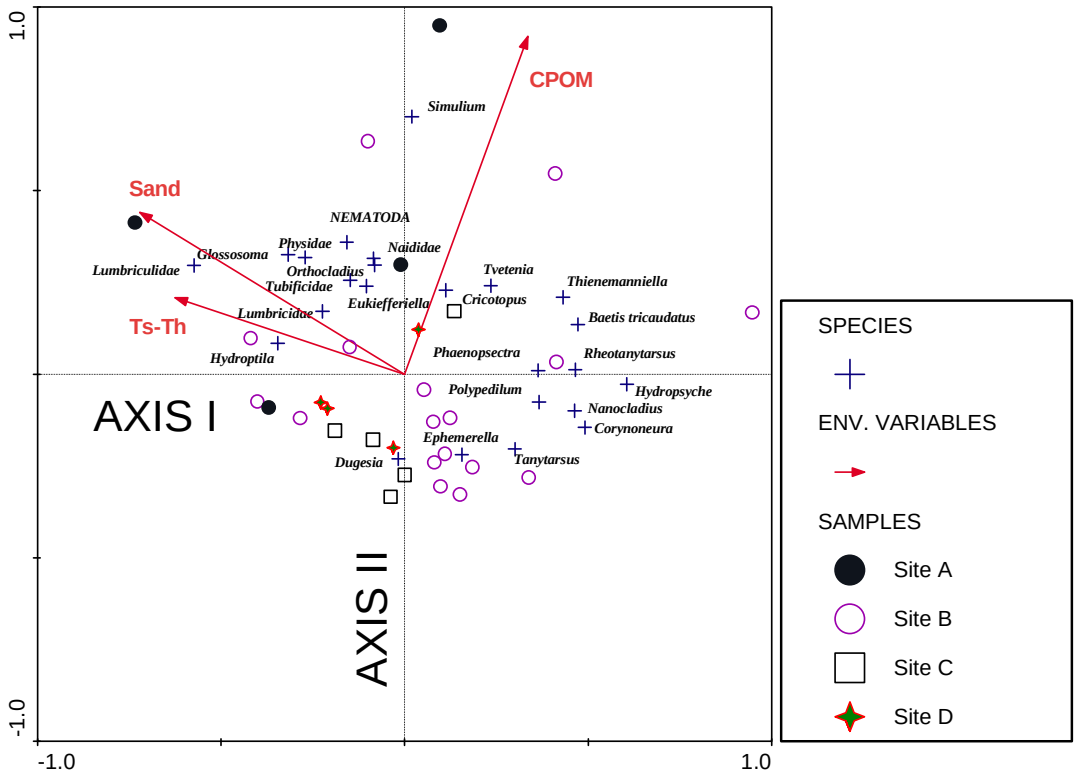


Figure 18. Relationship between sand found in samplers and Ephemeroptera abundance (*r*=-0.3771, *P*=0.0437).

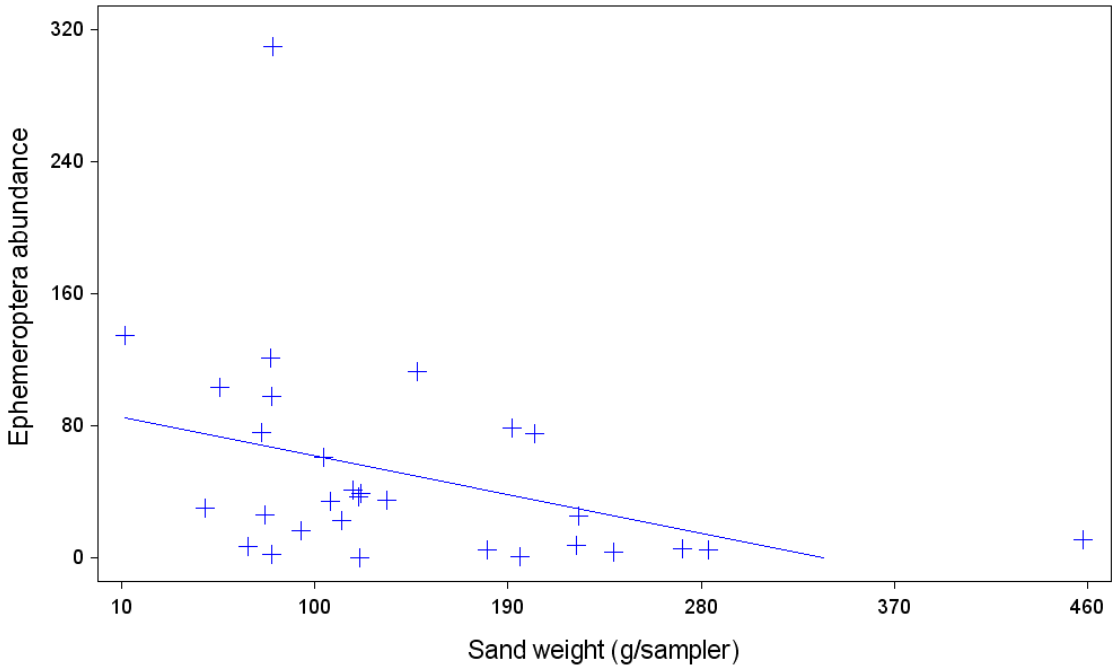
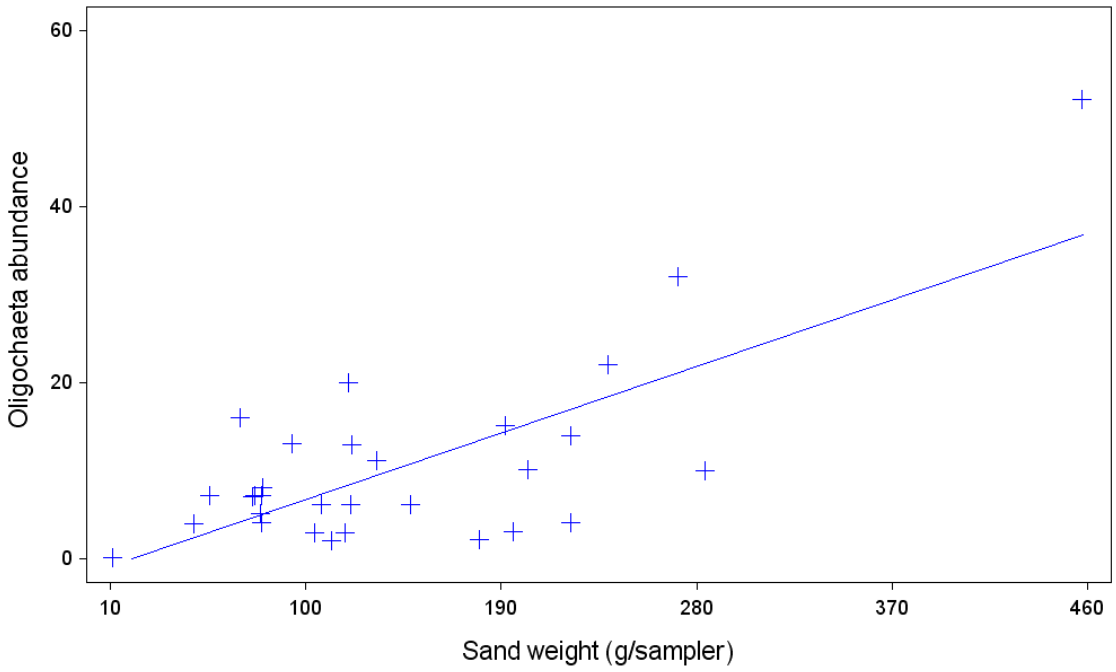


Figure 19. Relationship between sand found in samplers and Oligochaeta abundance (*r*=0.7303, *P*<0.0001).



Appendix A. Water quality and aquatic macroinvertebrate metrics for locations along the San Joaquin River.

Location	DATE	MONTH	surfDO	surftemp	surfcond	hypDO	hypDOinit	hyptemp	hypcond	Conddiff	tempdiff	weightsar	percsand	Depth	velocity	Head	taxa	abundanc
A1	10/20/2010	October	8.9	16.1	25	9.8	9.8	14.7	26	-1	1.4	M	M	275	1.24	10	M	M
A1	12/13/2010	Decembe	9.8	11.8	41	7.9	7.9	12.8	41	0	-1	180.2	5.565488	55	0.33528	-20	17	45
A1	2/23/2011	February	10.8	8.1	63	2	2	8.5	83	-20	-0.4	239.6	10.63	180	1.06	20	18	100
A2	10/20/2010	October	10.9	14.6	25	10.9	10.9	15.9	25	0	-1.3	M	M	275	0.97	30	M	M
A2	12/14/2010	Decembe	9.8	11.8	40	9.8	9.8	M	M	M	M	114.68	2.956663	85	0.3048	0	12	44
A2	2/23/2011	February	11	7.6	64	2	2	8.4	85	-21	-0.8	457.9	14.18	250	1.08	15	23	143
A3	10/20/2010	October	10.3	14.9	25	10.5	10.5	16	24	1	-1.1	M	M	175	1.39	30	M	M
A3	12/13/2010	Decembe	10.4	11.9	40	5.1	5.1	11.9	42	-2	0	M	M	55	0.09144	-20	M	M
A3	2/23/2011	February	10.3	7.7	63	3.7	3.7	8.8	68	-5	-1.1	271.7	7.93	285	0.97	0	20	97
B1	9/8/2010	Septembe	9.1	13	23.8	11.8	2	16.2	61	-37.2	-3.2	11.34	1.453189	160	M	M	13	697
B1	10/20/2010	October	9.2	13	26	9.6	9.6	14.4	39	-13	-1.4	M	M	164	1.03	-4	M	M
B1	12/14/2010	Decembe	10.3	12.8	42	8.9	8.9	12.3	47	-5	0.5	M	M	-15	0.06096	-20	M	M
B1	2/23/2011	February	12	9.3	66	3.6	3.6	10.2	81	-15	-0.9	222.7	9.69	120	0.9	-5	12	181
B2	9/8/2010	Septembe	9.7	13.1	23.6	10.1	8	14.6	50.9	-27.3	-1.5	103.99	6.019256	260	M	M	25	166
B2	10/20/2010	October	9.3	13.2	26	2.6	2.6	14.6	58	-32	-1.4	M	M	215	0.84	-30	M	M
B2	12/14/2010	Decembe	10.2	12.3	41	9.7	9.7	12.7	96	-55	-0.4	202.42	8.64402	85	0.18288	40	15	234
B2	2/23/2011	February	12.8	9.8	64	12.3	12.3	10.1	66	-2	-0.3	76.6	7.27	175	0.65	-20	17	206
B3	9/8/2010	Septembe	9.2	13.1	23.4	11.1	M	M	M	M	M	121.3	5.886732	258	M	M	24	322
B3	10/20/2010	October	9.9	13.4	27	9.9	9.9	14.3	27	0	-0.9	M	M	235	0.9	0	M	M
B3	12/14/2010	Decembe	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
B3	2/23/2011	February	12.1	9.7	66	13.8	13.8	10.3	65	-1	-0.6	79.7	8.13	180	0.88	20	23	691
B5	9/8/2010	Septembe	8.2	13.1	23.7	11.1	5.2	14.7	27.3	-3.6	-1.6	118.05	3.475597	260	M	M	19	318
B5	10/20/2010	October	9.6	13.3	26	4.5	4.5	14.1	34	-8	-0.8	M	M	245	0.45	-10	M	M
B5	12/14/2010	Decembe	7.4	12.3	38	7.4	7.4	13.3	39	-1	-1	283.72	13.97313	-15	0	0	8	101
B5	2/23/2011	February	12.2	9.7	69	4	4	10.9	175	-106	-1.2	121.6	10.53	210	0.39	-5	12	125
B6	9/8/2010	Septembe	10.2	13.2	23.5	11.5	6.6	14.4	24.6	-1.1	-1.2	75.44	1.694108	214	M	M	26	336
B6	10/20/2010	October	9.5	13.3	26	10.2	10.2	14.5	26	0	-1.2	M	M	235	0.83	20	M	M
B6	12/14/2010	Decembe	12.2	11.5	41	12.1	12.1	11.4	41	0	0.1	M	M	115	0.27432	0	M	M
B6	2/23/2011	February	11	9.4	65	12.7	12.7	11.7	64	1	-2.3	120.2	10.89	185	1.06	10	16	258
B7	9/8/2010	Septembe	9.8	13.1	26	10.3	8.8	15.3	26.9	-3.4	-2.1	112.57	7.731931	255	M	M	14	89
B7	10/20/2010	October	9.8	13.1	26	5.8	5.8	13.7	32	-6	-0.6	M	M	275	1.01	-10	M	M
B7	12/14/2010	Decembe	10.9	12.3	41	8.4	8.4	12.3	40	1	0	191.95	11.43108	125	0.57912	-40	16	204
B7	2/23/2011	February	12.8	9.7	65	10.9	10.9	10.7	70	-5	-1	69.5	7.59	215	1.08	-10	19	120
B8	9/8/2010	Septembe	9.4	13	23.4	11.8	9.2	15.1	26	-2.6	-2.1	56.01	3.367123	264	M	M	24	463
B8	10/20/2010	October	9.4	13.1	26	10	10	14.3	27	-1	-1.2	M	M	305	0.93	-50	M	M
B8	12/14/2010	Decembe	10.5	12.3	41	10.5	10.5	12.3	42	-1	0	M	M	35	0.24384	-100	M	M
B8	2/23/2011	February	11.5	9.7	65	12.8	12.8	11.3	66	-1	-1.6	93.6	8.49	225	0.98	-90	13	81
C1	9/9/2010	Septembe	11.8	15.7	28.5	10.1	2	13.9	44.8	-14.4	-1	148.01	9.734488	170	M	M	17	340
C1	10/20/2010	October	10.4	14.5	26	5.7	5.7	16.4	35	-9	-1.9	M	M	175	0.64	-10	M	M
C1	12/14/2010	Decembe	2.8	13.2	81	2.1	2.1	12.7	264	-183	0.5	48.85	1.995	-75	0	12	11	113
C1	2/24/2011	February	12.1	9.4	89	3.2	3.2	11.5	124	-35	-2.1	222.5	12.34	145	0.61	10	19	69
C2	9/9/2010	Septembe	12.1	16.1	26	10.4	5.6	17	44	-18	-0.9	79.68	3.482692	257	M	M	19	249
C2	10/20/2010	October	10.6	14.2	26	5.2	5.2	14.8	128	-102	-0.6	M	M	255	0.49	0	M	M
C2	12/14/2010	Decembe	9	12.5	42	2	2	12.5	103	-61	0	M	M	15	0.1524	0	M	M
C2	2/24/2011	February	12.1	9.7	88	10.1	10.1	10.3	96	-8	-0.6	80.1	7.25	235	0.55	0	9	45
D1	10/21/2010	October	9.7	13.7	26	9.3	9.3	14.7	28	-2	-1	M	M	235	0.86	20	M	M
D1	12/15/2010	Decembe	10.4	11.7	48	3.4	3.4	12	57	-9	-0.3	80.26	2.195714	35	0.21336	0	17	446
D1	2/24/2011	February	11.7	8.3	82	6.8	6.8	9	85	-3	-0.7	107.9	6.14	235	1.14	-10	10	51
D2	10/21/2010	October	10.1	14	26	6.6	6.6	14.2	40	-14	-0.2	M	M	275	1.09	10	M	M
D2	12/15/2010	Decembe	9.7	12.4	48	9.6	9.6	11.9	53	-5	0.5	M	M	85	0.64008	10	M	M
D2	2/24/2011	February	11.4	8.4	89	12.9	12.9	8.4	91	-2	0	133.4	5.72	225	1.04	0	12	76
D3	10/21/2010	October	9.9	13.6	26	8.4	8.4	13.9	35	-9	-0.3	M	M	245	0.75	0	M	M
D3	12/15/2010	Decembe	11.1	11.8	48	5.5	5.5	11.8	54	-6	0	M	M	65	0.33528	-60	M	M
D3	2/24/2011	February	11.7	8.3	89	6.8	6.8	9	92	-3	-0.7	195.9	13.71	245	0.78	-30	5	10

Appendix B. Substrate sizes collected from hyporheic samplers in September, December, and February.

SAMPLE I.D.				B - 1			B - 2			B - 3			B - 5			B - 6			B - 7			B - 8			C - 1			C - 2	
				9/8/2010			9/8/2010			9/8/2010			9/8/2010			9/8/2010			9/8/2010			9/8/2010			9/9/2010			9/9/2010	
Sieve	mm	Phi	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total
		Units	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight
64	64	-6	1828.46	49.20	50.80	0.00	100.00	0.00	0.00	100.00	0.00	446.76	90.52	9.48	763.96	81.16	18.84	0.00	100.00	0.00	0.00	100.00	0.00	542.90	87.20	12.80	490.80	88.61	11.39
32	32		1112.10	18.31	30.89	1461.47	61.85	38.15	1074.74	70.14	29.86	976.55	69.80	20.72	1263.38	49.99	31.16	800.53	79.66	20.34	2277.05	45.41	54.59	894.61	66.11	21.09	1462.63	54.67	33.94
25	25		206.69	12.57	5.74	350.75	52.69	9.16	640.14	52.36	17.78	692.59	55.10	14.70	414.81	39.76	10.23	581.34	64.88	14.77	318.09	37.78	7.63	646.87	50.86	15.25	287.68	47.99	6.68
16	16	-4	260.99	5.32	7.25	798.41	31.85	20.84	472.16	39.24	13.12	1033.45	33.18	21.93	766.41	20.86	18.90	804.65	44.44	20.45	607.50	23.22	14.57	620.74	36.22	14.63	918.48	26.68	21.31
	9.5	nterpolated		2.86			18.00			19.15			15.29			9.77			22.71			10.54			22.10			12.95	
8	8		109.03	2.29	3.03	652.79	14.81	17.04	890.20	14.51	24.73	1037.62	11.16	22.02	552.96	7.22	13.64	1051.99	17.70	26.73	650.70	7.61	15.60	737.47	18.84	17.39	728.01	9.79	16.89
	6.5	nterpolated		1.96			11.01			11.23			7.92			4.93			13.26			5.80			15.33			7.00	
#5	4	-2	18.75	1.77	0.52	232.56	8.73	6.07	189.18	9.26	5.26	244.04	5.98	5.18	148.41	3.55	3.66	279.77	10.59	7.11	121.13	4.71	2.90	238.12	13.22	5.61	191.95	5.33	4.45
#10	2	-1	11.34	1.45	0.32	103.99	6.02	2.71	121.30	5.89	3.37	118.05	3.48	2.50	75.44	1.69	1.86	112.57	7.73	2.86	56.01	3.37	1.34	148.01	9.73	3.49	79.68	3.48	1.85
#14	1.41	-0.5	7.92	1.23	0.22	55.33	4.57	1.44	72.07	3.88	2.00	51.58	2.38	1.09	22.35	1.14	0.55	50.46	6.45	1.28	34.45	2.54	0.83	67.85	8.13	1.60	28.56	2.82	0.66
#18	1	0	10.25	0.95	0.28	58.79	3.04	1.53	60.82	2.19	1.69	44.88	1.43	0.95	13.08	0.82	0.32	53.20	5.10	1.35	36.80	1.66	0.88	66.67	6.56	1.57	30.32	2.12	0.70
#20	0.84	0.25	3.85	0.84	0.11	21.63	2.48	0.56	17.04	1.72	0.47	13.83	1.14	0.29	3.43	0.74	0.08	20.08	4.59	0.51	12.01	1.37	0.29	25.04	5.97	0.59	13.20	1.81	0.31
#25	0.71	0.5	5.75	0.68	0.16	29.50	1.71	0.77	20.06	1.16	0.56	16.26	0.79	0.35	4.57	0.62	0.11	32.31	3.77	0.82	15.63	1.00	0.37	49.05	4.82	1.16	21.24	1.32	0.49
#35	0.5	1	7.74	0.47	0.22	36.15	0.76	0.94	19.26	0.63	0.54	18.50	0.40	0.39	7.29	0.44	0.18	54.58	2.38	1.39	17.85	0.57	0.43	92.04	2.65	2.17	31.64	0.58	0.73
#45	0.35	1.5	4.72	0.34	0.13	13.57	0.41	0.35	7.27	0.43	0.20	7.46	0.24	0.16	4.29	0.34	0.11	42.60	1.30	1.08	7.95	0.38	0.19	58.00	1.28	1.37	13.12	0.28	0.30
#60	0.25	2	3.30	0.24	0.09	5.05	0.28	0.13	3.20	0.34	0.09	3.18	0.17	0.07	2.81	0.27	0.07	26.86	0.61	0.68	4.03	0.28	0.10	27.94	0.62	0.66	6.36	0.13	0.15
#80	0.177	2.5	1.87	0.19	0.05	2.13	0.22	0.06	1.83	0.29	0.05	1.54	0.14	0.03	1.60	0.23	0.04	11.49	0.32	0.29	2.07	0.23	0.05	11.80	0.34	0.28	2.49	0.07	0.06
#120	0.125	3	1.65	0.15	0.05	1.71	0.18	0.04	1.73	0.24	0.05	1.30	0.11	0.03	1.41	0.19	0.03	4.90	0.20	0.12	1.78	0.19	0.04	5.11	0.22	0.12	1.05	0.05	0.02
#150	104		0.75	0.13	0.02	0.60	0.16	0.02	0.84	0.22	0.02	0.56	0.10	0.01	0.63	0.18	0.02	1.07	0.17	0.03	0.73	0.17	0.02	1.30	0.19	0.03	0.29	0.04	0.01
#230	0.0625	4	1.98	0.07	0.06	2.80	0.09	0.07	3.22	0.13	0.09	1.57	0.07	0.03	2.69	0.11	0.07	2.38	0.11	0.06	2.69	0.11	0.06	3.12	0.12	0.07	0.86	0.02	0.02
Pan	<0.0625		2.53		0.07	3.31		0.09	4.56		0.13	3.14		0.07	4.53		0.11	4.33		0.11	4.45		0.11	4.98		0.12	0.95		0.02
Total Weight			3599.67			3830.54			3599.62			4712.86			4054.05			3935.11			4170.92			4241.62			4309.31		

SAMPLE I.D.				B-2			B - 5			B -7			C-1			A-1			A-2			D-1	
				12/14/2010			12/14/2010			12/14/2010			12/14/2010			12/14/2010			12/14/2010			12/15/2010	
Sieve	mm	Phi	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total
		Units	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight
64	64	-6	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	388.55	90.38	9.62	0	100.00	0.00	0	100.00	0.00
32	32		1167.9	72.56	27.44	130.31	97.16	2.84	283.43	92.37	7.63	1056.07	68.99	31.01	398.89	80.50	9.88	547.27	84.50	15.50	1784.18	62.08	37.92
25	25		353.03	64.27	8.29	637.33	83.25	13.91	503.5	78.80	13.56	682.27	48.95	20.04	241.9	74.51	5.99	287.18	76.37	8.13	605	49.22	12.86
16	16	-4	692.08	48.01	16.26	1058.38	60.14	23.10	795.47	57.38	21.43	752.34	26.86	22.09	929.03	51.50	23.01	1004.36	47.92	28.45	954.37	28.93	20.29
8	8		1121.13	21.67	26.34	1376.11	30.11	30.04	1156.99	26.21	31.16	645.6	7.90	18.96	1292.25	19.50	32.00	1205.64	13.77	34.15	917.72	9.42	19.51
#5	4	-2	352.19	13.40	8.27	455.54	20.17	9.94	356.79	16.60	9.61	152.17	3.43	4.47	382.71	10.03	9.48	267.15	6.20	7.57	259.79	3.90	5.52
#10	2	-1	202.42	8.64	4.76	283.72	13.97	6.19	191.95	11.43	5.17	48.85	2.00	1.43	180.2	5.57	4.46	114.68	2.96	3.25	80.26	2.20	1.71
#14	1.41	-0.5	107.94	6.11	2.54	191.73	9.79	4.18	92.8	8.93	2.50	14.57	1.57	0.43	62.51	4.02	1.55	39.14	1.85	1.11	33.34	1.49	0.71
#18	1	0	104.64	3.65	2.46	205.53	5.30	4.49	87.84	6.57	2.37	10.94	1.25	0.32	52.63	2.71	1.30	25.81	1.12	0.73	26.33	0.93	0.56
#20	0.84	0.25	33.8	2.86	0.79	62.33	3.94	1.36	30.12	5.75	0.81	4.12	1.13	0.12	17.06	2.29	0.42	6.07	0.95	0.17	6.64	0.79	0.14
#25	0.71	0.5	41.15	1.89	0.97	71.92	2.37	1.57	42.83	4.60	1.15	7.63	0.90	0.22	22.85	1.73	0.57	7.74	0.73	0.22	7.73	0.62	0.16
#35	0.5	1	46.73	0.79	1.10	63.35	0.99	1.38	65.76	2.83	1.77	12.98	0.52	0.38	30.33	0.97	0.75	9.41	0.46	0.27	7.56	0.46	0.16
#45	0.35	1.5	17.32	0.38	0.41	20.24	0.55	0.44	49.08	1.51	1.32	6.75	0.32	0.20	18.75	0.51	0.46	5.61	0.30	0.16	4.41	0.37	0.09
#60	0.25	2	6.68	0.23	0.16	9.13	0.35	0.20	30.45	0.69	0.82	3.1	0.23	0.09	9.53	0.27	0.24	3.65	0.20	0.10	3.29	0.30	0.07
#80	0.177	2.5	2.71	0.16	0.06	4.46	0.25	0.10	12.06	0.36	0.32	1.44	0.19	0.04	3.51	0.19	0.09	1.61	0.15	0.05	2.08	0.25	0.04
#120	0.125	3	1.69	0.12	0.04	3.17	0.18	0.07	4.83	0.23	0.13	1.01	0.16	0.03	2.26	0.13	0.06	1.19	0.12	0.03	2.19	0.21	0.05
#150	104		0.63	0.11	0.01	1.04	0.16	0.02	1.09	0.20	0.03	0.35	0.15	0.01	0.71	0.11	0.02	0.3	0.11	0.01	0.95	0.19	0.02
#230	0.0625	4	1.7	0.07	0.04	2.8	0.10	0.06	2.39	0.14	0.06	1.43	0.11	0.04	1.64	0.07	0.04	1	0.08	0.03	3.02	0.12	0.06
Pan	<0.0625		2.96		0.07	4.49		0.10	5.13		0.14	3.62		0.11	2.97		0.07	2.86		0.08	5.76		0.12
Total Weight			4256.7			4581.58			3712.51			3405.24			4038.28			3530.67			4704.62		

