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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 (^{o}C) 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 ≥ 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 ± 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 effs 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 $13.1\text{-}14.3^{o}C$	Critical $14.4\text{-}15.6^{o}C$	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	381	--
Crangonyx		
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	

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[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.

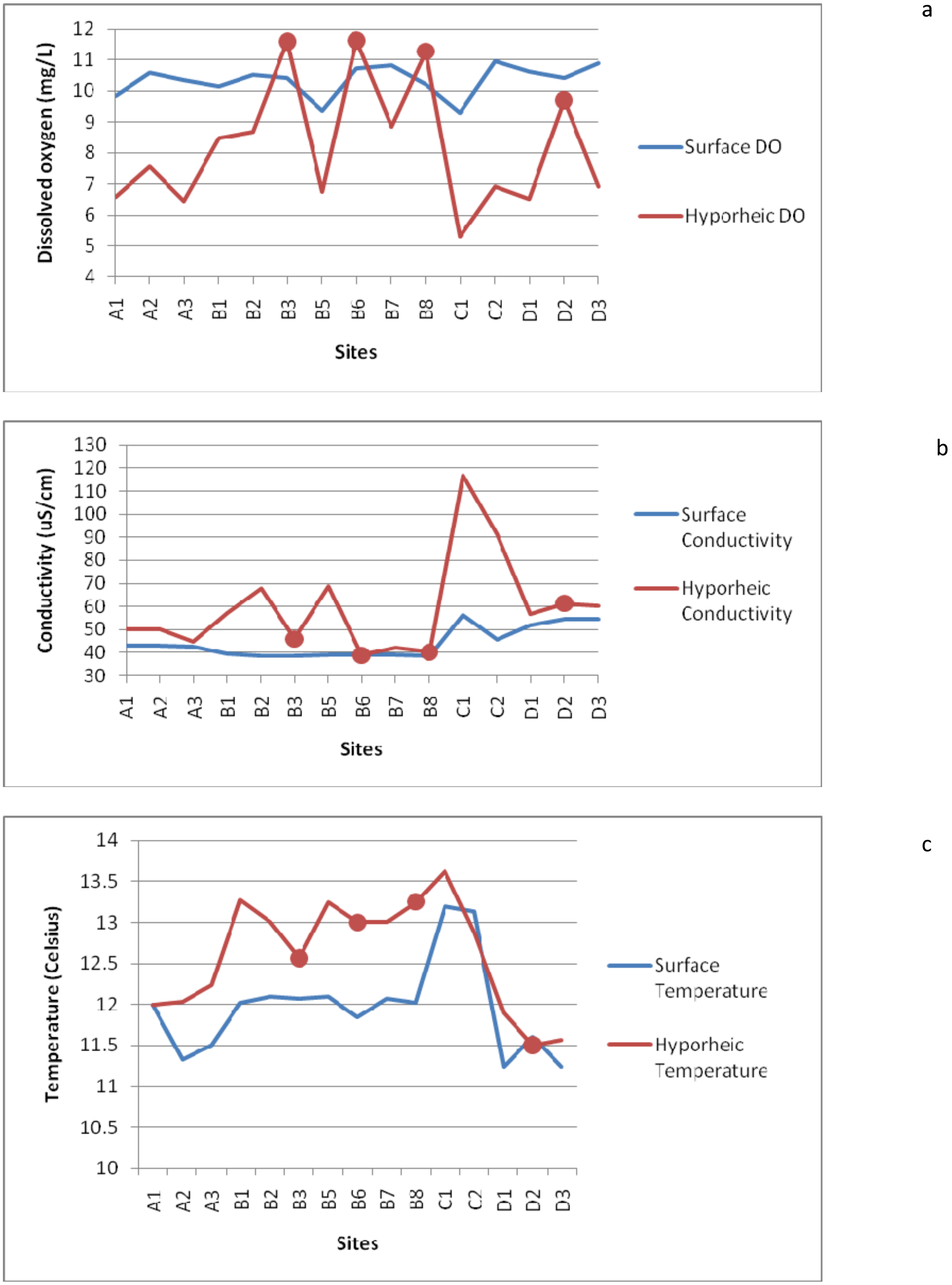


Figure 4. Mean sand per sampler from locations along the San Joaquin River. Error bars are standard error.

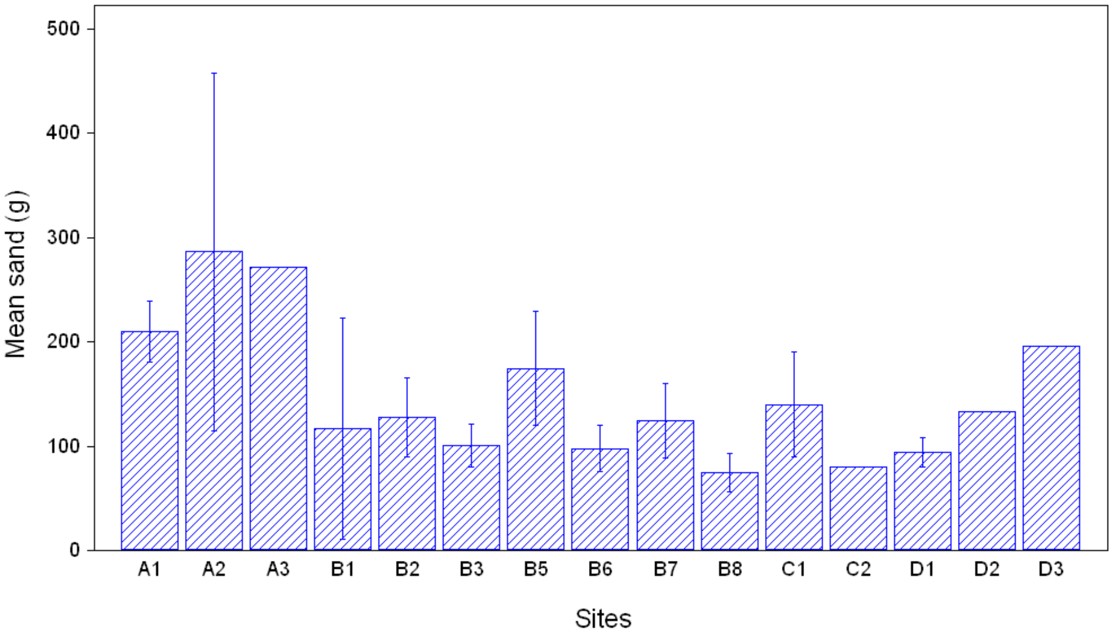


Figure 5. Relationship between the conductivity exchange index, C_s-C_h, and hyporheic DO (r=0.6814, P<0.0001).