SAMPLE I.D.			B - 1			B - 2			B - 3			B - 5			B - 6			B - 7			B - 8			C - 1			C - 2			A - 1			A - 2			A - 3			D - 1			D - 2			D - 3		
			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011			3/28/2011		
Sieve	mm	Phi	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total	Weight	% Finer	% of Total
		Units	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight	Retained (g)	Than Size	Weight
64	64	-6	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00
32	32		1126.8	75.19	24.81	1818.5	54.52	45.48	1068	72.08	27.92	1775.6	59.74	40.26	625.9	84.66	15.34	1429.1	62.86	37.14	443.5	88.67	11.33	1264	73.81	26.19	1603.4	62.24	37.76	1423.3	64.59	35.41	1126	69.23	30.77	304.9	93.28	6.72	1391	69.75	30.25	2258.9	51.29	48.71	769.5	84.02	15.98
25	25		466.4	64.92	10.27	451	43.24	11.28	676.1	54.41	17.67	354.4	51.71	8.04	573.7	70.60	14.06	736.7	43.72	19.14	550.9	74.59	14.08	517	63.09	10.71	702.2	45.70	16.54	551.6	50.87	13.72	271.7	61.80	7.43	516.3	81.89	11.38	593.4	56.84	12.91	373	43.24	8.04	708.9	69.30	14.72
16	16	-4	891	45.30	19.62	682.5	26.17	17.07	1059	26.73	27.68	859.8	32.21	19.49	1168.1	41.98	28.63	744.2	24.38	19.34	1183.7	44.34	30.25	712.8	48.32	14.77	708.3	29.01	16.68	540.2	37.43	13.44	643.1	44.23	17.58	932.5	61.33	20.56	1026.9	34.51	22.33	593.7	30.44	12.80	894.8	50.72	18.58
8	8		964.4	24.07	21.23	516.8	13.24	12.93	523.8	13.04	13.69	657.1	17.31	14.90	933.7	19.10	22.88	472	12.11	12.27	1062.5	17.18	27.15	1077.6	26.00	22.33	665.3	13.34	15.67	566.7	23.33	14.10	384.8	33.71	10.52	1617.8	25.66	35.67	962.8	13.57	20.94	769.7	13.84	16.60	1100.6	27.87	22.85
	6.3		214.6	19.34	4.72	78.9	11.27	1.97	45.5	11.85	1.19	89.8	15.28	2.04	106.3	16.49	2.61	47	10.89	1.22	126.4	13.95	3.23	198.7	21.88	4.12	91.8	11.18	2.16	96.8	20.93	2.41	69.6	31.81	1.90	236.9	20.43	5.22	110.1	11.17	2.39	123.4	11.18	2.66	223.9	23.22	4.65
#5	4	-2	215.7	14.60	4.75	83.1	9.19	2.08	62.6	10.21	1.64	87.5	13.29	1.98	108.3	13.84	2.65	57.6	9.39	1.50	120	10.88	3.07	238	16.95	4.93	86.9	9.14	2.05	174.4	16.59	4.34	187.2	26.69	5.12	295.2	13.92	6.51	123.3	8.49	2.68	119.8	8.60	2.58	261.9	17.78	5.44
#10	2	-1	222.7	9.69	4.90	76.6	7.27	1.92	79.7	8.13	2.08	121.6	10.53	2.76	120.2	10.89	2.95	69.5	7.59	1.81	93.6	8.49	2.39	222.5	12.34	4.61	80.1	7.25	1.89	239.6	10.63	5.96	457.9	14.18	12.51	271.7	7.93	5.99	107.9	6.14	2.35	133.4	5.72	2.88	195.9	13.71	4.07
#14	1.41	-0.5	120	7.05	2.64	45.6	6.13	1.14	59.2	6.58	1.55	114	7.95	2.58	88.4	8.72	2.17	50	6.29	1.30	68.4	6.74	1.75	98.9	10.29	2.05	43	6.24	1.01	121.7	7.60	3.03	240.8	7.60	6.58	115.5	5.39	2.55	66.5	4.70	1.45	73.4	4.14	1.58	123.4	11.15	2.56
#18	1	0	113.2	4.56	2.49	56	4.73	1.40	73.3	4.67	1.92	134.1	4.91	3.04	103	6.20	2.52	64.2	4.62	1.67	83.1	4.62	2.12	100.3	8.21	2.08	56.4	4.91	1.33	97.5	5.17	2.43	129.5	4.06	3.54	88.2	3.44	1.94	57.7	3.44	1.25	54.9	2.95	1.18	162.2	7.78	3.37
#20	0.84	0.25	32.8	3.84	0.72	26.5	4.07	0.66	26.6	3.97	0.70	42.1	3.95	0.95	36.1	5.32	0.88	26.1	3.94	0.68	30.3	3.85	0.77	44.1	7.29	0.91	27.8	4.25	0.65	29.7	4.44	0.74	30.7	3.22	0.84	28.5	2.81	0.63	18.8	3.03	0.41	15.5	2.62	0.33	61.8	6.50	1.28
#25	0.71	0.5	44.5	2.86	0.98	37.7	3.13	0.94	40.4	2.92	1.06	56.6	2.67	1.28	48.2	4.13	1.18	40.9	2.88	1.06	43.4	2.74	1.11	77.7	5.68	1.61	42.9	3.24	1.01	39.3	3.46	0.98	32.5	2.33	0.89	33.3	2.08	0.73	23.1	2.53	0.50	22.3	2.14	0.48	101.8	4.38	2.11
#35	0.5	1	49.3	1.77	1.09	62.6	1.56	1.57	56.1	1.45	1.47	58	1.36	1.32	63.2	2.59	1.55	55.4	1.44	1.44	51.1	1.43	1.31	139.1	2.80	2.88	74.5	1.49	1.75	53.8	2.12	1.34	36.4	1.34	0.99	48	1.02	1.06	39.5	1.67	0.86	34.2	1.40	0.74	119.2	1.91	2.48
#45	0.35	1.5	25.2	1.22	0.55	25	0.94	0.63	26.5	0.76	0.69	19.8	0.91	0.45	36	1.70	0.88	24.1	0.81	0.63	18.6	0.96	0.48	72.9	1.29	1.51	33.4	0.70	0.79	34.4	1.26	0.86	19.3	0.81	0.53	24.4	0.48	0.54	33.1	0.95	0.72	22.1	0.92	0.48	53	0.81	1.10
#60	0.25	2	16.6	0.85	0.37	9.9	0.69	0.25	9.7	0.50	0.25	9.9	0.68	0.22	27.6	1.03	0.68	10.5	0.54	0.27	9.8	0.71	0.25	33.8	0.59	0.70	16.2	0.32	0.38	21.9	0.72	0.54	12.3	0.47	0.34	10.6	0.25	0.23	22.9	0.45	0.50	13.7	0.63	0.30	21	0.37	0.44
#80	0.177	2.5	9.7	0.64	0.21	7.8	0.49	0.20	5.1	0.37	0.13	7.7	0.51	0.17	17.5	0.60	0.43	7.2	0.35	0.19	7.3	0.52	0.19	13.6	0.31	0.28	6.5	0.17	0.15	12.8	0.40	0.32	7	0.28	0.19	4.5	0.15	0.10	9.9	0.24	0.22	8.8	0.44	0.19	8.5	0.19	0.18
#120	0.125	3	9.1	0.44	0.20	8.1	0.29	0.20	5	0.24	0.13	8.2	0.32	0.19	10.7	0.34	0.26	6.7	0.18	0.17	7.2	0.33	0.18	7.3	0.16	0.15	3	0.10	0.07	8.4	0.19	0.21	4.9	0.15	0.13	2.9	0.09	0.06	5.4	0.12	0.12	8	0.27	0.17	4.4	0.10	0.09
#150	104		4	0.35	0.09	3.1	0.21	0.08	2.2	0.18	0.06	3.3	0.25	0.07	3.3	0.25	0.08	2.2	0.12	0.06	3.1	0.26	0.08	2.2	0.11	0.05	1	0.07	0.02	2.1	0.14	0.05	1.5	0.11	0.04	0.9	0.07	0.02	1.5	0.09	0.03	3.2	0.20	0.07	1.2	0.08	0.02
#230	0.0625	4	11.3	0.10	0.25	5.8	0.07	0.15	4.8	0.06	0.13	7.4	0.08	0.17	6.6	0.09	0.16	3.5	0.03	0.09	6.6	0.09	0.17	3.6	0.04	0.07	2.1	0.02	0.05	3.6	0.05	0.09	2.3	0.04	0.06	2.1	0.02	0.05	2.7	0.03	0.06	6.5	0.06	0.14	2.6	0.02	0.05
Pan	<0.0625		4.5	0.00	0.10	2.7	0.00	0.07	2.2	0.00	0.06	3.5	0.00	0.08	3.8	0.00	0.09	1.2	0.00	0.03	3.4	0.00	0.09	1.8	0.00	0.04	1	0.00	0.02	2	0.00	0.05	1.6	0.00	0.04	0.9	0.00	0.02	1.4	0.00	0.03	2.6	0.00	0.06	1.1	0.00	0.02
Total Weight			4541.8			3998.2			3825.8			4410.4			4080.6			3848.1			3912.9			4825.9			4245.8			4019.8			3659.1			4535.1			4597.9			4637.1			4815.7		

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Team Member: S. Mark Nelson Date: 9-28-11
Signature

Team Member: Gregory K. Reed Date:
Signature G. Reed 9-28-11

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San Joaquin River Restoration Program

Evaluation of Hills Ferry Barrier Effectiveness at Restricting Chinook Salmon Passage on the San Joaquin River

by

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EXECUTIVE SUMMARY

The California Department of Fish and Game (DFG) constructs the Hills Ferry Barrier (HFB) on the San Joaquin River (SJR) near Newman, California, in the fall to restrict passage of adult fall-run Chinook salmon *(Oncorhynchus tshawytscha)* and Central Valley steelhead *(Oncorhynchus mykiss*) upstream of the confluence of the Merced River where habitat and water quality may be unsuitable for these fish. The San Joaquin River Restoration Program will restore flows in the SJR from Friant Dam to the Merced River confluence and re-establish a self sustaining population of Chinook salmon and other native fish. Beginning October 1, 2009, the San Joaquin River Restoration Program initiated a program of Interim Flows to collect relevant data on flows, temperatures, fish needs, seepage losses, recirculation, recapture and reuse. Public Law 111-11 Section 10004 (h)(4) requires that the Secretary of the Interior, in consultation with the California Department of Fish and Game, evaluate the effectiveness of the Hills Ferry Barrier in preventing the unintended upstream migration of anadromous fish in the San Joaquin River and any false migratory pathways.

Barrier physical characteristics, river hydrology and bathymetry, as well as fish behavior in proximity to the barrier were examined and evaluated in order to develop refined operating guidance and determine effectiveness of the barrier at preventing or reducing fish passage. Dual-frequency identification sonar underwater camera (DIDSON™), Acoustic Doppler Current Profiler (ADCP), and visual observations were used to identify problems and limitations of the barrier. Sand, silt, and clay river substrate eroded around the barrier's support structures, footings, base, and conduit panels. Scour holes underneath and at the terminal ends of the barrier develop from erosion and enable adult Chinook salmon to evade the barrier and swim upstream of this location. Upon detection, staff sandbagged scour holes and replaced or extended conduit pickets. Clearing floating hyacinth mats removed panels for cleaning and temporarily created gaps in the barrier. In November 2010, twenty-two fall-run Chinook salmon passed the barrier and were found upstream at Sack Dam, Mendota Pool, and upstream canals.

Information gathered from DIDSON™, ADCP, and visual accounts identified potential improvements to barrier design, operation, and location to improve barrier effectiveness including:

1. Locate the barrier downstream of the 2010 location for improved hydraulics
2. Improved debris removal procedures to avoid gaps from panel removal.

The long-term use of the HFB is unknown; however, it is anticipated it will be used to block anadromous fish species from moving upstream until the Restoration Area is considered ready for salmon reintroduction. This report discusses observations and near-term structural and non-structural modifications that can improve the effectiveness of the HFB.

INTRODUCTION

The San Joaquin River Restoration Program (SJRRP) is a long-term effort to restore flows to a 246-km-long (153-mi-long) stretch of the San Joaquin River below Friant Dam to the confluence with the Merced River and re-establish a self-sustaining Chinook salmon (*Oncorhynchus tshawytscha*) fishery in the river while reducing or avoiding adverse water supply impacts from Interim and Restoration Flows. Under the *NRDC, et al., v. Kirk Rodgers, et al. 2006* Settlement two parallel goals were mandated: 1) a restoration goal to restore and maintain fish populations in "good condition" in the main stem San Joaquin River below Friant Dam to the confluence with the Merced River, including naturally reproducing and self-staining populations of salmon and other fish, and 2) a water management goal to reduce or avoid adverse water supply impacts to Friant Division Long-term Contractors that may result from the Interim and Restoration Flows provided for in the Settlement.

Public Law 111-11 Section 10004 (h)(4) states that the Secretary, in consultation with the California Department of Fish and Game (DFG), shall evaluate the effectiveness of the Hills Ferry Barrier (HFB) in preventing the unintended upstream migration of anadromous fish in the San Joaquin River and any false migratory pathways. If that evaluation determines any such migration past the barrier is caused by the introduction of the Interim Flows and that the presence of such fish will result in the imposition of additional regulatory actions against third parties, the Secretary is authorized to assist DFG in making improvements to the barrier. From funding made available in accordance with section 10009, if third parties along the San Joaquin River south of its confluence with the Merced River are required to install fish screens or fish bypass facilities due to the release of Interim Flows in order to comply with the Endangered Species Act of 1973 (16 U.S.C. 1531 et seq.), the Secretary shall bear the costs of the installation of such screens or facilities if such costs would be borne by the Federal Government under section 10009(a)(3), except to the extent that such costs are already or are further willingly borne by the State of California or by the third parties. This report evaluates the effectiveness of the HFB at preventing unintended migration of anadromous fish.

HFB (Figure 1) is a sliding pipe weir located approximately 300 m (328 yd) upstream of the San Joaquin and Merced River confluence (Figure 2), 5.5 km (3.4 mi) east of Newman, California. The barrier is intended to impede passage of fall-run Chinook salmon from ascending the San Joaquin River above the confluence with the Merced River where habitat and water quality (temperature) are unsuitable for these fish. The HFB also blocks the Central Valley (CV) steelhead *(Oncorhynchus mykiss)* from moving upstream, although the HFB is not in p lace during the CV steelhead's greatest potential to occur in the area (mid-December through mid-February). Identifying salmon, steelhead, and other native species use of the river is important to the SJRRP's recovery program, and it is beneficial to determine fish species that are encountering the barrier. Information regarding the presence of non-native species such as catfish, carp, and striped bass may also be helpful but is a secondary priority.

In 1988, DFG began an adult trapping and egg salvage effort in the San Luis Canal at the Los Banos Wildlife Area which continued through 1991. Fish were spawned and the eggs were transported to the Merced River Hatchery near Snelling, California, for incubation and rearing. Fish trapping efforts continued with modifications in location and design through 1991. This approach was abandoned due to high egg and juvenile mortality. During spawning season of fall 1992, DFG tested an electrical fish barrier made by Smith-Root, Inc., just upstream of the confluence of the San Joaquin and Merced Rivers to restrict adult Chinook salmon passage. The electrical barrier was later determined to be ineffective for this particular application due to corrosion of electrode cables from high water conductivity. A physical barrier was placed 46 m (50 yd) upstream of the electrical barrier on the San Joaquin River to act as a backup during electrical barrier feasibility assessments. Following the limited success of the electrical barrier, a physical barrier has been used until present. Physical barriers of several variations (*i.e.*, Alaskan, resistance board, sliding pipe weirs) have been in place seasonally (September–December) since 1992. For a detailed history of the Hills Ferry Barrier operation see Gates (2011).

Figure 1.—Hills Ferry Fish Barrier and fish trap on the San Joaquin River, California.

The current design used since 2004 is a sliding pipe weir constructed with wooden tripod support structures and aluminum channel that have 2.5-cm (1-in) holes to allow pieces of 1.9-cm (.75-in) electrical conduit to slide into the riverbed. This type of weir has been

used every year at the confluence with minor changes in location due to bank erosion. In 2010 the barrier was moved upstream approximately 100 m (109 yd) to deeper water to allow for a fish trap to be retrofitted to the weir structure.

The alluvial river substrate of sand, silt, and clay poses a challenge to the integrity of the barrier throughout the season once it is installed. River hydraulics around weir support structures, barrier footings, base of conduit bars, and barrier panels cause substrate erosion resulting in scouring holes underneath the barrier and along the shoreline. DFG personnel fill these scour holes with sandbags on a daily basis to maintain a relatively "fish tight" barrier. This labor intensive activity is a challenge due the physical conditions at the site and the impermanence of the structure. Adult Chinook salmon have been observed in the past to take advantage of scour holes and elude the barrier. Others have been witnessed to pass during cleaning operations when excessive water hyacinth loads and vegetative debris become lodged against the sliding pipes requiring temporary removal of a panel of conduit pickets to allow the plant matter to travel downstream.

Figure 2.—Merced and San Joaquin River confluence near Newman, California.

An assessment of the HFB was performed to evaluate its effectiveness throughout the installation period and under a wide range of flows to understand the current limitations of the structure. An evaluation to inhibit the migration of Chinook salmon up the San Joaquin River was performed during fall 2010. Physical characteristics of the barrier and river were examined as well as fish behavior adjacent to the barrier. Dual-frequency identification sonar underwater camera (DIDSON) and an Acoustic Doppler Current Profiler (ADCP) were used to identify problems and limitations, and information will be used to recommend improvements with barrier design, operation, and location. Scour holes and gaps in the barrier can be found and possibly predicted using erosion depth and sediment transition behavior. The goal of this task is to evaluate the barrier effectiveness and develop refined operating guidance and data collection protocols.

MATERIALS AND METHODS

Fish Barrier

The HFB is a sliding pipe weir design used to exclude large migrating fish from swimming upstream while allowing water and other smaller species to pass. The barrier was installed August 31, 2010 and was removed December 9, 2010, which is the timeline of peak migration of fall-run Chinook salmon to Central Valley Rivers. The general principle of this type of weir is that an aluminum channel with 2.5 cm (1-in) holes allowed pieces of 1.9-cm (0.75-in) electrical conduit to slide freely vertically in the corresponding holes and can be pushed into the riverbed (Figure 3). The weir consisted of anchor points on each side of the river and a cable that spanned the river about 2–3 m (6.56–9.84 ft) above the water level. Eighteen, 2.5-m-high (8.20-ft-high) tripods spaced approximately 0.5 m (1.64 ft) apart at their base were tethered to the overhead cable. Two horizontal rows of aluminum channel with 2.5-cm (1-in) holes machined every 3.8 cm (1.5 in) were affixed to the tripods. The 1.9-cm (.75-in) electrical conduit pickets were then slid through these holes to make a fish tight weir. The fish trap that was retrofitted to the barrier consisted of a 1-m-wide x 2-m-long x 1-m-high (3.28-ft-wide x 6.56-ft-long x 3.28-ft-high) box frame with 2.5-cm (1-in) bars spaced at 2.5 cm (1 in) and a funnel opening to deter escapement once fish entered (Figure 4). The trap was suspended upstream of the barrier by two pontoons. An opening in the weir was made by removing conduit pickets and affixing a net-tube that led from the weir to the trap. The trap was checked for fish daily when in operation.

Figure 3.—Hills Ferry Barrier is a sliding pipe weir constructed of aluminum channel with 2.5-cm (1-in) holes that allow 1.9-cm (.75-in) electrical conduit to slide freely vertically in the corresponding holes and are pushed into the riverbed.

Figure 4.—Fish trap retrofitted to the Hills Ferry Barrier sliding pipe weir design that consisted of a 1-m-wide x 2-m-long x 1-m-high (3.28-ft-wide x 6.56-ft-long x 3.28-ft-high) box frame with 2.5-cm (1-in) bars spaced at 2.5 cm (1 in) and a funnel opening to deter escapement. The net entrance led from the weir to the trap.

DIDSON Evaluation

Barrier effectiveness at blocking migrating fish under a variety of flow conditions was evaluated by assessing the location and behavior of sediment scouring using a dual-frequency identification sonar underwater camera (DIDSON; Sound Metrics Corp., Chesapeake, Virginia). The near video quality images of the DIDSON allowed detailed underwater inspections of the barrier structure and substrate in turbid water. The DIDSON camera was also used to observe fish interactions with the weir and determine fish species that encounter the barrier. The DIDSON was configured with a remotely operated pan and tilt actuator that allowed a scan of the weir and river bottom. The DIDSON camera was affixed to a transom mount that allowed for easy attachment to a jon boat and manually maneuvered across the channel directly adjacent the barrier (Figure 5). River-wide transects recording barrier condition as well as fish behaviors were performed above and below the weir on September 21st, October 20th and November 18th.

Figure 5.—River-wide transects were recorded along the barrier to monitor scouring and passage issues along with fish behaviors using a DIDSON camera affixed to a transom mount of a jon boat and manually maneuvered across the channel directly adjacent the barrier.

Water Velocities and Bathymetry

River transects were measured upstream and downstream of the barrier with a Teledyne RD Instruments StreamPro Acoustic Doppler Current Profiler (ADCP; Teledyne RD Instruments, Poway, California) to map changes in bed elevations and velocity distributions and to identify scour and depositional zones during barrier operation (Figure 6). The StreamPro includes a 2.0 MHz ADCP with four transducers at a 20 degree beam angle mounted to a small float. The bottom-tracking capability of the StreamPro provides the ability to move the instrument continuously across the river. A tagline was set up at seven locations and the instrument was floated across the river at a velocity slower than the water velocity and raw data were processed with specialized StreamPro software. Velocity data were collected with a vertical cell size of 7.6–10.1 cm (0.25–0.33 ft) depending on the maximum water depth. Velocity resolution of the instrument is 0.1 cm/s (0.04 in/s). A handheld computer collected data via a Bluetooth transmitter and raw data were processed in specialized StreamPro software. River transects were collected 0.6, 1.5, 3.0, 9.1 m (2, 5, 10, and 30 ft) upstream of the barrier and 0.6, 1.5, 3.0, 9.1 m (2, 5, 10, and 30 ft) downstream of the barrier. Data were not collected 9.1 m (30 ft) downstream of the barrier since the 1.5-m (5-ft) and 3.0-m (10-ft) transects did not show significant changes in velocity or bed elevation during October. The river stage was recorded from USGS site 11273400 (San Joaquin R AB Merced R near Newman, California) staff gage directly upstream of the barrier. Data were collected on October 19–20, 2010 and November 16–17, 2010. Additional field trips were scheduled in December 2010 and January 2011, but field work was canceled due to very high river flows producing unsafe working conditions.

Figure 6.—Measuring river velocity and bathymetric transects utilizing the Acoustic Doppler Current Profiler.

Telemetry

Chinook salmon behavior was monitored on the downstream side of the Hills Ferry Barrier to measure the effectiveness of the barrier at inhibiting passage using ultrasonic telemetry. However, due to concerns of fall-run Chinook salmon passing the barrier, additional monitoring was performed on the upstream side of the barrier to Mendota Pool at the request of the SJRRP and DFG Management. Adult fall-run Chinook salmon were collected in a fish trap attached to the HFB and other collected along the weir with a dip net. Initial plans were to collect and tag up to 30 fall-run Chinook salmon distributed throughout their run that spans late September to early December, generally peaking in mid-November, to determine movements and behavior in the proximity of the HFB and San Joaquin-Merced River confluence. Collected fall-run Chinook salmon were measured (fork length), sexed, scale sampled from the dorsal area posterior to the adipose fin, and tissue sampled from the pectoral fin for DNA studies. Fish were implanted with ultrasonic transmitters (Sonotronics model CT-82-1-I, Sonotronics, Inc., Tucson, Arizona) that emit high frequency sound which propagated mechanically through the water. Fish that received a telemetry transmitter were secondarily tagged with a colored Floy tag to facilitate quick identification of recaptured fish in the trap and alert hatchery personnel if ultrasonically tagged fish were collected.

Esophageal implant of transmitters is the desired technique for tracking adult salmonids during migration (Burger *et al.* 1985, 1995; Eiler 1990; Ruggerone *et al.* 1990; Ramstad and Woody 2003). Utilizing the "two percent" rule for implanted telemetry tags (Winter 1983, 1996, 2000), it is recommended that the ratio of transmitter weight to body weight (in air) should be less than 2 percent. We determined that a 12-g transmitter (Sonotronics model CT-82-1-I, 38 mm x 15.6 mm (1.5 in x 0.61 in) with 60 day life span; Figure 7) was appropriate for fish larger than 600 g (1.32 lb) and would easily allow for tagging of any adult Chinook encountered in the trap. Fourteen frequencies were used (69–83 kHz) and each tag had a unique pulse code (*e.g.*, Code 234 would sound 2 pulses–pause, 3 pulses–pause, 4 pulses–pause, repeat). Transmitter detection range varied depending on conditions (*e.g.*, water turbulence, watercraft presence, and pump motor disturbance) with a maximum range of about 200 m (219 yards) under good conditions.

Tags were activated, coated with glycerin for lubrication, and pushed passed the aortic sphincter into the upper stomach of the fish using an acrylic rod similar in diameter to the tag (Figure 8). Fish were held by an assistant while the tag was inserted. The entire handling procedure was performed without the use of anesthetic and took less than 4 minutes. The fish was then cradled in the trap until recovered and normal swimming behavior obtained. An ultrasonic handheld receiver was used to check the acoustic frequency emission of the tag and the fish released.

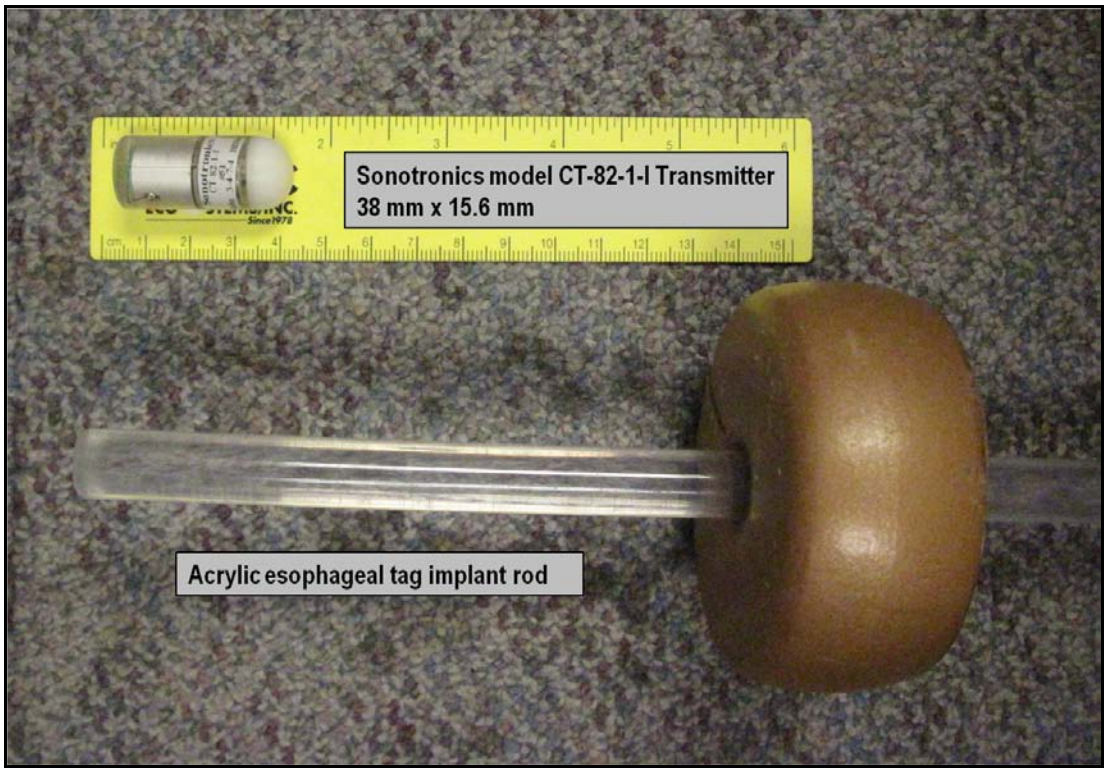


Figure 7.—Sonotronics model CT-82-1-I acoustic transmitter and acrylic rod used for esophageal tag insertion.

Figure 8.—Esophageal insertion of sonic transmitter into a Chinook salmon.

Manual tracking of acoustically-tagged fish was accomplished using a Sonotronics USR-5W wide band receiver with DH-4 directional hydrophone (Figure 9). Five SUR-1-2D submersible ultrasonic receivers (SUR; Figure 10) that allowed for fixed deployment and manual on-site download via laptop were strategically deployed. SURs are a stand-alone battery powered receiver that continuously scan for tags and can be deployed and stay unmaintained for months between downloads. Fixed deployment locations were SUR 1: ~180 m (~197 yd) upstream of HFB, SUR 2: attached to the HFB, SUR 3: ~220 m (~241 yd) below HFB, SUR 4: ~245 m (~268 yd) upstream of the San Joaquin-Merced River confluence in the Merced River, and SUR 5: ~540 m (591 yd) downstream of the San Joaquin-Merced River confluence in the San Joaquin River (Figure 11).

Figure 9.—Manual tracking of an acoustically-tagged Chinook salmon using a Sonotronics USR-5W wide band receiver with DH-4 directional hydrophone.

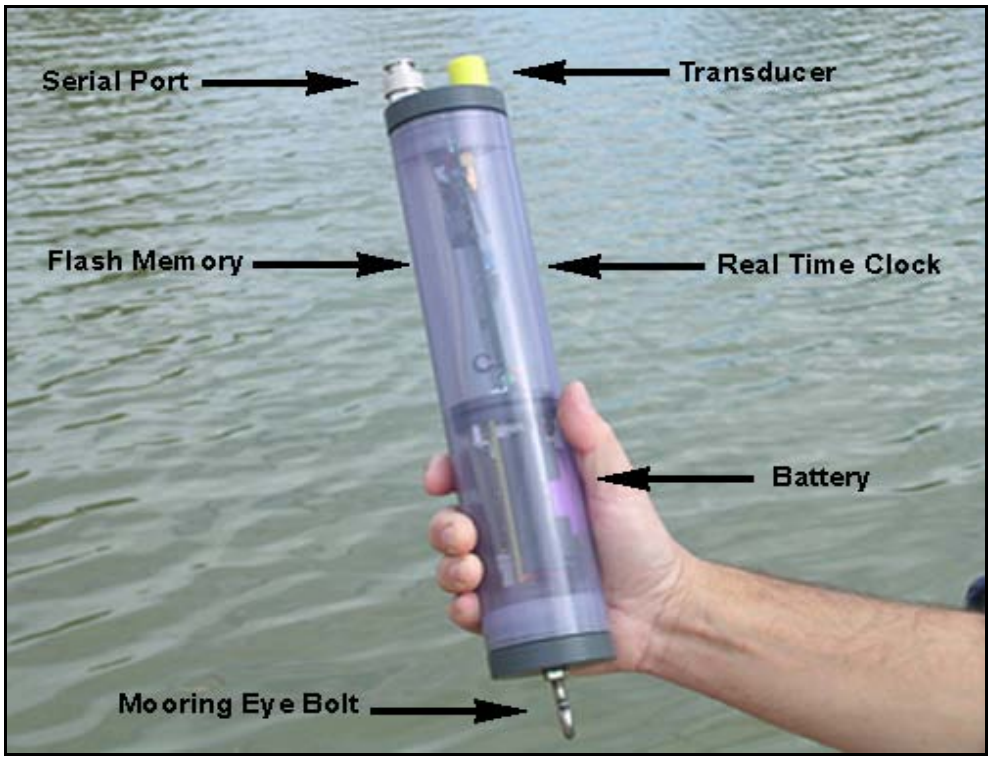


Figure 10.—Stand-alone submersible ultrasonic receiver (Photo courtesy of Sonotronics Inc.).

Figure 11.—Locations of fixed SUR-1-2D submersible ultrasonic receivers (SUR).

RESULTS

Fish Barrier

An assessment of the relative effectiveness of the current HFB at blocking native and non-native fish species was performed from August 31, 2010 until high flows caused the failure of the barrier and erosion of the river banks at the anchoring points on November 26, 2010. The HFB was removed for the season on December 6, 2010. Observations from the DIDSON camera, ADCP, and visual accounts identified problems and limitations with the structure in fall 2010. The location of scouring, gaps in the pickets, and openings in the barrier were discovered with these instruments along with visual observations (*i.e.,* Figures 12 and 13).

Figure 12.—Gaps in the conduit pickets can provide passage for adult Chinook salmon beyond the Hills Ferry Barrier.

Figure 13.—Bank erosion and scoring causes holes in the barrier which may provide upstream passage at the Hills Ferry Barrier.

DIDSON Evaluation

The near-video quality images of the DIDSON allowed detailed underwater inspections of the barrier and substrate; however the angle of the weir and the surface reflection posed some difficulties on the downstream side of the barrier. Carp (*Cyprinus carpio*), channel catfish (*Ictalurus furcatus*), white catfish (*Ameiurus catus*), striped bass (*Morone saxatilis*), threadfin shad (*Dorosoma petenense*), and Chinook salmon were identified, especially on the downstream side where the barrier was inhibiting their movement up-river and/or providing structure. Schools of threadfin shad swam freely on both sides of the barrier and occasionally passed through the conduit pickets (Figure 14). Chinook salmon and carp were observed to move along the barrier looking for holes for passage opportunity (Figures 15 and 16). The DIDSON provided an interesting observation of an unidentifiable species (most likely a carp), using its body to attempt to burrow under the conduit pickets in the substrate at the barrier's base, accelerating the erosion process. Acoustic images of missing pickets, scour holes, and eroded areas were also identified.

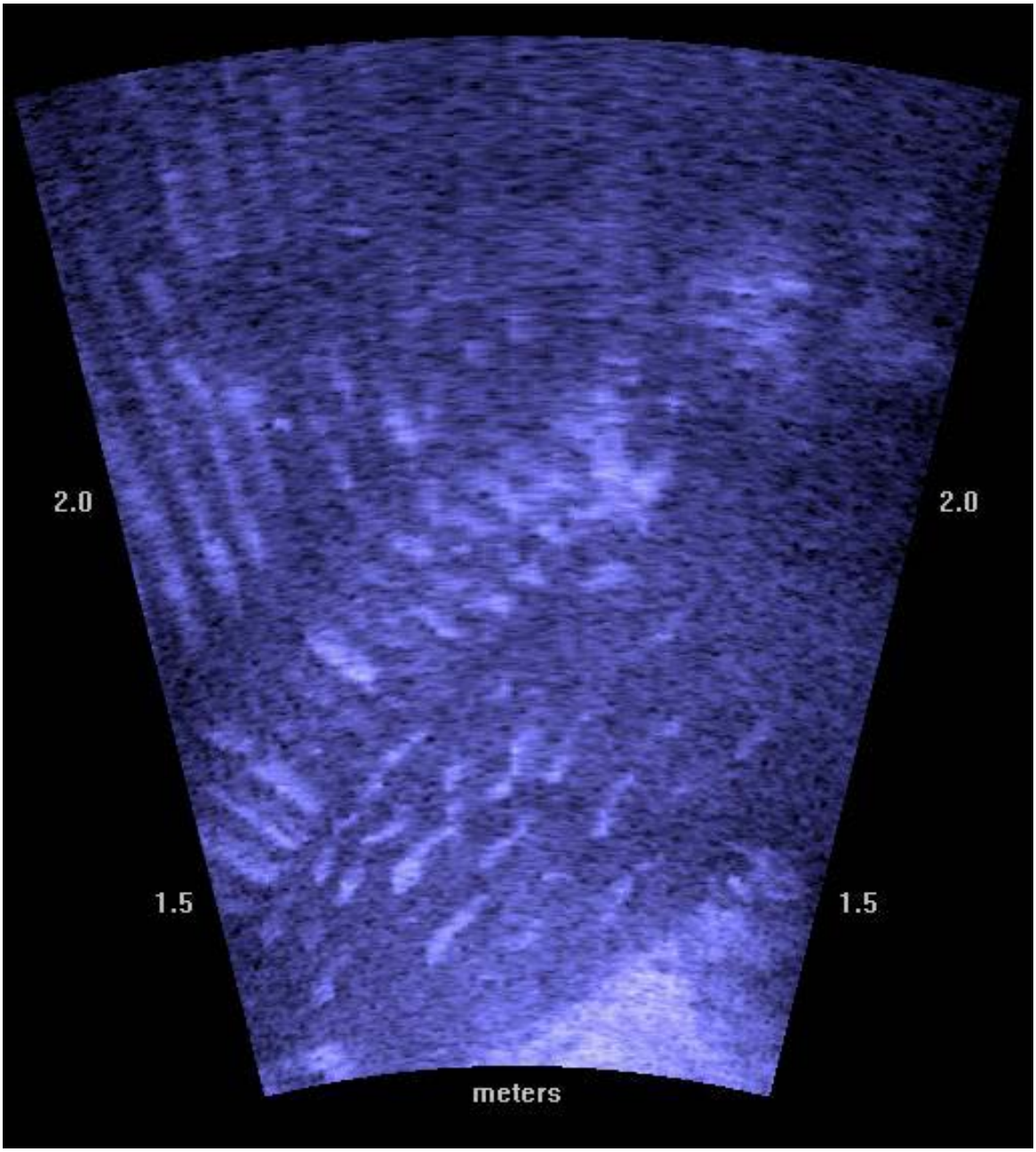


Figure 14.—DIDSON image of a school of threadfin shad swimming along the upstream side of the Hills Ferry Barrier.

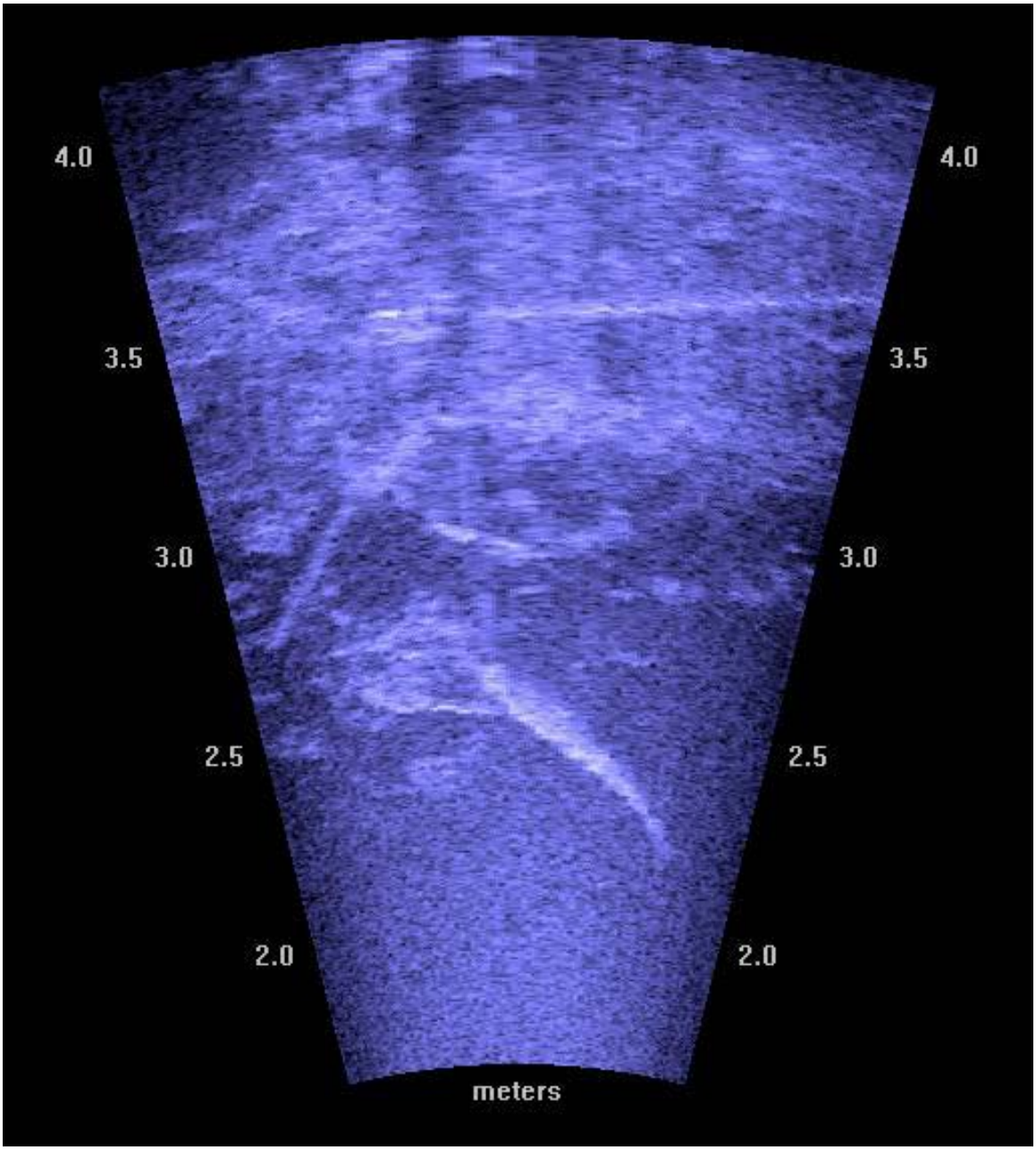


Figure 15.—Chinook salmon observed swimming directly downstream of the Hills Ferry Barrier searching for passage opportunity.

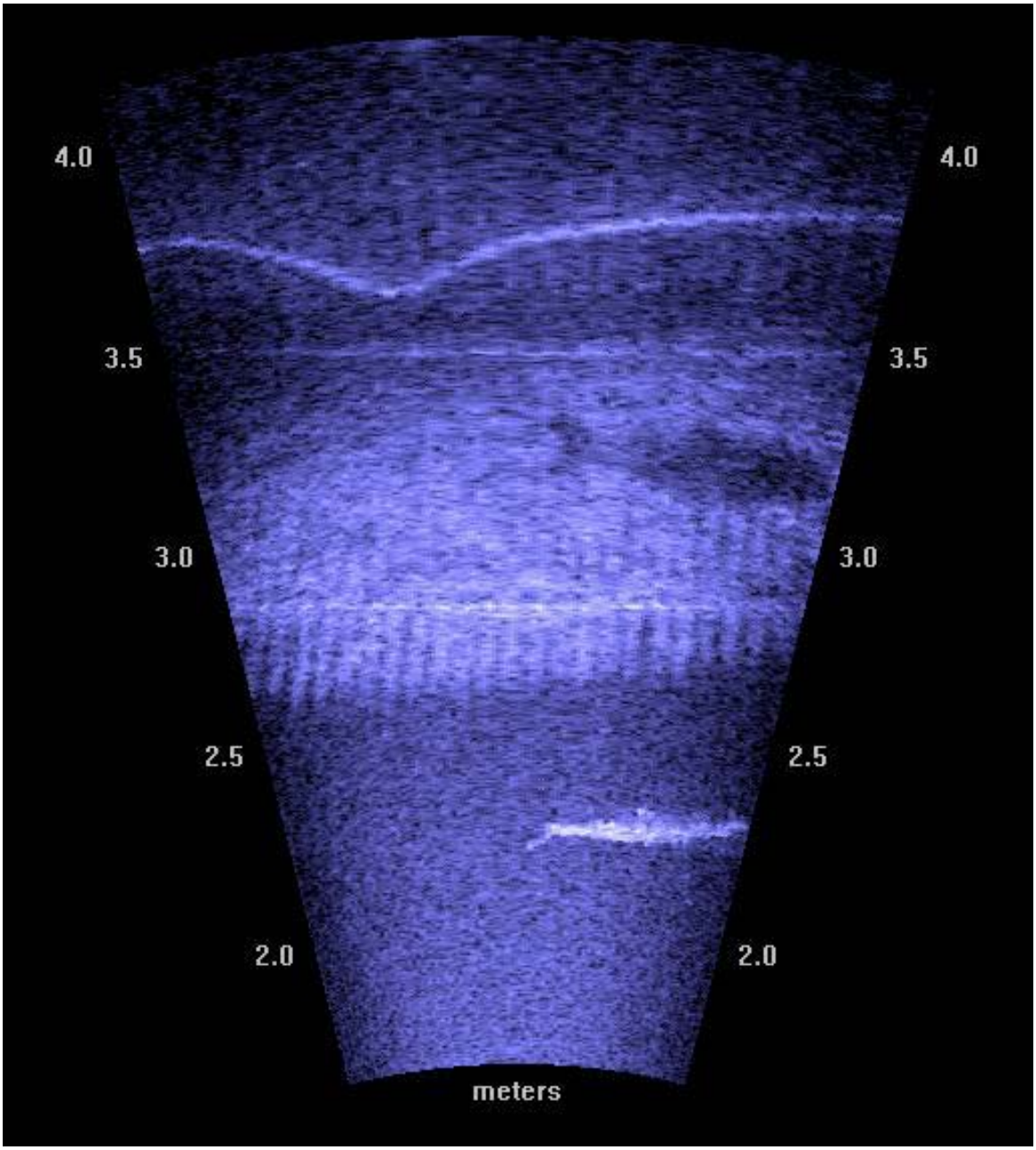


Figure 16.—A carp observed swimming along the downstream of the Hills Ferry Barrier seeking passage opportunity, note the conduit pickets in the background.

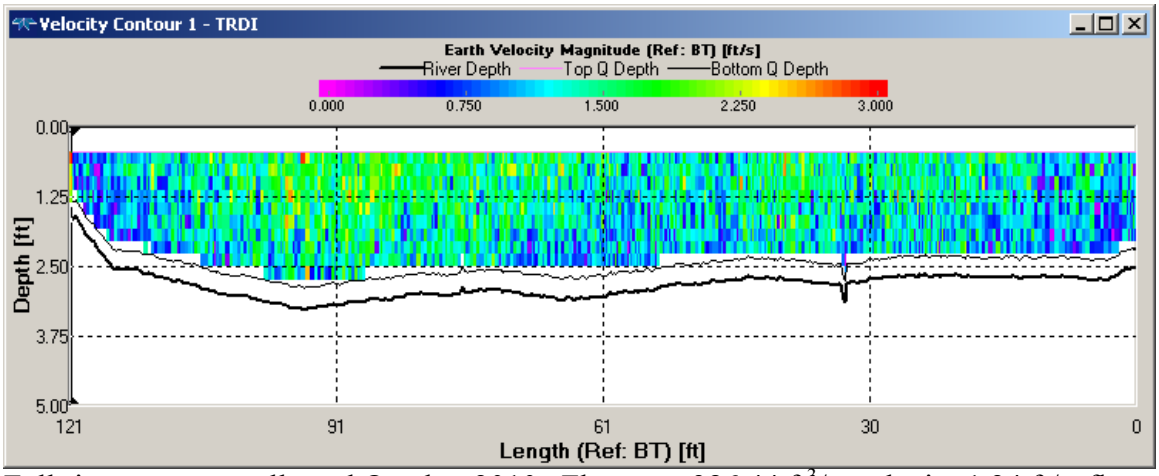
Water Velocities and Bathymetry

Data from the ADCP transects showed hydraulic conditions were similar in October and November with river flow rates slightly lower through mid-November (approximately 7 percent) and the water surface elevation approximately 0.61 m (2 ft) higher. Comparative data between October 19 and November 16, 2010 transects are displayed in Figures 17–23. The velocity magnitude is shown on a scale of 0–0.9 m/s (0–3 ft/s) across the width of the river. On the upstream side of the barrier, flow was distributed fairly uniformly in October. At 9.1 m (30 ft) upstream of the barrier, the average channel velocity was 0.38 m/s (1.24 ft/s; Table 1, Figure 12). At 0.61 m (2 ft) upstream of the barrier, the velocity on the left side of the fish trap was 0.38 m/s (1.24 ft/s) and the velocity of the right side of the trap was 0.36 m/s (1.18 ft/s; Table 1, Figure 20). In November, flow was greatly skewed to the left side of the channel. At 3.1 m (30 ft) upstream of the barrier, the average channel velocity was 0.37 m/s (1.20 ft/s). Average velocities were 0.61 m at (2 ft) upstream of the barrier, 0.52 m/s (1.70 ft/s) on the left side and 0.23 m/s (0.74 ft/s) on the right (Figure 20).

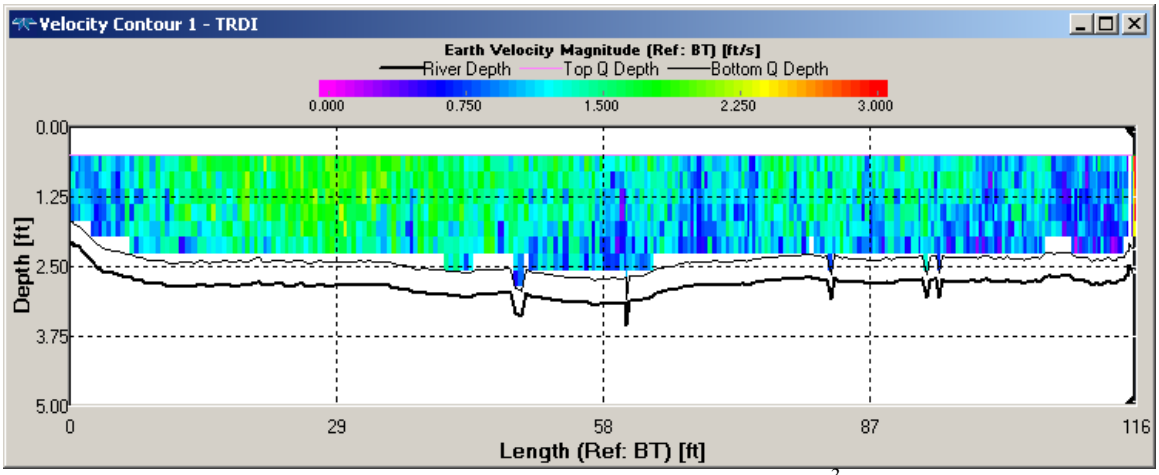
Deposition of loose fine material occurs on right river transect in November (Figures 19 and 20), while mid-channel scouring was occurring 0.61–3.0 m (2–10 ft) downstream of barrier between October and November (Figures 21–23). More aggressive scouring is noticeable 0.61 m (2 ft) downstream of barrier behind fish trap (Figure 21). The armored, riprap sill, upstream of the barrier on the left river bank remained stable throughout the evaluation period, and is seen as an elevation rise (Figures 18–20).

Table 1.—Hydraulic Hydraulic data collected at Hills Ferry Barrier in October and November 2010. 1 foot = 0.3 meters.

		Average			
	Test Date	**Flow Rate (ft^3/s)**	**Velocity (ft/s)**	**Flow Area (ft^2)**	**Water Surface Elevation (ft)**
Upstream 30 ft	10/19/2010	386.44	1.24	327.82	49.87
Full Transect	11/16/2010	371.13	1.20	315.55	50.05
Upstream 10 ft	10/19/2010	124.28	1.22	108.89	49.87
Left of Trap	11/16/2010	172.48	1.68	108.82	50.05
Upstream 10 ft	10/19/2010	224.43	1.28	185.2	49.87
Right of Trap	11/16/2010	181.88	0.91	213.12	50.05
Upstream 5 ft	10/19/2010	125.29	1.24	107.34	49.87
Left of Trap	11/16/2010	189.42	1.77	110.5	50.05
Upstream 5 ft	10/19/2010	226.73	1.27	193.03	49.87
Right of Trap	11/16/2010	156.28	0.83	200.08	50.05
Upstream 2 ft	10/19/2010	132.87	1.24	114.12	49.87
Left of Trap	11/16/2010	203.47	1.70	125.21	50.05
Upstream 2 ft	10/19/2010	229.78	1.18	211.5	49.87
Right of Trap	11/16/2010	140.25	0.74	205.85	50.05
Downstream 2 ft	10/19/2010	381.45	0.97	383.74	49.87
Full Transect	11/16/2010	343.88	0.65	453.45	50.00
Downstream 5 ft	10/19/2010	370.74	1.22	318.45	49.87
Full Transect	11/16/2010	348.58	0.76	427.82	50.00
Downstream 10 ft	10/19/2010	371.14	1.30	303.93	49.87
Full Transect	11/16/2010	347.01	0.95	363.24	50.00

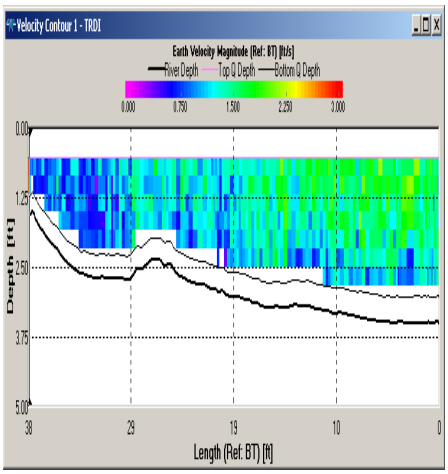


Full river transect collected October 2010. Flow rate 386.44 ft^3/s, velocity 1.24 ft/s, flow area 327.82 ft^2.

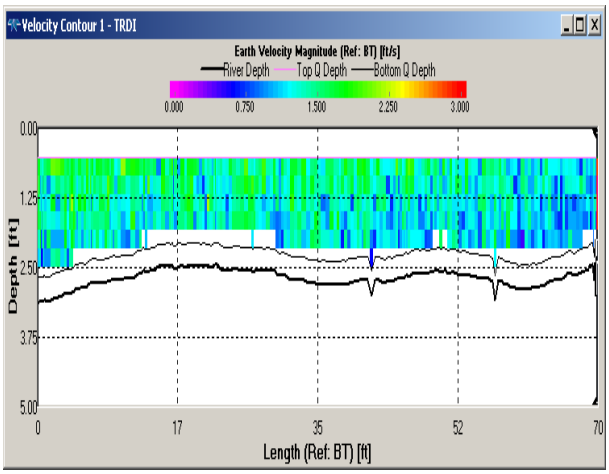


Full river transect collected November 2010. Flow rate 371.13 ft^3/s, velocity 1.20 ft/s, flow area 315.55 ft^2.

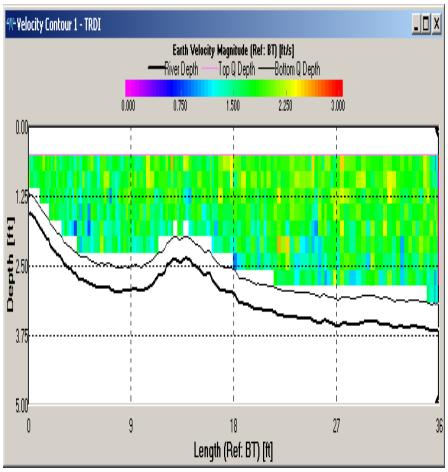
Figure 17.—River transect collected with an Acoustic Doppler Current Profiler at 9.1 m (30 ft) upstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)



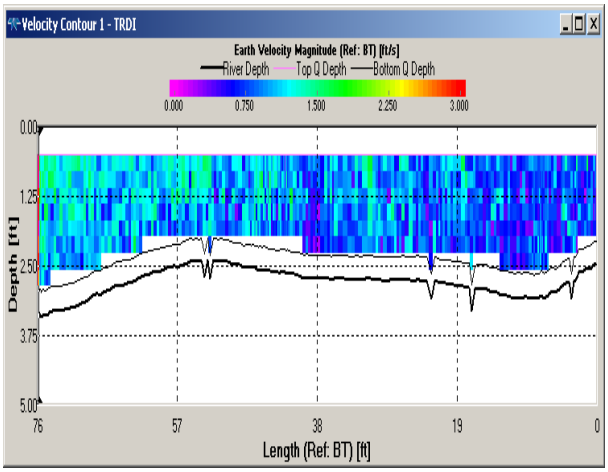
Left river transect collected October 2010. Flow rate 124.28 ft^3/s, velocity 1.222 ft/s, flow area 108.89 ft^2.



Right river transect collected October 2010. Flow rate 224.43 ft^3/s, velocity 1.28 ft/s, flow area 185.20 ft

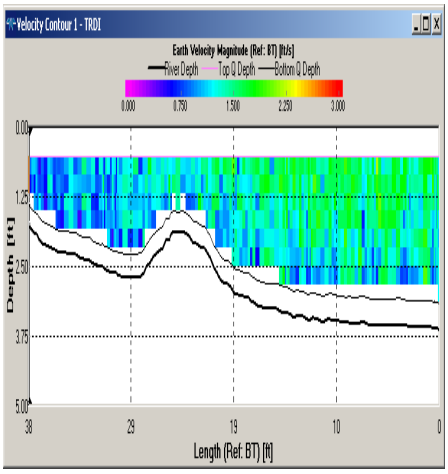


Left river transect collected November 2010. Flow rate 172.48 ft^3/s, velocity 1.68 ft/s, flow area 108.82 ft^2.

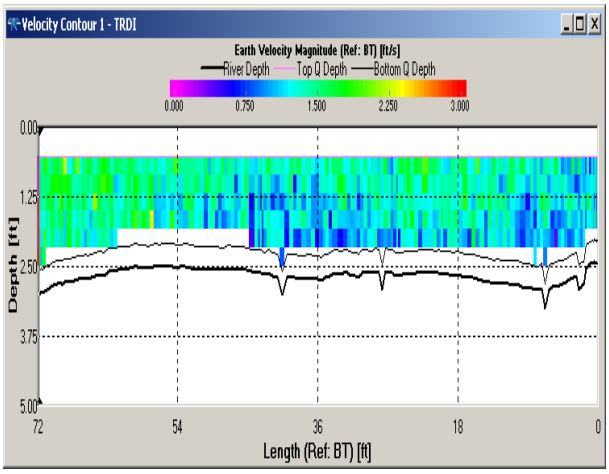


Right river transect collected November 2010. Flow rate 181.88 ft^3/s, velocity 0.91 ft/s, flow area 213.12 ft^2

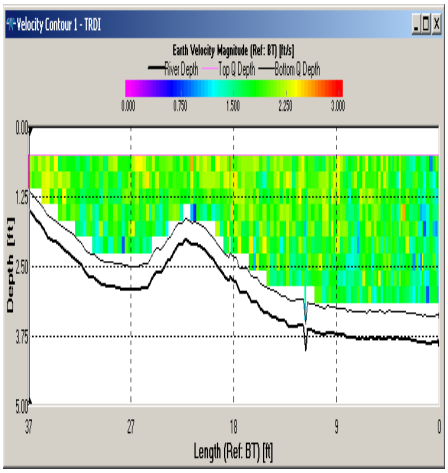
Figure 18.—River transect collected with an Acoustic Doppler Current Profiler at 3.0 m (10 ft) upstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)



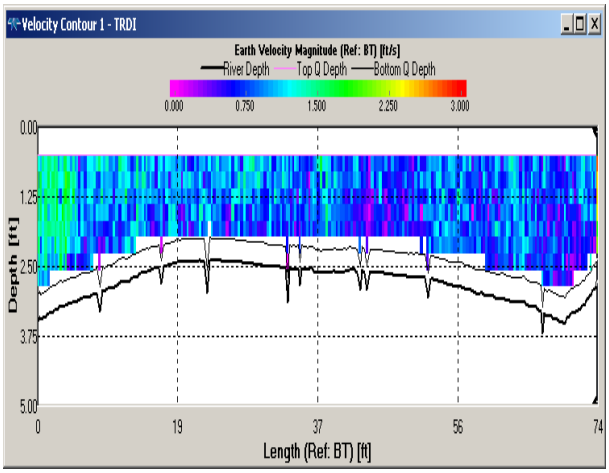
Left river transect collected October 2010. Flow rate 125.29 ft^3/s, velocity 1.24 ft/s, flow area 107.34 ft^2.