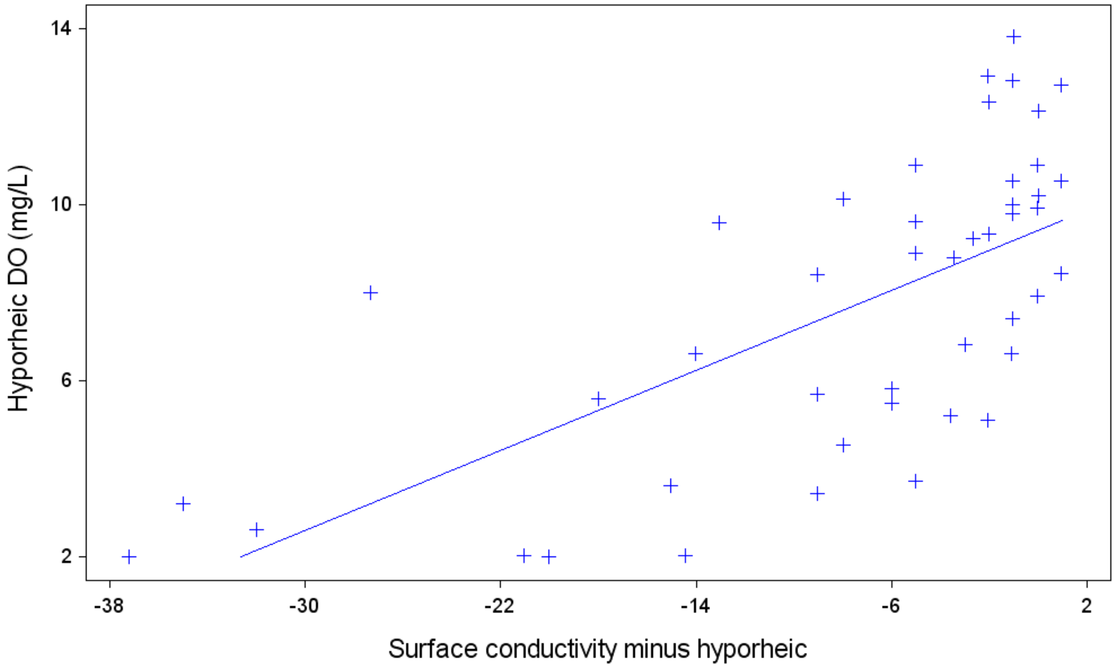


Figure 6. Relationship between sand and hyporheic DO (*r*=-0.3302, *P*=0.0748).

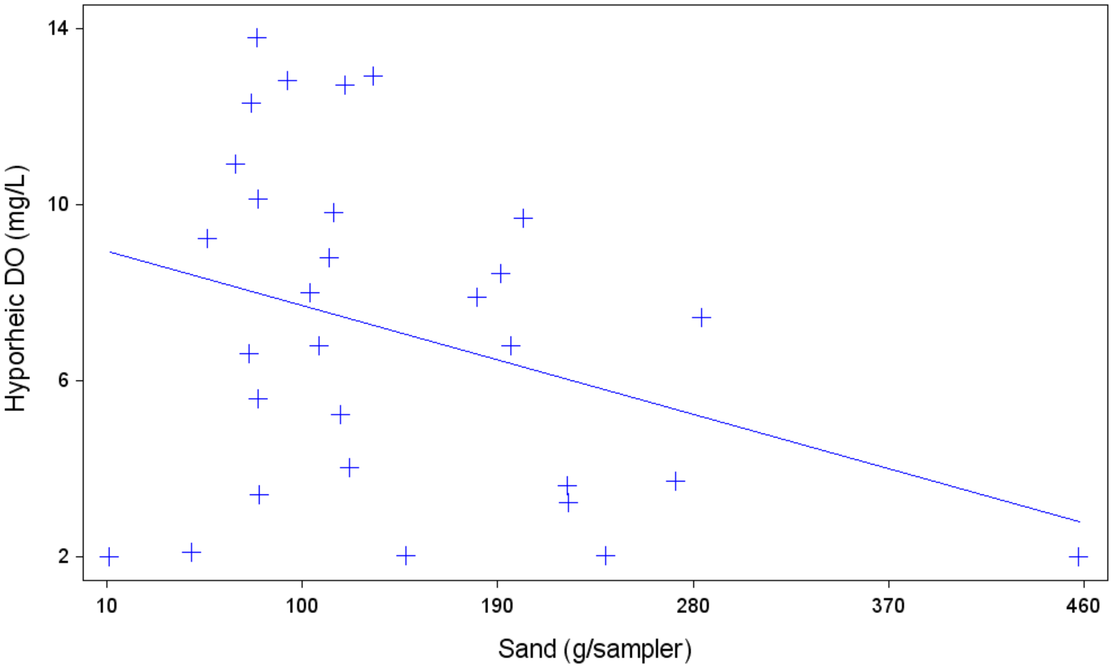


Figure 7. Relationship between velocity and hyporheic DO (*r*=0.2546, *P*=0.0994).

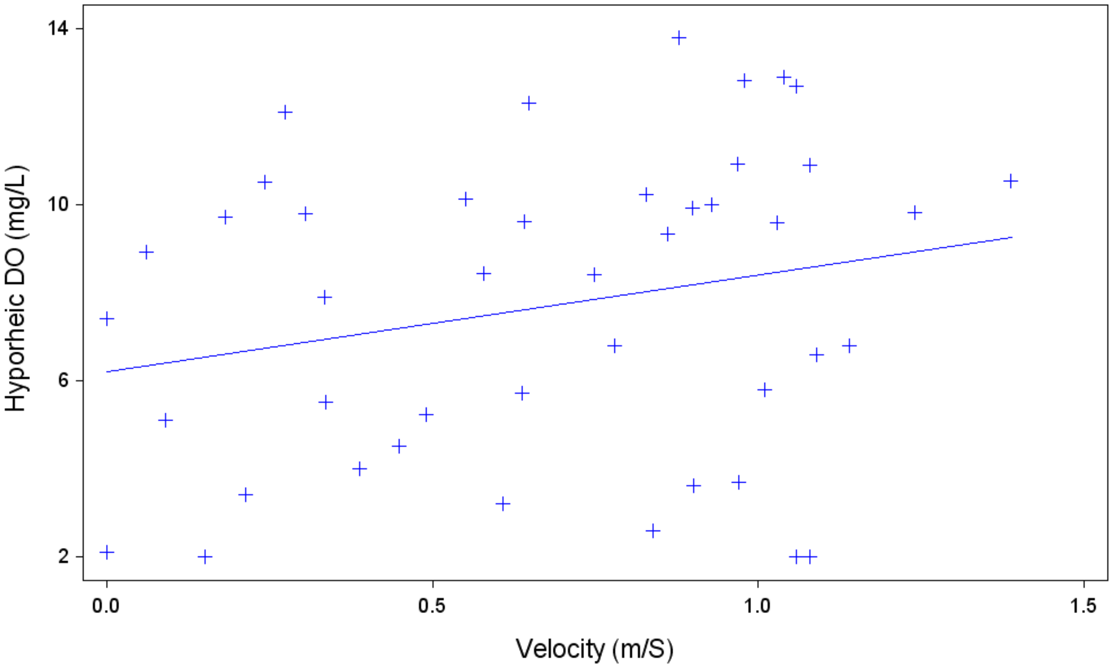


Figure 8. Hydraulic head measurements from locations along the San Joaquin River.