Right river transect collected October 2010. Flow rate 226.73 ft^3/s, velocity 1.27 ft/s, flow area 193.03 ft^2.

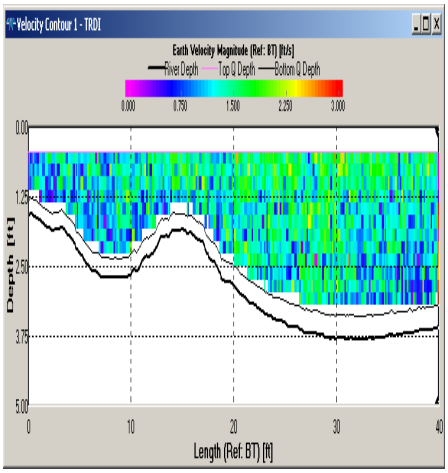


Left river transect collected November 2010. Flow rate 189.42 ft^3/s, velocity 1.77 ft/s, flow area 110.50 ft^2.

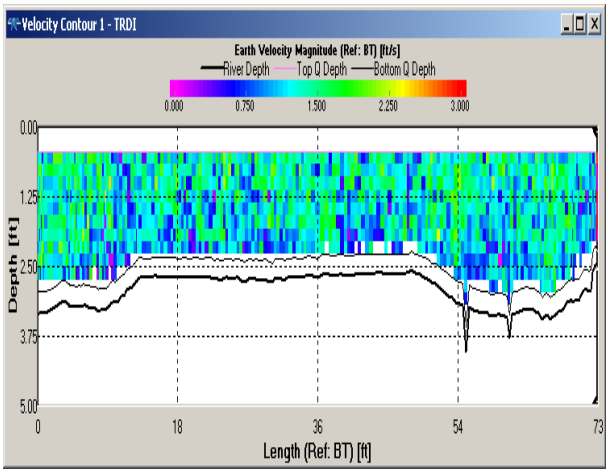


Right river transect collected November 2010. Flow rate 156.28 ft^3/s, velocity 0.83 ft/s, flow area 200.08 ft^2.

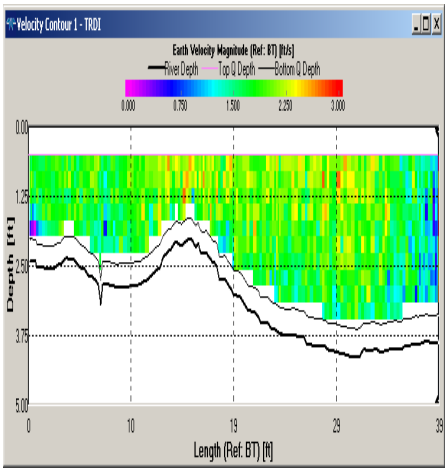
Figure 19.—River transect collected with an Acoustic Doppler Current Profiler at 1.5 m (5 ft) upstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)



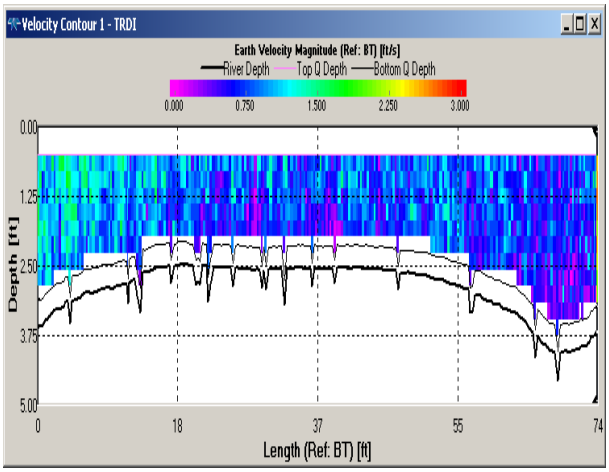
Left river transect collected October 2010. Flow rate 132.87 ft^3/s, velocity 1.24 ft/s, flow area 114.12 ft^2.



Right river transect collected October 2010. Flow rate 229.78 ft^3/s, velocity 1.18 ft/s, flow area 211.5 ft^2.

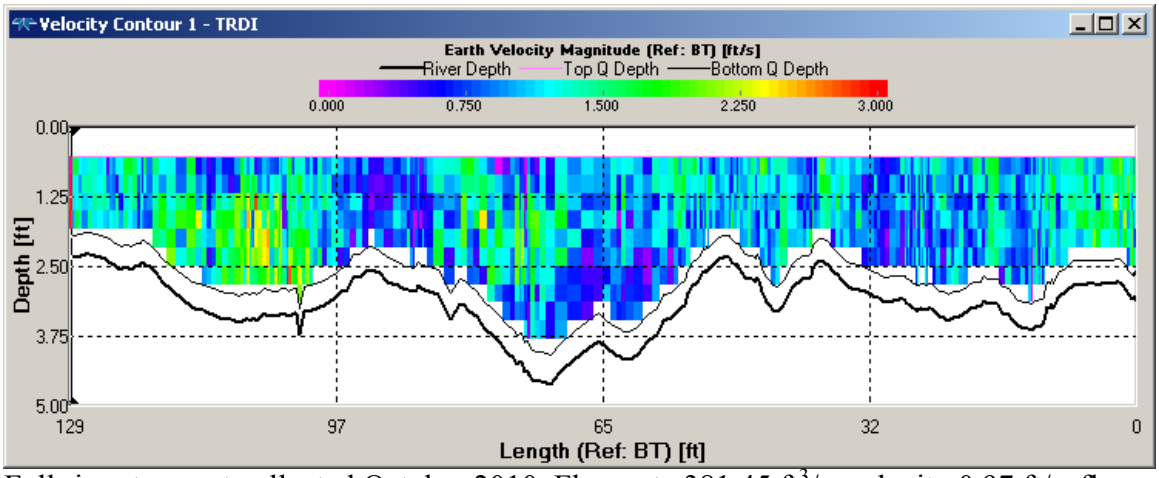


Left river transect collected November 2010. Flow rate 203.47 ft^3/s, velocity 1.70 ft/s, flow area 125.21 ft^2.

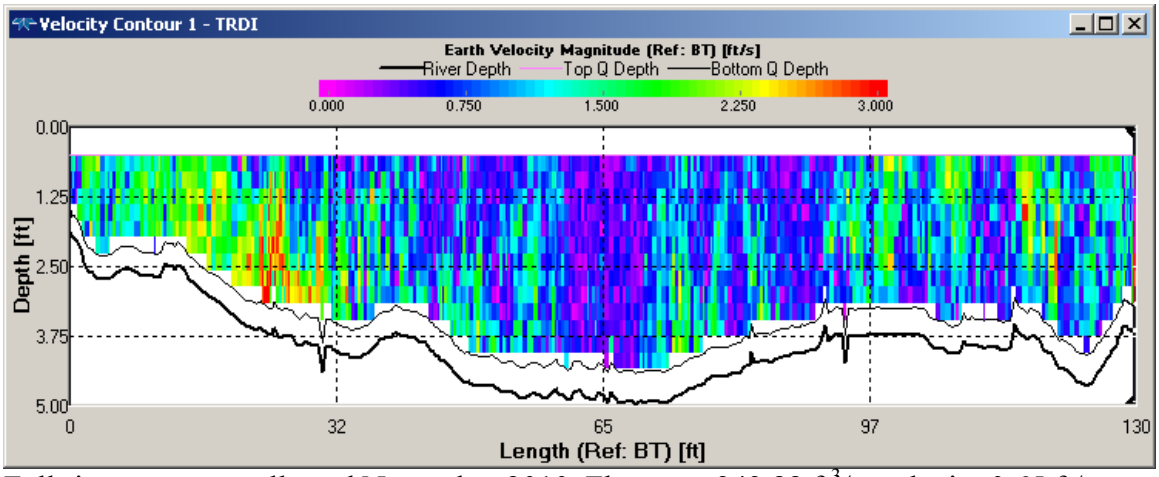


Right river transect collected November 2010. Flow rate 140.25 ft^3/s, velocity 0.74 ft/s, flow area 205.85 ft^2.

Figure 20.—River transect collected with an Acoustic Doppler Current Profiler at 0.61 m (2 ft) upstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)

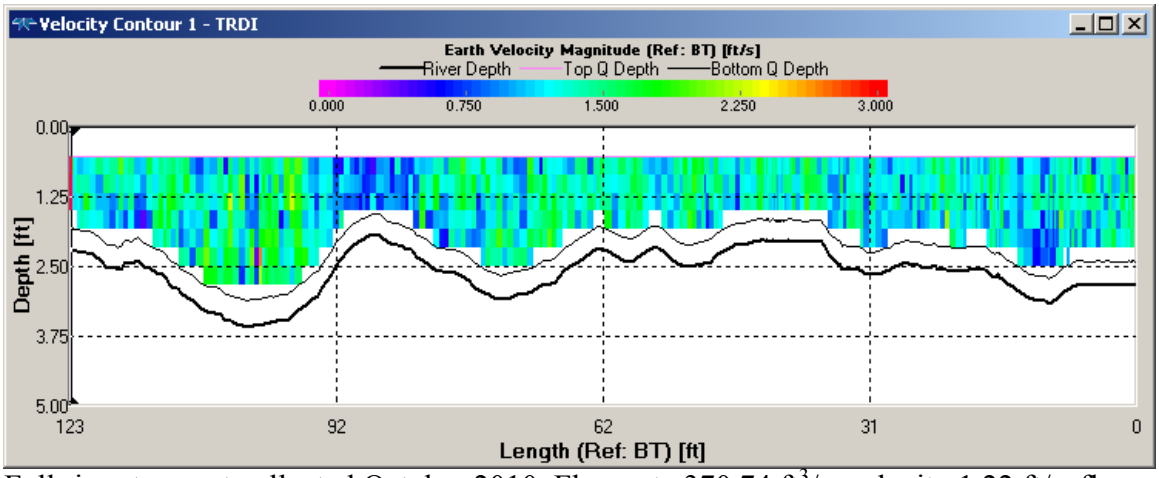


Full river transect collected October 2010. Flow rate 381.45 ft^3/s, velocity 0.97 ft/s, flow area 383.74 ft^2.

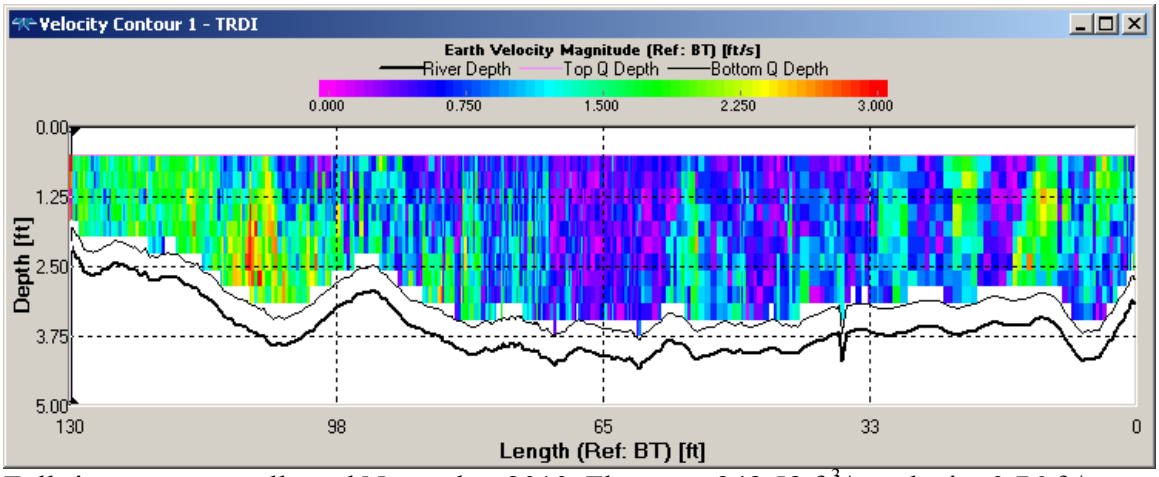


Full river transect collected November 2010. Flow rate 343.88 ft^3/s, velocity 0.65 ft/s, flow area 453.45 ft^2.

Figure 21.—River transect collected with an Acoustic Doppler Current Profiler at 0.61 m (2 ft) downstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)

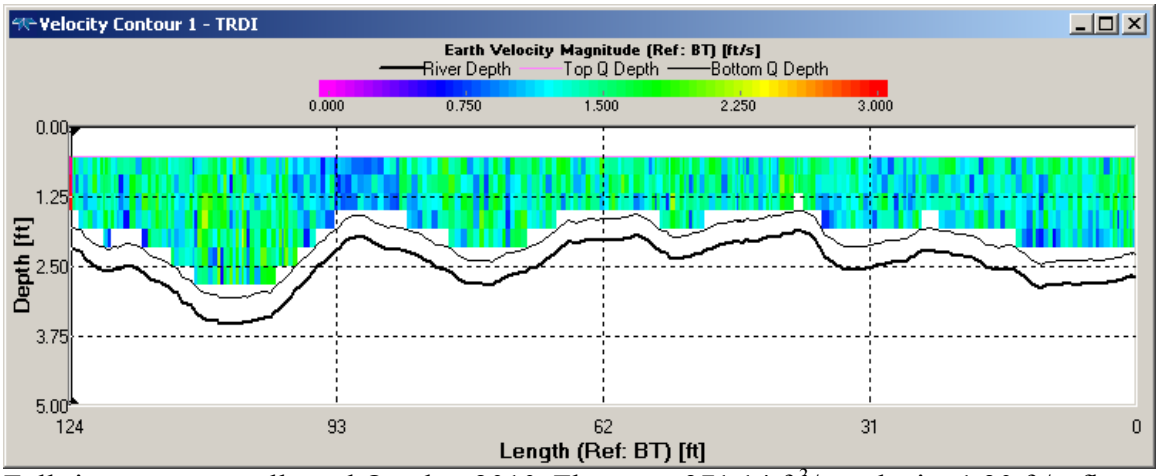


Full river transect collected October 2010. Flow rate 370.74 ft^3/s, velocity 1.22 ft/s, flow area 318.45 ft^2.

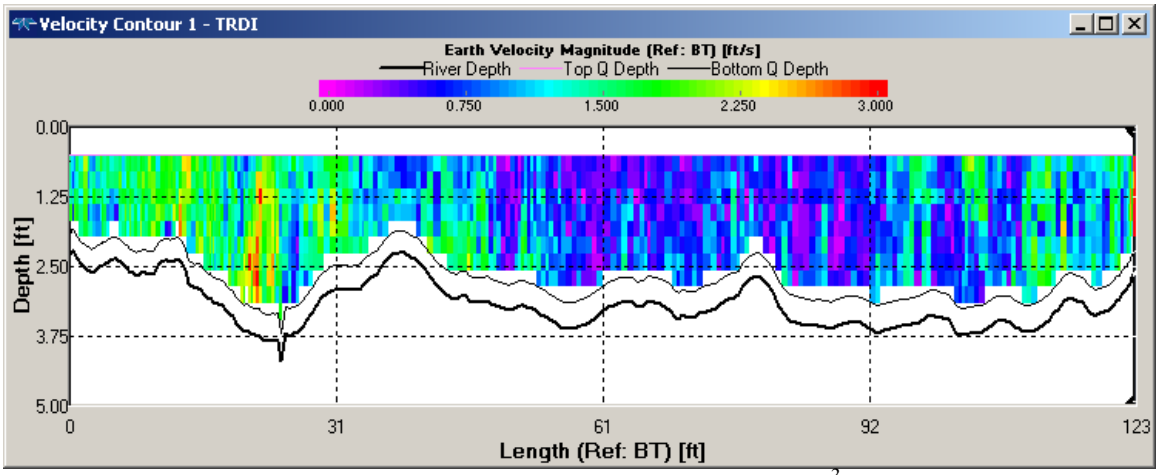


Full river transect collected November 2010. Flow rate 348.58 ft^3/s, velocity 0.76 ft/s, flow area 427.82 ft^2.

Figure 22.—River transect collected with an Acoustic Doppler Current Profiler at 1.5 m (5 ft) downstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)



Full river transect collected October 2010. Flow rate 371.14 ft^3/s, velocity 1.30 ft/s, flow area 303.93 ft^2.



Full river transect collected November 2010. Flow rate 347.01 ft^3/s, velocity 0.95 ft/s, flow area 363.24 ft^2.

Figure 23.—River transect collected with an Acoustic Doppler Current Profiler at 3.0 m (10 ft) downstream of the Hills Ferry Barrier for October (top) and November (bottom). West riverbank on left and east riverbank on right. (0.3 m = 1 ft.)

Telemetry

Adult Chinook salmon behavior was monitored using ultrasonic telemetry, primarily on the downstream side of the HFB to assist in determining the effectiveness of the barrier at inhibiting passage and movement patterns in the proximity of the HFB and San Joaquin-Merced River Confluence. The fish trap at HFB proved to be relatively ineffective at catching Chinook salmon but did capture carp and catfish daily. Only two salmon were captured in the trap during the study duration and were immediately released by DFG

without tagging due to fish condition and logistical restrictions. These fish were caught on October 13 and November 12, 2010, no data were made available.
Salmon sightings at the barrier increased through the month of November, peaking mid-month. On November 17 and 18, 2010 two male Chinook (69.0 and 68.5 cm fork length, respectively) were netted along the upstream side of the barrier that apparently passed during cleaning, through scour holes, or barrier gaps along the shore. These two fish were attempting to find passage back downstream when they were captured and tagged with ultrasonic transmitters, and released downstream of the barrier were they were tracked with five pre-positioned receivers and a hand-held mobile receiver. They were detected only on receivers below the barrier and confluence, and did not re-ascend the San Joaquin or Merced Rivers (Figures 24 and 25).

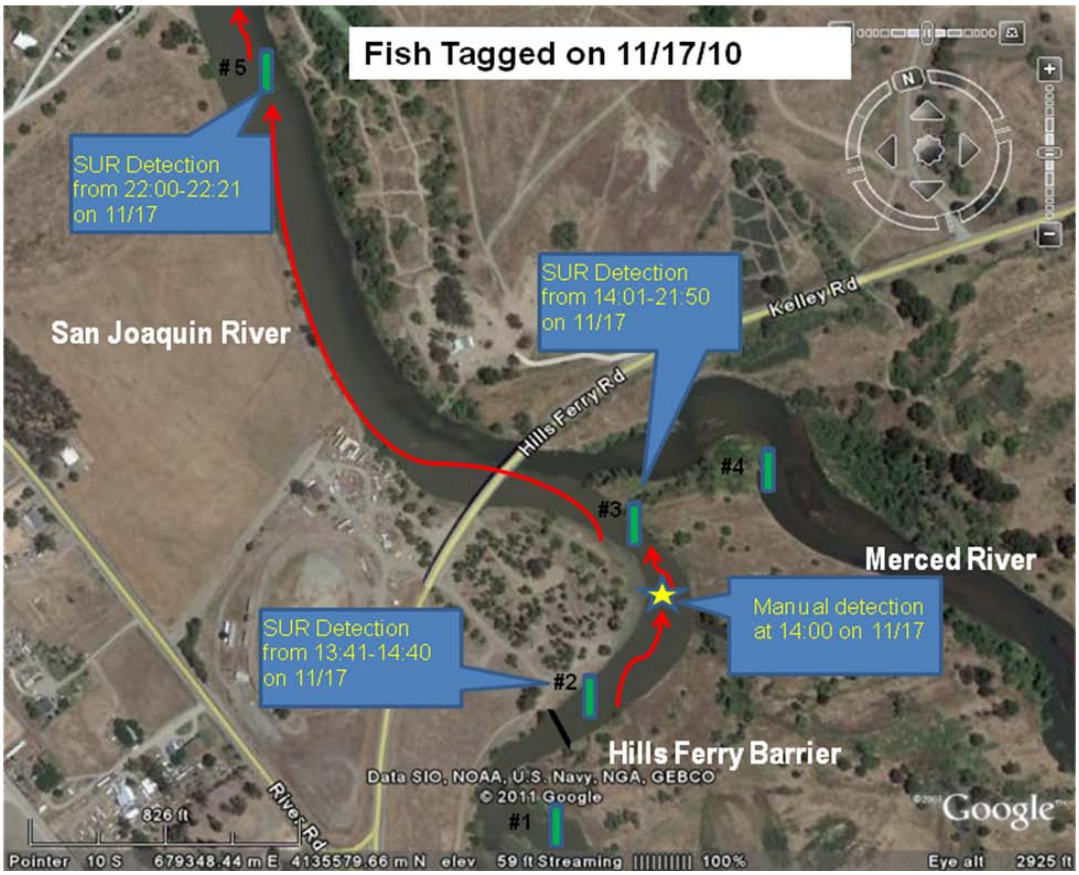


Figure 24.—Chinook salmon movement of fish tagged on 11/17/10 at Hills Ferry Barrier. This fish did not re-ascend the San Joaquin River and eventually moved downstream out of detection by the submersible ultrasonic receivers.

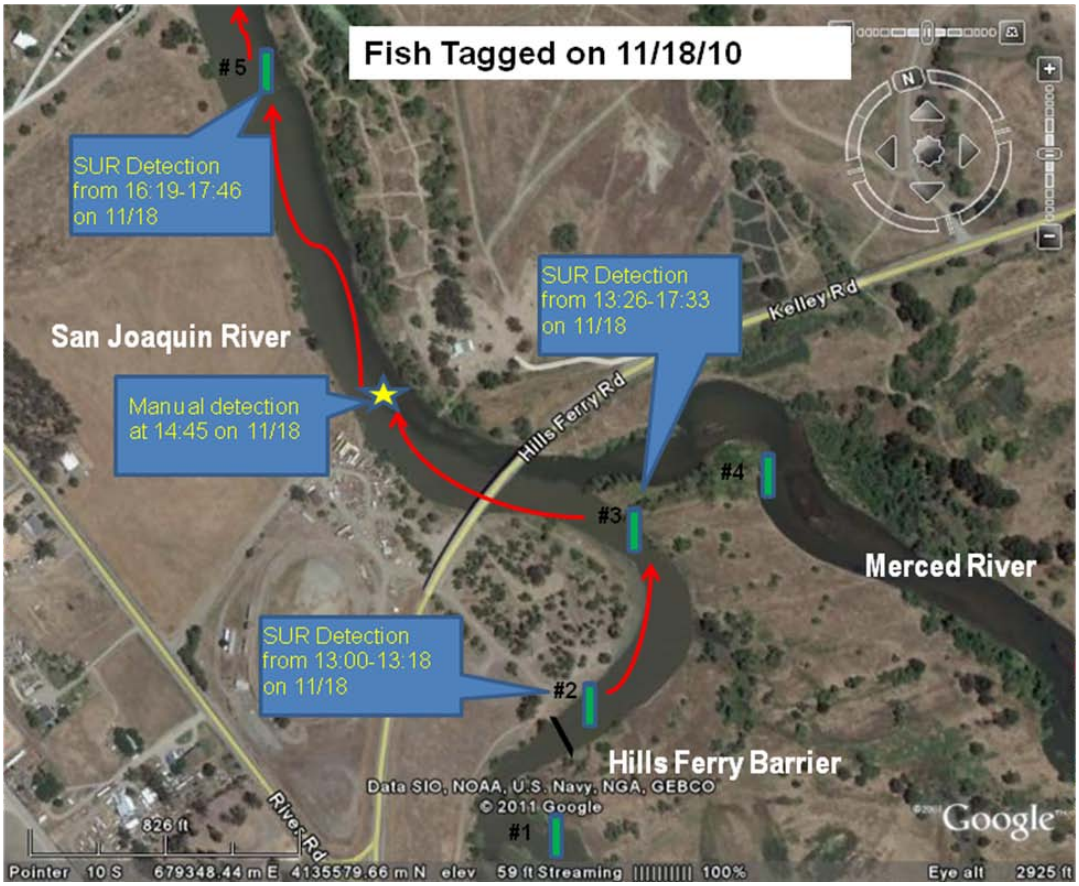


Figure 25.—Chinook salmon movement of fish tagged on 11/18/10 at Hills Ferry Barrier. This fish did not re-ascend the San Joaquin River and eventually moved downstream out of detection by the submersible ultrasonic receivers.

DISCUSSION

The SJRRP in its commitment to restore and maintain fish populations in the Restoration Area in accordance with the *NRDC, et al., v. Kirk Rodgers, et al. 2006* Settlement and Public Law 111-11 Section 10004 (h)(4) has evaluated the effectiveness of the Hills Ferry Barrier in preventing the unintended upstream migration of anadromous fish in the San Joaquin River. HFB integrity was compromised under flooding and high flows which resulted in excessive bank erosion and river bed scouring. Observations from the DIDSON camera, ADCP, and visual accounts identified problems and limitations with the structure in fall 2010. Twenty-two fish passed the barrier location and migrated upstream to the Mendota and Sack dams, canals, and sloughs. HFB improvements are currently being considered for the fall 2011 season in order to improve opportunities for data collection, manage fish movement, better evaluate barrier effectiveness, and increase the rigidity and "fish tightness" of the structure. Operational changes may reduce the threat of Merced River fishery straying to unsuitable habitat on the San Joaquin River. The monitoring of fish species encountering the barrier and analyzing fish behavior under

different hydraulic conditions at this location may provide information and create indices to help ensure the success of the restoration goal.

The river substrate poses a challenge to the integrity of the barrier. Loose benthic material and river hydraulics around weir support structures, barrier footings, base of conduit bars, and barrier panels cause substrate erosion resulting in scouring holes along the barrier and shoreline destabilization. Scour holes and eroding banks are fortified with sandbags and conduit picket extensions are driven further into the substrate on a daily basis to maintain a relatively "fish tight" barrier. Adult Chinook salmon have been observed in the past to take advantage of scour holes and elude the barrier. DFG personnel, when alerted to failures in the barrier, promptly respond to the issues by sandbagging, replacing conduit pickets, and making other minor changes.

It is not clear why the river flow was skewed to the left side of the channel in November, we recommend further investigation before installing barrier at this location as this difference may cause increased erosion on this bank. Flow rates were slightly lower through mid-November and the water surface elevation approximately 0.61 m (2 ft) higher, which was most likely caused by the Merced River backing up into the San Joaquin River at the confluence. In November, scour was greater mid-channel, downstream of the barrier, particularly at the 0.61 m (2 ft) and 1.5 m (5 ft) transects (Figures 21 and 22). This erosion was exacerbated by eddy currents and hydraulic disturbances assumed to be caused by the fish trap. Velocities were reduced downstream of the barrier as cross sectional flow area increased. As a result, deposition of eroded material caused a rise in river bed beyond 3 m (10 ft) below the barrier. Additionally, we found that tying the jon boat to the barrier on the far left river bank caused downwelling eddies that scoured a large area of the substrate directly adjacent to the weir. Our water velocity and bathymetry information can be used to recommend improvements with barrier design, operation, and location. Scour holes and gaps in the barrier can be predicted using erosion depth and sediment transition behavior. Due to variable river flows and unstable river substrate at this site and the temporary nature of the barrier, erosion of the substrate will be a continuous problem unless redesigned.

Anecdotal information suggests that large fish pass through the barrier when excessive water hyacinth loads and vegetative debris become lodged against the sliding pipes and require a section of the barrier to be removed for a short period to allow the plant matter to travel downstream. The force created by the vegetative fouling on the pickets by water hyacinth and debris can cause weir failure if cleaning does not occur. Discussions to improve debris removal procedures are occurring to develop a strategy to maintain a "fish-tight" barrier design for fall 2011.

Monitoring Chinook salmon movements near the HFB and San Joaquin-Merced River confluence using ultrasonic telemetry was not successful due to only capturing two fish in good condition to tag and release. These two fish swam back down river never to return. The 2011 monitoring will to increase the number of receivers downstream, increasing the detection area for future efforts. Also, at least ten adult Chinook salmon per month is recommended for future tagging and tracking to successfully monitor

migration and behavior at this site. This may be difficult to achieve due to the small quantity of fish that were caught in the past, however better traps and capturing techniques may increase capture success. Fall 2011 data will provide information regarding the "fish-tight" capability of the barrier, microhabitat utilization downstream of the barrier and at the confluence, and help improve knowledge on salmon migratory decision making when encountering the barrier inhibiting movement upstream in the San Joaquin River.