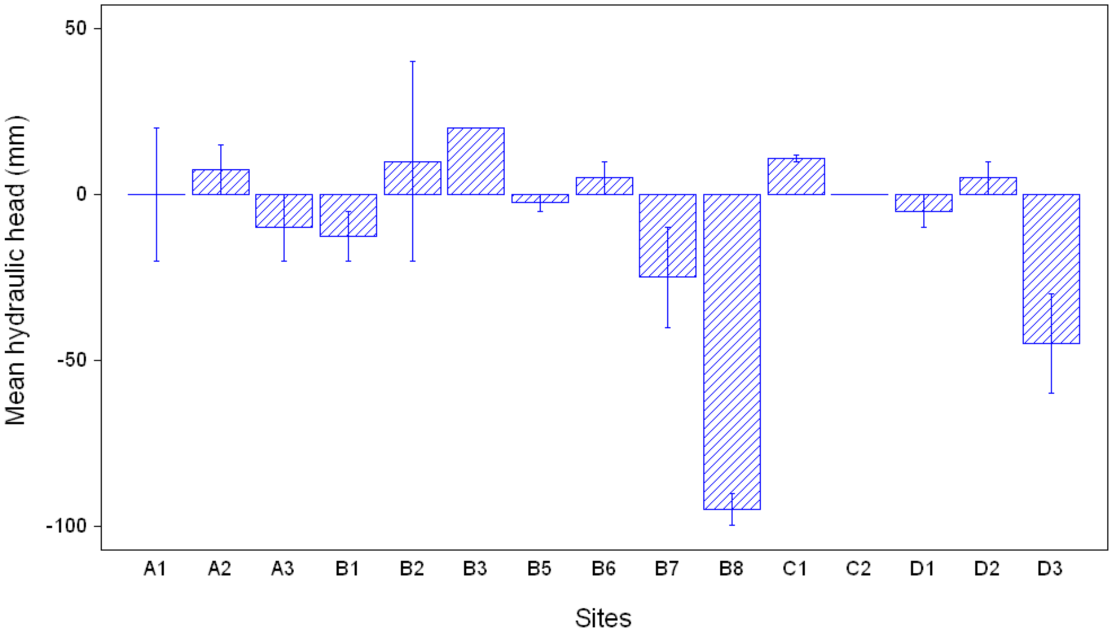


Figure 9. Mean hyporheic DO by season. No significant difference was detected in DO between months.

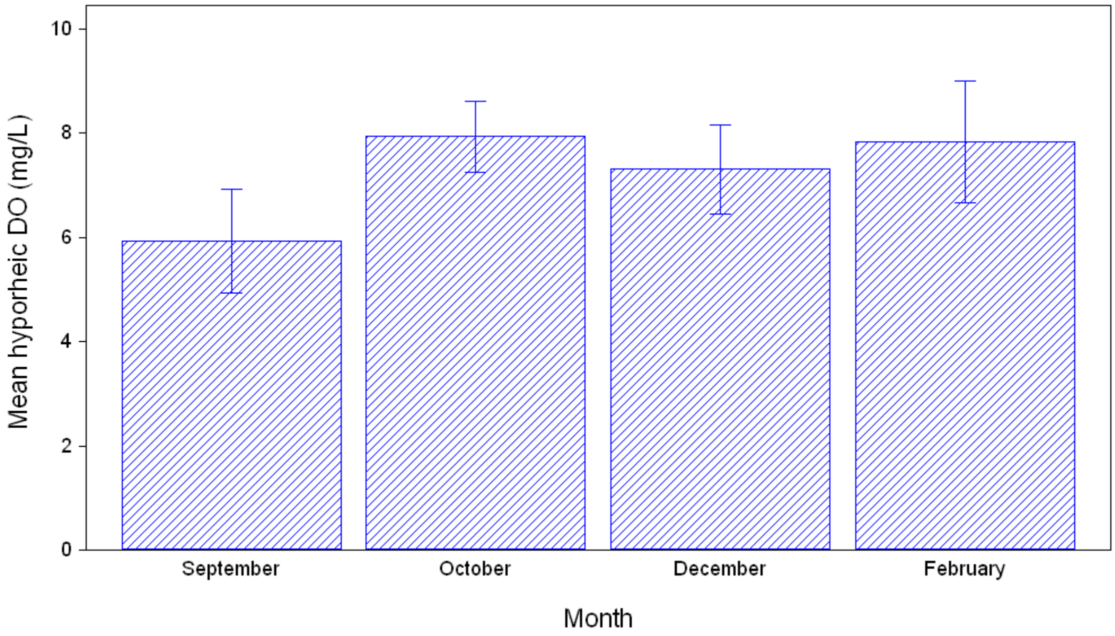


Figure 10. Hyporheic conductivity by season. Months with the same letter do not differ significantly (*P*>0.05).