Numbers of salmon reported above the barrier were greater in 2010 than in recent years (Gates 2011), most likely the result of the barrier breach under high flows. Nevertheless, past data dwarfs these numbers and indicates that much great quantities of salmon once maneuvered past the HFB upstream on the San Joaquin River. Current understanding is that the HFB is operational at flows up to approximately 28.3 m^3/s (1,000 ft^3/s), however further investigation is needed to evaluate the effectiveness of the HFB during higher flows to understand the current limitations. San Luis Canal Company (SLCC) employees, Department of Water Resources (DWR) staff, and fishermen alerted Reclamation and Department of Fish and Game (DFG) biologists to four fish below Sack Dam where one female was later tagged by Reclamation biologists with an ultrasonic transmitter and released upstream of the dam. This fish was later tracked to a pool directly below the base of Mendota Dam (Eric Guzman, DFG, personal communication). SLCC staff reconfigured the stop logs in the Sack Dam fish ladder to allow passage of other salmon that evaded the HFB. Reclamation and DFG biologists later observed several salmon (12 or more) below the base of Mendota Dam and DFG sonically tagged a few females and released them into Mendota Pool. Two males were also captured at a later date and transported to the base of Friant Dam and released (Matt Bigelow, DFG, personal communication). The HFB did not restrict all passage to fall-run Chinook salmon during the fall 2010. Twenty-two fish were observed at Sack and Mendota dams, irrigation canals, and sloughs upstream of HFB during the later part of the barrier implementation season (Gates 2011).

CONCLUSIONS AND RECOMMENDATIONS

The long-term use of the HFB is unknown; however, it will be used to block anadromous fish species from moving upstream until the Restoration Area is considered ready for salmon reintroduction. After salmon reintroduction, it may be necessary to continue to utilize the HFB for fall-run Chinook salmon and steelhead actions. The HFB may potentially be operated as a control structure to minimize interactions between spring-run and fall-run Chinook salmon once populations are established. The barrier may function to minimize hybridization between spring-run and fall-run Chinook salmon. Hybridization can reduce fitness parameters (*i.e.,* growth, survival, and reproduction). Excessive hybridization can result in outbreeding depression, degraded performance (*e.g.,* swimming performance, sexual maturity, and size), disrupt homing mechanisms, and lead to reduced survival and increased straying in fishes (Fish Management Plan 2010). HFB may also be used to reduce risk of redd superimposition among Chinook salmon runs.

Regardless of the future of the barrier, near-term structural and non-structural modifications are necessary. The location needs to be moved downstream towards the confluence where there is a reduced risk of overtopping and bank erosion because the river channel is wider and shallower. Barrier improvements may be necessary due to the Settlement's requirement of water releases (*i.e.*, Interim Flows and Restoration Flows) below Friant Dam, because these releases may potentially affect barrier performance if flows are greater than 28.3 m^3/s (1,000 ft^3/s). It is believed that the current barrier design cannot withstand high flows greater than this and substantial erosion will occur (Gates 2011). Long-term efforts may require a permanent concrete sill installed to stabilize erosion and provide a solid barrier foundation with suitable anchoring points.

Methods for successful removal of floating hyacinth mats may need to be incorporated in the barrier's future design. Water hyacinth buildup on the barrier compromises structure integrity and risk failure from the force of water held back once clogged with debris. Barrier effectiveness is also reduced when conduit picket panels are removed to float excessive quantities of hyacinth through the structure for cleaning. Conduit panels should never be removed for cleaning because it allows for gaping holes in the barrier for extended periods of time allowing passage opportunity. Cleaning the barrier twice daily is recommended to reduce the accumulation of vegetative debris collected on the upstream side of the structure.

Other passage locations upstream of HFB need to be considered and investigated. Open flow and exchange of water from the Merced River to the San Joaquin River through a small slough upstream of HFB that connects the rivers during high flows should be evaluated and a barrier installed if determined to allow potential migration. Fish that were found upstream of HFB in the fall of 2010 before the HFB failure in November may have passed using this opportunity.

Lastly, due to poor capture success of the barrier-incorporated trap design and increased erosion associated with the upstream placement of the trap, a new design is being proposed for the fall 2011 survey. A modified fyke net with wingwalls to guide fish to the trap opening, independent of the weir, will be used to collect salmon downstream of the barrier for use in telemetry experiments.

ACKNOWLEDGMENTS

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31.0 Fall-Run Captive Rearing Update

31.1 Introduction/Background

The FMP of the SJRRP (FMWG, 2010a) sets population goals for Chinook salmon (*Oncorhynchus tshawytscha*) to achieve the Restoration Goal of restoring self-sustaining populations of wild spring- and fall-run Chinook salmon to the San Joaquin River. The Fisheries Implementation Plan (FIP) (FMWG, 2010b) prioritized studies to address information needs for fish restoration. The FIP identified the Captive Rearing Study as a high priority prior to the reintroduction of salmon, which is required by the Settlement by December 31, 2012 (NRDC vs. Rodgers, 2006). The study is also identified in the SJRRP's Hatchery and Genetic Management Plan (FMWG 2010c), which was submitted to National Oceanic and Atmospheric Administration (NOAA) Fisheries as an Appendix to the 10(a)1(A) Enhancement of Species permit application (USFWS 2011).

The SJRRP analysis of how best to accomplish the fish Reintroduction Goals is described in the SJRRP's Stock Selection Strategy, Reintroduction Strategy, and Hatchery and Genetics Management Plan. Through this process, it was recognized that the federal and state protection of the remaining spring-run Chinook in California will significantly limit their availability to the SJRRP. Successful restoration will require a sufficient number and continuous supply of donor fish for restoration. In order to achieve this without negative impact to the donor populations, it was determined that a captive rearing program will be used as a major component of restoration in combination with other non-hatchery reintroduction strategies.

Captive rearing has been successfully used to increase depleted numbers of salmon nationwide, including wild sockeye salmon in the Redfish Lake Recovery Program (Hebdon et al., 2004), the USFWS Winter-run Chinook Salmon Program at Livingston Stone National Fish Hatchery (Shasta Lake, CA), and it is currently in use by CDFG's Russian River Coho Recovery Program at Warm Springs Hatchery (Geyserville, CA).

Due to the technical challenges experienced by these programs and the time required to establish new hatchery facilities, a pilot-scale interim facility was proposed for practice rearing of non-listed salmon to refine rearing techniques and protocols prior to handling Endangered Species Act (ESA) listed fish. The facility would also provide a staging location for other studies and be used for rearing spring-run Chinook while full-scale hatchery facilities are under construction.

Therefore, a pilot-scale Interim Conservation Facility was developed in the fall/winter of 2010/2011 adjacent to the San Joaquin Fish Hatchery (Friant, California) and a small group of fall-run Chinook from Merced River Hatchery were introduced to begin captive rearing investigations.

31.2 Methods

31.2.1 Spawning

During the 2010 Central Valley fall-run Chinook spawning season, 55 paired matings were performed at CDFG's Merced River Hatchery (MRH). Matings occurred on the 1st, 11th, 18th and 22nd of November. According to the standard practices at the hatchery, individual females were crossed with between 1 - 4 males depending on the size and fecundity of the female, resulting in several half-sibling crosses. Females were mated with males of an equal or greater size. Tissue samples from each adult were collected and sent to the CDFG's Anadromous Resources Tissue Archive in Rancho Cordova, California. A sample of between 50 and 200 newly fertilized eggs was segregated from each cross, placed in a cheesecloth pouch and suspended in a 5-gallon bucket with flowing hatchery water. Eggs were disinfected with iodophore for approximately 15 minutes and were allowed to water harden for 1 hour. Eggs were then counted and transferred to vertically stacked incubator trays that were fitted with 4 - 8 partitions to accommodate the small number of eggs. Each stack of trays was supplied with approximately 5 gallons per minute of water flow and covered with opaque plastic panels to minimize light exposure. After approximately 30 days when eggs developed a strong eye, eggs were addled to remove dead eggs, and 10 eggs were collected from each cross and combined.

31.2.2 Hatching and Quarantine

On December 10th and 27th, a total of 550 eggs were transferred to the CDFG Silverado Fisheries Base (Yountville, California) for hatching and quarantine. Eggs were disinfected on arrival with iodophore and placed in vertically stacked incubator trays for hatching. Once hatched and yolk sacks were nearly completely absorbed, fry were transferred to aluminum rearing troughs. Approximately 30 days prior to transportation, 60 juveniles were sacrificed for fish health assessment by CDFG's Fish Health Laboratory in Rancho Cordova. No major pathogens were identified.

31.2.3 Transportation of Juveniles

On March 11, 2011, fish were transferred to the Interim Facility using a 500-gallon double-walled insulated aluminum tank (Aquaneering INC, San Diego, California) equipped with two mechanical aerators (Fresh-flo Corporation, Sheboygan, Wisconsin) and pure oxygen gas supplied from pressurized cylinders through two ceramic micro-bubble diffusers (Point Four Systems, Coquitlam, British Columbia). Oxygen levels were maintained at or above saturation during transport. At the Interim Facility, fish were divided into two 3-foot-diameter by 30-inch-deep fiberglass circular tanks. Dissolved oxygen (DO), temperature, and feed quantity were measured daily.

31.2.4 Growth Rate Monitoring

Fish weights and lengths were measured monthly or bimonthly. Individual fish weights and fork length were measured on May 25, June 30, July 28, and August 24, and group weights were measured on December 7, 2011. For most group weights, the entire lot of wish was weighed. For the July 28 weighing, only 50 fish were sampled. For individual fish weighings, fish were anaesthetized with 50 - 75 mg/L tricaine methanesulfonate

(MS-222). Temperature in the anaesthetization tank was maintained to within 2º F of the source water using a flow-through water bath, and gaseous DO was maintained by using compressed oxygen gas cylinders through air stones.

At the Interim Facility, fish were initially fed a standard salmon feed (BioOregon®, Longview, Washington) with the quantity fed based on the accompanying feed table that recommends feeding a percentage of the total fish weight and is adjusted according to fish size and water temperature. In addition, feed level was modified in attempt to maintain the condition factor between 1.2 and 1.3. Once precocity was identified in October 2011, the sexes were separated and a strict feed regime was instituted in effort to modulate growth rates using GROW, a Microsoft Excel based program developed for the Oregon Department of Fish and Wildlife. The program uses Average Growth Rate (AGR) for Chinook salmon, temperature, average body weight, and feed conversion to estimate the feed amount. Females were offered a full ration [100% or more for Chinook salmon AGR] and all males were offered a half ration (i.e. 50% of AGR). Before instituting the feeding program, average weight for immature males (124 g) was slightly higher than females (120 g). By December, the reverse was achieved and, on average, females (175 g) outweighed immature males (159 g; Figure 2).

31.2.5 PIT Tagging

On May 25th, fish were anaesthetized with 50 mg/L of MS-222, then weighed, measured and tagged by intraperitoneal injection (IP) using 12 mm preloaded Passive Integrated Transponder (PIT) tags (Biomark, Boise, Idaho). After tagging, fish were transferred to a single 6-foot diameter by 4-foot diameter circular fiberglass tank.

31.2.6 Tissue Sampling

On August 24, 2011, broodstock were anaesthetized with 50 mg/L MS-222, tissue sampled, weighed and measured. Each fish's PIT tag was scanned and recorded. Using clean scissors a small piece of fin tissue (approximately 2 mm by 2 mm) was removed from each caudal fin and transferred to individual 2 mL cryopreservation vials filled with 95 percent ethanol. Each vial was labeled with PIT tag number, date, brood year, and river origin. Between clippings, scissors were wiped, rinsed in 10 percent bleach solution (one part bleach: nine parts distilled water), rinsed in distilled water and 95 percent ethanol. Vials were stored at room temperature and later transferred to the DFG Tissue Archive (Sacramento, California).

31.2.7 Sex Identification

Sex identificationwas completed by the Genomic Variation Laboratory, Department of Animal Science, University of California-Davis (UCD) using the process described by Brunelli et al. (2008). This technique identifies sex according to the presence of one (female) or two (male) bands from amplification of the OtY3 genetic marker. Note that Williamson and May (2007) found that some Central Valley Chinook females possess Y chromosome OtY1 associated markers, but develop into normal functioning females. Meek et al. (unpublished data) found this also to be true with OtY3. Therefore, it is anticipated that some portion of XY phenotypic females will be misidentified as males.

On October 21, 2011, the gender data were used to segregate fish according to sex. At that time, 28 male fish were identified as precocious and placed in a separate tank. Precocious fish were initially identified by a larger body size, darker skin color, and deeper bodies. Gonadal development was then confirmed by sonography (SonoSite MicroMaxx 3.4.1 high-resolution digital ultrasound, Wallingford, Connecticut). On December 16, 2011, eight more males were determined to be precocious, totaling 35 fish or 15 percent of the genotypic males.

31.2.8 Cryopreservation

On October 21, during the gender sort, 28 precocious males were identified and segregated in a separate tank. On November 18, each precocious male was anesthetized, weighed, and measured. Milt was expressed from each fish into a pre-labeled 2-by-4-inch Ziploc bag and placed on ice in a small cooler. A sheet of paper was placed between the milt bag and the ice to prevent freezing.

Sperm motility was then tested for each sample. A 10 micrograms per liter (µL) pipettor was used to place a small amount of semen on a 1-by-3-inch plain glass microscope slide. The slide was then positioned in prefocused microscope were recorded in a Microsoft Access database. Every 3 months, liquid nitrogen will be added to the container to account for evaporation at 400 power and a small amount of sperm activating solution (500 mL distilled water, 4.5 g sodium chloride, 0.605 gram tris(hydroxymethyl)aminomethane (TRIS) and 0.75 gram glycine) (Negus 2008) was added to the sperm and covered with a glass cover slip. Motility was then immediately observed and the percent motility was estimated and recorded. Care was taken to not confuse movement attributed to fluid dynamics with sperm motility.

Next, semen from each sample was removed from cold storage and cryopreserved. Several methods for filling cryopreservation straws were practiced before settling on the following technique. One part semen was pipetted from a storage bag into individual test tubes and mixed with 3 parts freezing solution (10.8 grams glucose, 20 mL dimethyl sulfoxide (DMSO), 26.6 mL chicken egg yolk, top with distilled water to make 200 mL solution) to produce a maximum of 12 mL per test tube. Test tubes were held in a test tube rack that was placed in a flow-through water-cooled bath. A pipette bulb was then placed on a 5 mL cryopreservation straw and up to 5 mL of the semen solution was pipetted into the straw. Each straw was capped with a colored plastic ball on each end, wiped clean, and labeled with a fish identification (ID) number, preservation date, and preservation location. Straws were then placed on a 1-pound block of dry ice and allowed to freeze. Once frozen, whole straws were placed in holding canes suspended in a 34 L liquid nitrogen storage container for long-term storage. Data for each straw including milliliters of semen solution, ball color, sample ID, PIT tag number, preservation date, cane ID number, and initial motility were recorded in a Microsoft Access database. Every 3 months, liquid nitrogen will be added to the container to account for evaporation.

31.3 Results

Tables A-31-1 through A-31-3 and Figures A-31-1 through A-31-3 present results from the study.

Table A-31-1.
Percent Survival of Merced River Hatchery Hatchery Experimental Broodstock from November 2010 to December 2011

Survival	Survival Rate (percent)
Green egg to eyed egg survival	94%
Survival from eyed egg stage to May 25th (1^{st} inventory at Interim Facility)	90.2%*
Transportation Mortality (Yountville to Friant, 3 total)	0.67%
Mortality during PIT Tagging (2 total)	0.45%
Survival through 12/7 from green egg stage	88.6%*

Notes:
*Excludes fish sacrificed for pathology

Table A-31-2.
Biologic Data Inventory

Inventory	County
MRH eggs take (December 2010)	550
Fish taken for pathology	60
Initial inventory – Interim Facility 3/11/11	444
Current inventory – December 7, 2011	434
Total Males	240
Immature Males	206
Precocious Males	34
Females	194

Table A-31-3.
Growth Data

Growth	Weight (grams)
Initial Average Weight – Interim Facility 3/11/11	1.4 grams
Current Average Weight – December 7, 2011	168 grams

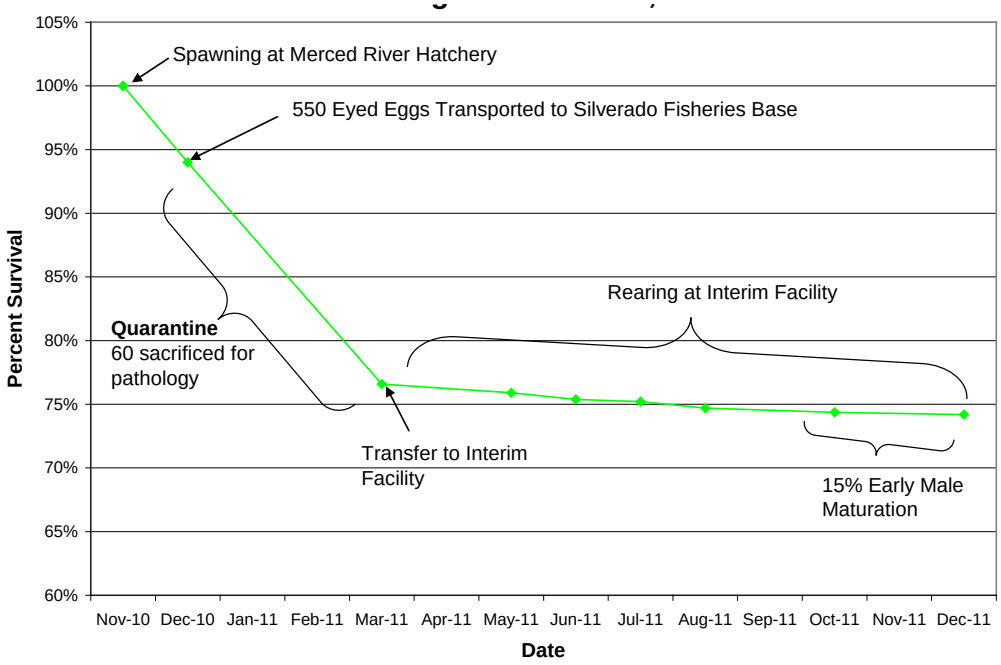

Figure A-31-1.
Captive Rearing Study Overview from Spawn Through December 7, 2011

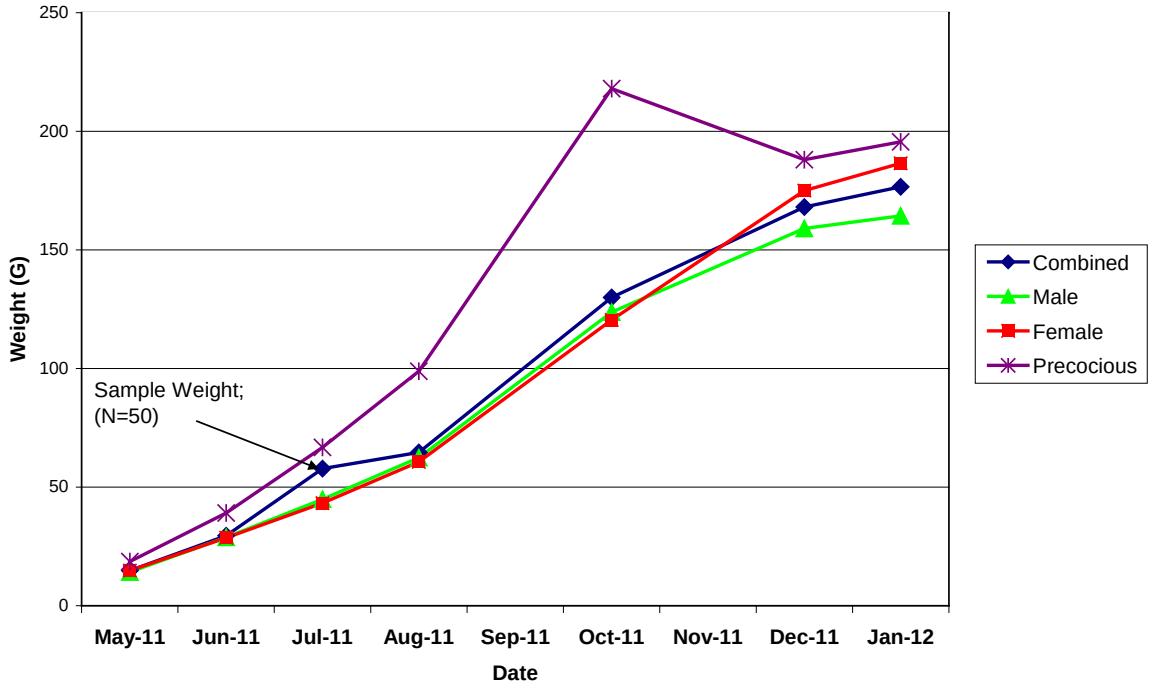

Figure A-31-2.
Average Fish Weight by Gender and Precocity of Experimental Broodstock Reared at the Interim Facility (Friant, California)

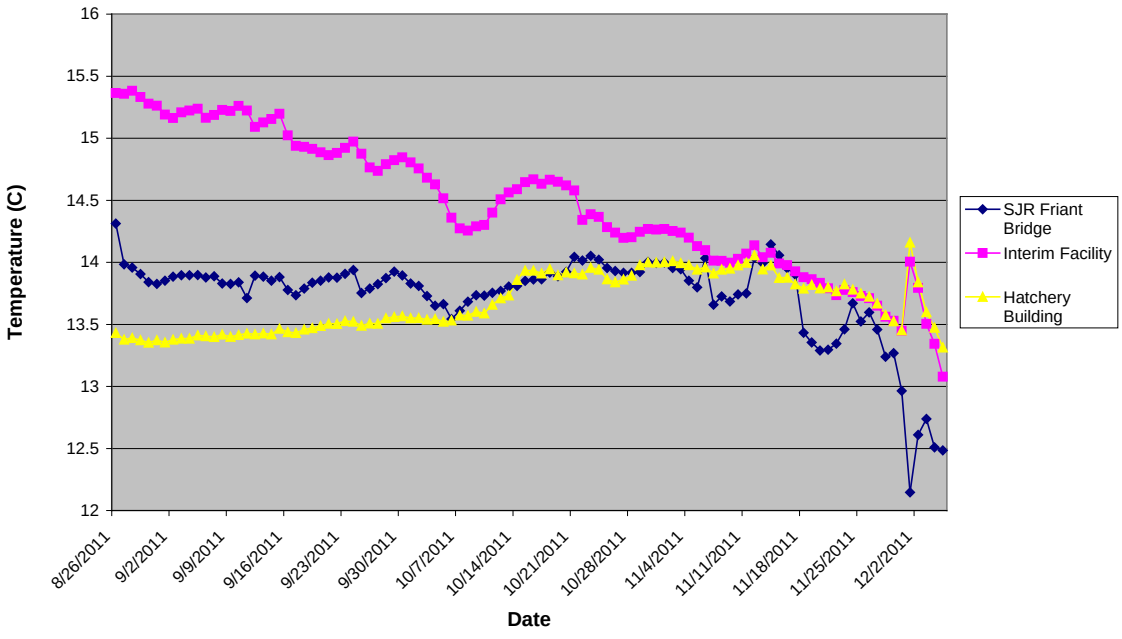

Figure A-31-3.
Average Daily Temperatures at San Joaquin Hatchery Complex, August 26 Through December 5, 2011

31.4 Discussion

The Captive Rearing Study has proven to be a valuable resource for testing new equipment, refining conservation practices, investigating existing conditions, and developing data management forms and software. Conservation hatcheries are a relatively new invention and it is reported that no conservation hatcheries existed prior to 1999 (Flagg and Nash, 1999). This first phase of investigation has focused largely on facility development and is ongoing. Due to of current water-use limitations at the facility, water recirculation technology will be increasingly used until permitting and contracting is completed for acquiring additional water.

To date, fish survival from the time of egg fertilization has been relatively high at 74.2 percent. Much of the loss occurred during the green to eyed egg stage (6 percent) or due to the intentional sacrifice of 60 fish for fish health assessment (11 percent). Survival of fish during rearing at the Interim Facility has been very high at 96.8 percent and nearly all mortality following transfer to the Interim Facility was associated with handling and procedural problems (i.e., fish jumping out of tanks), with little indication of disease. High survival rates are likely the result of low densities, high DO concentrations, and moderate temperatures (Figure A-31-3), and are indicative of good conditions for rearing trout and salmon on upper San Joaquin River water.

Growth rate modulation will be essential for controlling sexual development. High hatchery growth rates are known to trigger male sexual maturation (precocity) during the first year or two of development. Conversely, efforts to slow growth rates can negatively impact female egg quality and fecundity. Therefore, by separating sexes, a tailored feed ration can be provided that should be capable of reducing precocity and maintain egg quality. maintaining egg quality. Before instituting the tailored feeding program in October, average weight for immature males (124 grams) was slightly higher than females (120 grams). By December, the reverse was achieved and on average females (175 grams) out weighed immature males (159 grams).

31.5 Conclusions and Recommendations

The Captive Rearing Study is proving to be valuable for testing new equipment, refining rearing techniques, and identifying existing conditions for captive rearing. The following are recommendations for the following year:

- Implement water recirculation technology to maximize available water until contracting and permitting is completed for additional water.
- Identify target growth rates to minimize male precocity and maximize egg quality and fecundity.
- Investigate conservation rearing practices aimed at minimizing hatchery induced selection.

- Closely monitor summer water temperatures and identify any negative effects associated with high temperatures.

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32.0 Thermal Tolerance Report

32.1 Introduction

This study will test thermal tolerance of fall-run Chinook salmon in a controlled laboratory environment to evaluate gene expression under different thermal regimes. Experimentation using fall-run Chinook salmon will allow for investigation using non-ESA-listed species before working with listed (spring-run Chinook salmon) species. This study will be conducted by the University of California, Davis (UCD) Genomic Variation Laboratory.

Thermal tolerance is well studied in Chinook salmon and is a variable for fitness at various life stages. It is therefore a key factor to consider in a successful reintroduction program. This is particularly critical for the reintroduction of Chinook salmon to the San Joaquin system, the southernmost limit of the species' native range; great potential exists for climate change impacts to be felt early and severely in this portion of the range. Higher temperatures are known to directly affect salmonid growth and mortality, and to indirectly affect other variables such as behavior (e.g., habitat selection, swimming performance, relationship to prey-predator community structure) (Angilletta et al, 2008, Richter and Kolmes, 2005); all of which likely have some degree of genetic basis and heritability (Perry et al., 2001; Perry et al., 2005). Obtaining a gene expression profile of fall-run Chinook under variable thermal regimes will improve our understanding of the genetic basis of thermal tolerance in this run and other genetically similar runs, such as spring-run Chinook. Specifically, genes with significantly different expression patterns at extreme thermal regimes in fall-run Chinook will enable a candidate gene approach to be undertaken for spring-run Chinook, which will increase study efficiency and lower sample sizes for this listed species. Gene expression patterns will be useful in understanding the mechanisms of response to heat shock and in monitoring and predicting changes in wild populations facing thermal stress (e.g., juveniles in the rewatered upper San Joaquin). Juveniles have been selected as the experimental life stage as they are biologically sensitive and likely to be present in-stream during the warmest times of year (Coutant, 1973).

32.2 Methods

The thermal tolerance study consists of two similar experiments, (1) a thermal expression experiment, and (2) a loss of equilibrium thermal expression experiment.

- For both experiments:
    - All experimental activity conducted under an approved UCD Animal Care and Use protocol, and DFG Scientific Collection permit.

  - Collect a total of 500 fertilized eggs from 10 to 20 different single pair fall-run Chinook matings (so that multiple families are represented in each temperature treatment) performed at Merced River hatchery as crosses are made. Fin clips from parents will also be taken at that time. All fin clips will be sent to the DFG Tissue Archive.

  - Keep families separated until individually tagged.

  - All rearing and experimentation performed at Academic Surge, UCD.

  - Incubate eggs and rear juveniles at a common acclimation temperature (12°C) before initiation of experiments.

- Thermal expression experiment:

  - Conduct three replicates of five temperature exposures (12, 15, 18, 21, and 25°C) for the experimental timeframe (3 hours) performed on juvenile Chinook. Exposures are followed by a 1-hour recovery period at the acclimation temperature.

  - Collect tissue from individuals, immediately after being euthanized, from each temperature treatment at relevant time points for use in gene expression analysis via RNAseq.

  - Loss of equilibrium thermal expression experiment:
  - Expose fish to a raising thermal regime, 6°C per hour from 12°C to 23°C.