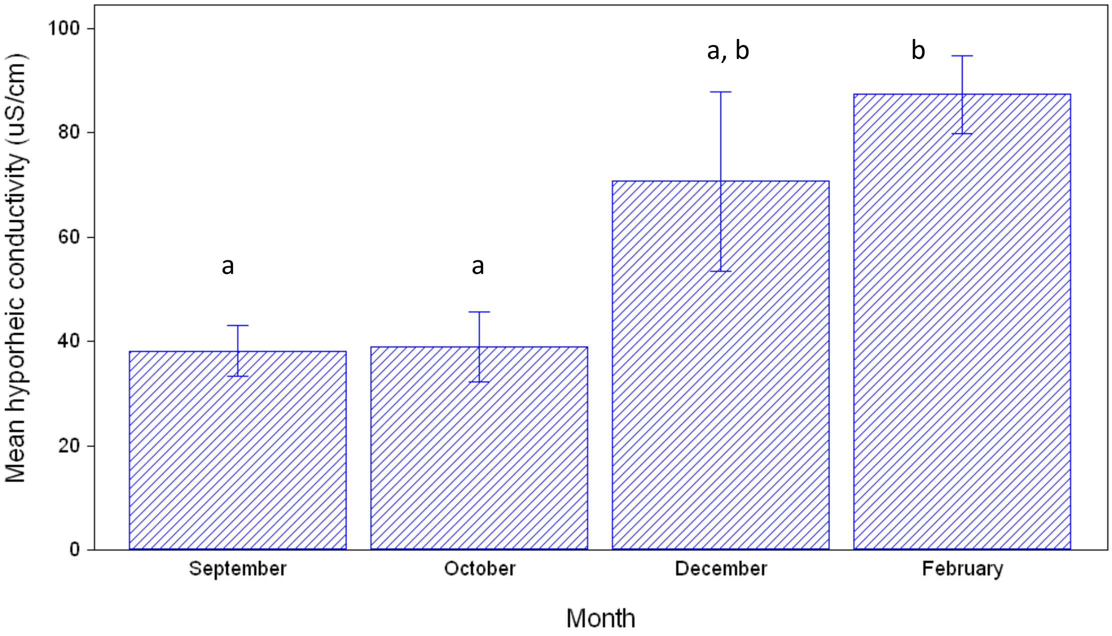


Figure 11. Mean sand in hyporheic samplers by month. No significant differences (*P*>0.05) were detected between months.

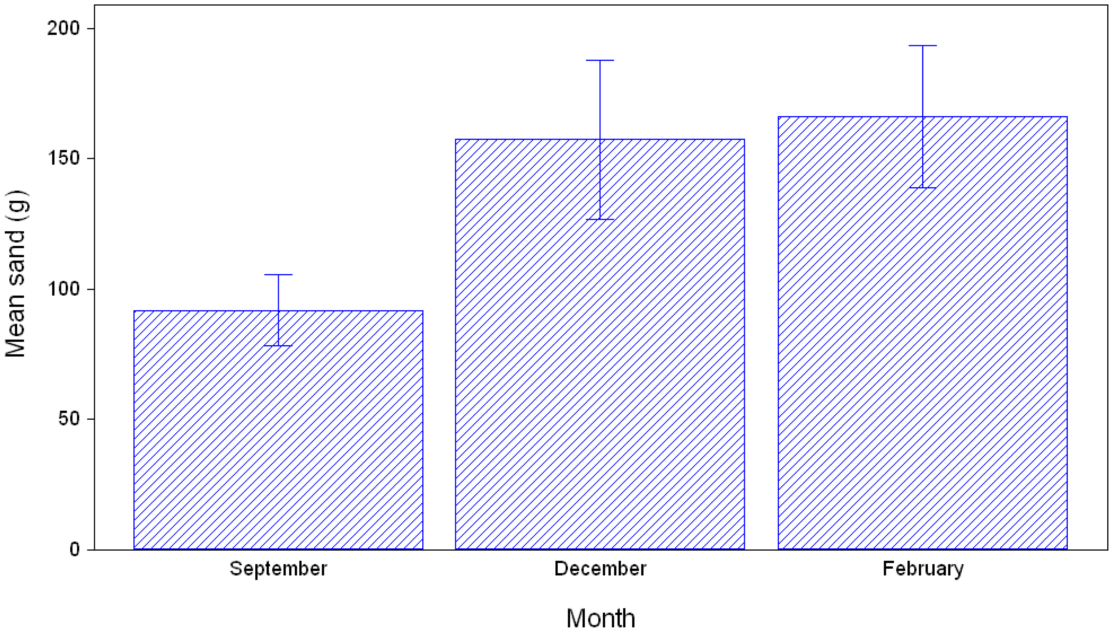


Figure 12. Mean hyporheic temperature derived from all locations by month. Bars with the same letter are not significantly different, while those with different letters differ significantly ($P \leq 0.05$).

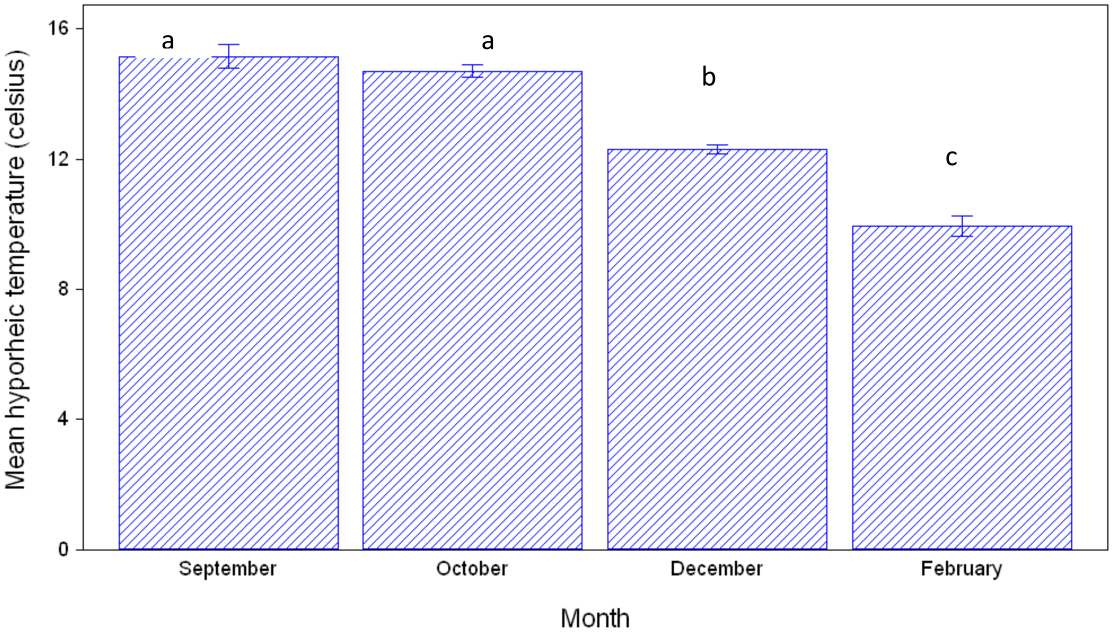


Figure 13. San Joaquin hydrograph from the sampling period. Sampler installation and sample collection dates are represented by filled triangles.

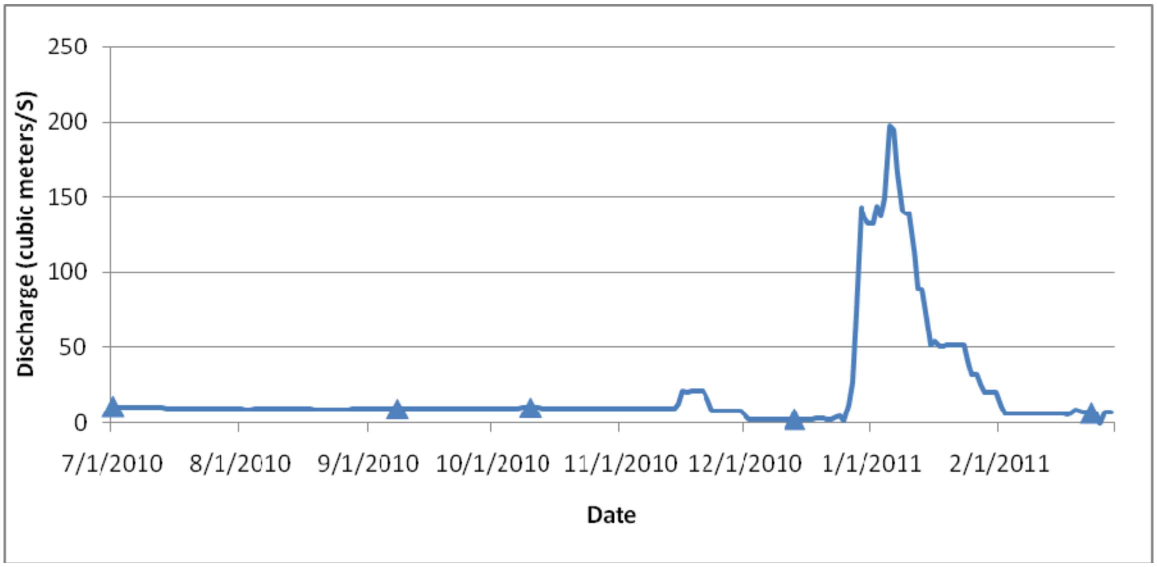


Figure 14. Mean water depth during study months. Water depth in December differed significantly (P<0.05) from that in other months.

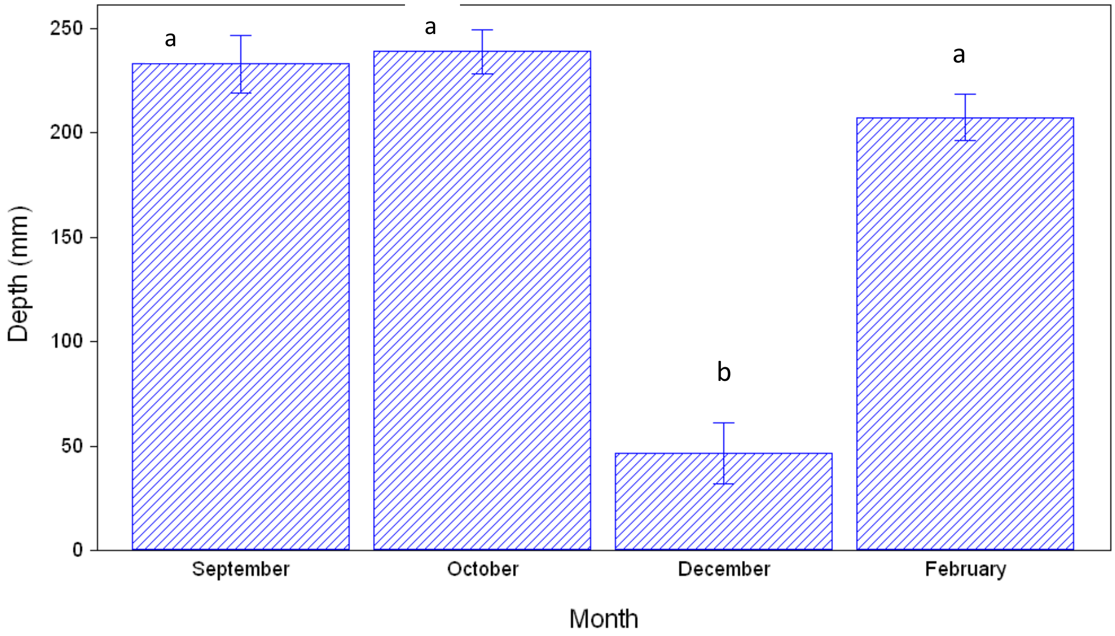


Figure 15. Mean hyporheic zone water temperatures at site locations from upstream (A) to the furthest downstream site (D).

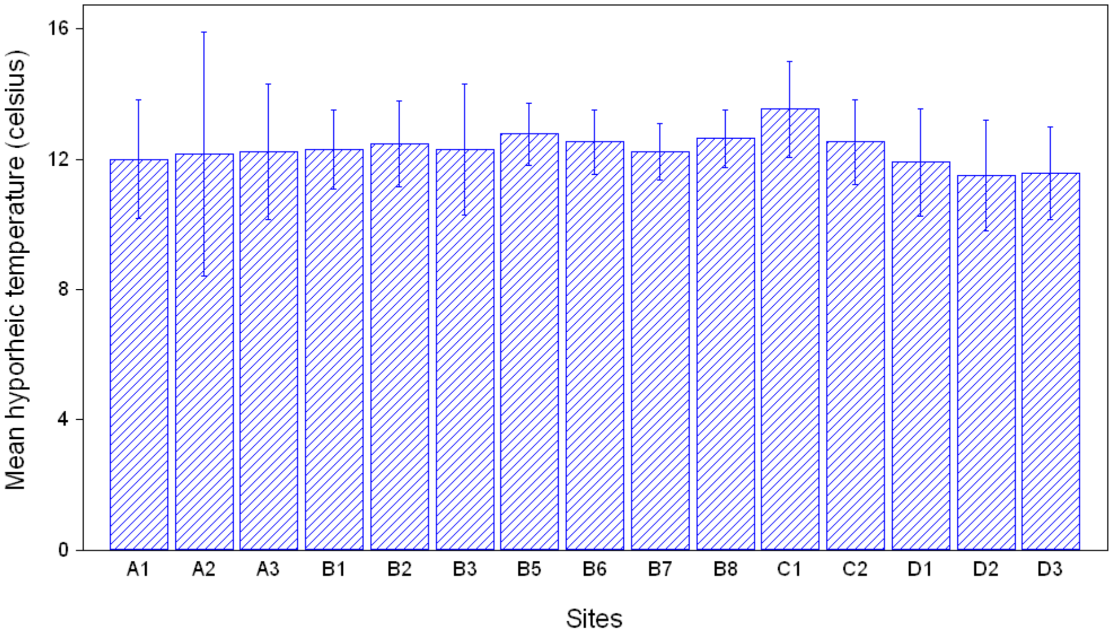


Figure 16. Biplot based on a detrended correspondence analysis (DCA) of paired surface and hyporheic samples. Samples are represented as open circles for those collected with a Surber sampler and filled circles for those collected with hyporheic samplers. All samples were converted to number/m^3 prior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