  - Increase thermal regime to 0.5°C per 30 minutes until the temperature reaches 26°C.

  - During the thermal regime exposure, observe fish behavior for loss of equilibrium.

  - Once fish have lost equilibrium, immediately collect tissue from these individuals for use in gene expression analysis via RNAseq.

32.3 Results

This study is ongoing. Results are currently not available.

32.4 Discussion

Merced River Hatchery (MRH) fall-run Chinook salmon, Brood Year 2010, were used for this study. MRH fish were preferred for this study as they are the Chinook population geographically closest to the reintroduction area. While studies suggest that California fall-run Chinook are genetically homogenous (Williamson and May, 2005), slight genetic

differences have been found between MRH fall-run and other Central Valley fall-run (Garza et al., 2008). Additionally, there may be local adaptation that has not been detected with the limited number of markers used to study California Central Valley Chinook to date (Bekessy et al., 2002).

The temperature spread, in the Thermal Expression Experiment, is meant to approximate very low, medium, and high temperature stress. One fish from each of the 11 families was included in each exposure group. Tissues collected include blood, gill, liver, muscle, and fin. The next steps are to isolate mRNA and proceed with RNAseq to obtain quantitative comparisons of genome-wide gene expression at these different temperature exposures.

The Loss of Equilibrium Expression Experiment is designed to identify gene expression differences between more and less heat-tolerant individuals from within a group of fish. A group of 110 fish composed of individuals from each of the 13 families was used. Loss of equilibrium was used as a physiologic time point at which to sample the fish. The first 15 fish and the last 15 fish to lose equilibrium were sampled. Ten fish not exposed to any thermal regimes, and kept at 12°C, were sampled as a control. Tissue samples included blood, gill, liver, brain, and muscle.

DFG and UCD scientist assisted MRH staff during the spawning period, to collect a small number of eggs from different crosses. Eggs from 13 different crosses were collected and kept separate in incubation trays at the MRH. Eyed eggs were transferred from the MRH to the UCD Center for Aquatic Biology and Aquaculture Facility (CABA). Hatching occurred around late December 2010, and families were reared in separate tanks at CABA from January through March 2011. In April 2011 families were tagged using visible implant elastomer tagging, and 11 families were pooled into three tanks for rearing in a common environment. Two out of the 13 families had insufficient numbers for the Thermal Expression Experiment; however, they were used in the Loss of Equilibrium Thermal Expression Experiment. In May 2011, the Thermal Expression Experiment. was conducted, and in June, the Loss of Equilibrium Thermal Expression Experiment was conducted.

32.5 Conclusions and Recommendations

Studies are ongoing. It is premature to make conclusions and recommendations at this time. However, a similar study may be repeated with spring-run fish, pending availability of fish and permitting, after 2012, using the candidate genes or the approach identified in the fall-run study.

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33.0 Benthic Macroinvertebrate Bioassessment

33.1 Introduction/Background

Benthic macroinvertebrate (BMI) communities, the subject of this report, are both bioindicators of stream condition and a food resource for fish. The main purpose of assessing the biological condition of aquatic communities is to determine how well a water body supports aquatic life. Biological communities comprise the effects of different pollutant stressors, such as increased temperature, toxic chemicals, excessive nutrients, and sediment loading. The BMI within these communities respond to different types of human disturbance, physical changes in riparian vegetation, and instream habitat heterogeneity. In addition, BMI are key food sources for the native and potentially reintroduced fish in the San Joaquin River.

We do not know whether or not the San Joaquin River Restoration Flows will significantly improve physical habitat conditions or elicit changes in the abundance and diversity of BMIs. As portions of the river are restored and vegetated, BMIs can respond as a result of changes in stream condition because of alterations to water chemistry and physical habitat. Therefore, by collecting BMI and physical habitat data in different areas of the San Joaquin River, we can help assess water chemistry and identify habitat features responsible for the restoration of ecological integrity (Harrington, 1999; Rehn and Ode, 2005). Restoration Flows in the San Joaquin River could impact ecological integrity as a result of changes in habitat suitability.

This report provides information about the ecological integrity of the San Joaquin River system within the Restoration Area. The report directly addresses habitat objectives set forth in the SJRRP FMP and has been identified by the FMWG as an ongoing need for the SJRRP (FMWG, 2010). The main objective of this study requires that the ecological integrity of the Restoration Area be restored as a result of improved streamflow, water quality conditions, and the biological condition of aquatic communities. Our original goal was to find that 50 percent of the total target river length was observed to be in good condition (benthic index of biotic integrity (B-IBI) = 61-80) or very good condition (B-IBI=81-100). In addition, none of the study sites should be in “very poor condition” (B-IBI=0-20). We hypothesized that the community composition of BMI will vary among individual survey sites and river Reaches 1 through 5 because of changes in physical habitat and water chemistry.

33.2 Methods

33.2.1 Reconnaissance Surveys Through Reaches 1 Through 5 of the Restoration Area

Sampling locations were selected from a random set of 150 sites distributed through Reaches 1 through 5 that were generated with software developed by the Environmental Monitoring and Assessment Program (EMAP) of the EPA. We surveyed 30 sampling reaches (sites) that met a set of criteria including access conditions and wadeable depths, consistent with California's Surface Water Ambient Monitoring Program (SWAMP) Bioassessment Procedures (Figure A-33-1). Each sampling reach had a length of 150 meters or 250 meters, depending on the wetted width of the channel at the center of the reach.

33.2.2 Physical Habitat at Sampling Reaches

DFG and DWR staff characterized the physical habitat at 30 sites throughout the Restoration Area (Figure A-33-2). At each site, the crew delineated 11 river transects and 10 inter-transects according to the Reachwide Benthos Procedure (Ode, 2007). This procedure includes the measurement of ancillary water quality parameters and a general assessment of habitat complexity, riparian vegetation, bank stability, and human influence. This multiyear study intends to capture temporal and spatial variation in physical habitat features during a minimum period of 3 years between May and September from 2010 through 2012. The period between the months of May and September has been identified as the index period for SWAMP bioassessment in the Central Valley. This report presents the baseline information for 2010 surveys. We have successfully completed additional physical habitat surveys during the 2011 study period.

33.2.3 Benthic Macroinvertebrate Collection and Analysis

DFG and DWR staff collected benthic macroinvertebrate samples at the designated sampling locations during the SWAMP index period of late May through the end of September in 2010 and 2011(Figure A-33-2). Subsamples collected at each transect in a particular site were combined in a composite sample for each location. We included 10 percent duplicate samples each season to serve as controls for the sampling technique. The samples were delivered to the DFG's Aquatic Bioassessment Laboratory (ABL) at Rancho Cordova, California. At the laboratory, ABL taxonomists performed quality control and quality assurance of the samples and logged in the sample information. Samples were identified according to the Standard Taxonomic Effort (STE) Level 2 of the Southwestern Association of Freshwater Invertebrate Taxonomists (SAFIT), using a fixed-count of organisms per sample. Level 2 entailed identification down to species for the more crucial indicator species and genus or higher taxonomic level for other species such as some nonarthropod invertebrates.

33.3 Results

33.3.1 Reconnaissance Surveys Through Reaches 1 Through 5 of the Restoration Area

We surveyed a total of 30 random sampling sites throughout the Restoration Area in 2010 and 2011 (Figure A-33-1). All of the sites were visited before each survey to ensure that they met sampling criteria set forth by SWAMP. Physical habitat characterization and BMI sample collection occurred simultaneously at a rate of one sampling reach per work-day. All of the San Joaquin river reaches, except Reach 4A, were surveyed in the 2010 study. Reach 4A samples and the rest of the Restoration Area were represented in 2011.

Agriculture was the dominant land use in the bioassessment study area, although wildlife area land use became dominant in Reaches B2 and 5 (Table A-33-1).

33.3.2 Physical Habitat at Sampling Reaches

Physical habitat features and ancillary *in situ* water quality measures have been recorded in association to BMI samples. Key physical habitat parameters describe different components of instream habitat complexity, river bed substrate, bank stability, riparian vegetation and human disturbance (Table A-33-2). We compared water chemistry parameters to the water quality criteria set forth by the FMWG (FMWG, 2010, Exhibit B) to determine if water quality at the sites reflected unsuitable conditions for BMI and Chinook salmon.

Water temperatures during the summer-fall index period in 2010 exceeded most of the recommended thresholds for spring-run Chinook salmon spawners, incubating eggs, emerging fry, and rearing juveniles in all of the surveyed sites, except for two sites in Reach 1A. These two sites in Reach 1A had the lowest temperatures at 12.15°C and 15.89°C.

Salinity objectives were exceeded at some of the sampling sites. The maximum specific conductivity (1298 microsiemens per centimeter (µS/cm)) recorded reflects exceedances of salinity objectives for both the irrigation (700 µS/cm from April to August) and the non-irrigation (1,000 µS/cm from September to March) seasons based on the State Water Resources Control Board (SWRCB) water quality standards. The two sites surveyed in Reach 4B1 had specific conductivity values of 1,197 µS/cm and 1,298 µS/cm. As we moved downstream, specific conductivity standards are exceeded again at the three lowermost sites in Reach 5 (1,172, 1,066 and 1,015 µS/cm). Similarly, salinity measurements were highest at these sites. For instance, we did not record salinity values above zero at any of the sites above Mendota Pool and Dam. However, all of the sites below Mendota Pool and Dam had non-zero salinity measurements (range 0.01 to 0.69 ppt).

Other water quality constituents did not exceed the recommended habitat objectives. The mean total dissolved solids concentration did not exceed the SJRRP objectives (0.243 mg/L) during the survey period. Also, DO measurements were above the water quality standards for the Restoration Area (greater than 6.0 mg/L). Moreover, recorded pH

values did not exceed the recommended criteria for freshwater and aquatic life protection (instantaneous maximum is 6.5 to 9 units).

Bed substrate and bank stability showed marked transitions throughout the study area. Cobble substrate was only present in Reaches 1A and 1B. Fine and coarse gravel substrate became sparse or absent below the San Mateo Crossing. Bedrock and boulder substrates were not represented in the 2010 evaluation, while sand and fines were predominant throughout the study area. Eroded sandy banks dominated (frequency greater than 50 percent) all of the study sites in Reach 2A and most sites in Reach 2B.

We recorded flow habitats at every sampling site. Flow habitats were quantified as fast water habitats (runs and riffles) or slow water habitats (pools and glides). Slow water habitats were predominant throughout Reaches 2A, 2B, 4B2, and 5.

33.3.3 Benthic Macroinvertebrate Collection and Analysis

We estimated the abundance of the indicator taxonomic levels of arthropod and nonarthropod invertebrates present in the sample (Tables A-33-3 through A-33-10). Abundance was determined by weighing the total number of organisms collected within each taxa by the number of samples collected within a particular reach of the Restoration Area. Our data shows that different BMI taxa showed restricted or unrestricted distribution throughout the study area. Their distinctive distribution patterns could be associated to their intrinsic tolerance for environmental degradation.

Coleopterans, commonly known as water beetles, were mostly confined to Reach 1A and 1B (Table A-33-3). They did not occur anywhere else downstream, except for one observation in Reach 3.

A large diversity of Dipterans, commonly known as true flies, occurred throughout the study area. A few taxa within the Chironomidae family dominated Reaches 2A, 2B, and 3 (Table A-33-4).

Ephemeropterans, commonly known as mayflies, include a few sensitive families (Table A-33-5). In general, Ephemeropterans play a considerable role in aquatic environments because of their diversity and abundance. Two of their families, Ephemerellidae and Leptohyphidae, were predominant in Reach 1A. The family Ephemerellidae was only present in Reach 1A. Also, *Tricorythodes* larvae from the family Leptohyphidae were the dominant Ephemeroptera in Reach 1A and its abundance decreased sharply in downstream samples. None of these sensitive larvae were recovered at Reaches 4B2 and 5.

Hemipterans, also known as the true bugs, are considered pollution tolerant and tend to prefer warm, slow water with abundant vegetation (Table A-33-6). Corixid larvae, from the order Hemiptera, were most abundant in Reach 5.

Lepidopterans, also known as aquatic moths, have at least one family (Pyralidae) that can have successful aquatic stages. We observed *Petrophila* larvae, belonging to the aquatic pyralid moths, only at Reach 1A (Table A-33-7).

Benthic larvae belonging to the order Odonata occurred throughout the study area (Table A-33-8). Odonatans, also known as dragonflies and damselflies, can be fairly tolerant to environmental degradation.

Different Trichopteran taxa, commonly known as caddisflies (Figure A-33-2), occurred throughout the study area (Table A-33-9). However, caddisflies were observed in higher numbers in Reaches 1A and 1B. Those groups with the lowest tolerance values (TV) occurred mostly or only in sites within Reaches 1A and 1B.

Most non-insects can tolerate water pollution and can live in mud or even low-oxygen waters (Table A-33-10). We observed that non-insect groups were widely represented throughout the study area, with few exceptions. In particular, Oligochaeta, also known as segmented aquatic worms, can be found in silty substrate and detritus. They were among the most abundant non-insect BMI detected in this study, and were found in greater numbers in Reach 4B2. We know that their abundance can indicate sedimentation.

Taxonomic observations were used to estimate a number of metrics associated to the relative abundance of different groups, their feeding mechanisms, habits and diversity. We simplified the taxonomic data into indices of biotic integrity (IBI) that measure biological condition at each site (Table A-33-11). High IBI scores reflect good ecological conditions while low IBI scores reflect poor ecological conditions. A previous study by Rehn et al. (2008) was the first to set expectations for Central Valley BMI assemblages and has been used here as a general interpretive framework for benthic samples collected within the Restoration Area. We have measured and scored five metrics for inclusion in IBI estimations for the sampling reaches: collector richness, predator richness, percent Ephemeroptera, Plecotera, Trichoptera (EPT) taxa, percent clinger taxa and the Shannon diversity measure. Our results show that most of the study sites are in poor condition (60 percent). The only two sites with good biological condition are within Reaches 1A and 1B (Figure A-33-3).

We explored the potential relationship between the calculated IBIs and four multimetric scores estimated from the physical habitat data (Figure A-33-4): the riparian human disturbance index (W1_HALL) (Kaufmann et al., 1999), the mean mid-channel canopy density, riparian vegetation complexity and in-stream habitat heterogeneity. The W1_HALL is a proximity-weighted sum of all types of human disturbance metrics scored at each sampling site (Figure A-33-2). Human disturbance indicators scored at each sampling site included the following: walls/riprap/dams, buildings, pavement/cleared lots, road/railroads, pipes, landfill/trash, park/lawns, row crops, pasture, range, logging operations, mining activity, vegetation management, bridges/abutments and orchards/vineyards. The mean mid-channel canopy density was calculated from the densitometer readings at the center of each transect at each sampling site. Riparian vegetation complexity averages the cover estimates for three vegetation layers (upper canopy, lower canopy, and ground cover) for the whole reach. Finally, in-stream habitat heterogeneity combines the scores for different habitat features within the channel including: filamentous algae, aquatic macrophytes, emergent vegetation, boulders, woody debris, undercut banks, overhanging vegetation, live tree roots, and artificial structures.

Preliminary analysis shows a significant association between the W1_HALL index and the B-IBI within the study area ($r=0.322$, $p<0.05$) (Figure A-33-4a).

33.4 Discussion

33.4.1 Interpretation

The BMI bioassessment study used our ability to rank sampling sites relative to a set of biological expectations and applied it to the San Joaquin River Restoration monitoring.

The biological condition goal was to find that at least 50 percent of the total target river length, as represented by the area covered in this study, was in good condition B-IBI = 61-80) or very good condition (B-IBI=81-100). In addition, we did not anticipate to find that any of the study sites showed a "very poor condition" (B-IBI=0-20). We also hypothesized that the community composition of BMI would vary among individual sites and Reaches 1 through 5 because of changes in physical habitat and water chemistry.

A preliminary analysis shows that we did not meet the original expectation of finding that about half of the surveyed area would be in a "good" or "very good" condition. However, we did not find study sites in a "very poor" biological condition either. Also, as expected, the community composition of BMI varied among individual sites and reaches, presumably because of changes in physical habitat and water chemistry. The abundance and distribution of the taxa indicate a possible response to relative environmental degradation within the reaches.

33.4.2 Applicability

Study results can be used to inform the SJRRP of potential biological and physical habitat degradation indicators within the Restoration Area. Besides answering questions about stream habitat condition and water quality, we are able to quantify food availability for reintroduced fish, as reflected by the relative abundance of BMI taxa throughout the Restoration Area.

The present study addresses two main needs that have been identified during previous efforts: increase in biomonitoring scope and identification of local food resources. Recent studies in the San Joaquin River Basin recommended additional biomonitoring at more sites over a longer period of time to fully understand the effects of water quality and habitat conditions in the composition of macroinvertebrate communities in the San Joaquin River watershed (e.g., Brown and May, 2004). Moreover, studies have shown that Chinook salmon tend to feed mainly on autochthonous organisms (e.g., Esteban and Marchetti, 2004), which highlights the need to identify local food sources in the Restoration Area, rather than extrapolating results from other locations. We know that salmonid diets are correlated with both benthic and drift invertebrate abundance (Esteban and Marchetti, 2004). By combining the results of the bioassessment study with other lines of evidence (e.g., drift surveys and stomach samples of rearing fall-run Chinook salmon), the FMWG and other fisheries biologists will gain a better understanding of the prey base and abundance (food production) within the SJRRP Restoration Area.

Our findings about biological condition within different reaches in the Restoration Area can be applied to the Ecosystem Diagnosis and Treatment (EDT) framework that is currently under development for the SJRRP (FMWG 2010 and 2011). The EDT framework can incorporate existing information about environmental attributes such as food resource availability and stream condition within discrete segments of the San Joaquin River. As a result, results of the present study can help improve modeling of fish-habitat relationships with EDT.

33.4.3 Limitations

Future analyses of bioassessment results over a longer time period need to include a multivariate analysis to help identify both the most sensitive biological metrics and the most influential physical habitat and water chemistry stressors in the Restoration Area. Thus, we might be able to clarify the physical or chemical variables that have the greatest impacts on biological and ecological integrity, also reflected by changes in the multimetric IBI. Such analyses could also help clarify the underlying associations between the B-IBI and other multimetric ranking of physical habitat features.

33.5 Conclusions and Recommendations

Preliminary study results show the baseline conditions of BMI in the San Joaquin River Restoration Area. Ecological integrity of instream habitat in the Restoration Area was evaluated with a benthic macroinvertebrate assessment, using an approach described by the California's SWAMP. This report provided information about species richness and benthic community composition, response to perturbation and tolerance/intolerance to environmental conditions in the Restoration Area. In addition, the report provided baseline parameters with which to evaluate the impact of restoration actions.

The study was designed as a 3-year effort to ensure that we gather enough data to provide spatial-temporal baseline information for BMI communities and understand their variability in the entire Restoration Area. Future surveys can potentially show if ongoing restoration actions can improve the existing biological condition within the study area. Ongoing stream restoration actions in the Central Valley should consider the restoration of biological condition and food production as reflected by existing benthic macroinvertebrate communities.

33.6 References

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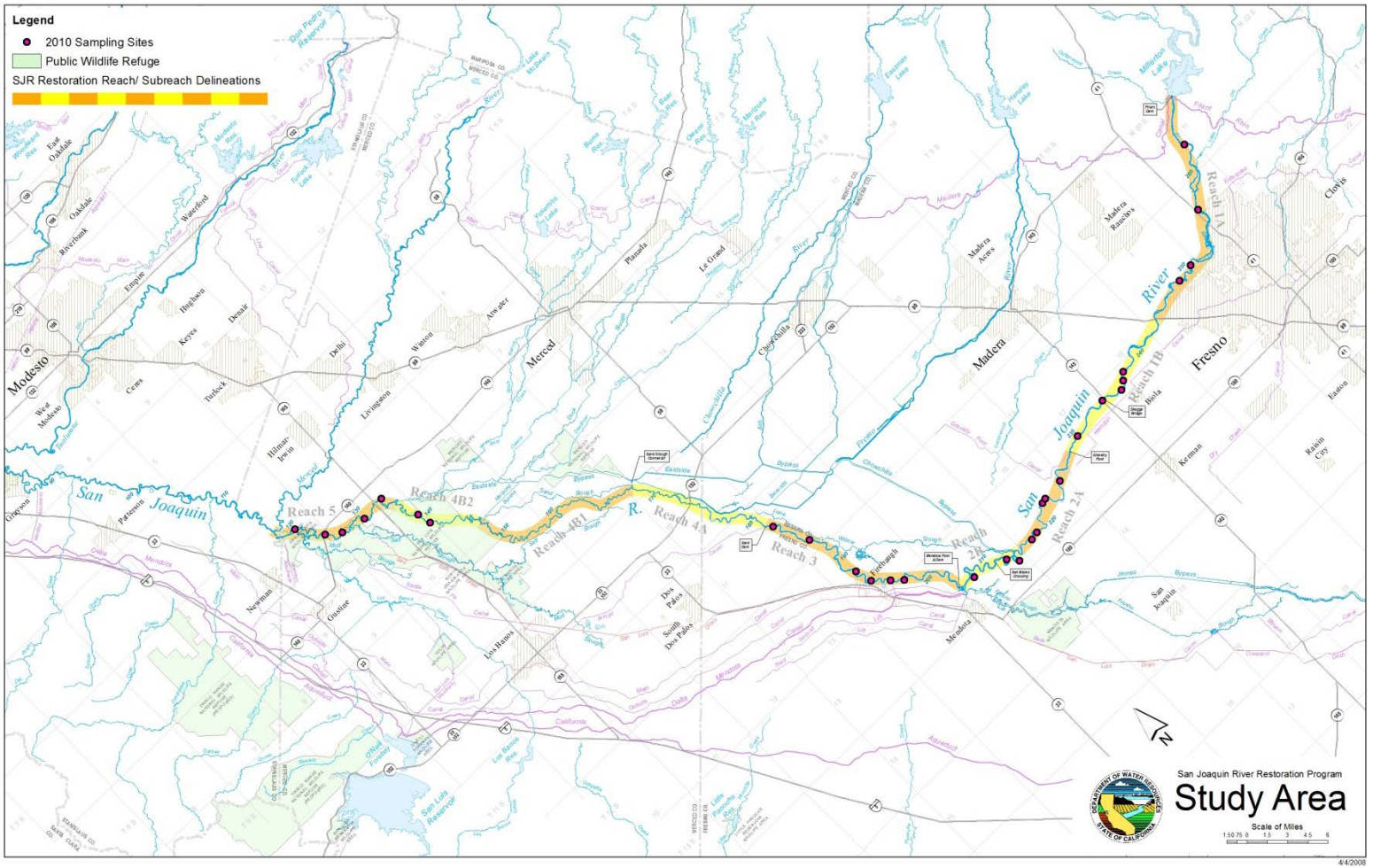

Figure A-33-1.
Benthic Macroinvertebrate Bioassessment Sampling Sites Within the San Joaquin River Restoration Area

Figure A-33-2.
Physical Habitat Characterization and Benthic Macroinvertebrate Collection

Table A-33-1.
Land-Use Predominance in the San Joaquin River Restoration Program Benthic Macroinvertebrate Bioassessment Study Area

Type of Land use	Number of Sites	Frequency of Dominance (percent)
Agricultural land use	24	62.5
Wildlife Area/other land use	24	25
Urban/industrial land use	24	4.17
Rangeland land use	24	4.17

Table A-33-2.
Summary of Physical and Chemical Variables Associated with Benthic Samples Collected in the San Joaquin River Restoration Area (Summer-Fall 2010)

Variable	Number of sites	Mean	Min	Max
width (m)	30	32.34	12.46	118.89
depth (cm)	30	50.32	11.04	102.15
specific conductivity (µS/cm)	26	351.9	27.3	1298
salinity (ppt)	29	0.16	0	0.69
DO (mg/L)	3	8.9	8.86	8.95
pH	29	8.045	7.24	8.83
temperature (°C)	29	22.28	12.15	29.13
turbidity (NTU)	5	18.68	0.19	24
total dissolved solids (mg/L)	24	0.2433	0.01754	0.831
Percent concrete	30	0.2539	0	3.81
Percent bedrock	30	0	0	0
Percent boulder	30	0	0	0
Percent wood	30	0.3503	0	2.857
Percent cobble	30	3.792	0	45.23
Percent gravel	30	10.335	0	48.57
Percent coarse gravel	30	7.344	0	42.86
Percent fine gravel	30	0.331	0	14.29
Percent hardpan	30	0	0	0
Percent sand	30	46.373	5.78	90.48
Percent fines	30	30.772	1	82.65
Percent algae	30	0.095	0	2.86

Table A-33-2.
Summary of Physical and Chemical Variables Associated with Benthic Samples Collected in the San Joaquin River Restoration Area (Summer-Fall 2010) (contd.)

Variable	Number of sites	Mean	Min	Max
mean embeddedness (quantitative = percent)	5	34.02	20	42.2
qualitative embeddedness	5	37.14	0	72.3
riparian disturbance index (W1_HALL)	30	13.01	0	68.34
mean mid-channel canopy density	30	13.78	0	68.447
riparian vegetation complexity	30	1.5864	0.779	2.398
instream habitat diversity	30	0.5802	0.3131	1.02
stable bank frequency (percent)	30	37.88	0	100
eroded bank frequency (percent)	30	28.18	0	86.36
vulnerable bank frequency (percent)	30	33.94	0	77.27
Percent fast-water habitat	30	36.44	0	86.5
Percent slow water habitat	30	61.94	11.5	100
Percent pool	30	33.04	0	92.5

Key:
°C = degree Celsius
µS/cm = microSiemens per centimeter
cm = centimeter
DO = dissolved oxygen
m = meter
Max = maximum
mg/L = milligrams per liter
Min = minimum
NTU = nephelometric turbidity unit
ppt = parts per thousand

Table A-33-3.
Abundance of Coleopterans in the San Joaquin River Restoration Area

Insecta: Coleoptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Coleoptera													
				Elmidae												
					Dubiraphia	Larvae	6	CG	CN	0.8	0.167					
					Microcylloepus	Larvae	4	CG	CN		1.167					
				Hydrophilidae												
					Berosus	Larvae	5	P	SW		0.167					
					Enochrus	Larvae	5	CG	BU	0.2						
					Laccobius	Larvae	5	P	--					0.167		

Notes:
TV= tolerance value. This value refers to the relative tolerance of BMI to environmental disturbances, with a 0 value representing the most sensitive (intolerant) BMI and a 10 representing the most insensitive (tolerant) one.

FFG= Functional Feeding Groups. This column indicates how the BMIs obtain their food.
CG= Collector-Gatherers, CF= Collector-Filterers, P= Predators, PA=Parasites, SH= Shredders, C= Collectors, G= Scrapers or Grazers, PH= Macrophyte Piercers, OM= Organic Matter Detritivores

Habit= Mode of existence. This column refers to how the BMI utilizes the system.
CN= Clingers, SW= Swimmers, SP= Sprawlers, CB = Climbers, BU= Burrowers

Table A-33-4.
Abundance of Dipterans in the San Joaquin River Restoration Area

Insecta: Diptera													**SJR Reach**						
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4B2	5
Arthropoda																		
	Hexapoda																	
		Insecta																
			Diptera															
				Ceratopogonidae														
							Bezzia/ Palpomyia	Larvae	6	P	BU			0.143				
							Ceratopogon	Larvae	6	P	BU			0.286	0.667	0.167	0.5	0.2
				Ceratopogonidae				Pupae	6	P	--		0.167	0.286				
				Ceratopogonidae				Pupae	6	P	--				1.333			
							Dasyhelea	Larvae	6	CG	SP					0.333		0.4
							Probezzia	Larvae	6	P	BU		0.167	0.429	4.667	0.5		0.2
				Chironomidae														
					Chironominae													
						Chironomini												
							Apedilum	Larvae	6	CG	SP					5.833		
						Chironomini		Larvae	6	CG	--	0.2		0.143		3.5	2	1
						Chironomini		Pupae	6	CG	--		0.333			0.333	1	
							Chironomus	Larvae	10	CG	BU		0.333			6		0.2
							Cladopelma	Larvae	9	CG	BU					0.333	25.5	0.6
							Cladopelma	Pupae	9	CG	BU						1.5	
							Cryptochironomus	Larvae	8	P	SP			0.429	2	1.833	8	1.2
							Cryptochironomus	Pupae	8	P	SP				0.667	0.167		
							Cryptotendipes	Larvae	6	CG	BU				0.667	6.333		0.2
							Cryptotendipes	Pupae	6	CG	BU					0.167		
							Dicrotendipes	Larvae	8	CG	BU	0.8		1.571	0.667	16.333		0.4
							Dicrotendipes	Pupae	8	CG	BU	0.8				0.333		
							Glyptotendipes	Larvae	10	CG	BU				0.333		67.5	41.8

Table A-33-4.
Abundance of Dipterans in the San Joaquin River Restoration Area (contd.)