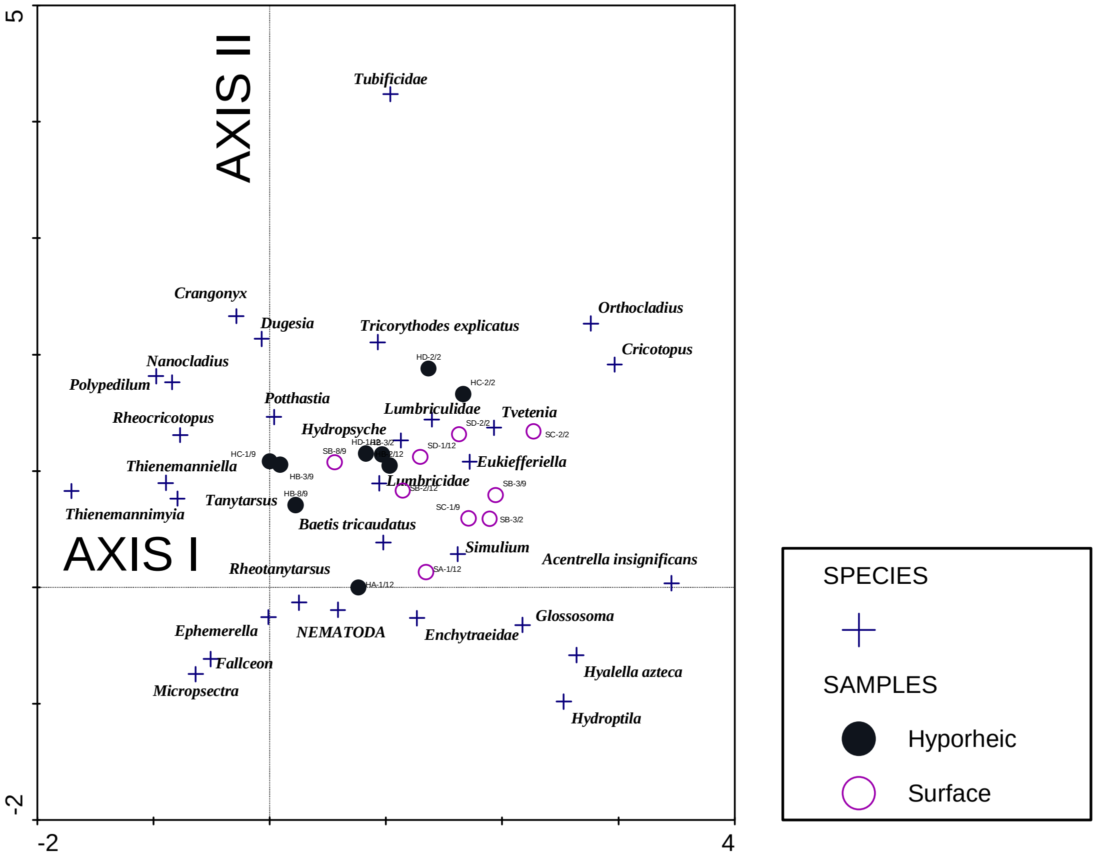


Figure 17. Triplot based on a redundancy analysis (RDA) of sites and taxa with respect to environmental variables. Environmental variables were related to community attributes as shown by arrows. Site samples are represented as geometric shapes as shown in the legend, while species are represented as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

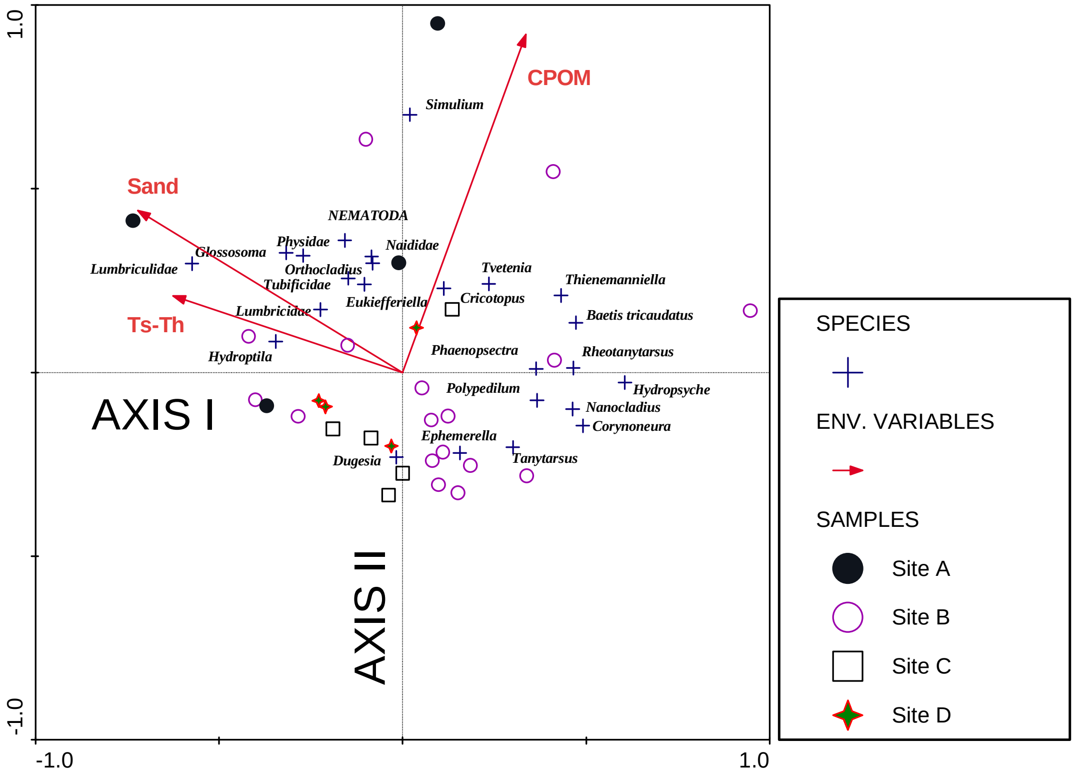


Figure 18. Relationship between sand found in samplers and Ephemeroptera abundance (*r*=-0.3771, *P*=0.0437).