Insecta: Diptera													**SJR Reach**						
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4B2	5
Arthropoda	Hexapoda	Insecta	Diptera	Chironomidae	Chironominae	Chironomini	*Glyptotendipes*	Pupae	10	CG	BU							0.2
							Microchironomus	Larvae	6	CG	BU					0.833		0.6
							Parachironomus	Larvae	10	P	SP			0.143			3.5	1.2
							Parachironomus	Pupae	10	P	SP	0.4						
							Paracladopelma	Larvae	7	CG	SP		0.167			0.167		
							Paralauterborniella	Larvae	8	CG	--					0.333		
							Phaenopsectra	Larvae	7	SC	CN	0.4						
							Polypedilum	Larvae	6	OM	CN	2.6	4.167	2.714	5.333	12	1	3.2
							Polypedilum	Pupae	6	OM	CN		0.167		0.333	0.167		
							Robackia demeijerei	Larvae	6	CG	BU	1.2	1	2	0.333	0.833		0.2
						Pseudochironomini												
							Pseudochironomus	Larvae	5	CG	BU	0.2			0.667			
						Tanytarsini												
							Cladotanytarsus	Larvae	7	CG	CB	2.6	0.5	7.714	76.333	46.167	4.5	
							Cladotanytarsus	Pupae	7	CG	CB							0.2
							Cladotanytarsus	Pupae	7	CG	CB			0.143	2	2.667		
							Micropsectra	Larvae	7	CG	CB	0.8						
							Paratanytarsus	Larvae	6	CF	CN	4			0.333	0.167		1.2
							Paratanytarsus	Pupae	6	CF	CN	0.2						
							Rheotanytarsus	Larvae	6	CF	CN	3	2.833	2.286			14.5	2.2
							Rheotanytarsus	Pupae	6	CF	CN			0.286			1.5	
							Stempellina	Larvae	2	CG	CB	0.2	2.667	2	3			
							Stempellina	Pupae	2	CG	CB				0.333			
							Stempellinella	Larvae	4	CF	SP	0.4				0.167		
						Tanytarsini		Larvae	6	CG	--			0.571	19.667	0.167		
						Tanytarsini		Pupae	6	CG	--	0.4		0.143		0.5		
							Tanytarsus	Larvae	6	CF	CN	5	1.167	24.857	34.667	3		
							Tanytarsus	Pupae	6	CF	CN	0.6		0.429	4.667			
					Diamesinae													
						Diamesini												
							Potthastia longimana group	Larvae	2	CG	SP	0.4						

Table A-33-4.
Abundance of Dipterans in the San Joaquin River Restoration Area (contd.)

Insecta: Diptera													**SJR Reach**						
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4B2	5
Arthropoda	Hexapoda	Insecta	Diptera	Chironomidae	Orthocladiinae													
							Cricotopus	Larvae	7	CG	CN		0.167	0.429				
							Cricotopus	Larvae	7	CG	CN	0.8			0.667	0.5		0.2
							Cricotopus	Pupae	7	CG	CN	0.4						0.4
							Cricotopus	Pupae	7	CG	CN		1.667	1.143		7.333		1.2
							Cricotopus bicinctus group	Larvae	7	CG	CN	1.4	2.833	5.286		19.333	6	4
							Cricotopus trifascia group	Larvae	7	CG	CN	0.4						
							Eukiefferiella	Larvae	8	OM	SP	0.4						
							Nanocladius	Larvae	3	CG	SP			1.571		0.5	0.5	3.6
							Nanocladius	Pupae	3	CG	SP		0.333		0.333			0.4
							Nanocladius	Pupae	3	CG	SP			0.143				
					Orthocladiinae			Larvae	5	CG	BU	1	0.667	0.286				
					Orthocladiinae			Larvae	5	CG	BU	0.4						
					Orthocladiinae			Pupae	5	CG	BU			0.143				
					Orthocladiinae			Pupae	5	CG	BU	0.2						0.2
							Orthocladius complex	Larvae	6	CG	--	9.4	8.167	0.429		3.333		0.4
							Parakiefferiella	Larvae	4	CG	SP	10.6						
							Parakiefferiella	Pupae	4	CG	SP	0.2						
							Synorthocladius	Larvae	2	CG	--	0.2						
							Synorthocladius	Pupae	2	CG	--	0.2						
							Synorthocladius	Pupae	2	CG	--	0.2						
							Tvetenia discoloripes group	Larvae	5	CG	SP	0.2						
						Corynoneurini													
							Thienemanniella	Larvae	6	CG	SP		1.833	1		3.167		0.2
							Thienemanniella	Pupae	6	CG	SP					0.167		
							Thienemanniella	Pupae	6	CG	SP		0.333	0.143		1.167		
					Tanypodinae			Larvae	7	P	BU	0.6		0.143		0.5	0.5	
					Tanypodinae			Pupae	7	P	BU					0.167		
					Tanypodinae			Pupae	7	P	BU			0.429	0.667	0.167		

Table A-33-4.
Abundance of Dipterans in the San Joaquin River Restoration Area

Insecta: Diptera													**SJR Reach**						
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4B2	5
Arthropoda	Hexapoda	Insecta	Diptera	Chironomidae		Pentaneurini												
							Ablabesmyia	Larvae	8	CG	SP	0.2	0.667	0.429	0.333	1.667		
							Larsia	Larvae	6	P	SP			0.143				
							Pentaneura	Larvae	6	P	SP	0.2	0.5	0.286				
							Pentaneura	Pupae	6	P	SP		0.167					
							Thienemannimyia group	Larvae	6	P	SP	0.2		4.143	10	0.167		
							Zavrelimyia/ Paramerina	Larvae	7	P	SP		0.167	0.286				
						Procladiini												
							Procladius	Larvae	9	P	SP	0.6	0.167		0.667	1.333	2	1
						Tanypodini												
							Tanypus	Larvae	10	P	SP						4.5	
				Dolichopodidae				Larvae	4	P	SP					0.167		
				Empididae														
							Clinocera	Larvae	6	P	SP	0.2						
				Empididae				Larvae	6	P	SP		0.167					
				Empididae				Pupae	6	P	SP	0.2	0.333					
							Hemerodromia	Larvae	6	P	SP	0.4	3.833	0.143				
							Neoplasta	Larvae	6	P	SP	0.2		0.143				
				Ephydridae				Larvae	6	CG	--					0.167		
							Hydrellia	Larvae	6	SH	BU					0.167		
							Notiphila	Larvae	6	CG	BU			0.286				
				Simuliidae														
							Simulium	Larvae	6	CF	CN	1.6	0.333				5.5	
							Simulium	Pupae	6	CF	CN	0.2	0.167					

Table A-33-5.
Abundance of Ephemeropterans in the San Joaquin River Restoration Area

Insecta: Ephemeroptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Ephemeroptera													
				Baetidae												
					Acentrella	Larvae	4	CG	SW	2.6						
					Acentrella insignificans	Larvae	4	CG	SW	8.8						
					Apobaetis etowah	Larvae	--	--	--		0.167	0.143		0.5		
				Baetidae		Larvae	4	CG	SW	1.6	1.83					
					Baetis tricaudatus	Larvae	6	CG	SW	31.6	3.667					
					Callibaetis	Larvae	9	CG	SW	0.4			0.333			
					Camelobaetidius	Larvae	4	CG	SW	0.2				0.167		
					Camelobaetidius warreni	Larvae	4	CG	SW		13.667	0.143				
					Centroptilum	Larvae	2	CG	SW	8.6	4.333	1.286	14	0.167		
					Fallceon	Larvae	4	CG	SW	1.6	16.333	2.714		0.333		
					Paracloeodes minutus	Larvae	4	CG	SW		1	37.714	59.333	0.333		
				Caenidae		Larvae	7	CG	SP							0.4
					Caenis	Larvae	7	CG	SP	0.2		0.143		0.167		0.2
					Caenis bajaensis	Larvae	7	CG	SP					0.167		
					Caenis latipennis	Larvae	7	CG	SP			0.714	13.333	0.333	5.5	1
				Ephemerellidae												
					Serratella	Larvae	2	CG	CN	0.2						
					Serratella micheneri	Larvae	1	CG	CN	0.8						
				Leptohyphidae												
					Tricoryhyphes	Larvae	4	CG	--					0.333		
					Tricorythodes	Larvae	4	CG	SP	36	6.83	2.857	0.666	0.167		

Table A-33-6.
Abundance of Hemipterans in the San Joaquin River Restoration Area

Insecta: Hemiptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Hemiptera													
				Corixidae												
					Corisella	Larvae	8	P	SW				0.333			
				Corixidae		Larvae	8	P	SW	5.8				0.333		1.4
				Corixidae		Larvae	8	P	SW							10.6
					Trichocorixa calva	Adults	8	P	SW							0.8
				Naucoridae												
					Ambrysus	Larvae	5	P	CN	1.2						

Table A-33-7.
Abundance of Lepidopterans in the San Joaquin River Restoration Area

Insecta: Lepidoptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Lepidoptera													
				Pyralidae												
					Petrophila	Larvae	5	SC	CB	1.4						

Table A-33-8.
Abundance of Odonatans in the San Joaquin River Restoration Area

Insecta:Odonata										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Odonata													
				Aeshnidae		Larvae	5	P	CB				0.333			
				Calopterygidae												
					Hetaerina americana	Larvae	6	P	CB	1.4				0.333		
				Coenagrionidae												
					Argia	Larvae	7	P	CB	1.8	0.5			0.667		
				Coenagrionidae		Larvae	9	P	CB	1.6			3.333	9.333	1	0.8
				Gomphidae		Larvae	4	P	BU			0.143	1	0.333		
				Gomphidae		Larvae	4	P	BU			0.143				
					Octogomphus specularis	Larvae	4	P	SP					1		
					Ophiogomphus	Larvae	4	P	BU	0.2	0.333	0.571	1.333	0.167		
					Progomphus borealis	Larvae	4	P	BU				0.333			
				Libellulidae		Larvae	9	P	SP		2	0.571	0.667			
				Libellulidae		Larvae	9	P	SP				1			
					Sympetrum	Larvae	9	P	SP				0.333			

Table A-33-9.
Abundance of Trichopterans in the San Joaquin River Restoration Area

Insecta:Trichoptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Trichoptera													
				Glossosomatidae												
					Glossosoma	Larvae	1	SC	CN	1						
				Glossosomatidae		Pupae	0	SC	CN		2					
					Protoptila	Larvae	1	SC	CN	0.2	48.333					
				Hydropsychidae												
					Hydropsyche	Larvae	4	CF	CN	8.2	17.667	1.429		2.333	1	10.6
				Hydropsychidae		Larvae	4	CF	CN					0.167		
				Hydropsychidae		Larvae	4	CF	CN		1.167					
				Hydropsychidae		Pupae	4	CF	CN	0.4				0.167		
				Hydroptilidae												
					Hydroptila	Larvae	6	PH	CN	6	1	1.571		1.833	0.5	0.8
				Hydroptilidae		Pupae	4	PH	CB	0.4	0.167	0.143				0.2
					Oxyethira	Larvae	3	PH	CB	3	0.167					
					Oxyethira	Pupae	3	PH	CB	0.4						
					Oxyethira	Pupae	3	PH	CB	0.8	0.5					
				Lepidostomatidae												
					Lepidostoma	Larvae	1	SH	CB	0.4						
				Leptoceridae		Larvae	4	OM	--					0.167		
				Leptoceridae		Pupae	4	OM	--	1.2	0.333			0.333		
					Mystacides	Larvae	4	OM	SP				0.333			
					Nectopsyche	Larvae	3	OM	CN	85	42.167	1.143	0.333	8		
					Nectopsyche	Pupae	3	OM	CN		0.167					
					Oecetis	Larvae	8	P	CN	0.2				0.167		

Table A-33-10.
Abundance of Non-Insect Benthic Macroinvertebrates in the San Joaquin River Restoration Area

Non-Insects								**SJR Reach**						
								1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	TV	FFG							
Arthropoda														
	Crustacea													
		Malacostraca												
			Amphipoda											
				Corophiidae										
					Americorophium spinicorne	4	CF					6.833		0.4
				Gammaridae										
					Gammarus	6	CG	0.2	1.5			2.667		16
				Hyalellidae										
					Hyalella	8	CG	11.2	4.167		0.667	8.333	5	0.4
			Decapoda											
				Cambaridae										
					Procambarus clarkii	8	SH							0.2
				Palaemonidae										
					Exopalaemon modestus	8	SH							0.2
		Ostracoda				8	CG	18	0.333	3	1.333	1.667	12.5	
	Chelicerata													
		Arachnida												
			Trombidiformes			5	P	0.8		0.143			2	
			Trombidiformes			5	P			0.143			0.5	0.2
				Hygrobatidae										
					Atractides	8	P	0.2		0.286				
					Hygrobates	8	P	20.4	3.6667	1.143	1	0.167		
				Lebertiidae										
					Lebertia	8	P	29.8	31.667	43.571	11	2.333	0.5	
				Limnesiidae										
					Limnesia	5	P	0.4		0.143				
				Mideopsidae										
					Mideopsis	5	P		0.667			0.167		
				Sperchontidae										
					Sperchon	8	P	5.4						
				Torrenticolidae				0.2						
					Torrenticola	5	P	1.6						
				Torrenticolidae		5	P							
				Unionicolidae										
					Neumania	5	P	0.2		0.286	1			

Table A-33-10.
Abundance of Non-Insect Benthic Macroinvertebrates in the San Joaquin River Restoration Area (contd.)

Non-Insects								SJR Reach						
								1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	TV	FFG							
Annelida														
	Aclitellata													
		Polychaeta												
			Canalipalpata											
				Sabellidae										
					Eudistylia	--	--					0.333	1	
	Clitellata													
		Hirudinea				10	P					3.167	3.5	
			Arhynchobdellida											
				Erpobdellidae										
					Mooreobdella	8	P		0.167					
					Mooreobdella tetragon	8	P	0.2						
			Rhynchobdellida											
				Glossiphoniidae		8	P							0.4
				Glossiphoniidae		8	P		0.333			0.167		0.6
					Helobdella	6	PA	1						
					Helobdella stagnalis	6	PA	0.4				1.5	1	1.6
		Oligochaeta				5	CG	58	7.667	1.143	17.667	73	398.5	30.8
Coelenterata														
		Hydrozoa												
			Hydroida											
				Hydridae										
					Hydra	5	P		0.167	0.143		0.333		
Mollusca														
		Bivalvia												
			Veneroida											
				Corbiculidae										
					Corbicula	8	CF	8.4	8	1.143		5.167	1.5	1.2
				Sphaeriidae										
					Pisidium	8	CF	1.2	0.333		0.667	0.167		
				Sphaeriidae		8	CF							0.2

Table A-33-10.
Abundance of Non-Insect Benthic Macroinvertebrates in the San Joaquin River Restoration Area (contd.)

Non-Insects								**SJR Reach**						
								1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	TV	FFG							
Mollusca		Gastropoda												
			Basommatophora											
				Lymnaeidae										
					Lymnaea	7	SC	0.4	0.167		0.333	0.167	0.5	
				Physidae										
					Physa	8	SC	3.6	0.667	0.143	1.333	2		1
				Planorbidae				0.2						
					Helisoma	6	SC	0.2						
					Menetus opercularis	6	SC	0.2				0.833		0.4
				Planorbidae		6	SC							
			Hypsogastropoda											
				Cochliopidae										
					Tryonia	--	--					1.833		
Nemertea														
		Enopla												
			Hoplonemertea											
				Tetrastemmatidae										
					Prostoma	8	P	4.8	2.833	9.286		7	1.5	0.4
Platyhelminthes														
		Turbellaria				4	P	5.4	2.333	0.143	0.333	5.333	0.5	1.2

Table A-33-11.
Benthic Index of Biotic Integrity and Component Metrics for Benthic Macroinvertebrate Sampling Sites in the San Joaquin River Restoration Area

River Mile	Reach-ID	Collector richness	Predator richness	% EPT taxa	% Clinger taxa	Shannon diversity	Central Valley B-IBI	Biological condition
263	1A-154	7	7	38	36	1.84	52	Fair
257	1A-128	9	8	29	33	1.94	56	Fair
250	1A-144	8	10	28	31	2.62	62	Good
248	1A-132	9	10	31	25	2.21	56	Fair
238	1B-164	8	8	40	29	1.92	56	Fair
237	1B-148	6	5	31	29	1.57	38	Poor
236	1B-105	9	4	44	20	1.95	52	Fair
234	1B-121	9	7	43	40	2.68	70	Good
230	1B-109	9	5	53	31	2.2	56	Fair
226	2A-137	5	7	31	28	1.54	42	Fair
224	2A-129	5	4	40	17	1.29	36	Poor
223	2A-113	6	3	64	22	0.96	36	Poor
220	2A-149	4	5	42	22	1.1	36	Poor
219	2A-133	6	2	50	29	1.08	36	Poor
216	2B-117	5	8	23	0	1.64	32	Poor
213	2B-101	7	5	43	11	1.05	36	Poor
207	2B-125	6	5	14	0	1.73	24	Poor
198	3-134	5	7	17	40	1.83	42	Fair
197	3-106	8	8	21	27	2	48	Fair
195	3-145	6	10	17	27	2.66	52	Fair
193	3-161	6	7	22	25	1.79	38	Poor
187	3-151	4	5	24	40	1.2	34	Poor
183	3-135	6	6	24	25	1.17	32	Poor
141	4B-115	4	4	20	43	1.11	32	Poor
140	4B-136	5	2	22	33	0.64	28	Poor
134	5-120	6	6	16	25	1.22	28	Poor
131	5-104	3	3	22	25	1.26	22	Poor
128	5-186	4	2	18	25	1.67	26	Poor
125	5-139	4	1	25	25	1.17	22	Poor
121	5-143	3	2	17	33	1.31	24	Poor

Key:
B-IBI = Benthic Index of Biotic Integrity
EPT = Ephemeroptera, Plecoptera and Trichoptera

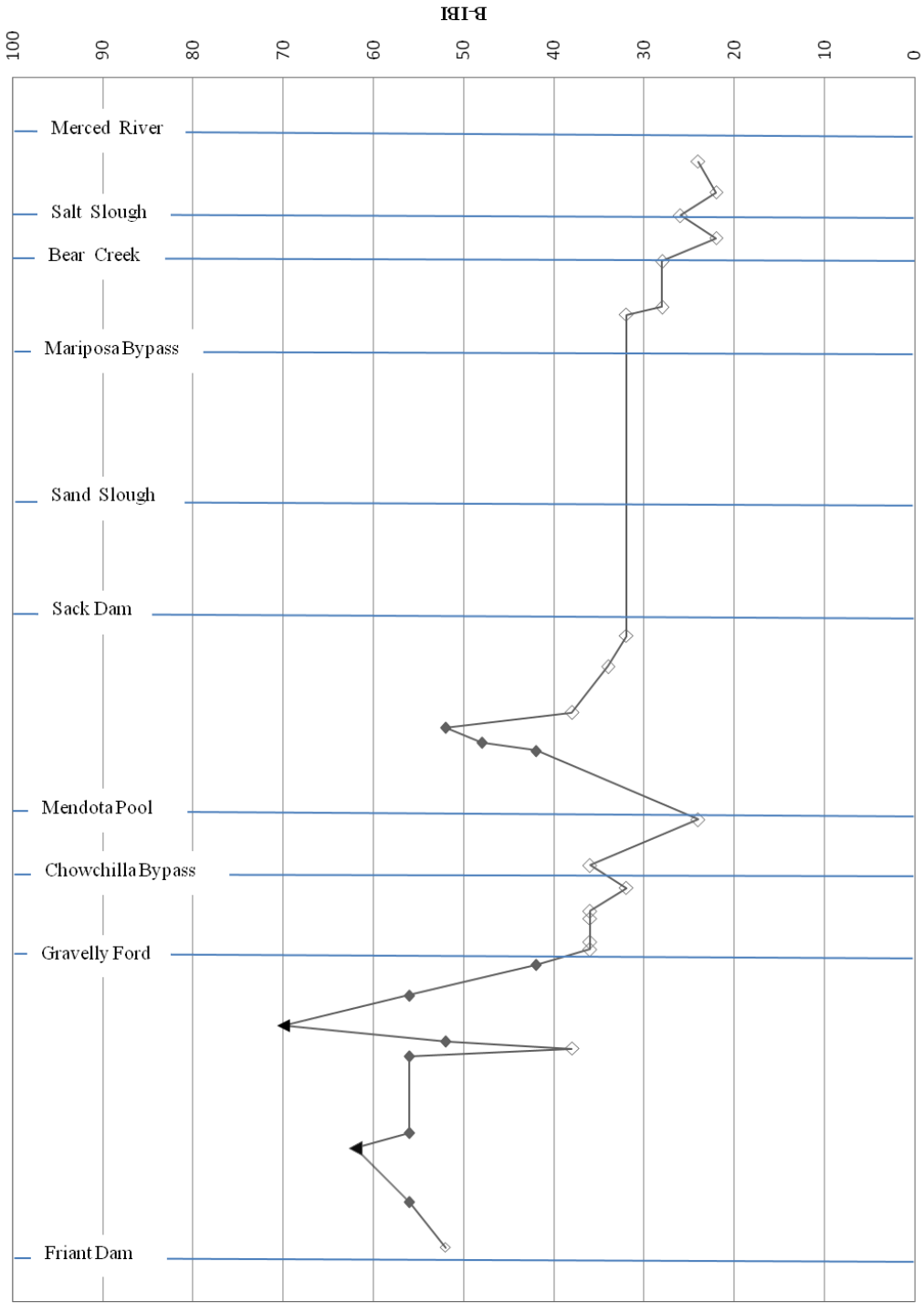

Figure A-33-3.
Benthic Macroinvertebrate Index of Biotic Integrity in the San Joaquin River Restoration Area

Figures A-33-4a through A-33-4d show linear association of the Central Valley B-IBI with (a) W1_HALL, (b) mid-channel canopy density, (c) riparian vegetation complexity, and (d) in-stream habitat diversity.