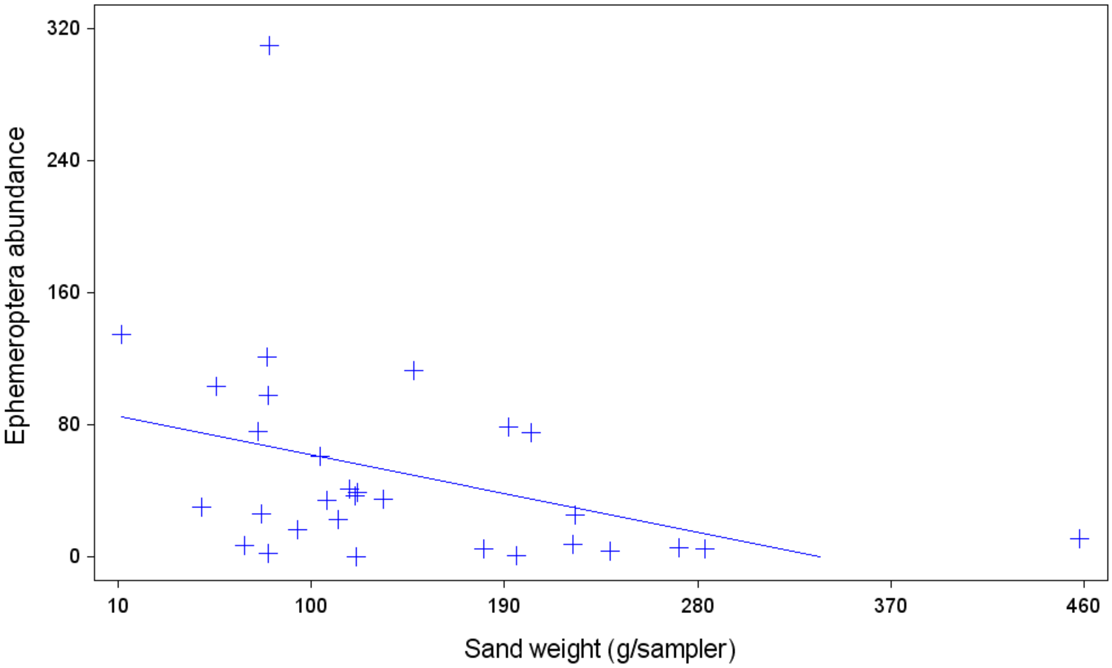
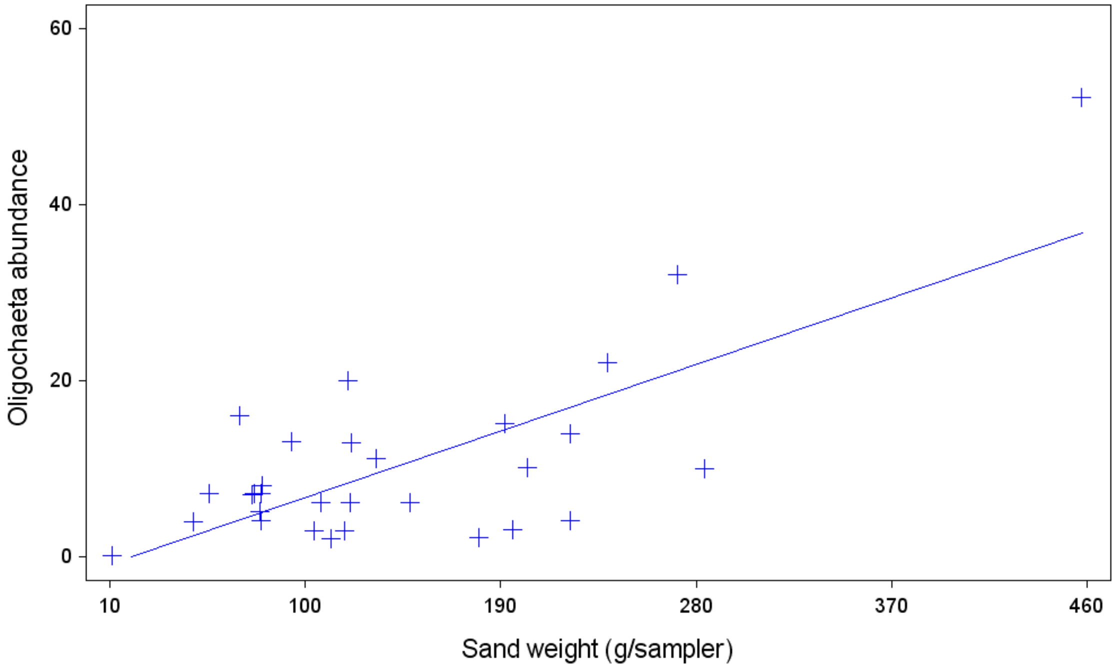


Figure 19. Relationship between sand found in samplers and Oligochaeta abundance (*r*=0.7303, *P*<0.0001).



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 Units	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total 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 Units	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total 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		
			3/28/2011			3/28/2011			3/28/2011			3/28/2011		
Sieve	mm	Phi Units	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight
64	64	-6	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
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
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
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
	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
#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
#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
#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
#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
#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
#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
#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
#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
#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
#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
#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
#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
#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
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
Total Weight			4541.8			3998.2			3825.8			4410.4		

SAMPLE I.D.			B - 6			B - 7			B - 8			C - 1		
			3/28/2011			3/28/2011			3/28/2011			3/28/2011		
Sieve	mm	Phi Units	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight Retained (g)	% Finer Than Size	% of Total Weight
64	64	-6	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00
32	32		625.9	84.66	15.34	1429.1	62.86	37.14	443.5	88.67	11.33	1264	73.81	26.19
25	25		573.7	70.60	14.06	736.7	43.72	19.14	550.9	74.59	14.08	517	63.09	10.71
16	16	-4	1168.1	41.98	28.63	744.2	24.38	19.34	1183.7	44.34	30.25	712.8	48.32	14.77
8	8		933.7	19.10	22.88	472	12.11	12.27	1062.5	17.18	27.15	1077.6	26.00	22.33
	6.3		106.3	16.49	2.61	47	10.89	1.22	126.4	13.95	3.23	198.7	21.88	4.12
#5	4	-2	108.3	13.84	2.65	57.6	9.39	1.50	120	10.88	3.07	238	16.95	4.93
#10	2	-1	120.2	10.89	2.95	69.5	7.59	1.81	93.6	8.49	2.39	222.5	12.34	4.61
#14	1.41	-0.5	88.4	8.72	2.17	50	6.29	1.30	68.4	6.74	1.75	98.9	10.29	2.05
#18	1	0	103	6.20	2.52	64.2	4.62	1.67	83.1	4.62	2.12	100.3	8.21	2.08
#20	0.84	0.25	36.1	5.32	0.88	26.1	3.94	0.68	30.3	3.85	0.77	44.1	7.29	0.91
#25	0.71	0.5	48.2	4.13	1.18	40.9	2.88	1.06	43.4	2.74	1.11	77.7	5.68	1.61
#35	0.5	1	63.2	2.59	1.55	55.4	1.44	1.44	51.1	1.43	1.31	139.1	2.80	2.88
#45	0.35	1.5	36	1.70	0.88	24.1	0.81	0.63	18.6	0.96	0.48	72.9	1.29	1.51
#60	0.25	2	27.6	1.03	0.68	10.5	0.54	0.27	9.8	0.71	0.25	33.8	0.59	0.70
#80	0.177	2.5	17.5	0.60	0.43	7.2	0.35	0.19	7.3	0.52	0.19	13.6	0.31	0.28
#120	0.125	3	10.7	0.34	0.26	6.7	0.18	0.17	7.2	0.33	0.18	7.3	0.16	0.15
#150	104		3.3	0.25	0.08	2.2	0.12	0.06	3.1	0.26	0.08	2.2	0.11	0.05
#230	0.0625	4	6.6	0.09	0.16	3.5	0.03	0.09	6.6	0.09	0.17	3.6	0.04	0.07
Pan	<0.0625		3.8	0.00	0.09	1.2	0.00	0.03	3.4	0.00	0.09	1.8	0.00	0.04
Total Weight			4080.6			3848.1			3912.9			4825.9		

SAMPLE I.D.			C - 2			A - 1			A - 2			A - 3		
			3/28/2011			3/28/2011			3/28/2011			3/28/2011		
Sieve	mm	Phi Units	Weight Retained (g)	% Finer Than Size	% of Total Weight	Weight etained (g	% Finer Than Size	% of Total Weight	Weight etained (g	% Finer Than Size	% of Total Weight	Weight etained (g	% Finer Than Size	% of Total Weight
64	64	-6	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00
32	32		1603.4	62.24	37.76	1423.3	64.59	35.41	1126	69.23	30.77	304.9	93.28	6.72
25	25		702.2	45.70	16.54	551.6	50.87	13.72	271.7	61.80	7.43	516.3	81.89	11.38
16	16	-4	708.3	29.01	16.68	540.2	37.43	13.44	643.1	44.23	17.58	932.5	61.33	20.56
8	8		665.3	13.34	15.67	566.7	23.33	14.10	384.8	33.71	10.52	1617.8	25.66	35.67
	6.3		91.8	11.18	2.16	96.8	20.93	2.41	69.6	31.81	1.90	236.9	20.43	5.22
#5	4	-2	86.9	9.14	2.05	174.4	16.59	4.34	187.2	26.69	5.12	295.2	13.92	6.51
#10	2	-1	80.1	7.25	1.89	239.6	10.63	5.96	457.9	14.18	12.51	271.7	7.93	5.99
#14	1.41	-0.5	43	6.24	1.01	121.7	7.60	3.03	240.8	7.60	6.58	115.5	5.39	2.55
#18	1	0	56.4	4.91	1.33	97.5	5.17	2.43	129.5	4.06	3.54	88.2	3.44	1.94
#20	0.84	0.25	27.8	4.25	0.65	29.7	4.44	0.74	30.7	3.22	0.84	28.5	2.81	0.63
#25	0.71	0.5	42.9	3.24	1.01	39.3	3.46	0.98	32.5	2.33	0.89	33.3	2.08	0.73
#35	0.5	1	74.5	1.49	1.75	53.8	2.12	1.34	36.4	1.34	0.99	48	1.02	1.06
#45	0.35	1.5	33.4	0.70	0.79	34.4	1.26	0.86	19.3	0.81	0.53	24.4	0.48	0.54
#60	0.25	2	16.2	0.32	0.38	21.9	0.72	0.54	12.3	0.47	0.34	10.6	0.25	0.23
#80	0.177	2.5	6.5	0.17	0.15	12.8	0.40	0.32	7	0.28	0.19	4.5	0.15	0.10
#120	0.125	3	3	0.10	0.07	8.4	0.19	0.21	4.9	0.15	0.13	2.9	0.09	0.06
#150	104		1	0.07	0.02	2.1	0.14	0.05	1.5	0.11	0.04	0.9	0.07	0.02
#230	0.0625	4	2.1	0.02	0.05	3.6	0.05	0.09	2.3	0.04	0.06	2.1	0.02	0.05
Pan	<0.0625		1	0.00	0.02	2	0.00	0.05	1.6	0.00	0.04	0.9	0.00	0.02
Total Weight			4245.8			4019.8			3659.1			4535.1		

SAMPLE I.D.			D - 1			D - 2			D - 3		
			3/28/2011			3/28/2011			3/28/2011		
Sieve	mm	Phi Units	Weight etained (g	% Finer Than Size	% of Total Weight	Weight etained (g	% Finer Than Size	% of Total Weight	Weight etained (g	% Finer Than Size	% of Total Weight
64	64	-6	0	100.00	0.00	0	100.00	0.00	0	100.00	0.00
32	32		1391	69.75	30.25	2258.9	51.29	48.71	769.5	84.02	15.98
25	25		593.4	56.84	12.91	373	43.24	8.04	708.9	69.30	14.72
16	16	-4	1026.9	34.51	22.33	593.7	30.44	12.80	894.8	50.72	18.58
8	8		962.8	13.57	20.94	769.7	13.84	16.60	1100.6	27.87	22.85
	6.3		110.1	11.17	2.39	123.4	11.18	2.66	223.9	23.22	4.65
#5	4	-2	123.3	8.49	2.68	119.8	8.60	2.58	261.9	17.78	5.44
#10	2	-1	107.9	6.14	2.35	133.4	5.72	2.88	195.9	13.71	4.07
#14	1.41	-0.5	66.5	4.70	1.45	73.4	4.14	1.58	123.4	11.15	2.56
#18	1	0	57.7	3.44	1.25	54.9	2.95	1.18	162.2	7.78	3.37
#20	0.84	0.25	18.8	3.03	0.41	15.5	2.62	0.33	61.8	6.50	1.28
#25	0.71	0.5	23.1	2.53	0.50	22.3	2.14	0.48	101.8	4.38	2.11
#35	0.5	1	39.5	1.67	0.86	34.2	1.40	0.74	119.2	1.91	2.48
#45	0.35	1.5	33.1	0.95	0.72	22.1	0.92	0.48	53	0.81	1.10
#60	0.25	2	22.9	0.45	0.50	13.7	0.63	0.30	21	0.37	0.44
#80	0.177	2.5	9.9	0.24	0.22	8.8	0.44	0.19	8.5	0.19	0.18
#120	0.125	3	5.4	0.12	0.12	8	0.27	0.17	4.4	0.10	0.09
#150	104		1.5	0.09	0.03	3.2	0.20	0.07	1.2	0.08	0.02
#230	0.0625	4	2.7	0.03	0.06	6.5	0.06	0.14	2.6	0.02	0.05
Pan	<0.0625		1.4	0.00	0.03	2.6	0.00	0.06	1.1	0.00	0.02
Total Weight			4597.9			4637.1			4815.7		

PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name San Joaquin River Restoration WOID X5683 & SSGRP

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

Document Date September 2011

Team Leader S.Mark Nelson

Document Author(s)/Preparer(s) S. Mark Nelson and Gregory K. Reed

REVIEW CERTIFICATION

Reviewers: See Acknowledgements

Preparer - I have appraised the above document and review comments of the Peer Reviewers and believe that this review is completed, and that the document will meet the requirements of the project.

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

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