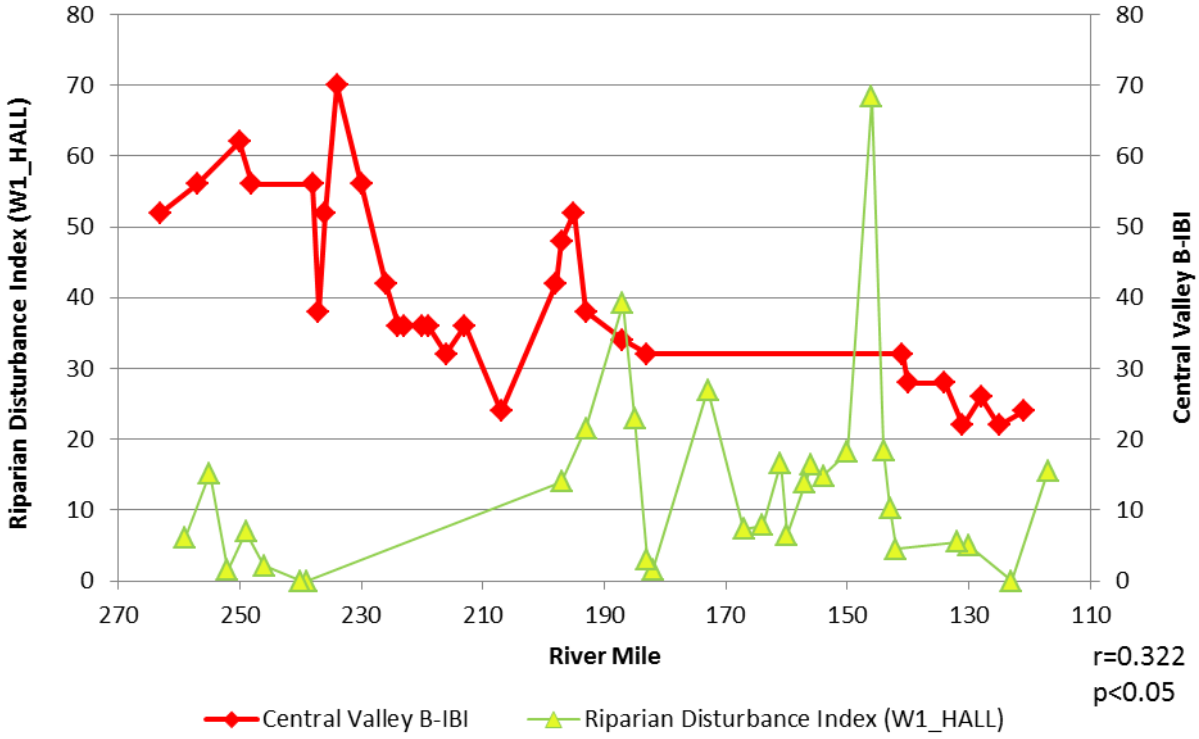

Figure A-33-4a.
Riparian Disturbance

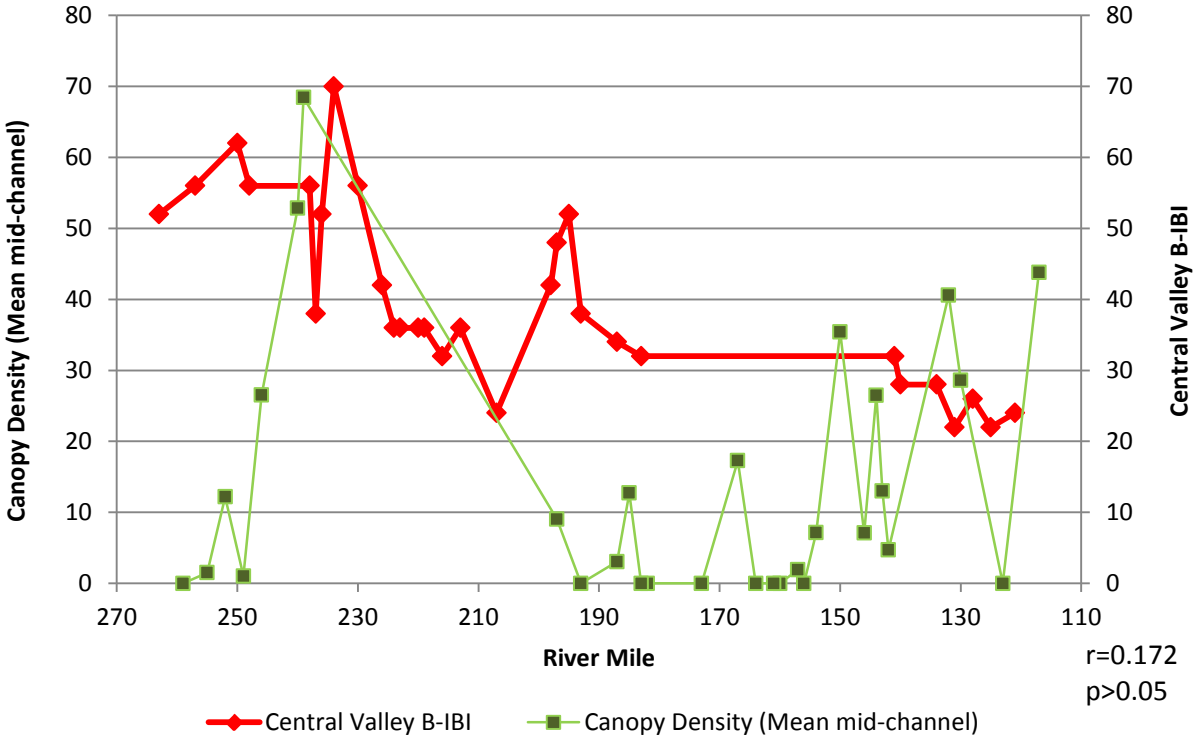

Figure A-33-4b.
Canopy Density

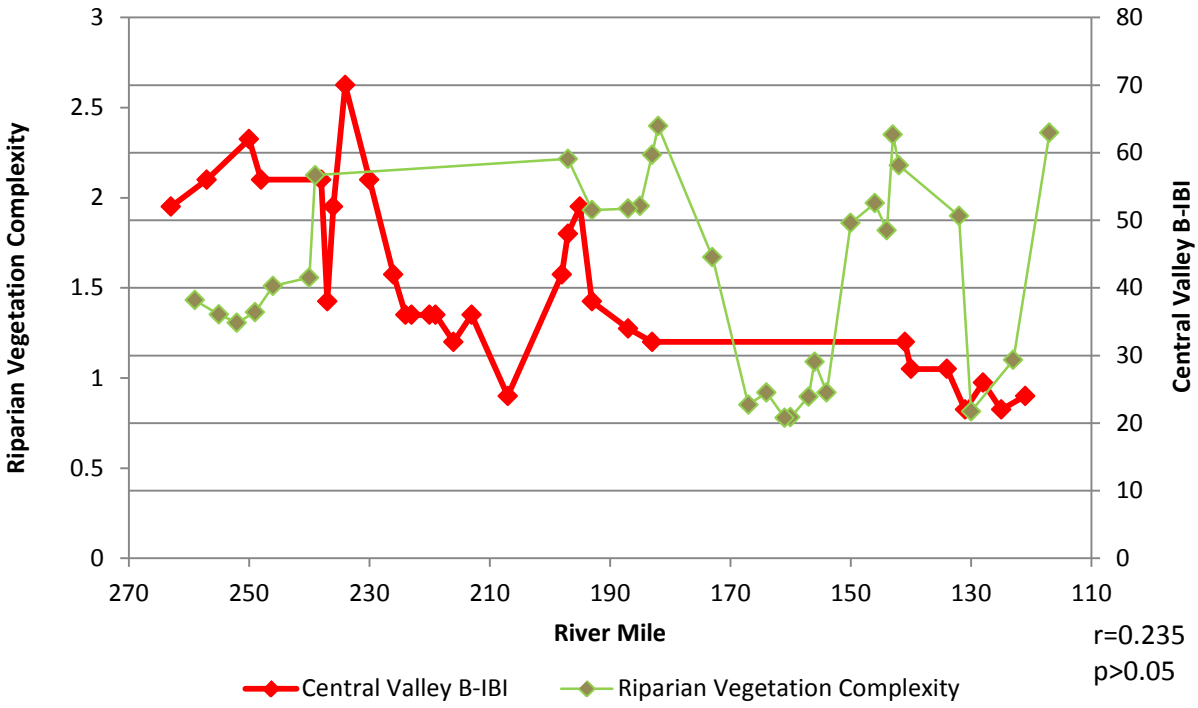

Figure A-33-4c.
Riparian Vegetation Complexity

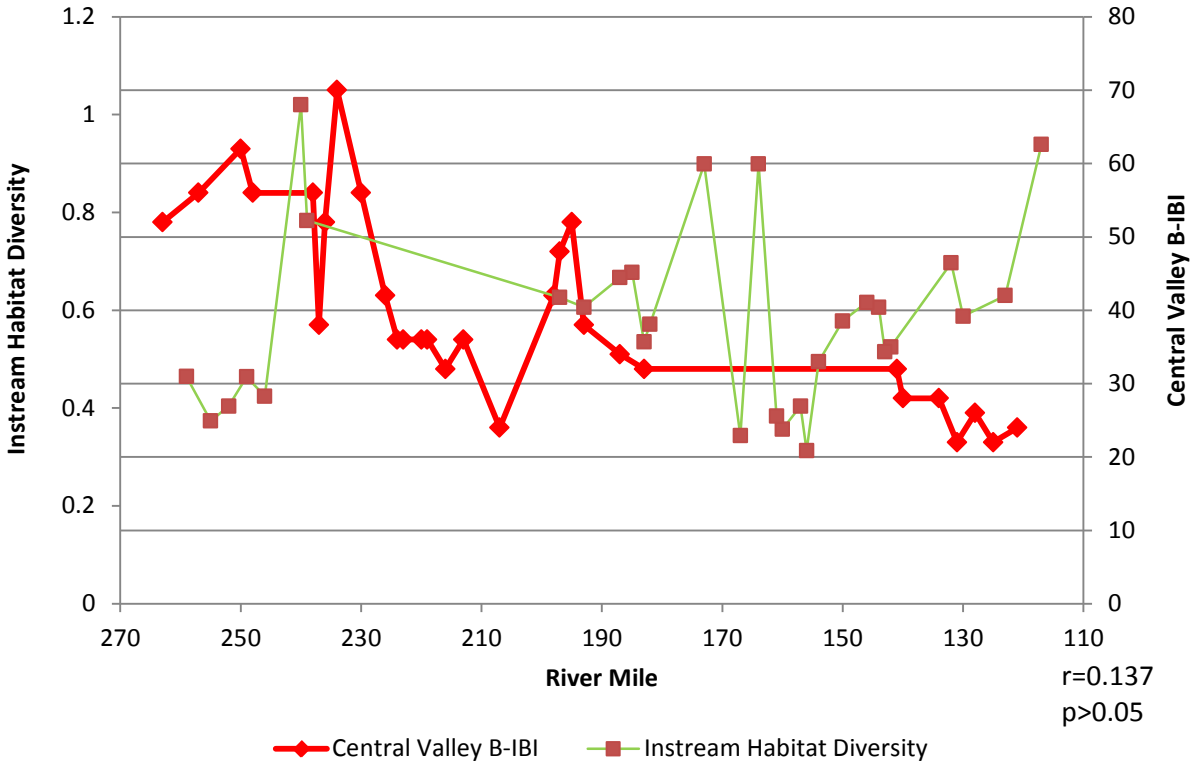

Figure A-33-4d.
Instream Habitat Diversity

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34.0 Preliminary Report of Implementation of Chinook Salmon Egg Survival Study, Fall 2011

34.1 Introduction/Background

Incubating salmon eggs require appropriate conditions (water temperatures, spawning gravel size distribution and hyporheic flow rates) to survive and hatch successfully (FMWG, 2009). The survival of spring-run and fall-run Chinook salmon eggs can be impacted by high temperatures, excessive sedimentation, turbidity, reduced hyporheic flow rates, and redd superimposition due to the crowding of spawners into limited habitat. Some or all of these factors may contribute to unsuitable conditions for egg survival in portions of the 10-mile-long spawning reach immediately downstream from Friant Dam.

In foot surveys conducted by FMWG representatives in 2007, only four gravel beds, three of which were highly silted, were identified in the 5-mile reach (RM 262.5 to RM 267.5) below Friant Dam; whereas there were 22 potential spawning beds in the lowermost 5-mile section of the historical spring-run spawning reach in July 2007 (FMWG, 2007). The fall 2009 Interim Flow Studies (Reclamation, 2010) collected substrate bulk samples from seven gravel beds in the primary 10-mile spawning reach (RM 257.5.9 to 267.5). The results indicated that six gravel beds were composed of at least 35 percent fines (D_{35} greater than 2.0 mm), which is clearly unsuitable for Chinook salmon eggs (Kondolf, 2000); five of these beds were composed of at least 50 percent fines, whereas one bed at RM 263.3 had a D_{16} of 4.23 mm, which may provide suitable spawning habitat. The low number of gravel beds, particularly near Friant Dam, could result in spawner crowding and redd superimposition.

Sedimentation, which is the amount of fine sediment (less than 2 mm) in the spawning beds in the San Joaquin River, appears to be at high levels, based on substrate bulk sampling conducted during the fall 2009 Interim Flow Studies (Reclamation, 2010). The infiltration of these materials into the redd environment, in addition to poor water quality conditions (temperature and DO) in the hyporheic environment may result in decreased survival of eggs and prevent the SJRRP from meeting the targets identified in the FMP (FMWG, 2010). Female salmon typically clean the fine sediments from their redds during redd construction; however, fines are easily mobilized and they can accumulate in redds over time either suffocating the eggs or entombing the alevins in the gravel. Modeling can predict impacts to egg survival from these factors (Tappel and Bjornn, 1983). It is likely that fines will accumulate in salmon redds over time considering the high levels of fines present in the existing gravel beds (Reclamation, 2010).

The Settlement requires minimum flows for spring-run spawning in September of 210 cfs, 260 cfs, and 350 cfs during Critical Low, Critical High, and Dry type and wetter years, respectively. Settlement flows decline to 160 cfs during October in Critical Low and Critical High years, whereas they remain at 350 cfs during Dry type and wetter years. The fall 2009 Interim Flow Studies indicated that maximum water temperatures remained less than about 13.5°C (56.3°F) for about 3 miles (RM 264.7) below Friant Dam at flows of 210 cfs during September (Reclamation, 2010). The fall 2009 Interim Flow studies did not provide data on flow releases of 350 cfs during September, nor 160 cfs during October. During October 2009, when flows were increased to 350 cfs, water temperatures remained below about 13.5°C for at least 8 miles (RM 259.5). Several thermographs downstream from RM 259.5 were vandalized or placed in captured gravel mine pits, so it is possible that suitable water temperatures (less than 13.3°C) would extend further than 8 miles below the dam at flows of 350 cfs during October and presumably November and December. This year's study was conducted under low-flow conditions (less than 100 cfs Friant releases) due to maintenance in Mendota Pool. Results will represent a worst case flow scenario for fall-run Chinook salmon egg incubation conditions.

Water temperatures near Friant Dam may become sub-optimal in November for salmonid egg incubation until winter inflows restore the cold water pool in Millerton Reservoir, based on CE-QUAL-W2 model predictions (SJRRP, 2008a). Additionally, water temperatures increase with distance downstream from the dam until about mid-November due to declining air temperature, based on HEC-5Q model predictions (SJRRP, 2008b). As a result of these two factors, both spring-run and fall-run eggs and/or alevins may experience unsuitable water temperatures regardless of when spawning occurs or whether spawning occurs near Friant Dam or in the downstream areas near Highway 41. During this year's study, the release temperatures at Friant peaked at 14.2°C (57.6°F) on November 12 and 13, 2011, which is typical, compared to the CE-QUAL-W2 model predictions.

It is likely that the various stressors for salmon eggs, such as high water temperatures, have cumulative effects. For example, Chinook salmon eggs can tolerate water temperatures as high as 16.1°C (61°F) under laboratory conditions (Alderdice and Velsen, 1978); however, high rates of fall-run Chinook egg mortality occurred at temperatures between 13.3°C (56°F) and 15.6°C (60°F) in Stanislaus River spawning beds (CMC and KDH, 2009) and in Mokelumne River spawning beds (Biosystems Analysis, 1992). The in-river studies suggest that there are cumulative effects of stressors, such that sublethal levels of substrate fines, turbidity, DO, and/or hyporheic flow rates, decrease the threshold where water temperatures result in egg mortality. Additionally, site-specific data are needed to better understand the cumulative effects of these environmental conditions in the San Joaquin River Restoration Area.

The results of the fall 2009 Interim Flow studies and the reservoir and river temperature models suggest that spawning habitat may not be sufficient to support a self-sustaining population due to the lack of suitable gravel beds due in part to temperature and sediment impacts. Additional data are needed on the relationship between surface water quality (DO and temperature) and the hyporheic water quality, substrate sizes in potential spawning beds, and the relationship between egg survival, water temperature, and percent

fines in the primary spawning reach. Results of this study will be analyzed with the results of ongoing studies being conducted by DWR and Reclamation addressing particle size distribution, sediment infiltration rates, hyporheic conditions, and substrate permeability.

34.1.1 Site Description

Sites for this study were selected to represent a longitudinal gradient downstream from Friant Dam to assess variation in water quality and physical parameters through Reach 1a. They were also chosen to compliment a Reclamation study of egg survival using rainbow trout eggs in September and October 2011, and to facilitate the use of sediment data previously collected including bulk sediment samples, and pebble count transects in the assessment of data (DWR). Five sites (A through E) from the base of Friant Dam to the Highway 41 Bridge crossing were selected. Sites B through D were also used for assessing rainbow trout egg survival in a Reclamation-led study. The uppermost and lowermost sites (Site A and Site E) were not used in the Reclamation study (Figure A-34-1).

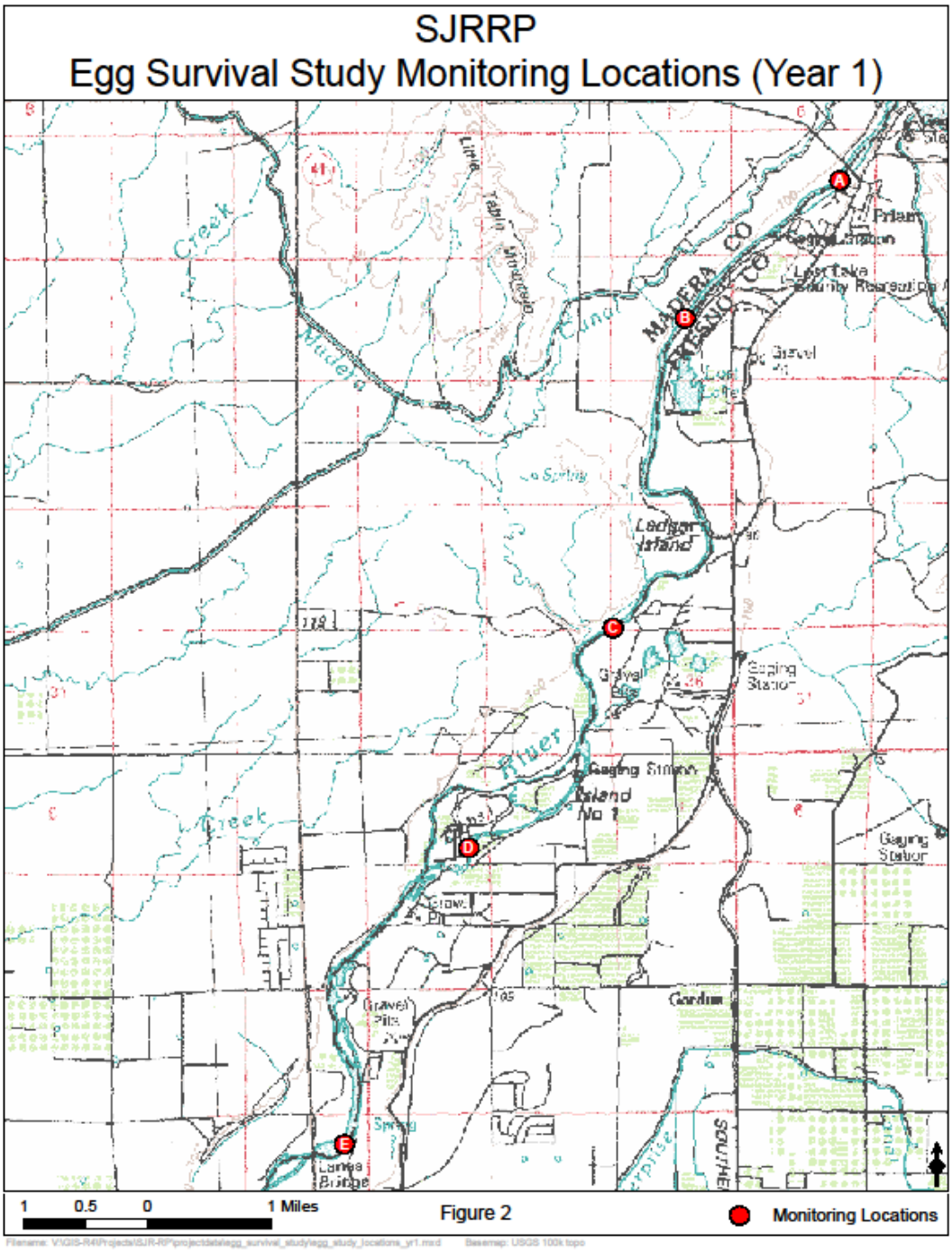


Figure A-34-1.
Artificial Redd/Egg Survival Study Sites, San Joaquin River, Fall 2011

34.2 Methods

34.2.1 Egg Tube Construction

Egg tubes were designed using a modification from Merz et al. (2004) and constructed of SDR 35-PVC pipe with two PVC caps used to close tube ends. Eighteen-19 mm evenly spaced holes were drilled into each tube. The tube inner surface was covered with a 0.35-mesh/mm plastic screen typically used for steelhead (*Oncorhynchus mykiss*) and Chinook salmon hatchery egg incubation (Leitritz and Lewis, 1980). The tube length was shortened from the Merz et al. (2004) study to accommodate placement through bottomless buckets for ease of burial (method described below).

34.2.2 Egg Handling/transport

Eggs were provided by the Feather River Fish Hatchery (FRFH). Study eggs were pulled randomly from 30 Heath incubation trays of fertilized 'surplus' egg lots from 2011 spawned Feather River fall-run-fish. Ovarian fluid from female spawners contributing to the egg lots used was collected for pathology testing before acquiring and using eggs. Eggs for this study were spawned on October 3, 2011, and ovarian fluid was processed by the DFG Fish Pathology Laboratory, for a 28-day assessment. On November 3, 2011, following 'release' of fish based on a clear pathology report, eggs were collected and sorted at the Feather River Fish Facility.

A 1-cup measure was used to extract 1 cup of eggs from each of 30 egg trays to provide a random sample of all available eggs, and reduce viability concerns specific to mating pair fecundity or fertility. From that random lot, viable eggs were sorted into cheesecloth packets of 50 eggs each and placed in a three-layer Styrofoam transport container. Moist egg packets were placed on the middle tier, below an isolated tier of ice. This configuration allows the ice to cool the eggs, melting ice drips down on eggs to keep them moist, while keeping eggs out of the water accumulating at the bottom. This allows for maximum oxygen exchange for the eggs, and follows standard hatchery transport practices (Paul Adelizi and A.J. Dill, DFG, personal communications).

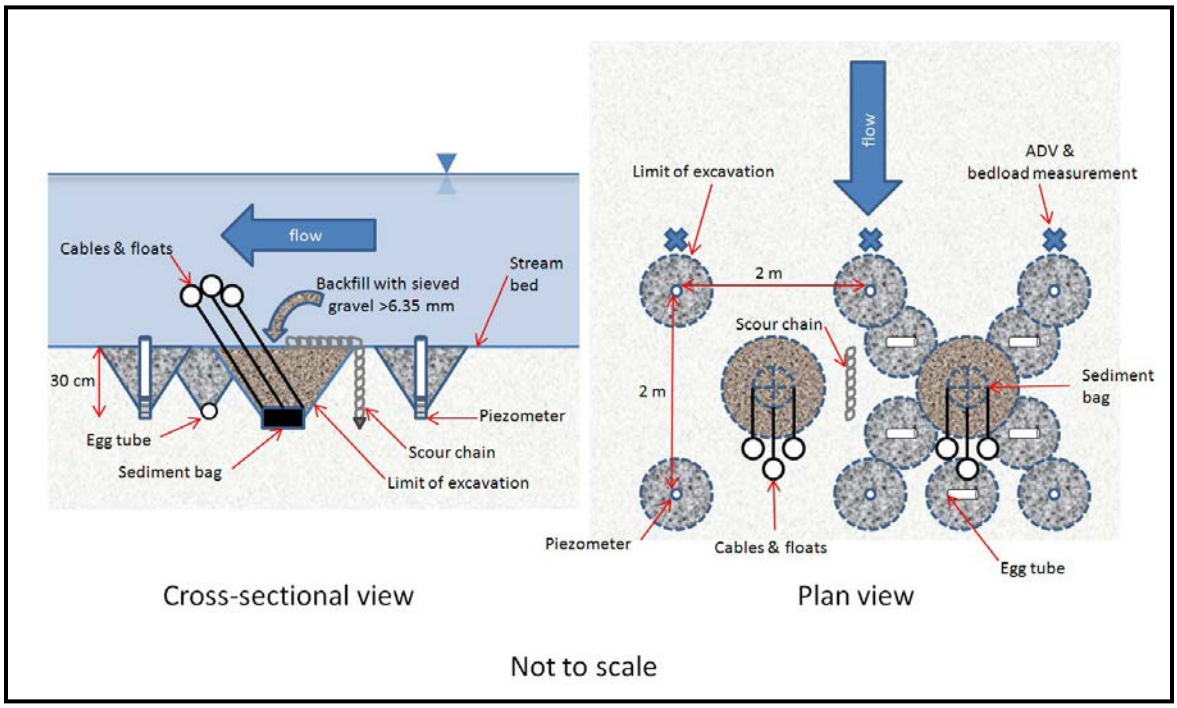
Fish were driven from the FRFF in a standard passenger vehicle, and kept overnight in the transport container, for release the following day.

34.2.3 Experimental and Control Groups

The design for this study included five egg tubes placed in one artificial redd in each of five study locations representing a longitudinal gradient through Reach 1a of the San Joaquin River Restoration Area. Each egg chamber received one packet, 50 eggs, during the study period. In addition to experimental groups, two control groups were kept at the FRFH to separate survival associated with travel stress from environmental river conditions, and to provide information related to empirical versus modeled emergence dates. One control group of five egg chambers was left at the FRFH in a Heath incubation tray, and experienced no travel. The second control group of five egg chambers was subjected to travel to the San Joaquin River and return travel to the FRFH over a 48-hour period in the cheesecloth packets, then placed in five egg chambers in a separate Heath incubation tray for the extent of the study.

34.2.4 Site Preparation and Egg Tube Placement

One day before acquiring eggs, a pair of artificial redds were constructed at each site for egg chamber placement. Site layout is described in Figure A-34-2 (courtesy of Matt Meyers, DWR). Two artificial redds were constructed at each location, each an approximate 10-by-10-foot area. The redd on river right contained the five sample egg tubes, and on river left was left without eggs. One sediment bag was positioned in the middle of each artificial redd, and a scour chain in the center of the two redds. The redds were constructed by hand digging the entire area starting in the downstream sections and working upstream with hand-held McLeods and potato rakes. These tools allow water current to carry fines out of the area much like during the natural spawning process. Five bottomless, 5-gallon (19-liter) buckets were placed in a chevron (or V) configuration with the apex in the downstream position to maintain the egg pocket for egg tube placement at a later date (Figure A-34-2). Pockets were constructed in an upstream progression, following the description of DeVries (1997). At each study site, egg incubation chambers were buried horizontally and perpendicular to stream flow at 22 cm deep, the approximate depth of egg pockets in Chinook salmon redds according to Healey (1991) and Montgomery et al. (1999). Bed material reserved upstream from pockets was used to cover each egg chamber. Peizometers for measuring hyporheic conditions were placed at the four corners of the artificial redds, and along the top margin and bottom margin in between the two artificial redds. One Hobo temperature logger was placed in the redd attached to the egg chamber in position C at each site.



Source: courtesy of Matt Meyers, DWR

Figure A-34-2.
Study Site Layout

At each study site, egg packets were transferred from cheesecloth bags to experimental egg chambers streamside, and then placed in bottomless buckets at appropriate depths. Bottomless buckets were slowly lifted as bed material was raked over the egg chamber to form an egg pocket. Red flagging approximately 24 to 30 inches long was secured to each egg tube to facilitate recovery.

34.2.5 Physical Measurements

At each site, a number of water quality parameters were measured at key times during the study: during redd construction, egg chamber placement, during egg incubation, and at egg chamber retrieval. These parameters included surface water temperature, surface depth and velocity at the head and tail of each artificial redd containing incubating eggs, hyporheic water temperature, DO and permeability.

Hyporheic DO was measured during site visits by deploying a YSI Pro model temperature and DO probe into two piezometers after initial purging. Hyporheic water temperature was monitored with a Hobo brand thermograph attached to one egg chamber per experimental site (Data Attached). Thermograph measurements were recorded at 30-minute intervals throughout the egg incubation period. Surface water temperature measurements were recorded as part of DFG standard temperature monitoring sites along the San Joaquin River, and provided in 30-minute intervals. Surface velocity was measured using a Marsh McBirney Flowmeter in cubic meters per sec.

Additional detailed discussion regarding the sediment monitoring components of this study can be found in the “Artificial Redd Survey” section of the Annual Technical Report (this volume).

34.2.6 Egg Development

Chinook salmon egg development is temperature dependent and can be calculated using the accumulated thermal unit (ATU), which is a unit of measurement describing the cumulative effect of temperature over time. One ATU is equal to 1 degree Celsius for 1 day. The ATU estimate for Chinook salmon egg development is 476 degree days (dd) for hatching and 724 dd for emergence (Beachum and Murray, 1990). Temperature in the FRFH during spawning and during the pathology testing, as well as surface temperatures in the San Joaquin River were used to develop an estimate of emergence timing, for egg chamber retrieval.

34.2.7 Data Analysis

Experimental outcomes will be assessed by comparing the dependent variables of percent survivorship. Level of development, and fry length will be compared to the independent variables of surface water temperature and velocity, surface DO concentration, hyporheic flow rate, hyporheic temperature and hyporheic DO, percent fines (less than 2 mm diameter), and bed permeability. Each egg chamber will provide an independent observation and regression analyses will be used to test for statistically significant relationships between egg survival and habitat variables among and between sites. Empirical data collected during this study will also be compared to modeled survival estimates generated using the methods of Tappel and Bjorn (1983).

34.3 Results/Discussion

Preliminary data collected during this study is summarized here. Final results including data analysis and discussion will be prepared for the summer 2012 ATR.

Egg survival through the five sites was variable both within and between sites. Survival ranged from 0 percent to 79 percent per individual egg tube. Highest average survival by site was 50 percent at Site A and lowest was 13 percent at Site C (Figure 1). Average survival in the two control groups was 66 percent and 51 percent for travel and non-travel controls, respectively (Table A-34-1).

Table A-34-1. Egg Survival in Artificial Redds in Reach 1A of the San Joaquin River Restoration Area

Location	Average Number	Range (min-max)	Average Percent
Site A	24.4	4-33	49.99%
Site B	17.2	0-31	35.87%
Site C	6.6	0-12	13.46%
Site D	16.4	0-28	28.57%
Site E	15.8	4-33	34.78%
Travel Control	32	20-43	66.47%
Non Travel Control	24.2	16-36	51.02%

Hyporheic temperatures were recorded at 15-minute intervals throughout the study. Average daily temperature in the redd environment ranged from 8.6 to 14.5^{o}C throughout the study period (Figure A-34-3).

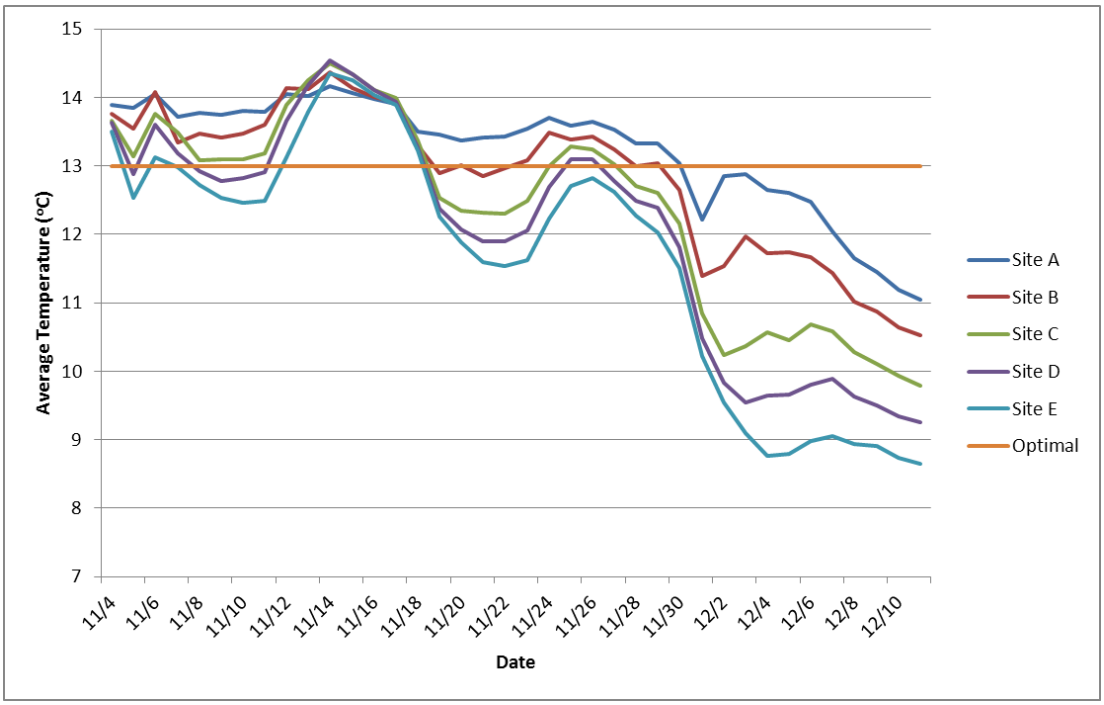


Figure A-34-3.
Average Daily Hyporheic Temperatures in Artificial Redds in Reach 1A of the San Joaquin River Restoration Area

34.4 Conclusions and Recommendations

It is anticipated that the results of the study will assist in determining whether restoration actions will be required to provide suitable spawning and egg incubation habitat for spring-run and fall-run Chinook salmon, and where those actions would be most valuable. Conclusions and recommendations will be provided in the summer 2012 ATR.

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35.0 Monitor Intragravel Dissolved Oxygen Concentrations in the San Joaquin River

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